

General Survey of Radio Frequency Bands – 30 MHz to 3 GHz

Version 2.0

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1.0 Introduction

Demand for wireless communications services is exploding, placing tremendous strain on the capacity of wireless communications networks. US government and industry stakeholders are aggressively searching for sustainable solutions to this ever-worsening problem.

One area of focus for addressing this challenge is radio frequency (RF) spectrum. While almost all RF spectrum is allocated, most of it is either unused or underutilized. The current spectrum allocation process for wireless communications is highly inefficient, leading to significant underutilization of spectrum in the face of explosive growth in demand.

In June of 2010, the Obama Administration ordered the National Telecommunications and Information Administration (NTIA) to work with the Federal Communications Commission (FCC) "to make available a total of 500 MHz of federal and nonfederal spectrum over the next 10 years, suitable for both mobile and fixed wireless broadband use." As a result, the NTIA, FCC, and other organizations are closely examining the current allocation and usage of RF spectrum to identify candidate spectrum bands for reallocation and sharing.

Shared Spectrum Company (SSC), a pioneer in the development of spectrum management solutions, has been promoting the more efficient use of RF spectrum for over ten years. SSC was the first company to file comments at the FCC suggesting the secondary use of TV white space frequencies for rural broadband Internet access. The company's spectrum utilization measurements are among the most cited in the wireless industry, and it has operated a "spectrum observatory" at its headquarters in Vienna, VA for the past three years.

Given the keen interest in the prime RF spectrum bands between 30 MHz and 3 GHz, SSC collected spectrum usage data at its spectrum observatory in these bands over a three-and-a-half day period in the fall of 2009. Two data collection antennas were placed on the rooftop of its seven-story, Vienna, Virginia headquarters building. The building is located in a dense urban area near Washington, DC. This document presents this data and briefly discusses some of the conclusions that can be drawn from them.

2.0 Data Collection Equipment Description

The equipment used for the spectrum occupancy measurements consisted of a spectrum analyzer, a low frequency discone antenna (Diamond D-130J), a high frequency discone antenna (AOR DA5000), a preselector, lightning protection grounding hardware, and a desktop computer. A diagram of the equipment configuration is shown in Figure 1.

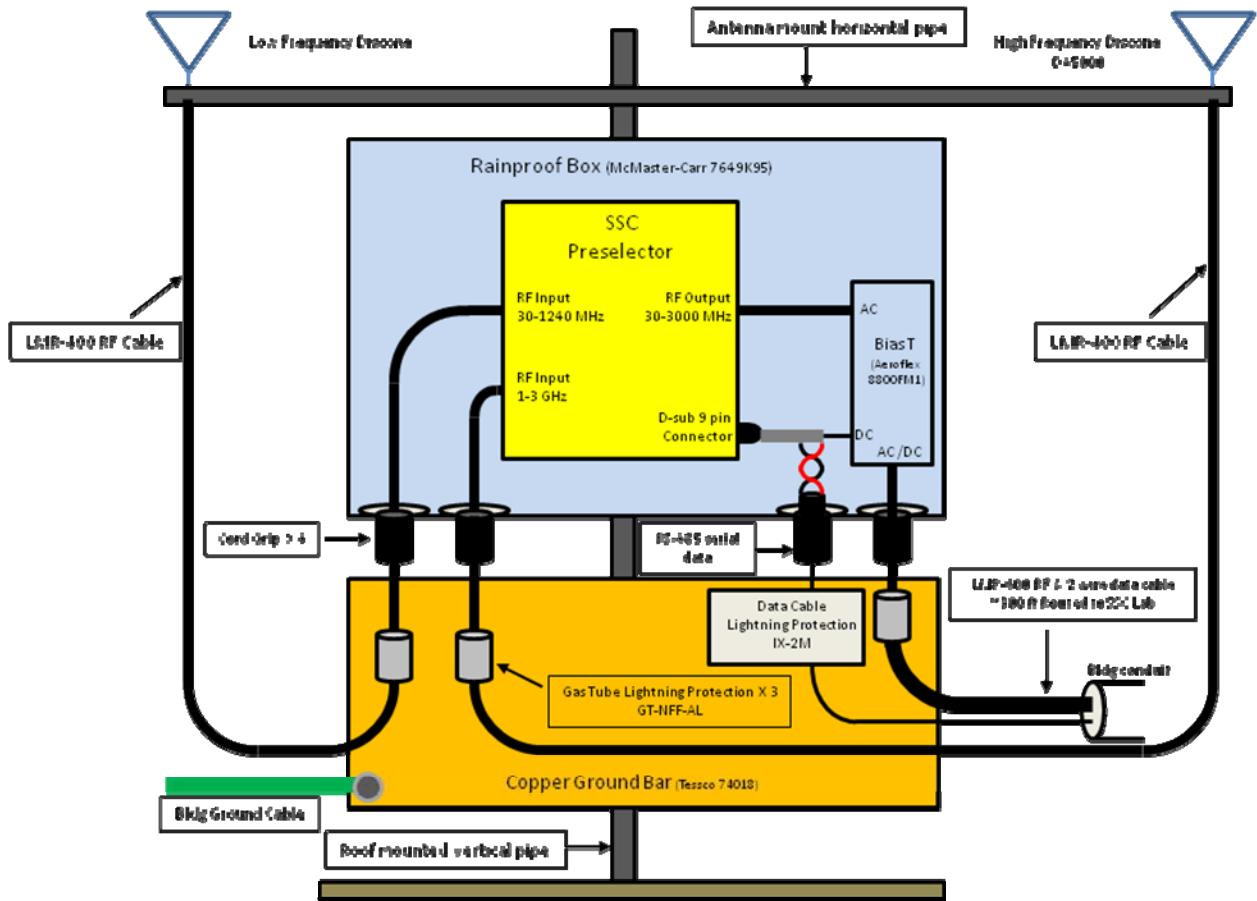


Figure 1. Rooftop Antenna Diagram

The low frequency discone antenna shown in Figure 2 was used to measure signals between 30 MHz and 1 GHz.



Figure 2. Low frequency Discone Antenna

The high frequency discone antenna shown in Figure 3 was used to measure signals between 1 GHz and 3 GHz.



Figure 3. High frequency discone antenna

A custom-designed preselector module (shown in Figure 4) was used as a receiver front end and is characterized by low noise (5 dB), high gain (+17 dB max) and the required out-of-band signal rejection characteristics.

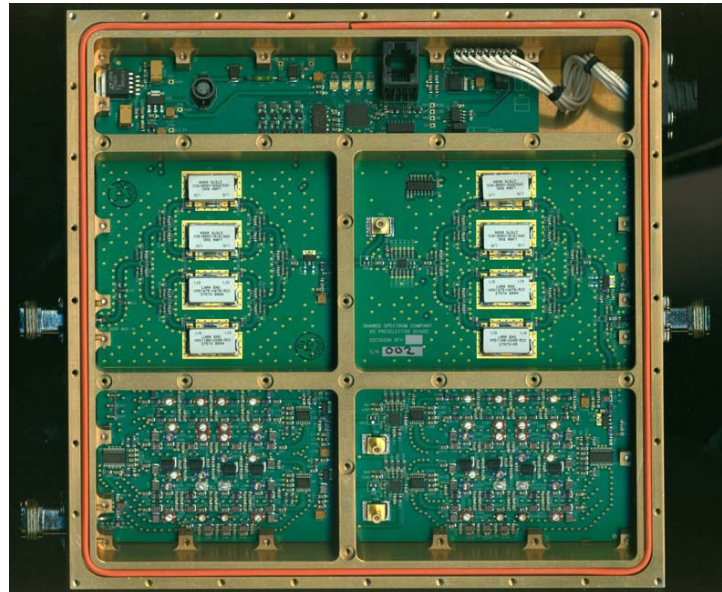


Figure 4. SSC preselector module

A photo of the data collection computer and spectrum analyzer is shown in Figure 5.



Figure 5. Data collection computer

3.0 Measurement Location

The spectrum measurements were made on SSC's office building roof in Vienna, VA, which is located approximately 18 km from Washington, DC as shown in Figure 6. This location is a dense urban area.

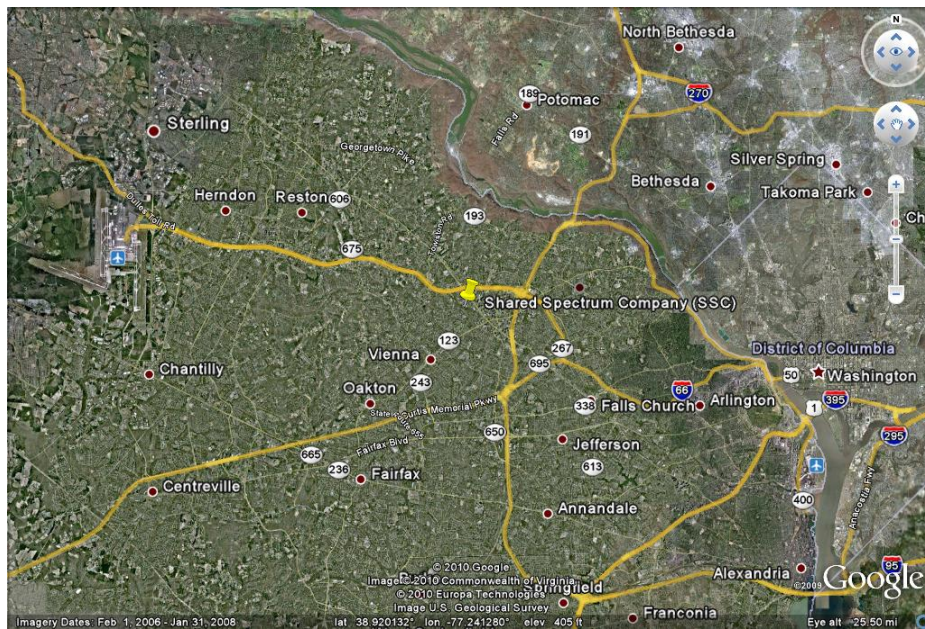


Figure 6 The measurement location – SSC's office in Vienna, VA

The measurement location had good line-of-sight in all directions. The view to the east (towards Washington, DC) is shown in Figure 7.



Figure 7 View from on top of the Shared Spectrum Company office building looking to the east.

4.0 Data Collection

Data was collected from 30 MHz to 3 GHz for 87 hours from September 1 through September 5, 2009. The data was divided into well known bands (e.g., the 1,850-to-1,990 MHz PCS band), and the following three plots were generated for each band:

- The first plot represents the maximum power value measured for each frequency (i.e., max hold) during the data collection period. The power values are the levels at the antenna port, and are corrected for cable, filter and amplifier losses. The measurement start and stop times are shown above the plot.
- The second plot is a “waterfall” plot showing frequency occupancy versus time. A frequency is considered occupied when the power measured at that frequency exceeds a specified threshold. The threshold value chosen for each band is determined based on the noise floor for the band of interest. The man-made noise level is high for the 30-54 MHz and 108-138 MHz bands. As a result, -100 dBm and -105 dBm threshold levels are used for these bands, respectively. Also, the noise figure of the measurement equipment is

higher above 2 GHz because of the cable losses associated with the antenna used to measure higher frequencies. As a result, a -105 dBm threshold is used for the 2.11 GHz band and above. Finally, a -110 dBm threshold was used for the remaining bands. The threshold value is shown as a faint dotted red line in the max hold plots.

- The third plot is the fraction of time each frequency is occupied (i.e., it's the frequency use duty cycle). For example, if the fraction of time is '1', it means that the frequency is occupied during the entire period that data was collected.

The spectrum occupancy plots are included in Appendix A.

5.0 Data Analysis

Examination of the plots in Appendix A reveals a number of things, including but not limited to, the following.

- There are a number of bands that have low measured spectrum occupancy. The signals in these bands are either very weak (e.g., they are low power satellite signals requiring a directional antenna for reception) or are either highly underutilized or almost never used. These include:
 - 420-450 MHz (Amateur/Radiolocation)
 - 745-810 MHz (Public Safety)
 - 960-1020 MHz (Aviation)
 - 1240-1300 MHz (Amateur)
 - 1330-1400 MHz (Military)
 - 1400-1430 MHz (Space/Satellite)
 - 1430-1520 MHz (Telemetry)
 - 1525-1710 MHz (Mobile Satellite/Meteorological)
 - 1710-1850 MHz (Fixed/Fixed Mobile)
 - 1990-2110 MHz (MSS/TX Auxiliary)
- TV bands are among the worst bands, if not *the* worst, for spectrum sharing. The TV bands exhibit far more activity than those listed above and are subject to a number of overly restrictive sharing requirements (e.g., out-of-band emissions limitations).
- The measurements confirm that the bands we expect to be the most active (i.e., cellular and PCS) are indeed so. The 900 MHz (Cellular) and 1900 MHz (PCS) bands show a great deal of downlink activity (usually a duty cycle of 1). Uplink activity, though, is very low (typically between 0% and 10%) in terms of transmit duty cycle. This would change a bit if a threshold lower than -110 dBm were used. Regardless, there is an opportunity for wireless service providers to more efficiently utilize the uplink portions of these bands, perhaps through some sort of spectrum sharing with other devices like femtocells.

- The Wi-Fi band (2400-2485 MHz) measurements show very low utilization (approaching 0% on most channels in the band). This is probably for a number of reasons including the fact that the outdoor rooftop antenna was out of range of most of the APs in the building below it. These results also confirm that there is very limited deployment of Wi-Fi technologies that dramatically extend range of coverage.
- The TV bands show periods of increased signal strength from distant TV stations presumably due to the tropospheric ducting.¹ The implication is that spectrum bands with fixed transmitters have a significant dynamic aspect.

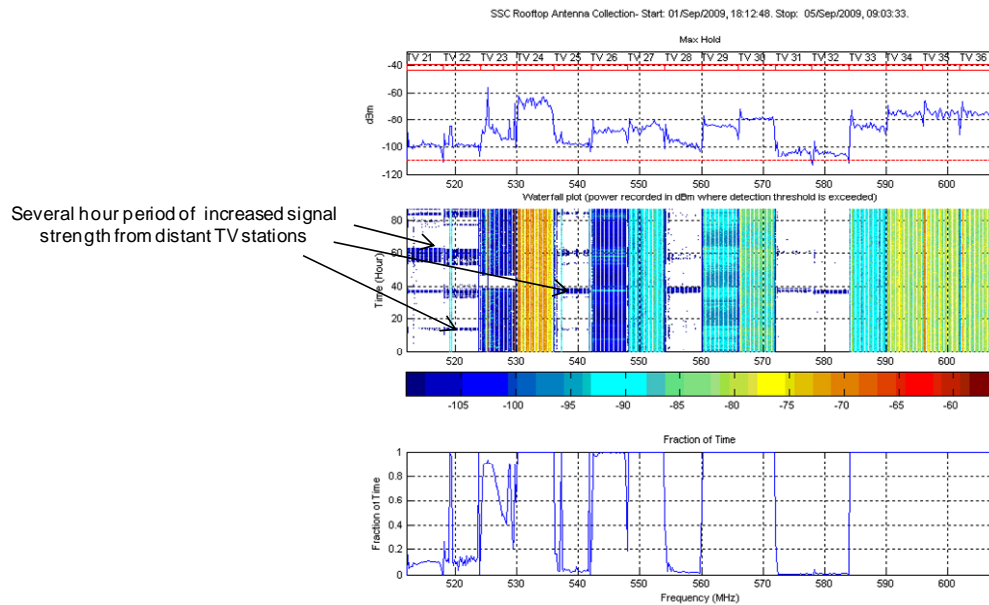


Figure 8 Example TV band spectrum measurement showing increased reception range due to tropospheric ducting.

- The waterfall plots can be visually deceiving. The plots attempt to show occupancy across an 87 hour period. A blue dot indicating occupancy during a very short period of time will render as a much larger period of time on the plot, and a grouping of these dots sometimes gives the impression that a band is full most or all of the time when that is not the case. A good example of this is the plot for the 30-to-54 MHz band where portions of the waterfall plot are rendered as solid blue while most sections of the associated duty cycle plots indicate far less activity. In cases where these two plots seem to be at odds, the duty cycle plot should be trusted.

A summary of the occupancy calculations across the bands can be found in the figure below.

¹ http://en.wikipedia.org/wiki/Tropospheric_propagation

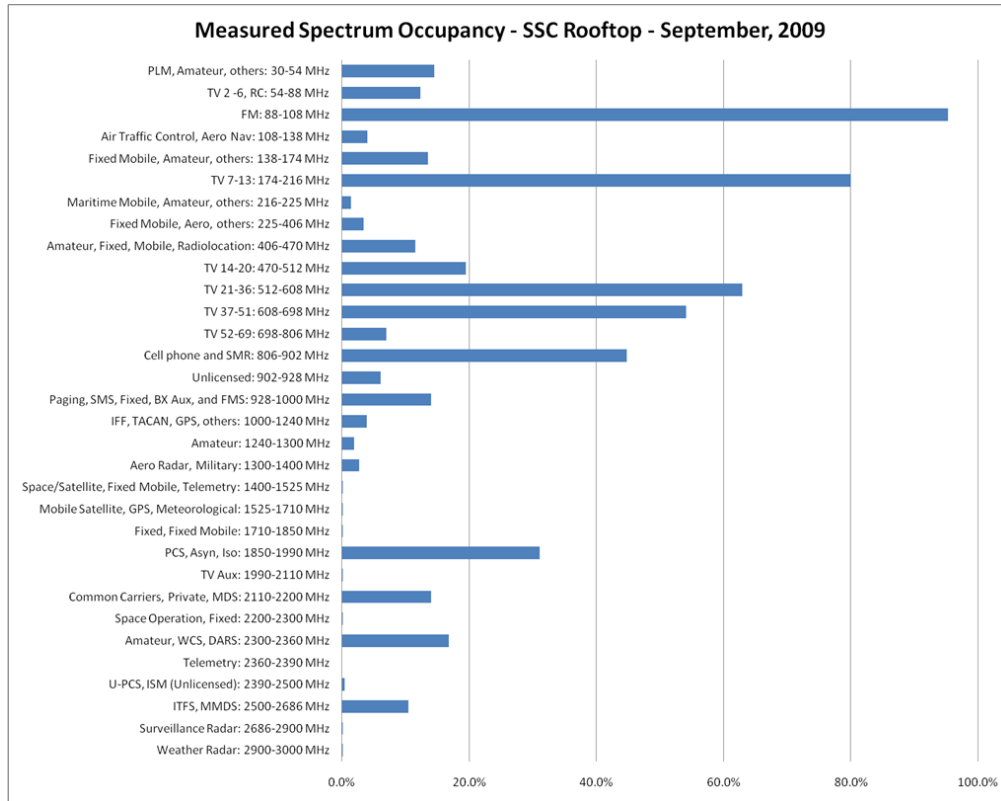


Figure 9. Summary of Spectrum Band Occupancy Calculations

The plots were further examined in search of 2 MHz wide spectrum holes. 2 MHz was chosen because it can support the smallest bandwidths supported by LTE and WiMAX (i.e., 1.4 MHz and 1.75 MHz, respectively). If a greater bandwidth than 2 MHz is required, we can look for groupings of continuous 2 MHz channels.

Spectrum hole plots can be found in Appendix B, Figure 44 through Figure 75. Figure 10 and Figure 11 below are included for illustrative purposes. Spectrum holes are shown in frequency versus time plots so that both the frequency and duration of holes can be seen. Figure 10 shows a sample spectrum hole analysis plot for the 174-216 MHz band. The green vertical lines show the start frequencies of 2.016 MHz wide, non-overlapping spectrum holes, and gaps in the lines indicate periods during which the slice of spectrum is unavailable. The hole width is slightly larger than 2 MHz due to the resolution bandwidth used in the analysis and its effect on calculations. Also, the sample plot below was simplified versus the one in Appendix B (Figure 49).

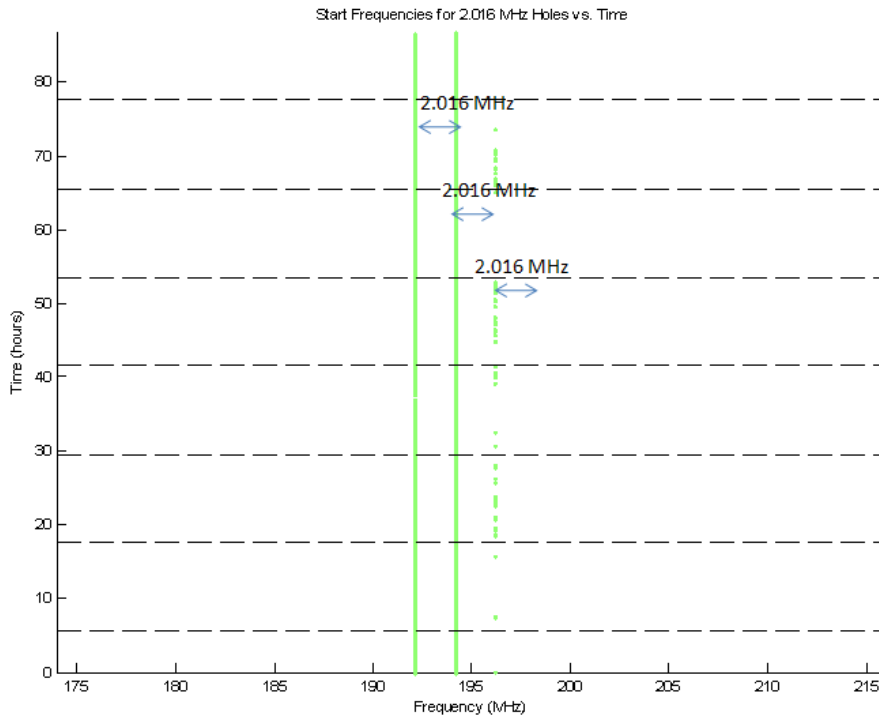


Figure 10. Spectrum Hole Analysis Sample Plot 1

A DSA device using a 2 MHz channel (or less) could use the spectrum holes indicated above during the time periods they are available.

Figure 11 below contains a sample Number of Holes vs Time plot showing the instantaneous number of 2.016 MHz wide holes available at any given time (which in this case varies between 0 and 3).

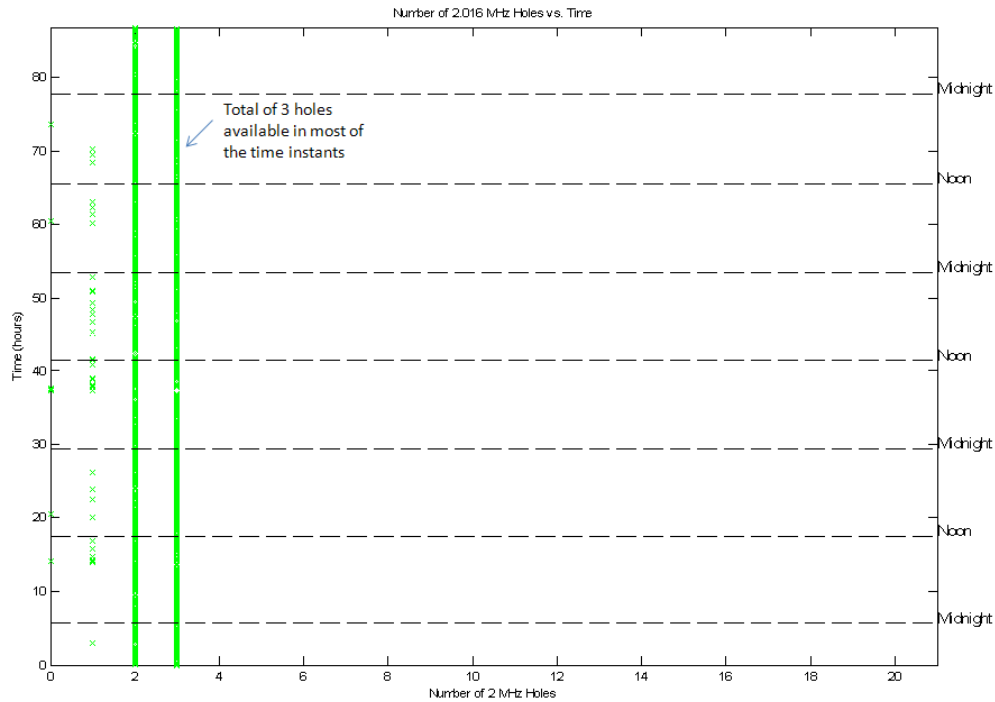


Figure 11. Spectrum Hole Analysis Sample Plot 2

Examination of the plots in Appendix B lends support to the observations cited in Section 5.0, the most important of which is that there are many channels available in most of the spectrum bands.

6.0 Conclusions

Spectrum usage data was collected from 30 MHz to 3 GHz at a single location over a three-and-a-half day period in the fall of 2009. An analysis of the data indicates that a number of spectrum bands may be excellent candidates for reallocation and/or spectrum sharing. Given the urgent need to identify additional spectrum for mobile broadband applications, this data should serve as motivation to perform a more detailed analysis to confirm the results herein. The follow up analysis would include the following.

- Measurements would be taken at numerous locations. This would eliminate any bias introduced by the single location used in the current analysis.
- Some measurements would focus on urban areas while others would be wide area. Wide area results could be made aurally using planes or balloons. The wide area measurements would focus on rural areas and help underscore differences with urban spectrum usage.

- Measurements would be taken at fixed and mobile locations.
- Measurements would be taken indoors and outdoors.
- More in-depth analysis of select bands (e.g., radiosonde, TV auxiliary, etc.) that offer the greatest potential for sharing. Analysis parameters like the detection threshold would be optimized for each band, and non-measurement factors (e.g., the challenges involved in protecting receive-only satellite stations) would be accounted for where necessary.

It is hoped that the more detailed analysis will confirm the results of the current report and provide the insight and motivation to regulators, service providers and other stakeholders to make well informed decisions that swiftly free up spectrum resources.

Appendix A – Data Plots

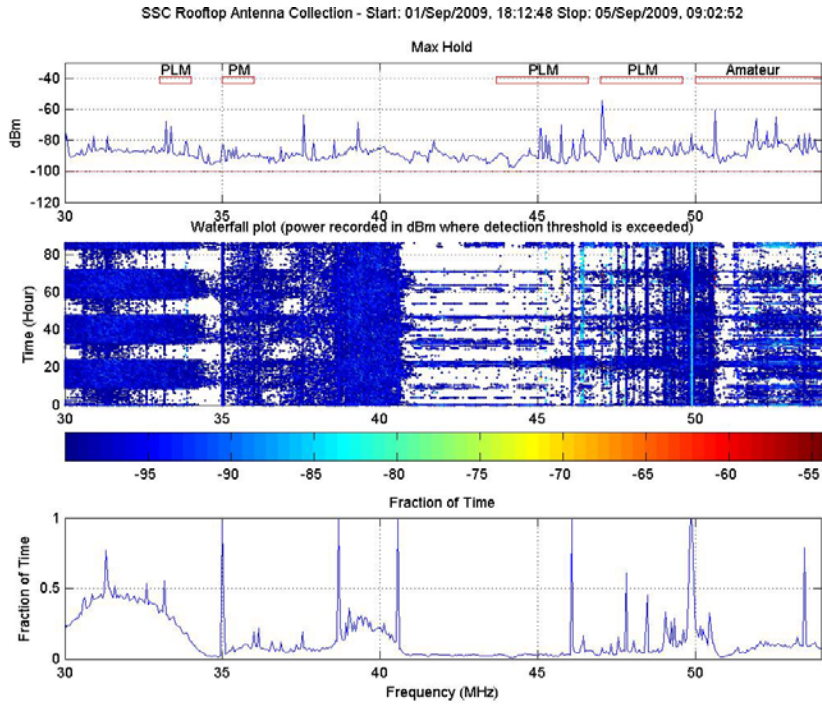


Figure 12. Max hold-waterfall-duty cycle plot 30-54 MHz

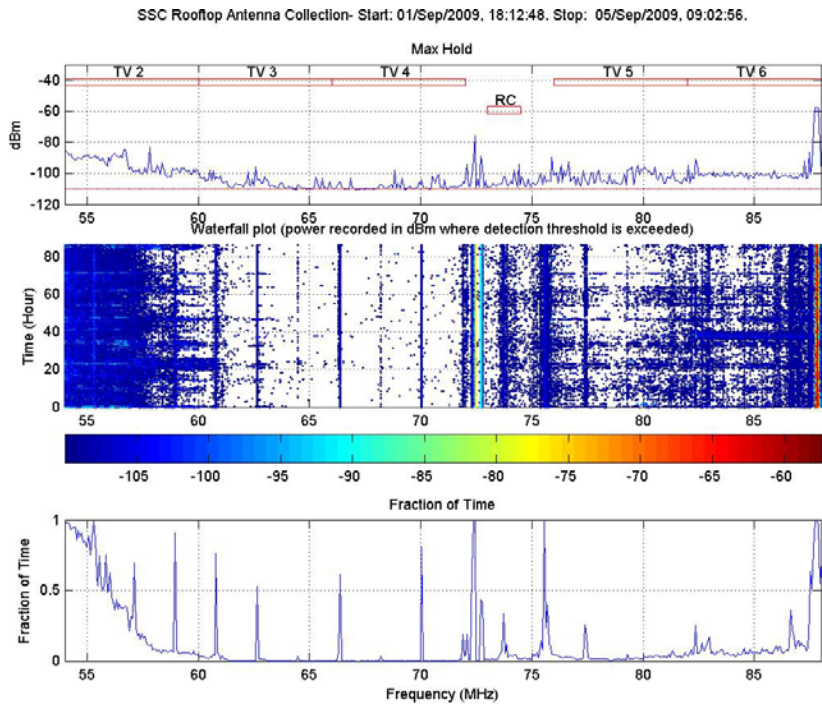


Figure 13. Max hold-waterfall-duty cycle plot 54-88 MHz

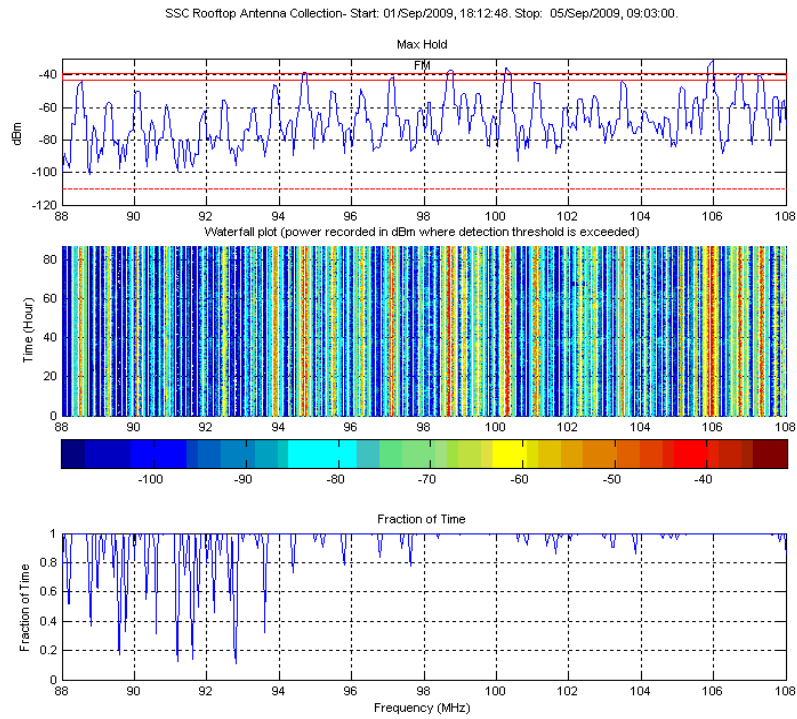


Figure 14. Max hold-waterfall-duty cycle plot 88-108 MHz

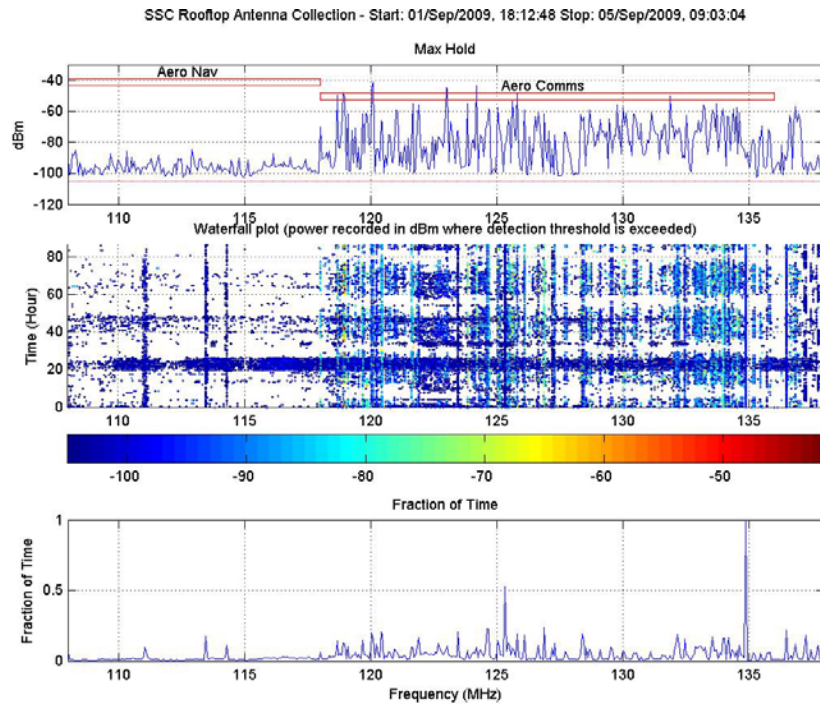


Figure 15. Max hold-waterfall-duty cycle plot 108-138 MHz

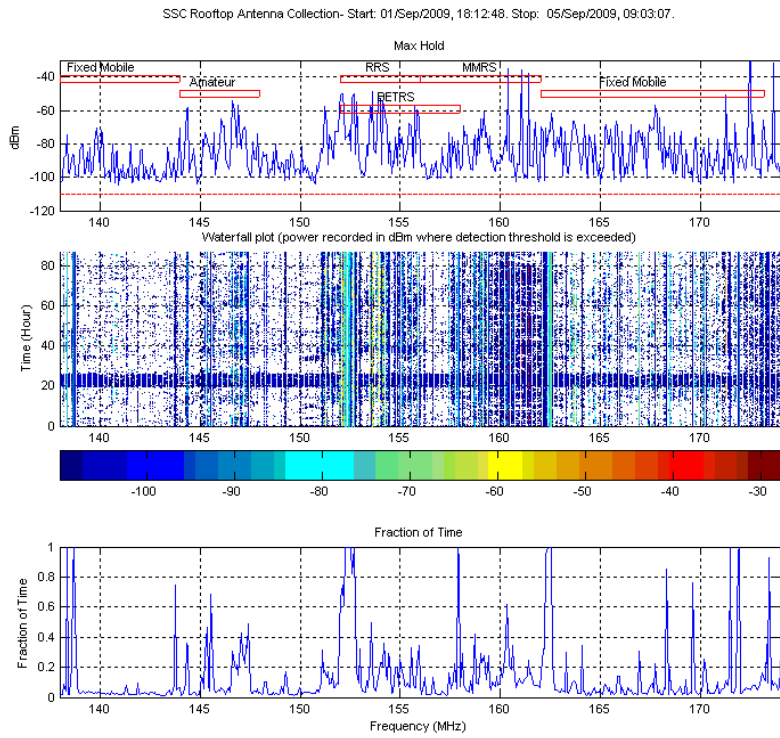


Figure 16. Max hold-waterfall-duty cycle plot 138-174 MHz

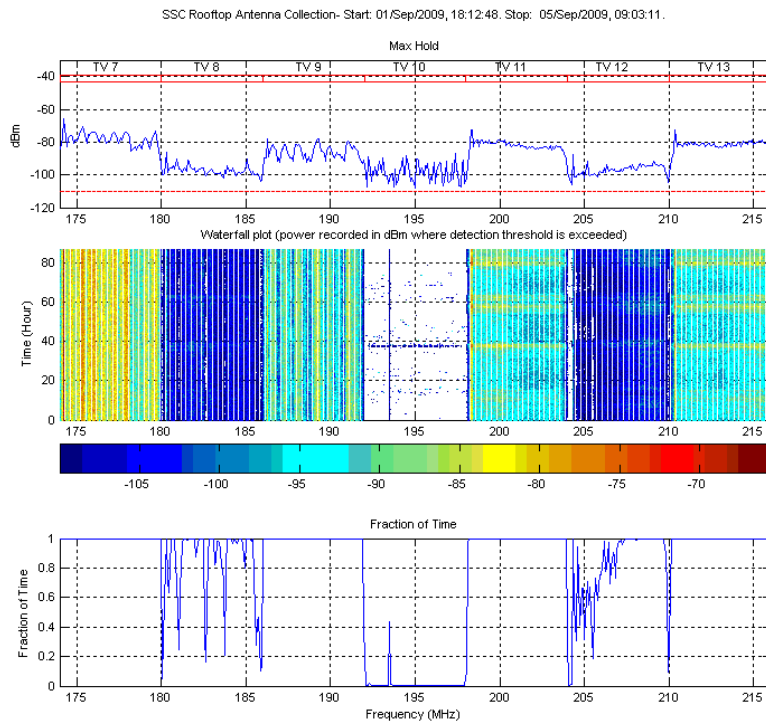


Figure 17. Max hold-waterfall-duty cycle plot 174-216 MHz

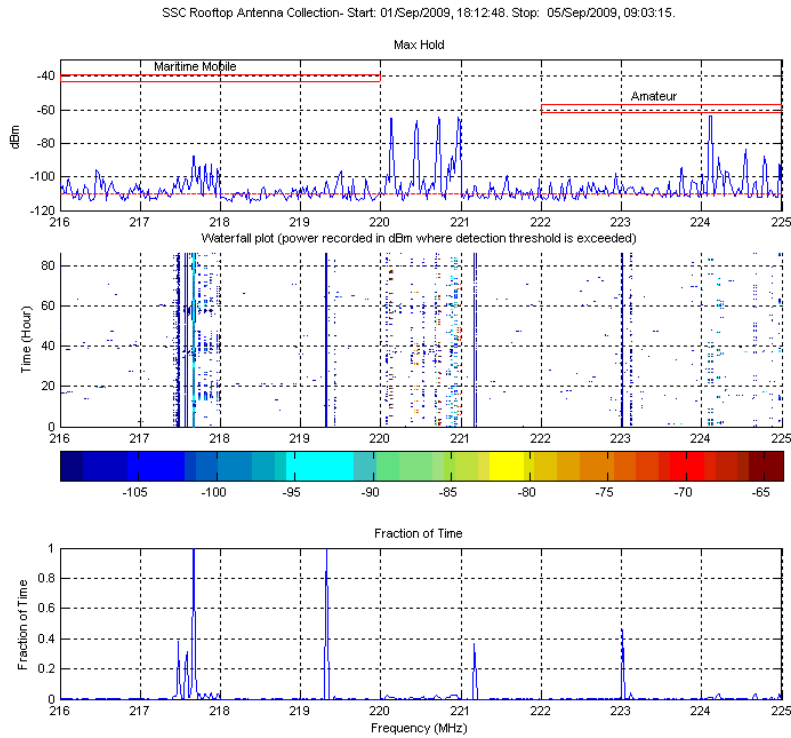


Figure 18. Max hold-waterfall-duty cycle plot 216-225 MHz

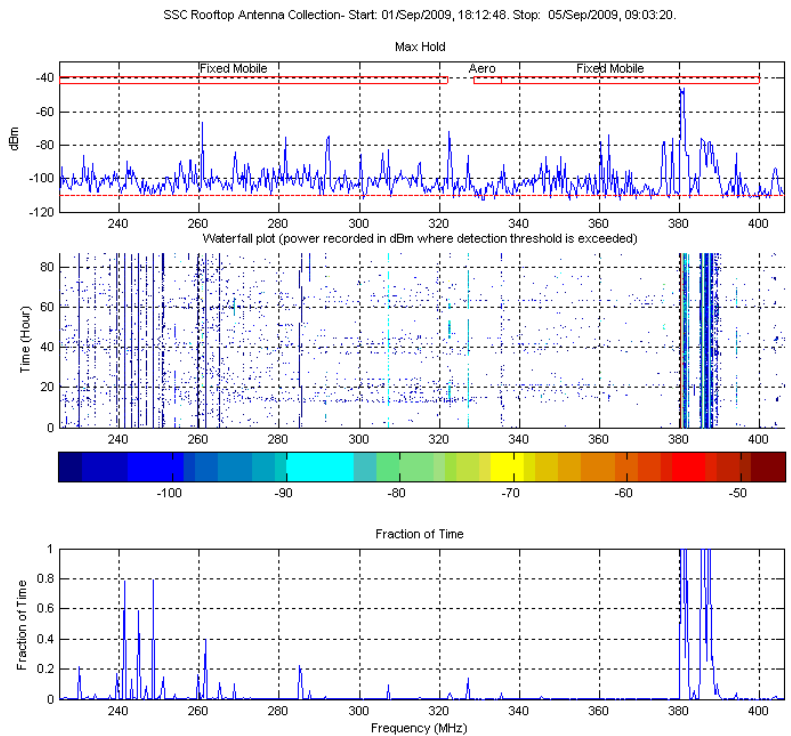


Figure 19. Max hold-waterfall-duty cycle plot 225-406 MHz

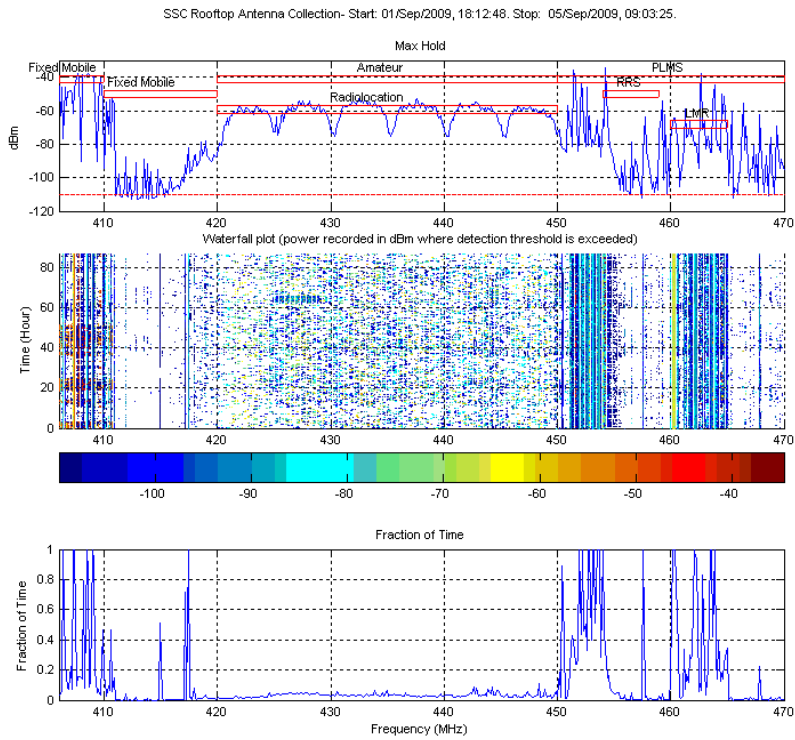


Figure 20. Max hold-waterfall-duty cycle plot 406-470 MHz

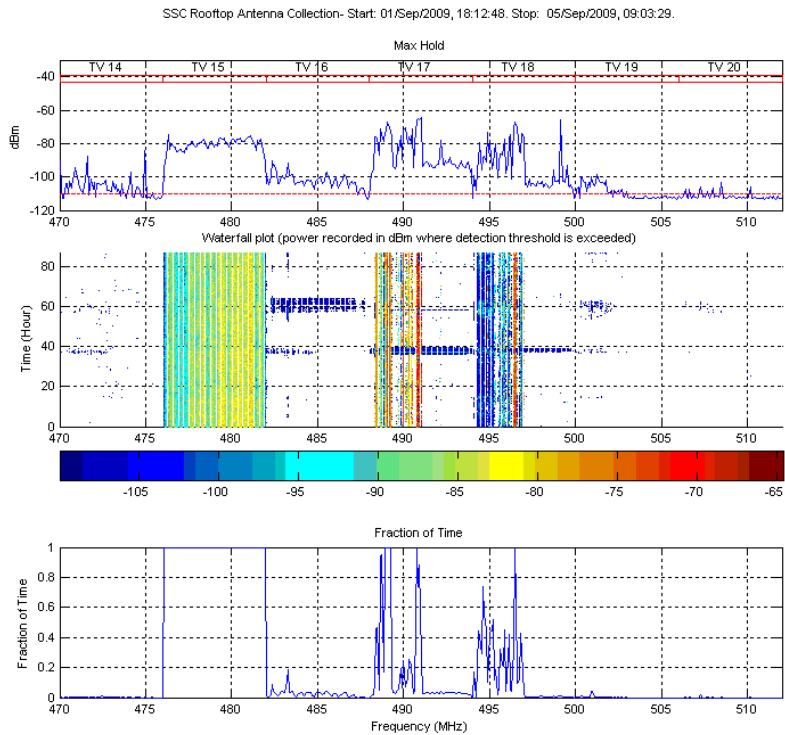


Figure 21. Max hold-waterfall-duty cycle plot 470-512 MHz

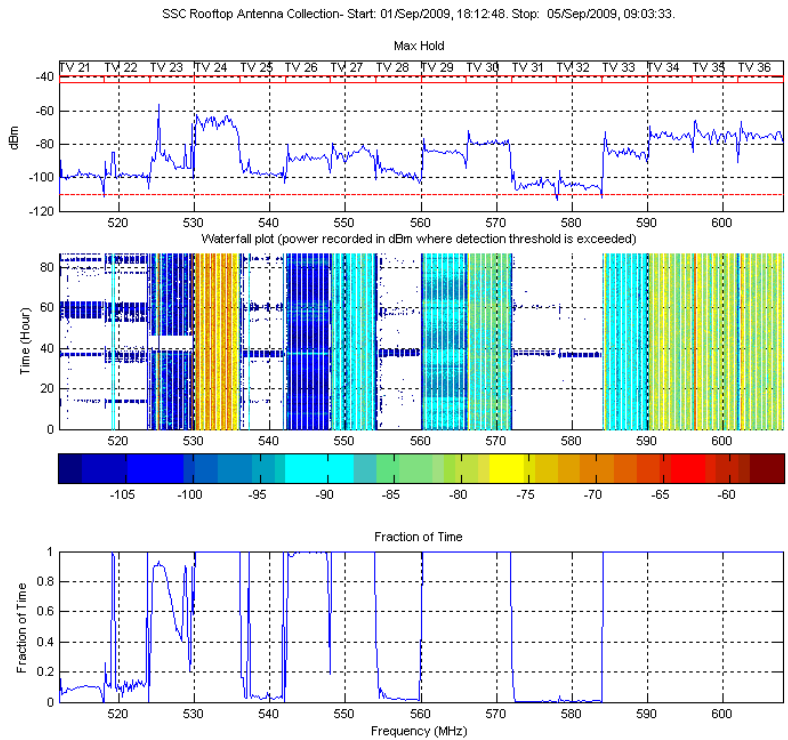


Figure 22. Max hold-waterfall-duty cycle plot 512-608 MHz

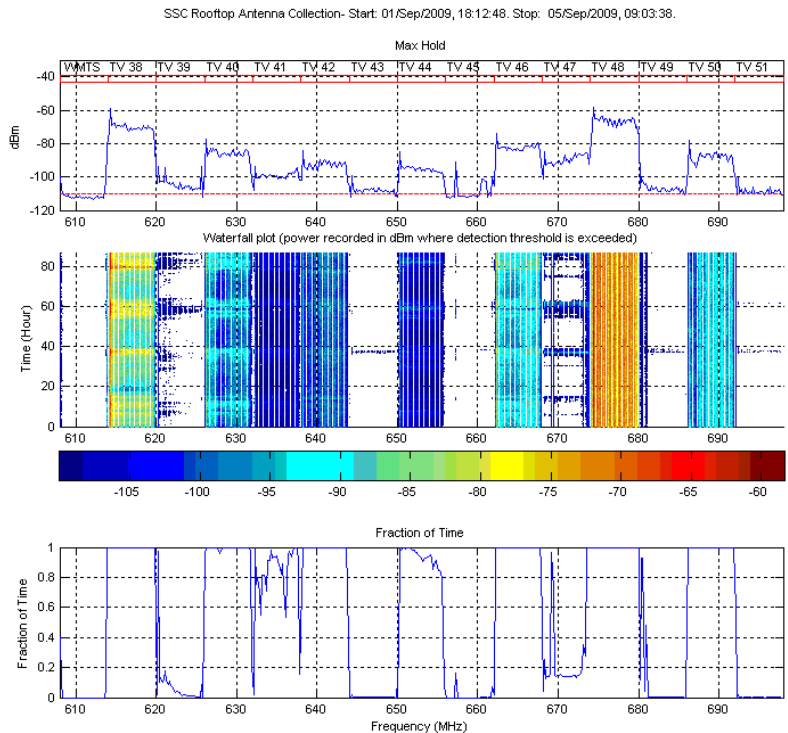


Figure 23. Max hold-waterfall-duty cycle plot 608-698 MHz

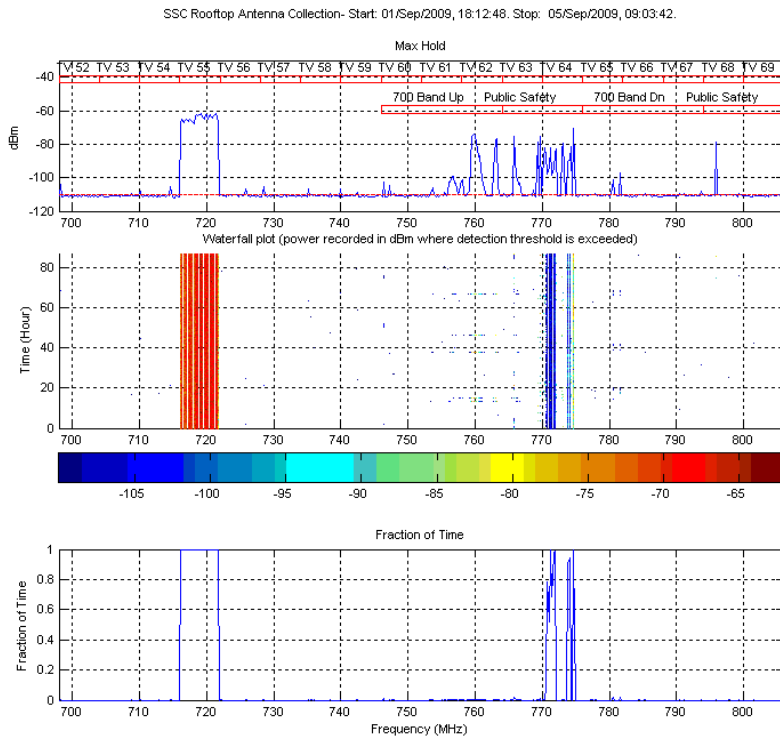


Figure 24. Max hold-waterfall-duty cycle plot 698-806 MHz

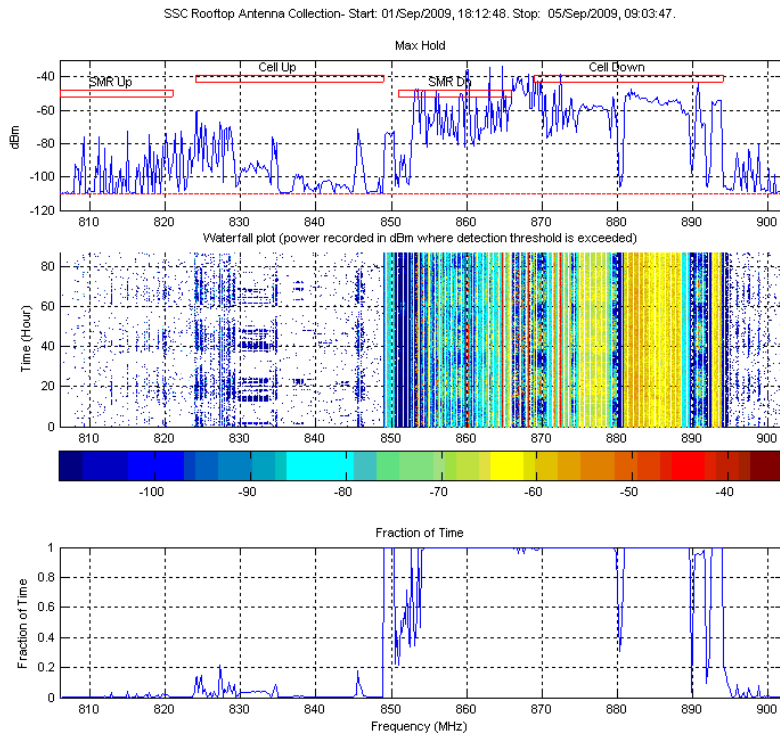


Figure 25. Max hold-waterfall-duty cycle plot 806-902 MHz

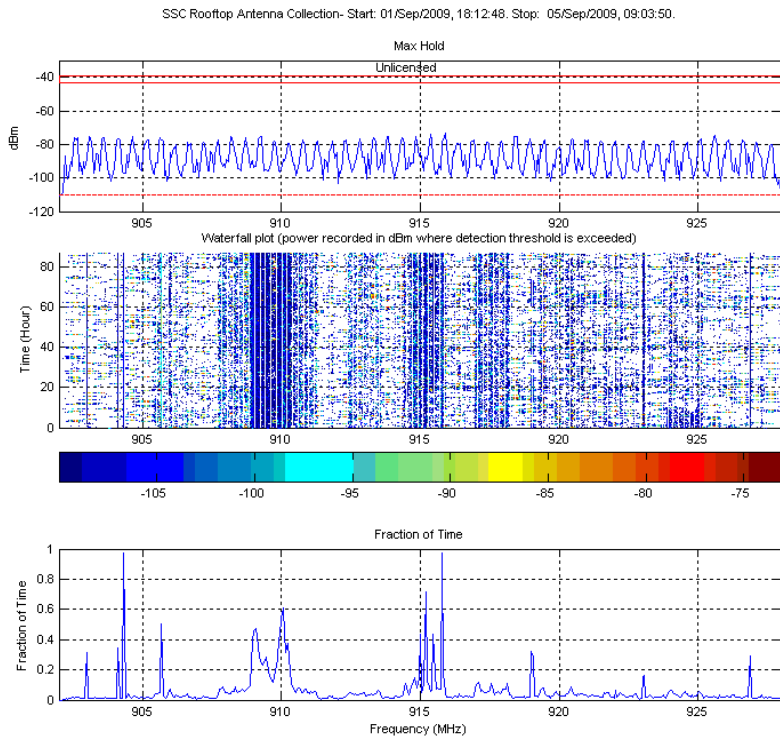


Figure 26. Max hold-waterfall-duty cycle plot 902-928 MHz

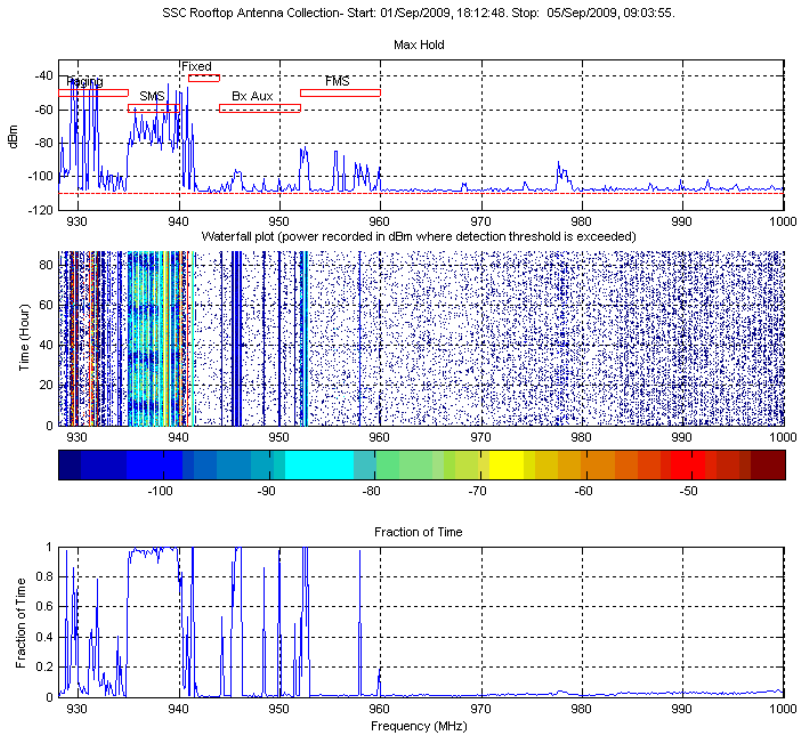


Figure 27. Max hold-waterfall-duty cycle plot 928-1000 MHz

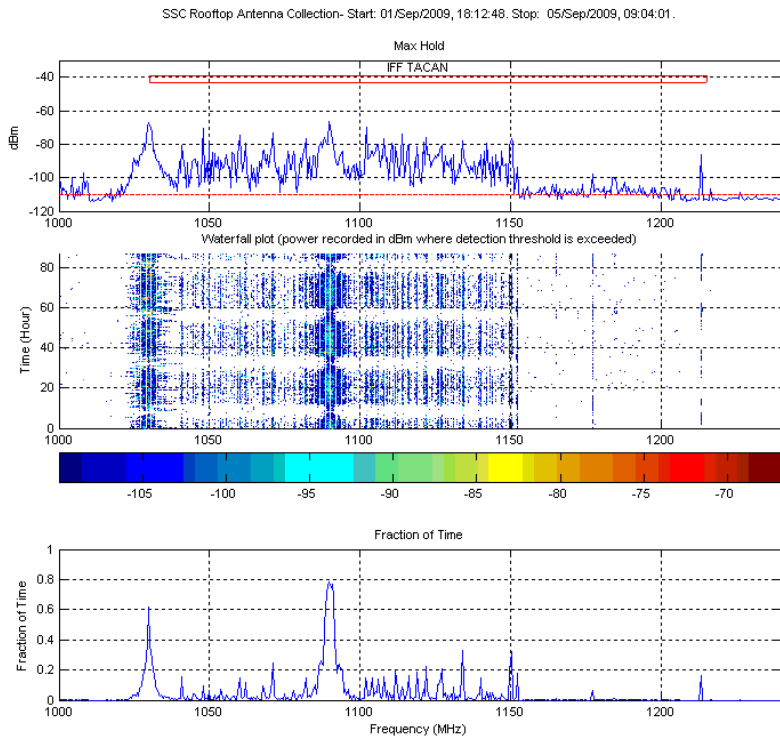


Figure 28. Max hold-waterfall-duty cycle plot 1000-1240 MHz

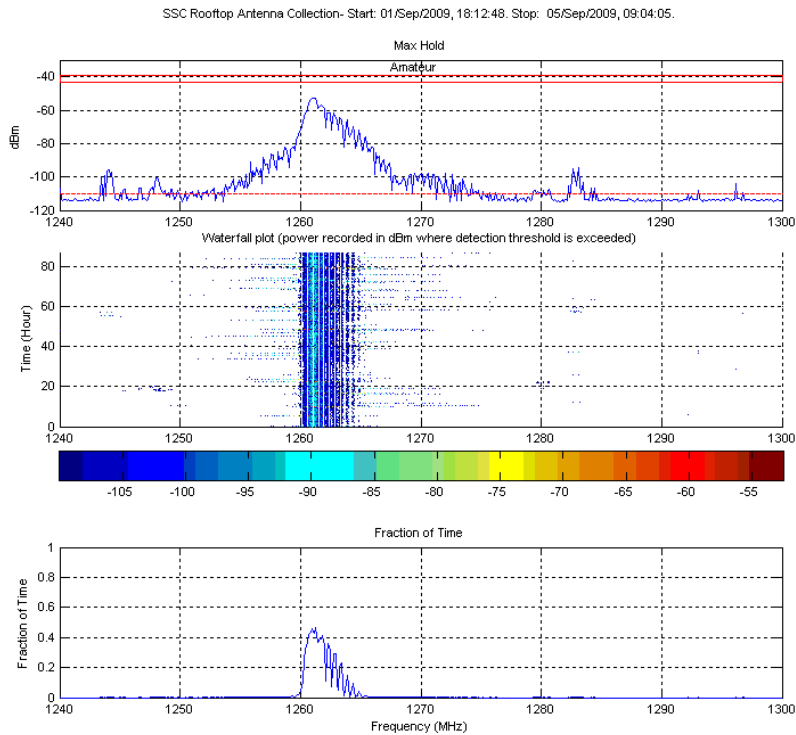


Figure 29. Max hold-waterfall-duty cycle plot 1240-1300 MHz

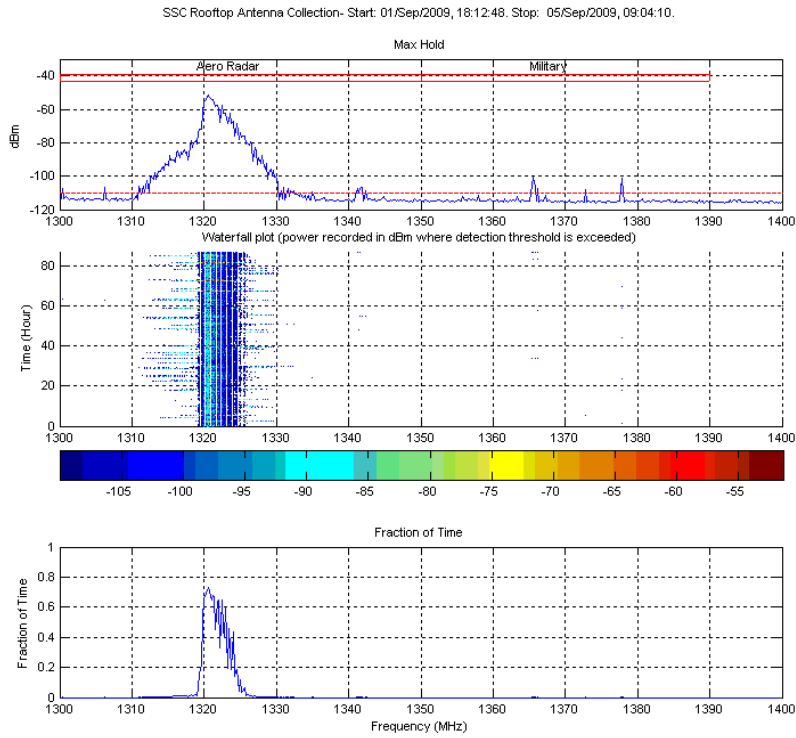


Figure 30. Max hold-waterfall-duty cycle plot 1300-1400 MHz

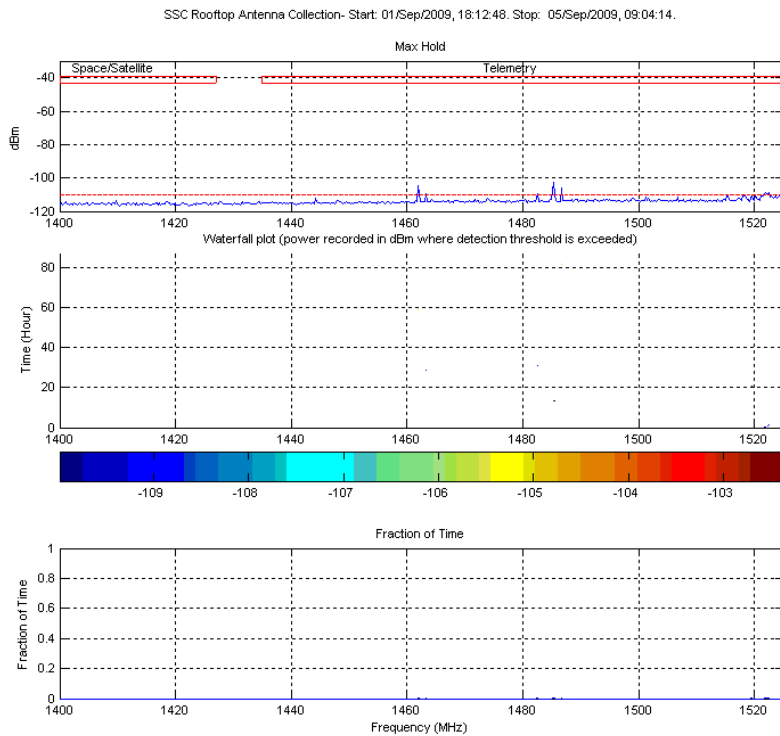


Figure 31. Max hold-waterfall-duty cycle plot 1400-1525 MHz

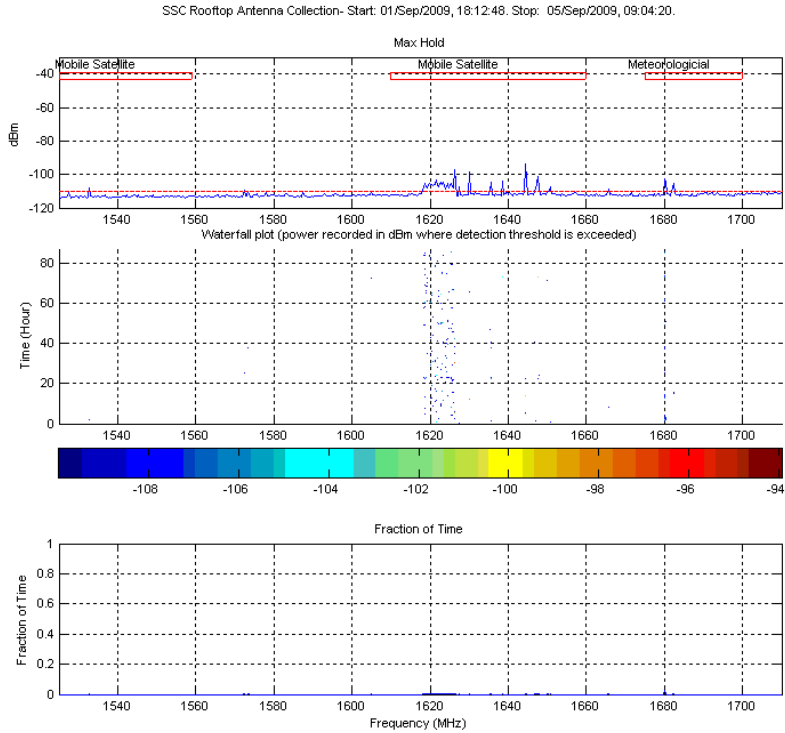


Figure 32. Max hold-waterfall-duty cycle plot 1525-1710 MHz

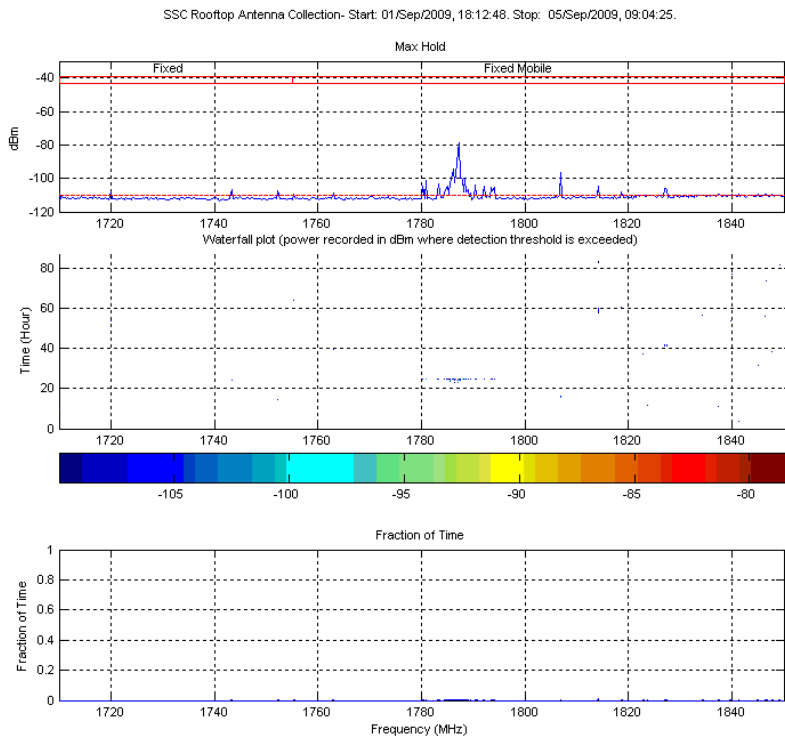


Figure 33. Max hold-waterfall-duty cycle plot 1710-1850 MHz

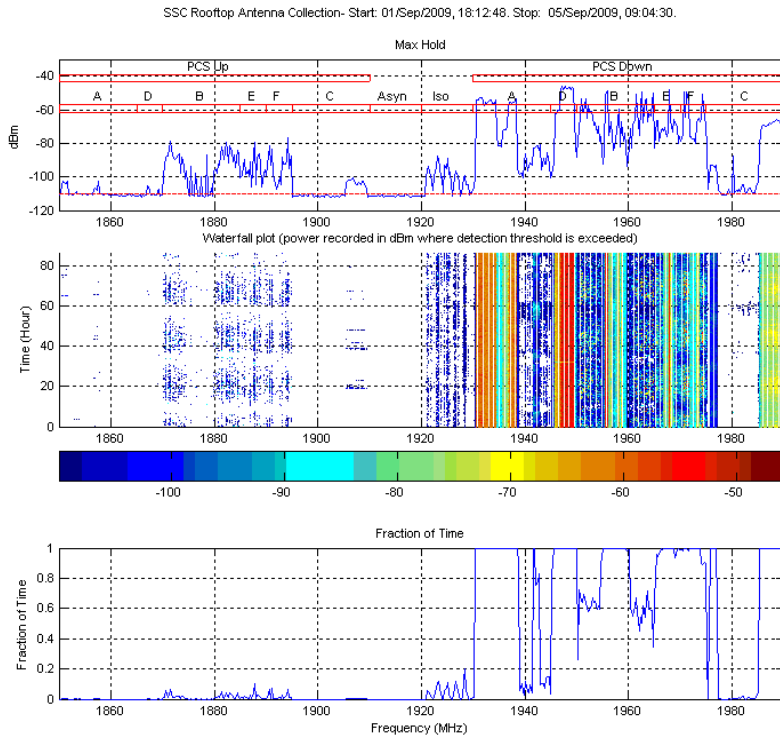


Figure 34. Max hold-waterfall-duty cycle plot 1850-1990 MHz

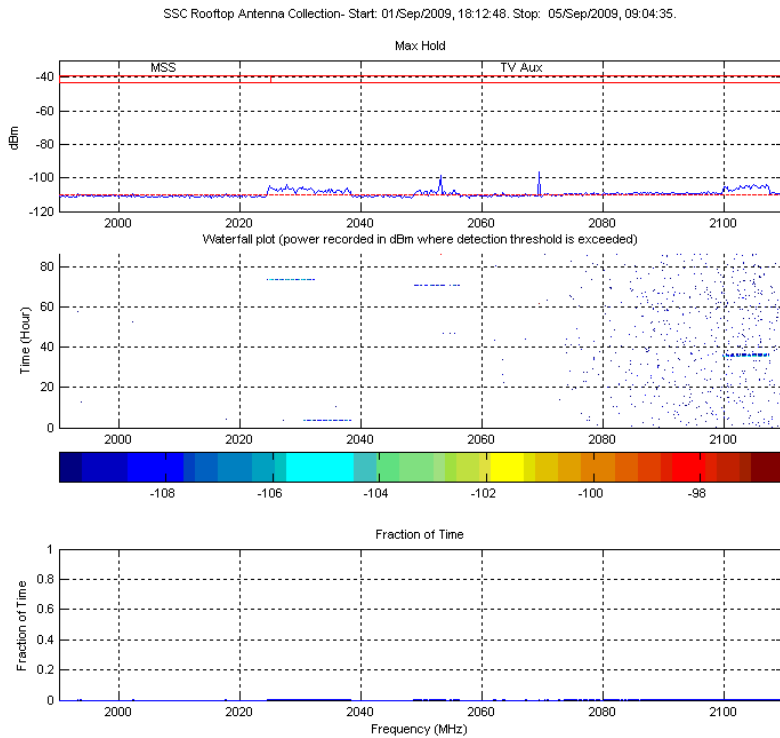


Figure 35. Max hold-waterfall-duty cycle plot 1990-2110 MHz

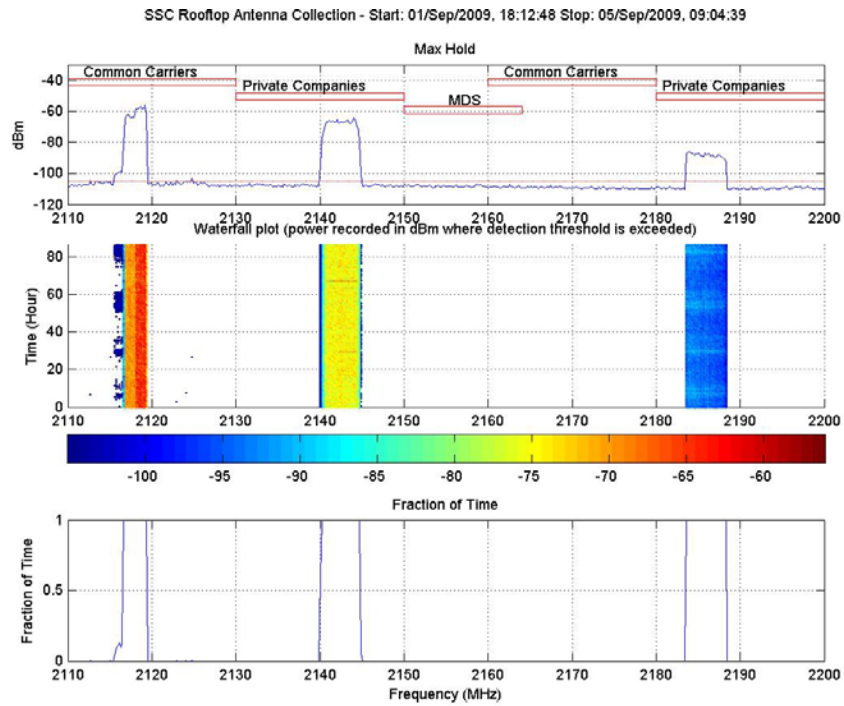


Figure 36. Max hold-waterfall-duty cycle plot 2110-2200 MHz

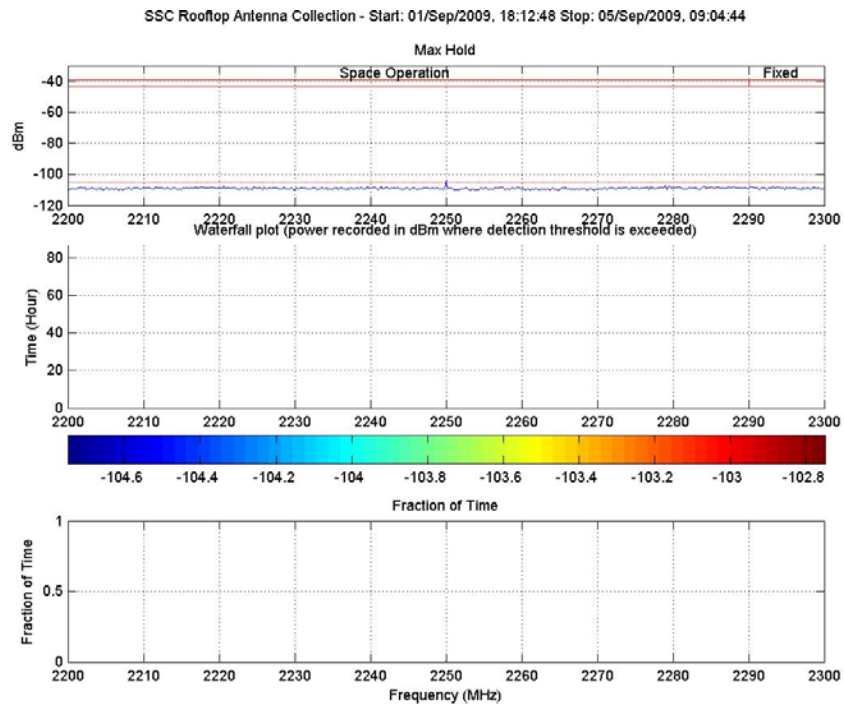


Figure 37. Max hold-waterfall-duty cycle plot 2200-2300 MHz

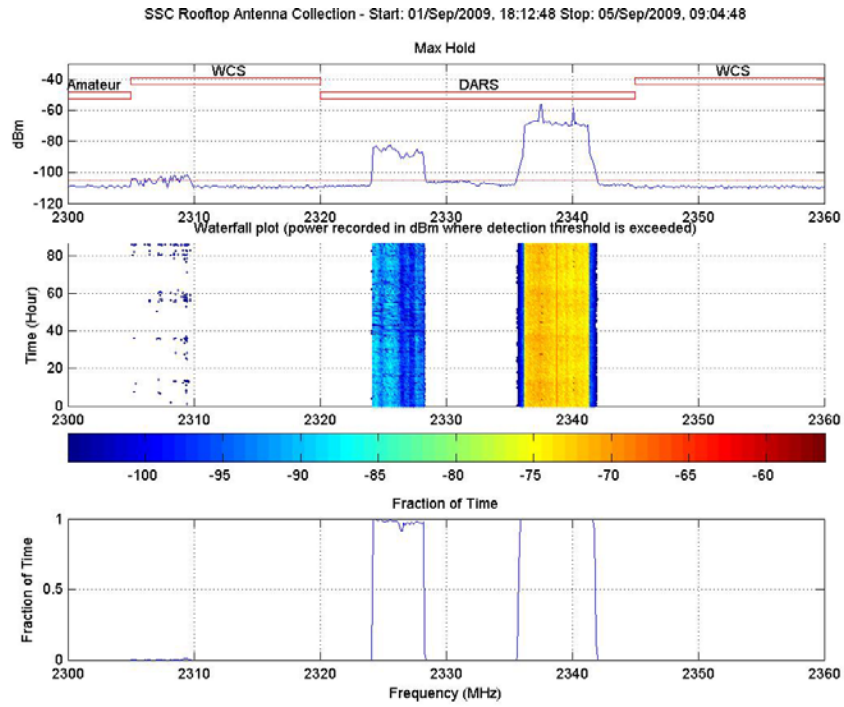


Figure 38. Max hold-waterfall-duty cycle plot 2300-2360 MHz

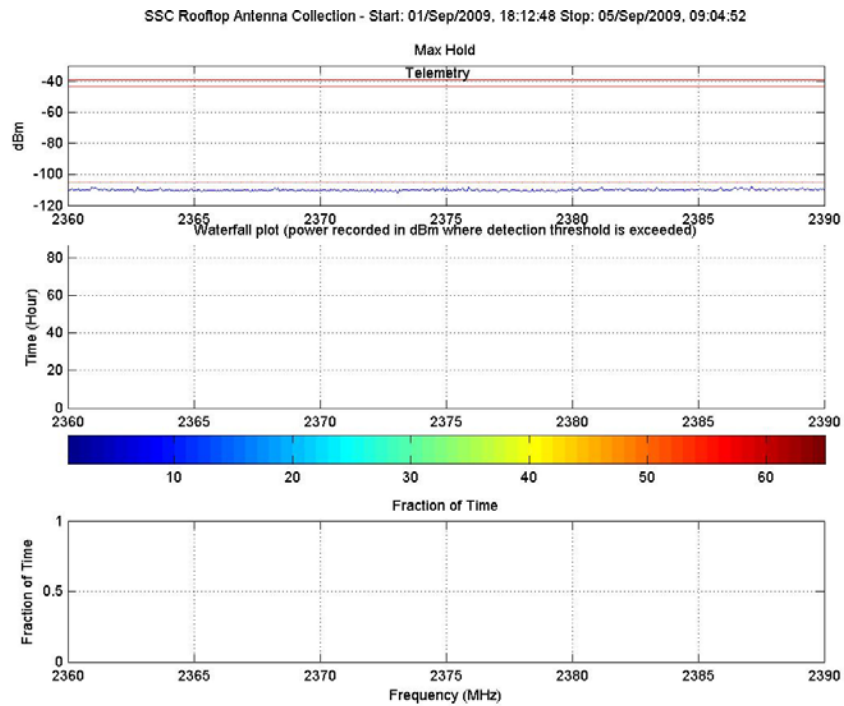


Figure 39. Max hold-waterfall-duty cycle plot 2360-2390 MHz

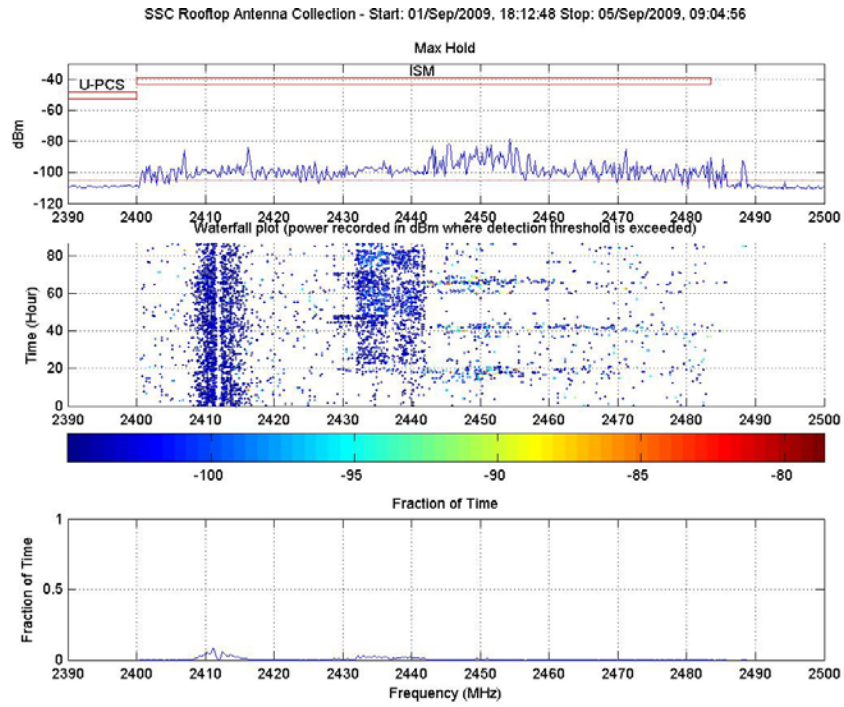


Figure 40. Max hold-waterfall-duty cycle plot 2390-2500 MHz

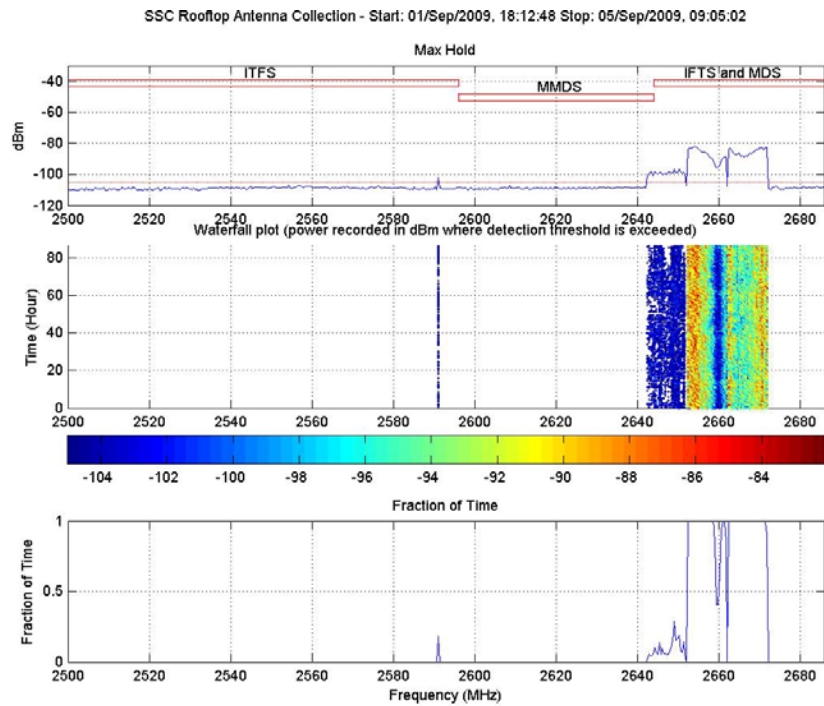


Figure 41. Max hold-waterfall-duty cycle plot 2500-2686 MHz

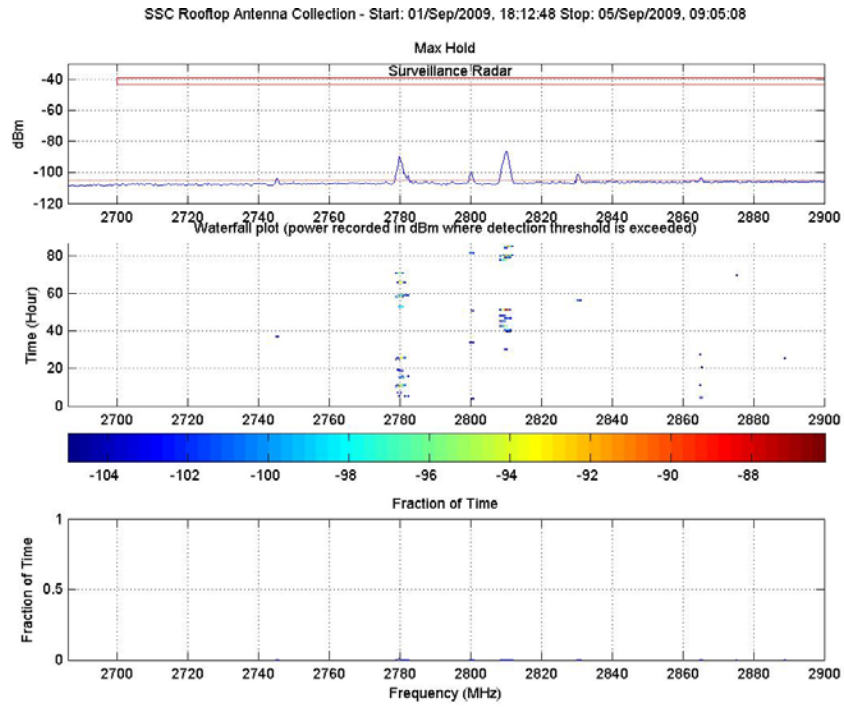


Figure 42. Max hold-waterfall-duty cycle plot 2686-2900 MHz

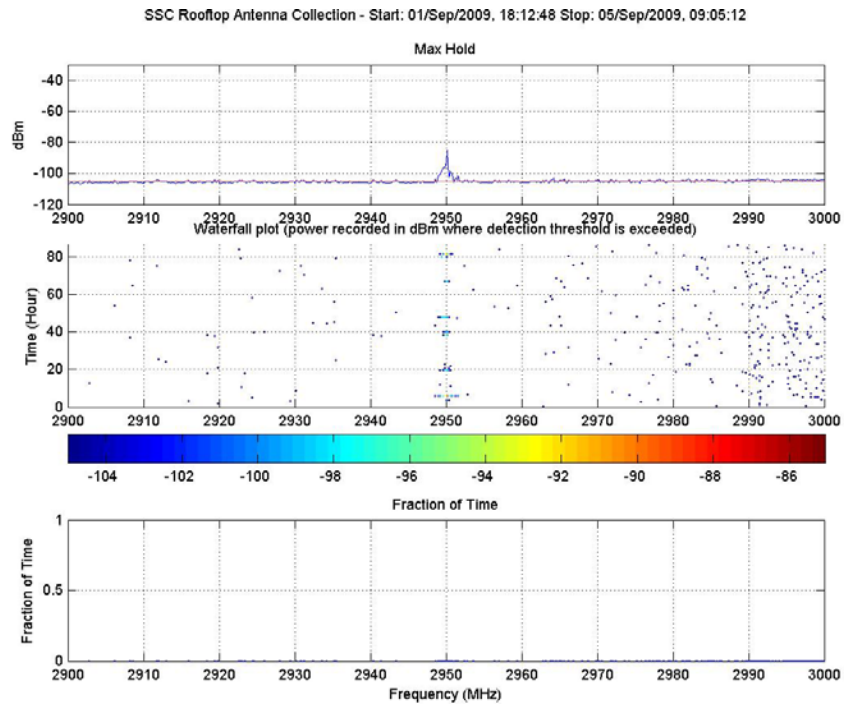


Figure 43. Max hold-waterfall-duty cycle plot 2900-3000 MHz

Appendix B – Spectrum Hole Plots

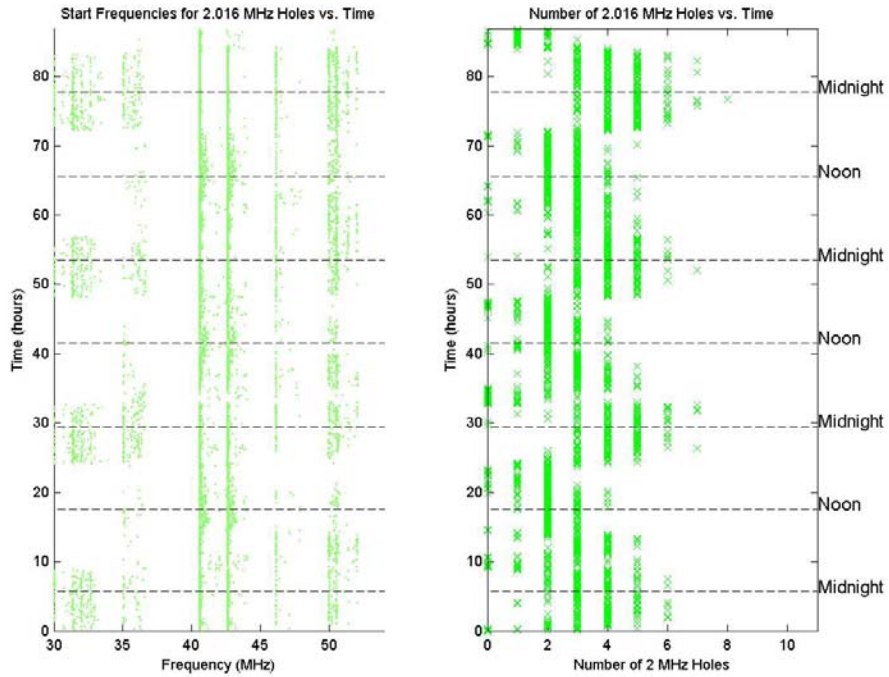


Figure 44. Spectrum hole analysis plot for 30-54 MHz band – Band 1

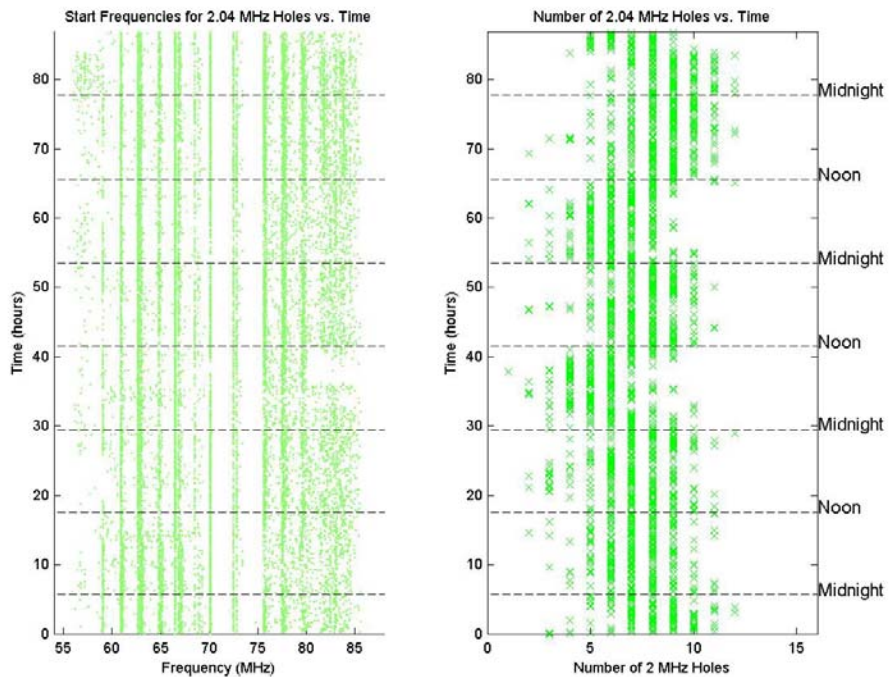


Figure 45. Spectrum hole analysis plot for 54-88 MHz band – Band 2

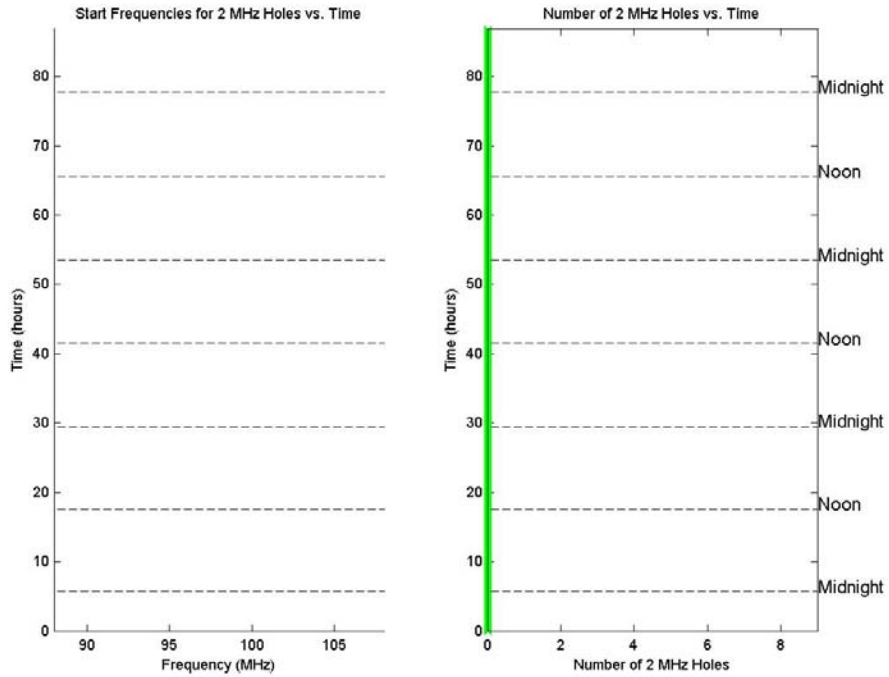


Figure 46. Spectrum hole analysis plot for 88-108 MHz band – Band 3

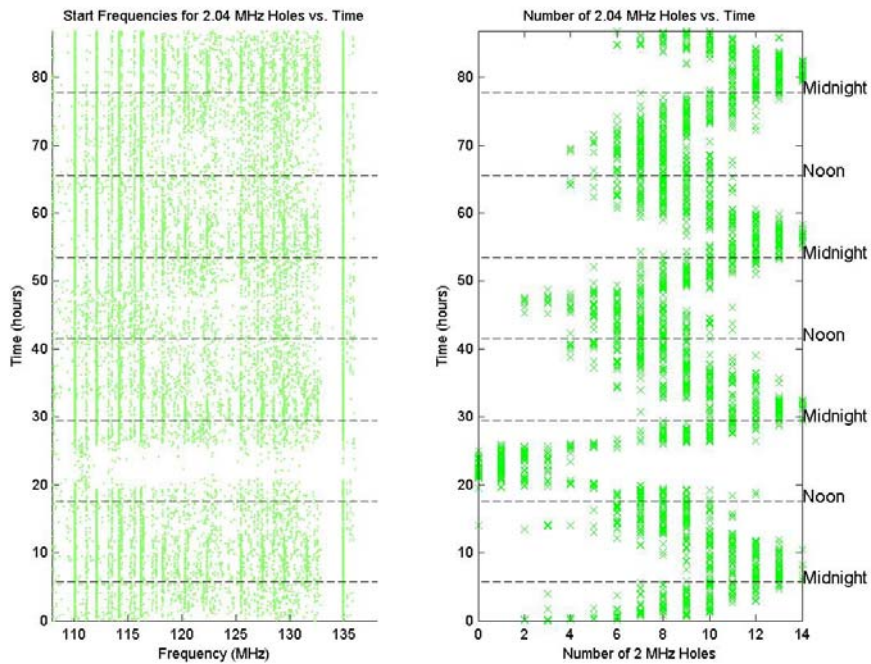


Figure 47. Spectrum hole analysis plot for 108-138 MHz band – Band 4

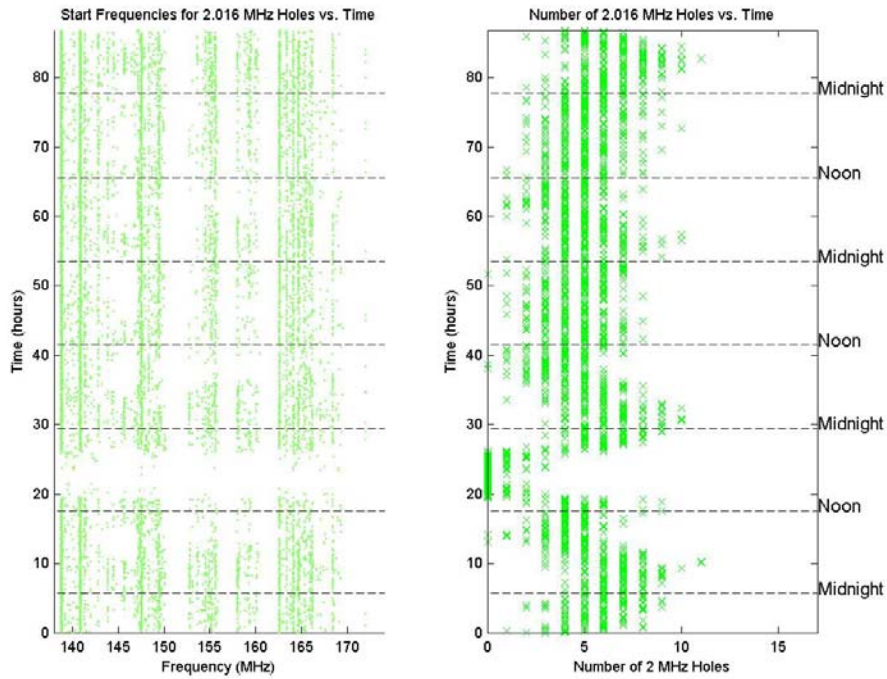


Figure 48. Spectrum hole analysis plot for 138-174 MHz band – Band 5

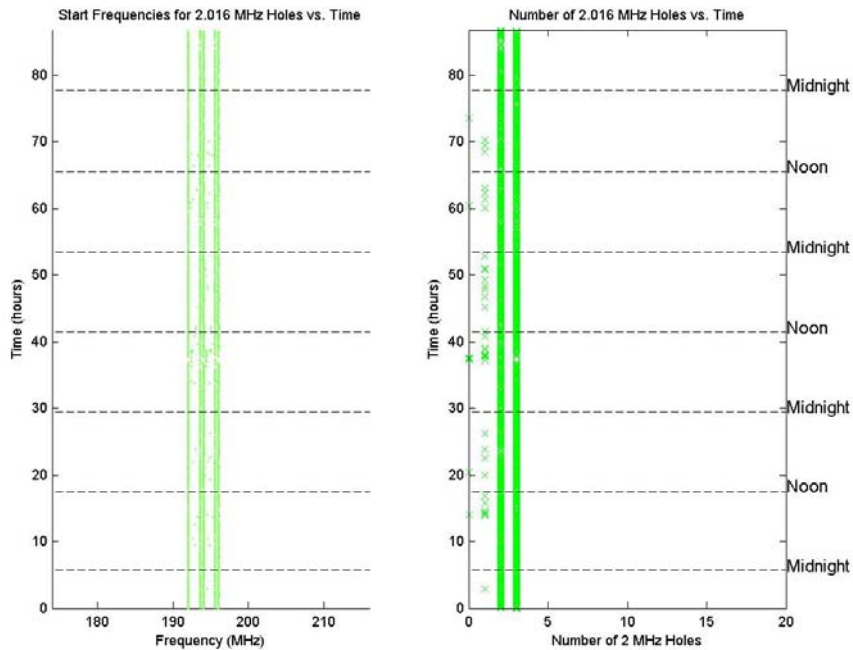


Figure 49. Spectrum hole analysis plot for 174-216 MHz band – Band 6

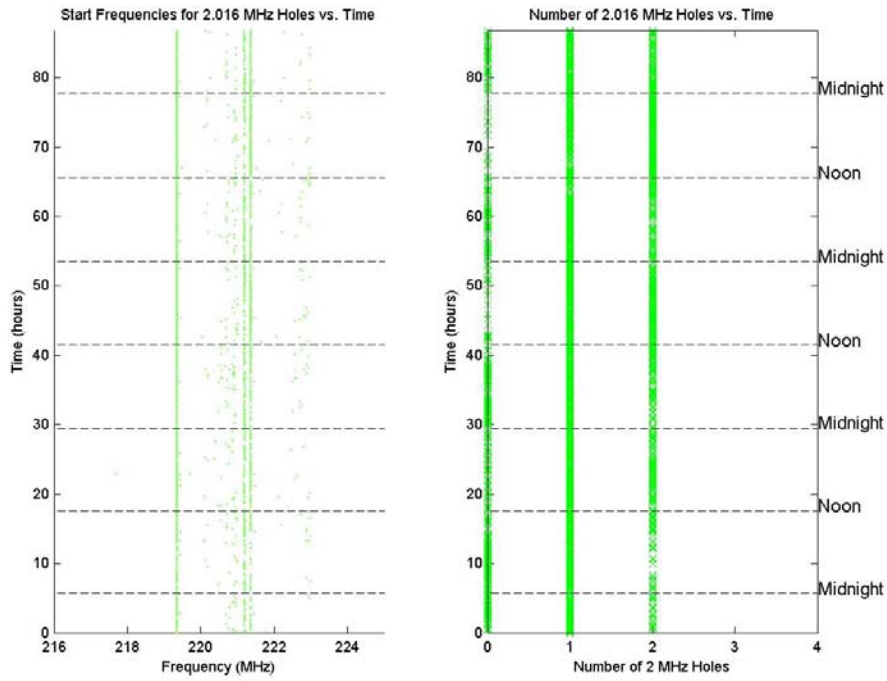


Figure 50. Spectrum hole analysis plot for 216-225 MHz band – Band 7

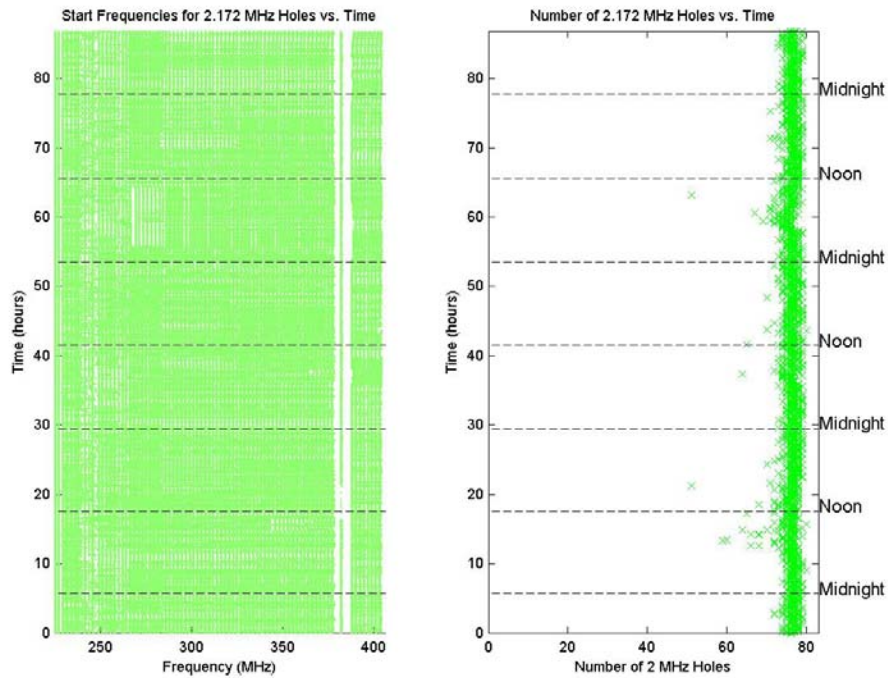


Figure 51. Spectrum hole analysis plot for 225-406 MHz band – Band 8

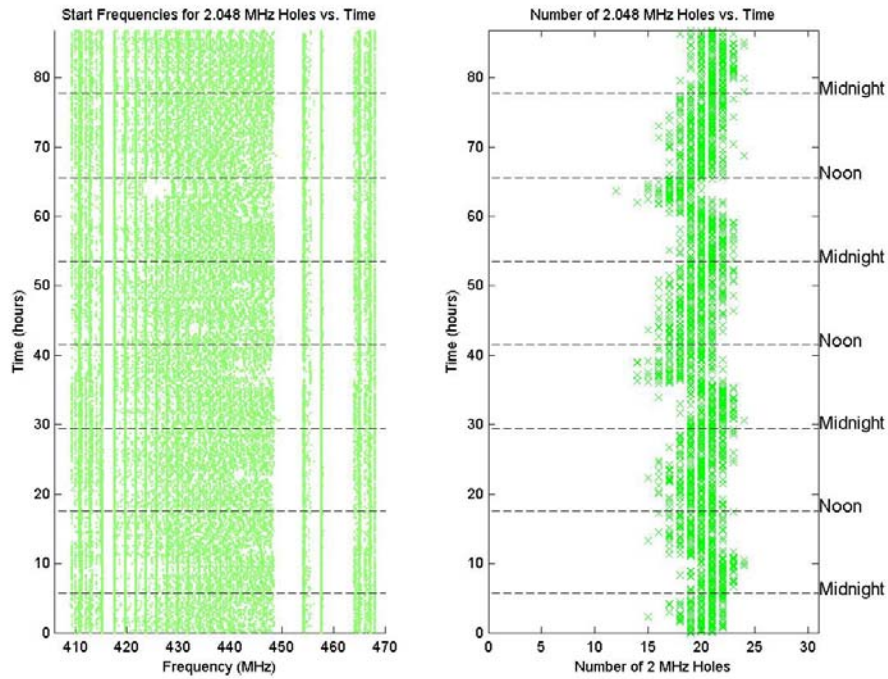


Figure 52. Spectrum hole analysis plot for 406-470 MHz band – Band 9

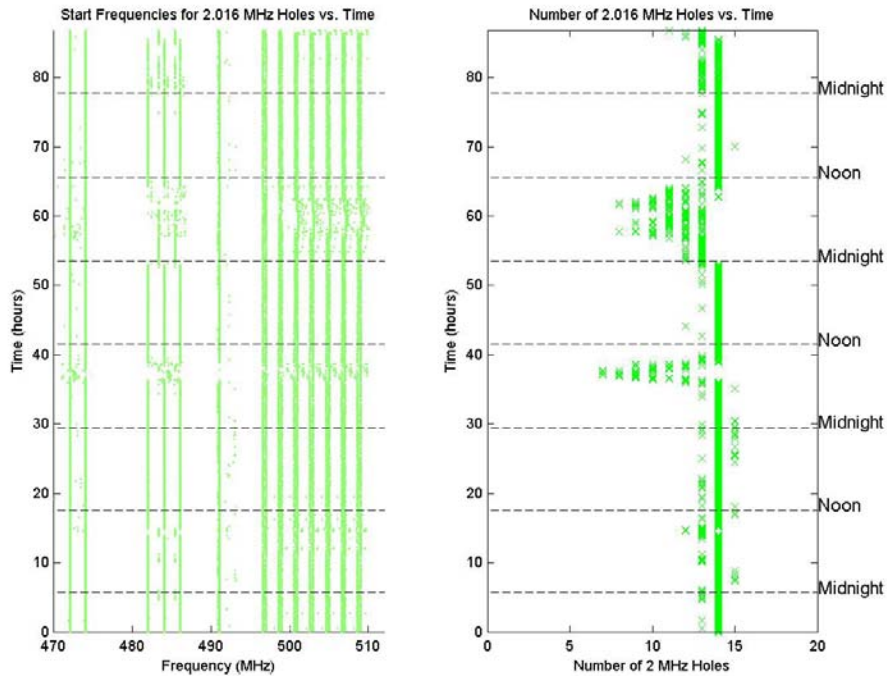


Figure 53. Spectrum hole analysis plot for 470-512 MHz band – Band 10

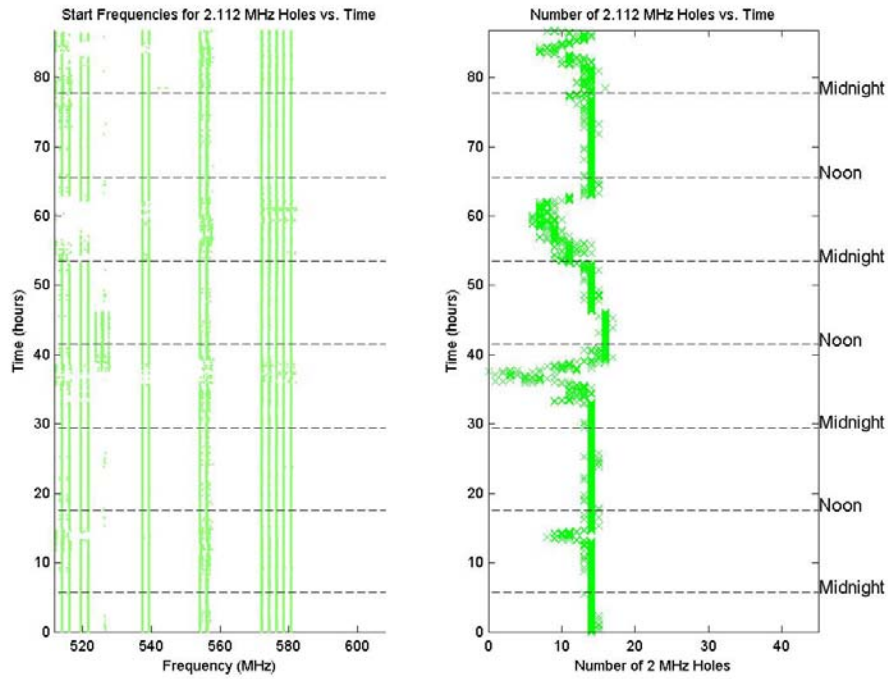


Figure 54. Spectrum hole analysis plot for 512-608 MHz band – Band 11

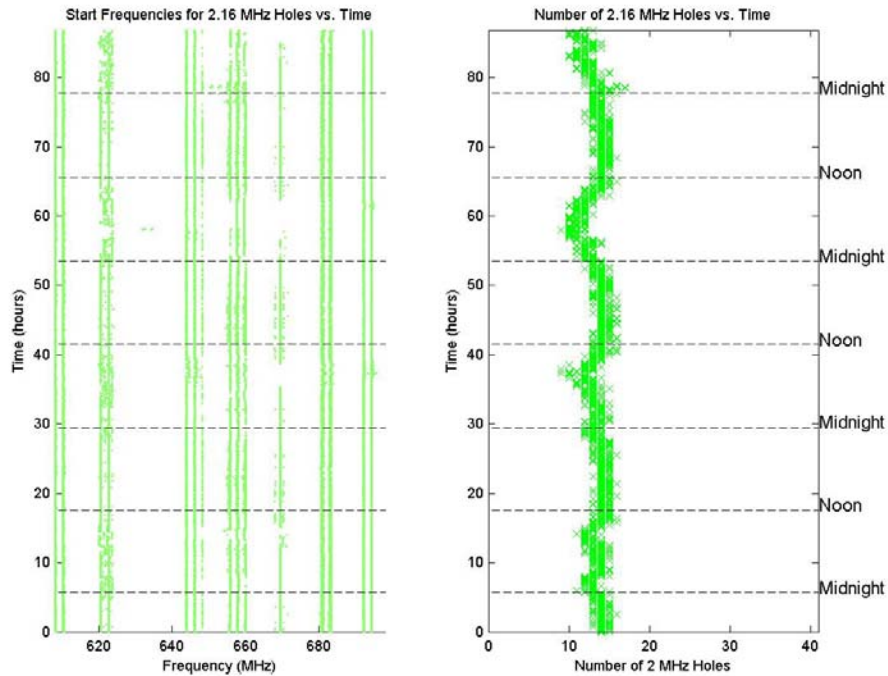


Figure 55. Spectrum hole analysis plot for 608-698 MHz band – Band 12

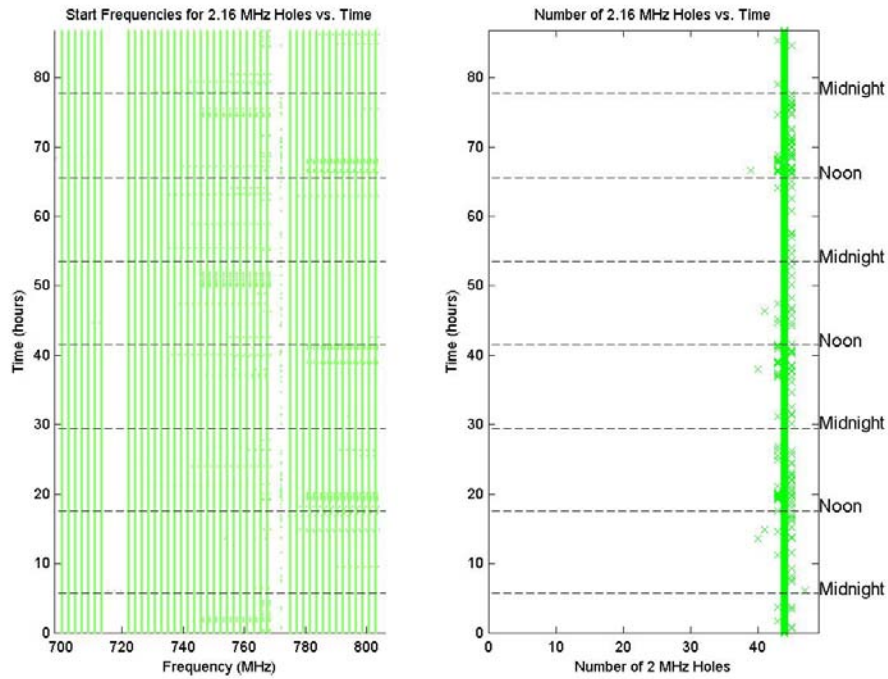


Figure 56. Spectrum hole analysis plot for 698-806 MHz band – Band 13

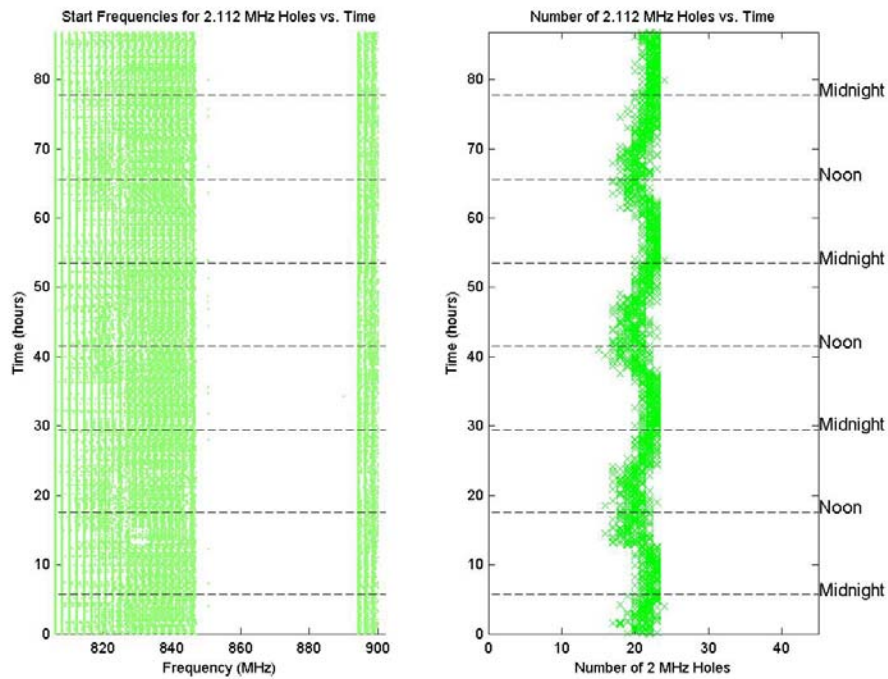


Figure 57. Spectrum hole analysis plot for 806-902 MHz band – Band 14

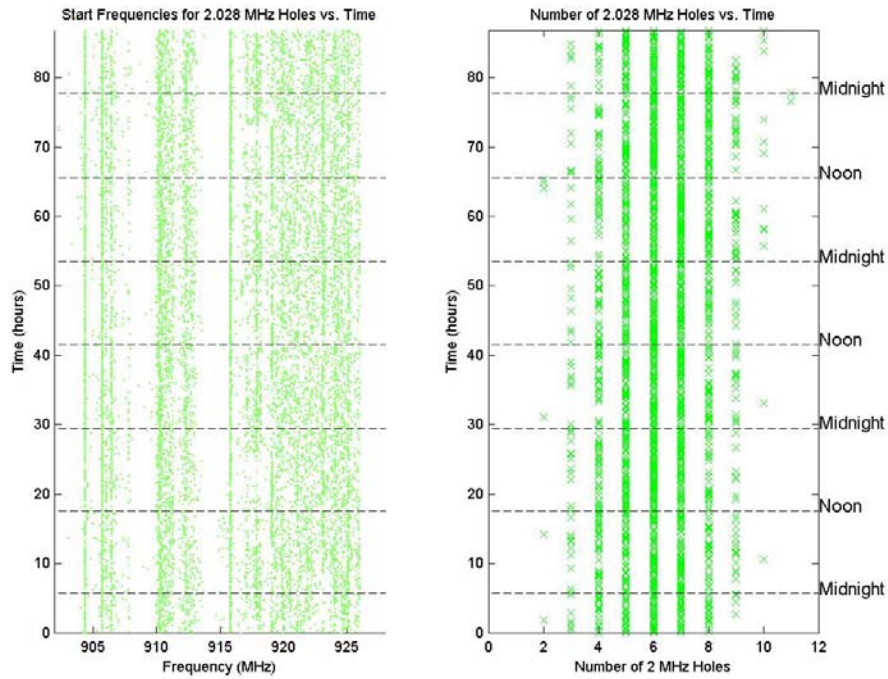


Figure 58. Spectrum hole analysis plot for 902-928 MHz band – Band 15

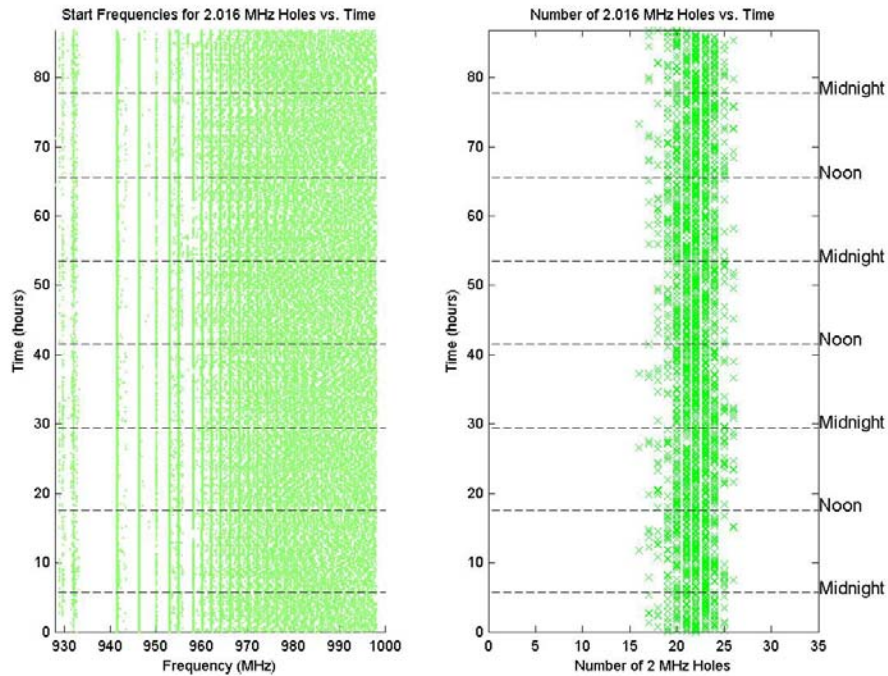


Figure 59. Spectrum hole analysis plot for 928-1000 MHz band – Band 16

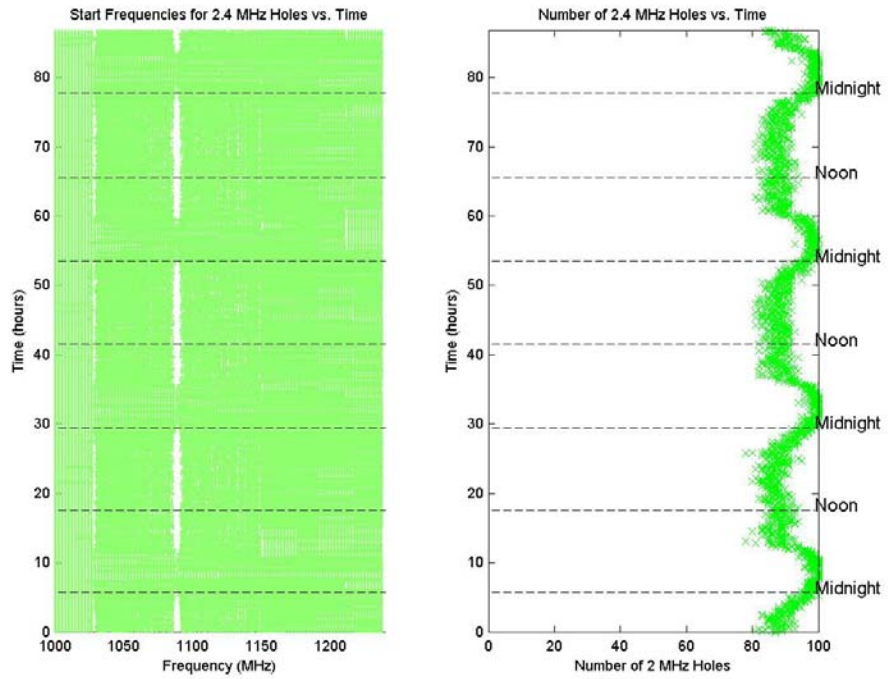


Figure 60. Spectrum hole analysis plot for 1000-1240 MHz band – Band 17

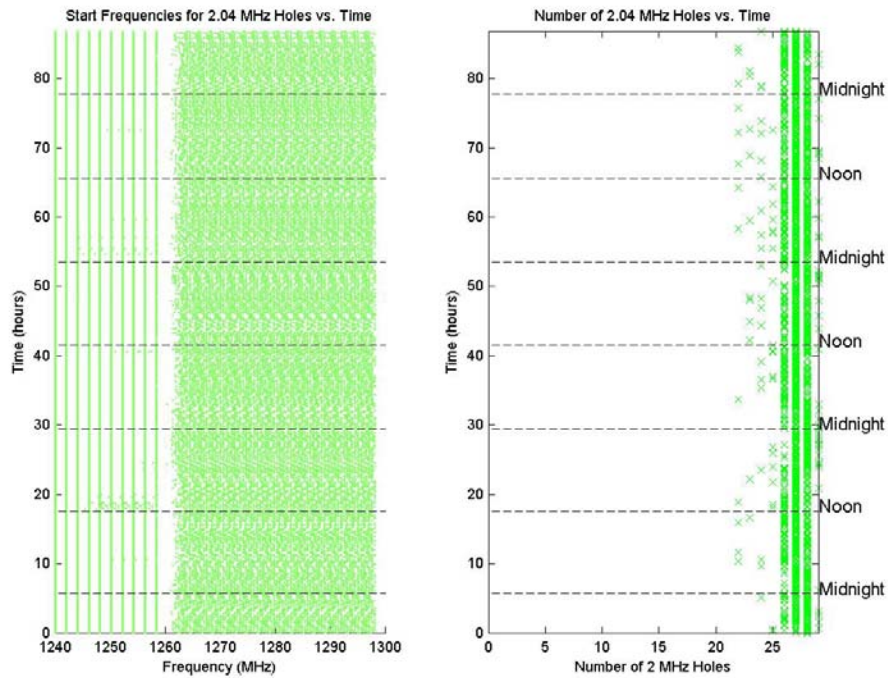


Figure 61. Spectrum hole analysis plot for 1240-1300 MHz band – Band 18

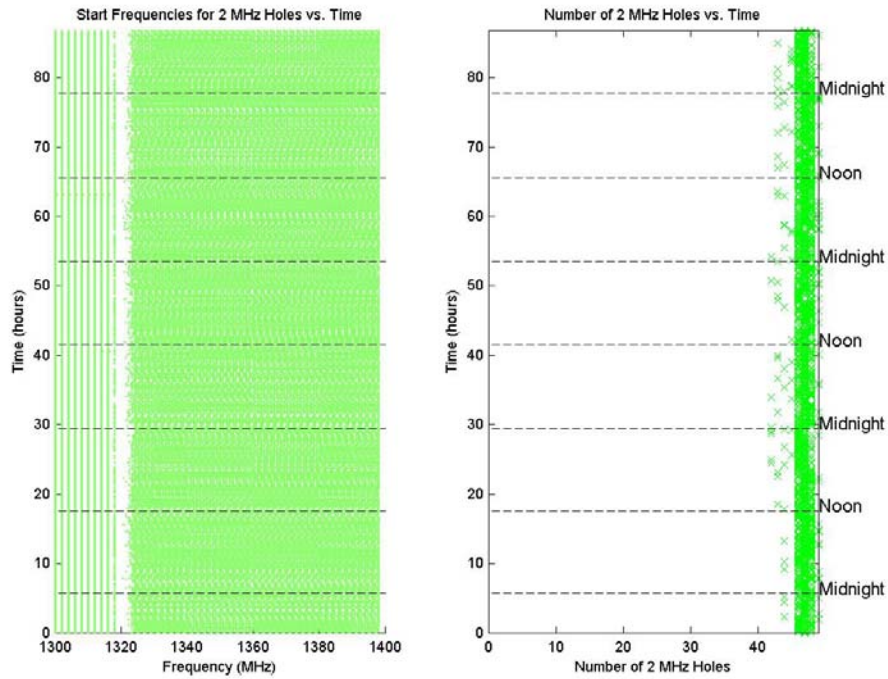


Figure 62. Spectrum hole analysis plot for 1300-1400 MHz band – Band 19

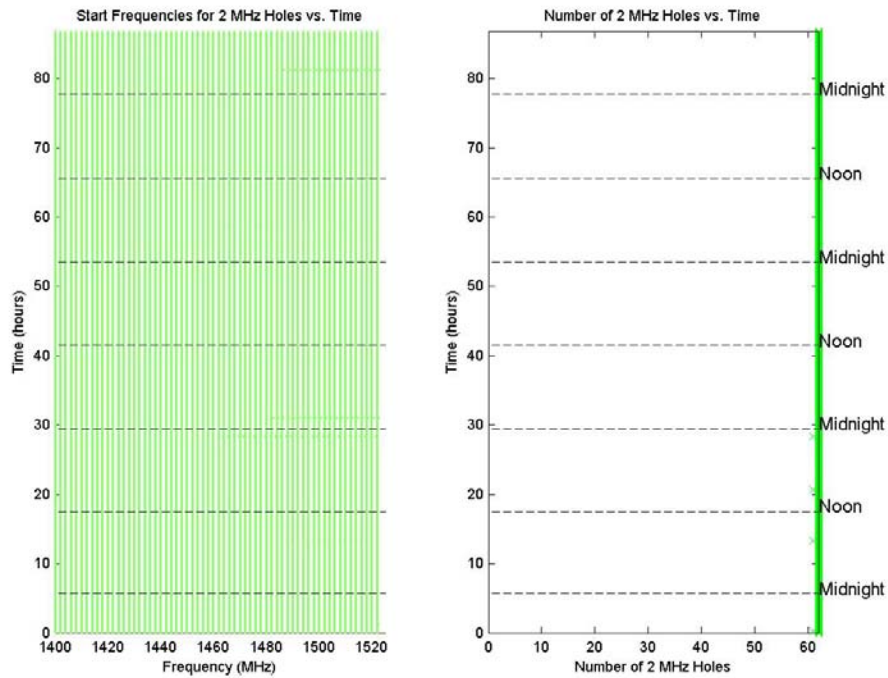


Figure 63. Spectrum hole analysis plot for 1400-1525 MHz band – Band 20

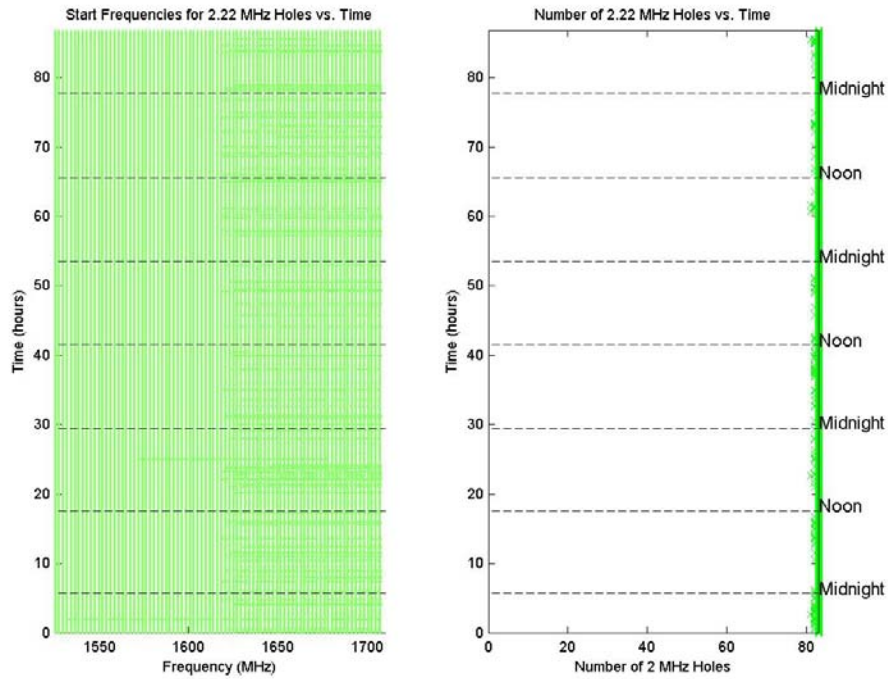


Figure 64. Spectrum hole analysis plot for 1525-1710 MHz band – Band 21

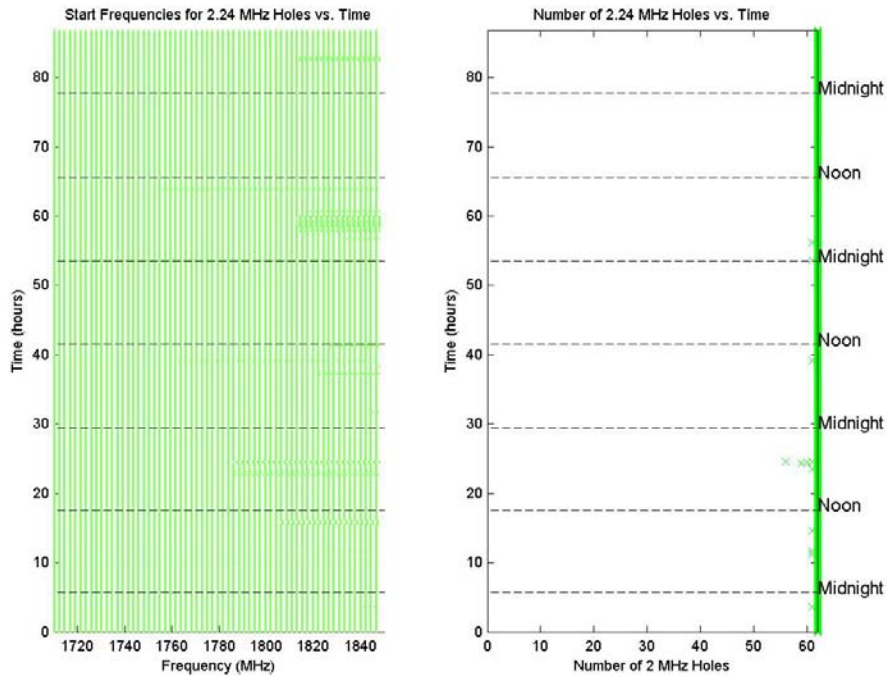


Figure 65. Spectrum hole analysis plot for 1710-1850 MHz band – Band 22

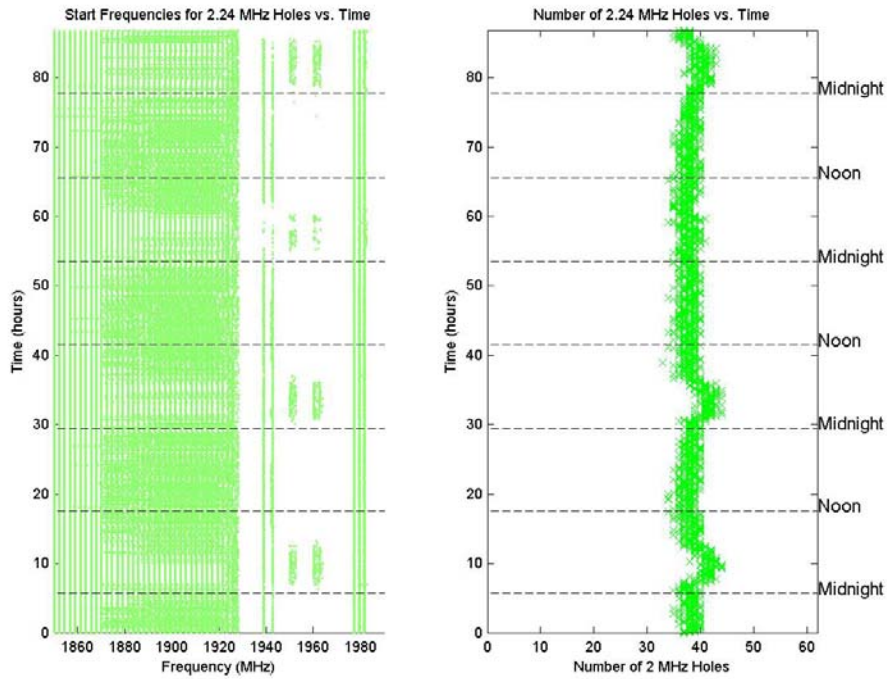


Figure 66. Spectrum hole analysis plot for 1850-1990 MHz band – Band 23

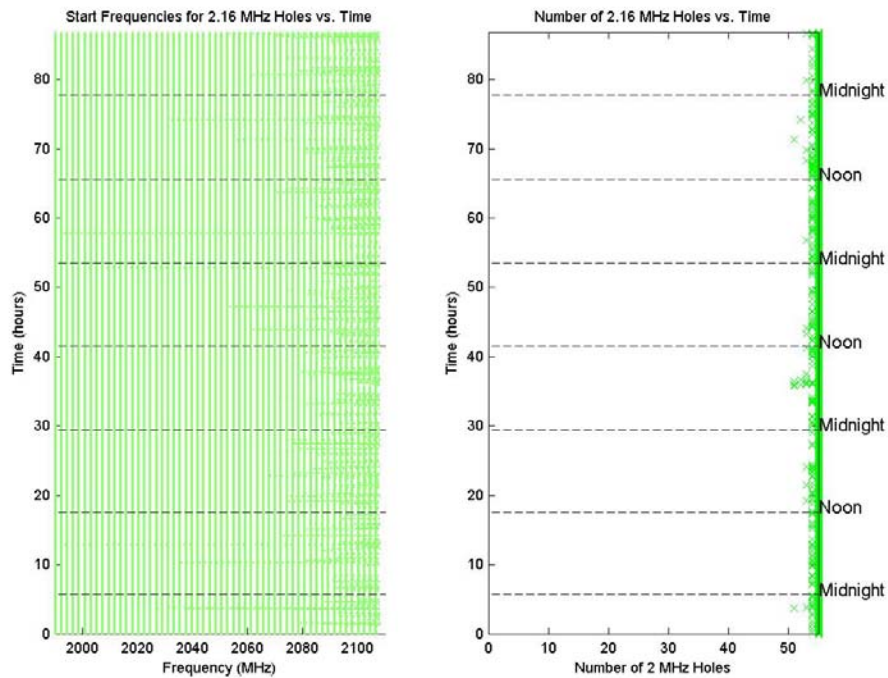


Figure 67. Spectrum hole analysis plot for 1990-2110 MHz band – Band 24

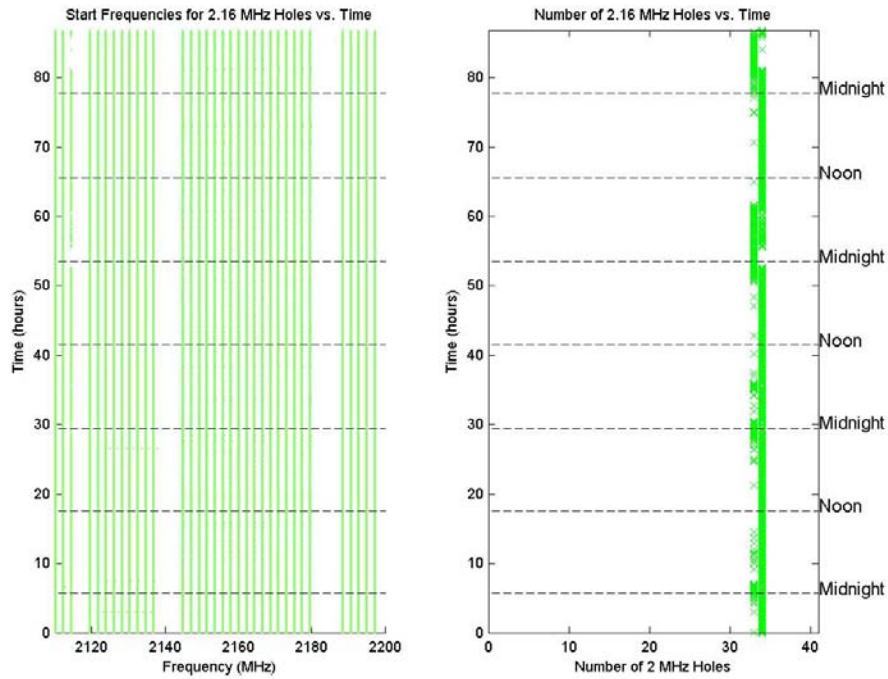


Figure 68. Spectrum hole analysis plot for 2110-2200 MHz band – Band 25

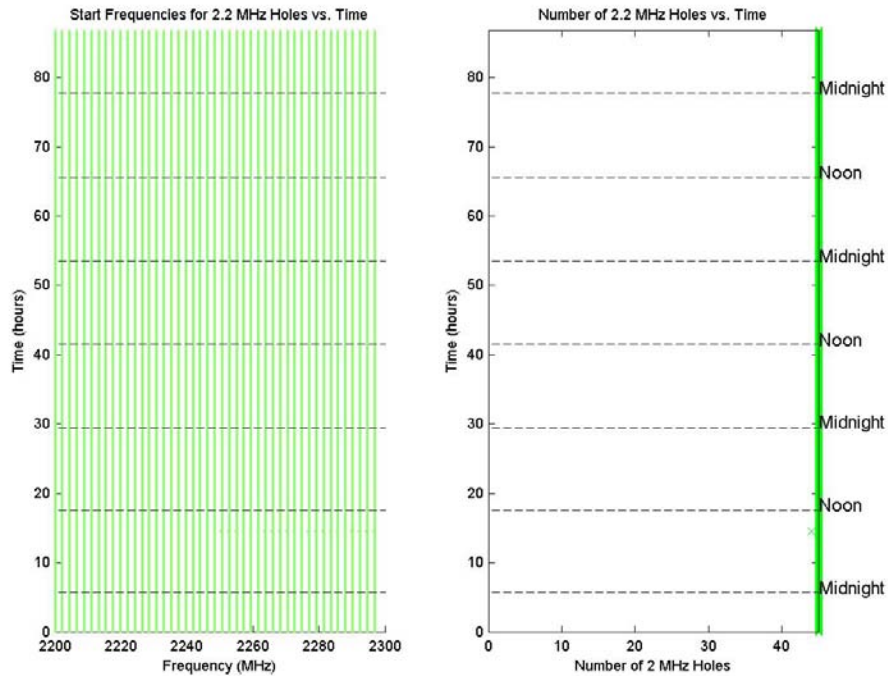


Figure 69. Spectrum hole analysis plot for 2200-2300 MHz band – Band 26

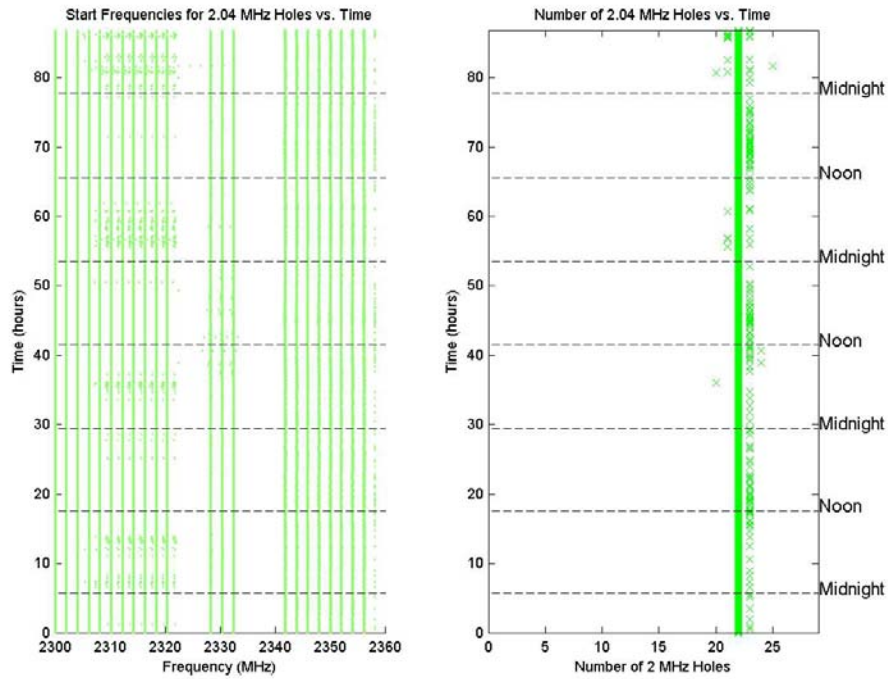


Figure 70. Spectrum hole analysis plot for 2300-2360 MHz band – Band 27

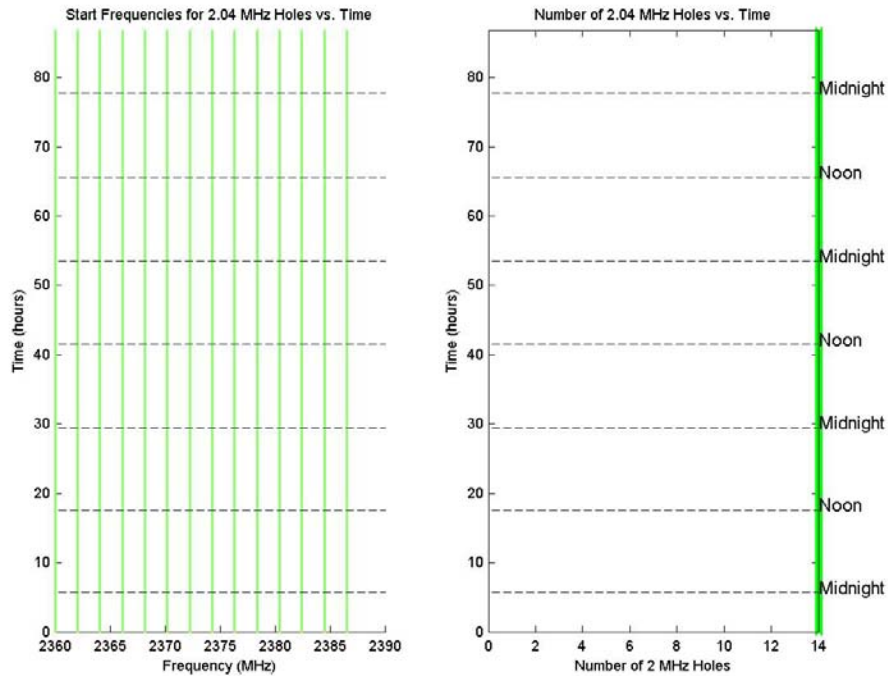


Figure 71. Spectrum hole analysis plot for 2360-2390 MHz band – Band 28

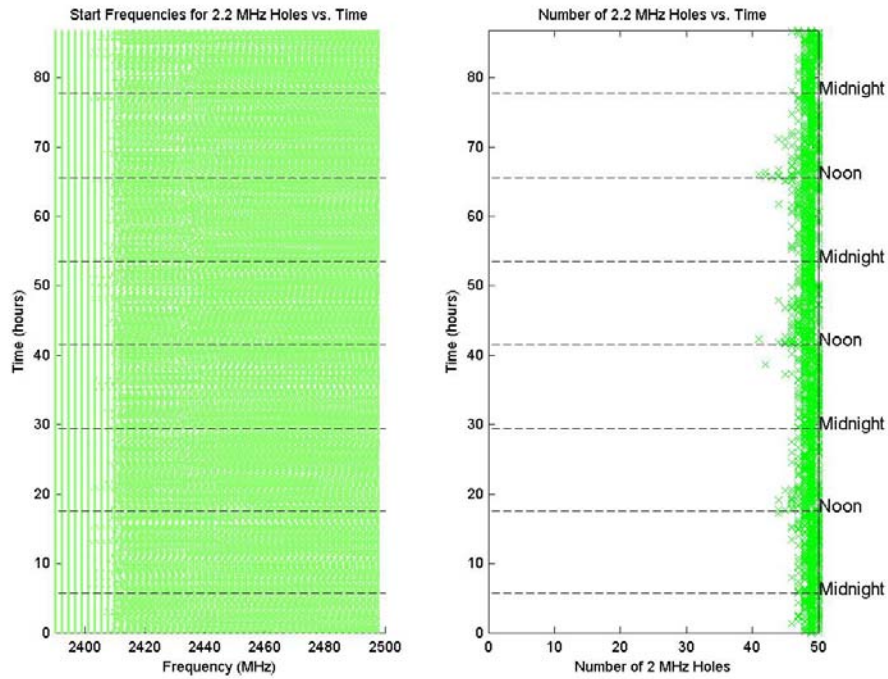


Figure 72. Spectrum hole analysis plot for 2390-2500 MHz band – Band 29

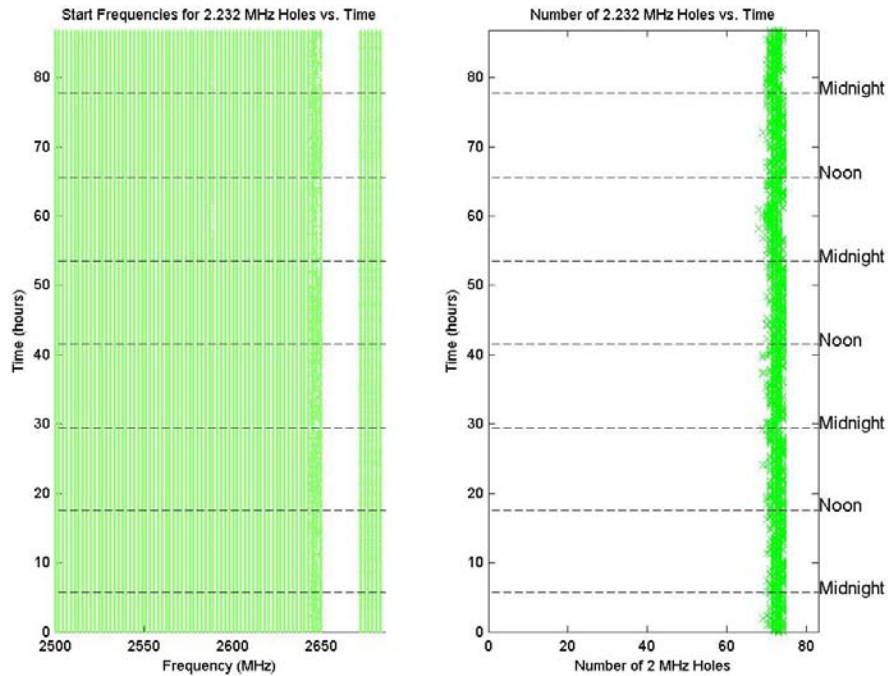


Figure 73. Spectrum hole analysis plot for 2500-2686 MHz band – Band 30

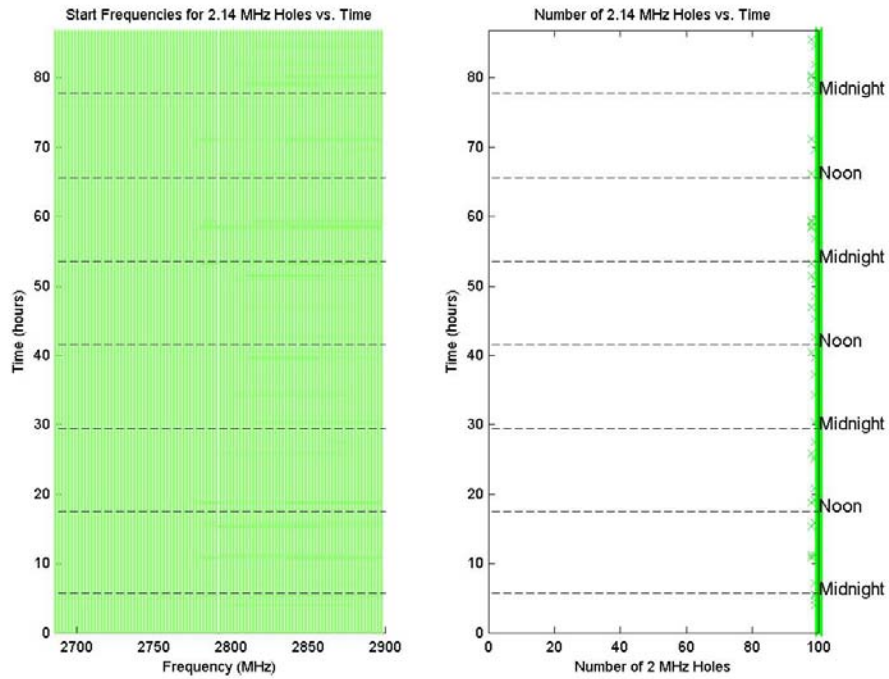


Figure 74. Spectrum hole analysis plot for 2686-2900 MHz band – Band 31

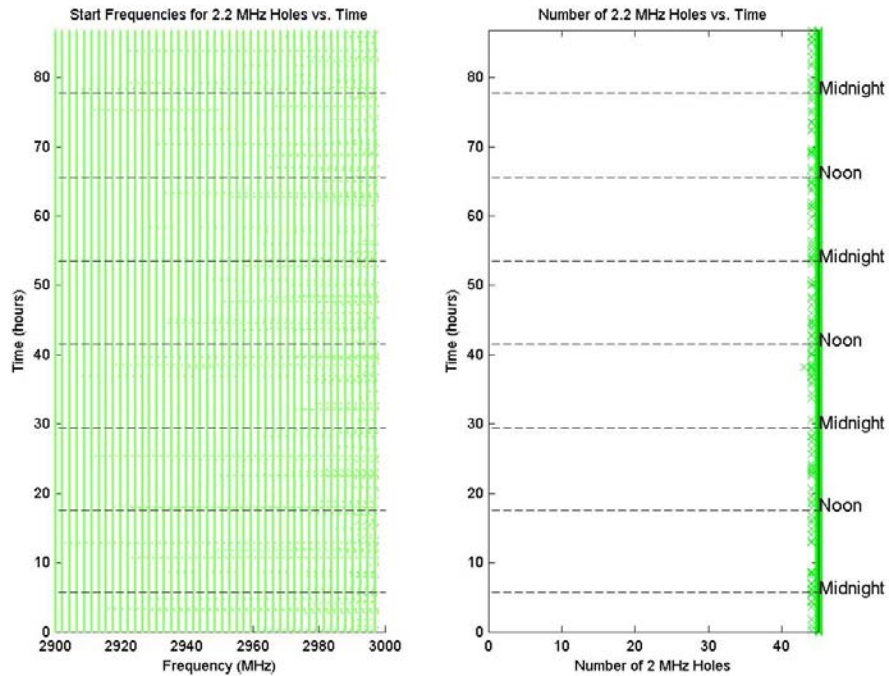


Figure 75. Spectrum hole analysis plot for 2900-3000 MHz band – Band 32