LWA1 RFI SURVEY

KENNETH S. OBENBERGER & JAYCE DOWELL

1. Introduction

In order to get a clearer understanding of the RFI environment at the LWA1 site, a 24 hour survey was taken using one antenna in DRX mode. Every minute, 15 seconds of data was taken and was processed using LWA Software Library[1] with 10 ms integrations. Each tuning was broken up into 16384 channels with each covering 1.2 kHz. The survey was started at 10 PM on September 14, 2011 and was concluded at 10PM MDT on September 15, 2011. The survey covered frequencies from 10 MHz to 90 MHz. Using 3 beams with two tunings each, centered at 18, 34, 50, 66, 82, and 74. Each tuning covered a 20 MHz bandwidth. The last tuning centered at 74 MHz was just a repeat of sections in the 66 and 82 MHz tunings. This memo is a report of the findings.

2. Lightning

Throughout the data set we see short broad band pulses across the entire 80 MHz bandwidth. The pulses occur in the later half of the data run and vary in amplitude. I was able to correlate the timing of the pulses of largest amplitude with the data from the lightning detector (See Fig. 1). Therefore we believe that these broad band sources are indeed lightning. This lightning was one of the biggest contributors of RFI across all frequencies. However this is only a problem during the monsoon season of late summer and early fall.

As far as we could tell the radio signal from the lightning just raises the overall noise signal, indicating even power over the entire band.

From the fact that the lightning detector only detected the very strongest strikes, it is clear that the LWA1 itself is a far superior lightning detector than the one installed at the station.

Plots of 8 such strikes can be seen in Figure 2. Each strike lasts between tens and hundreds of milliseconds, and vary greatly in shape. Judging by the multiple peaks of some of the strikes it would make sense that they are multiple strikes. The

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[1]http://fornax.phys.unm.edu/lwa/trac

lightning sources hit amplitudes up to 18 dB, 14 dB higher than the value of the noise at the observed frequency.

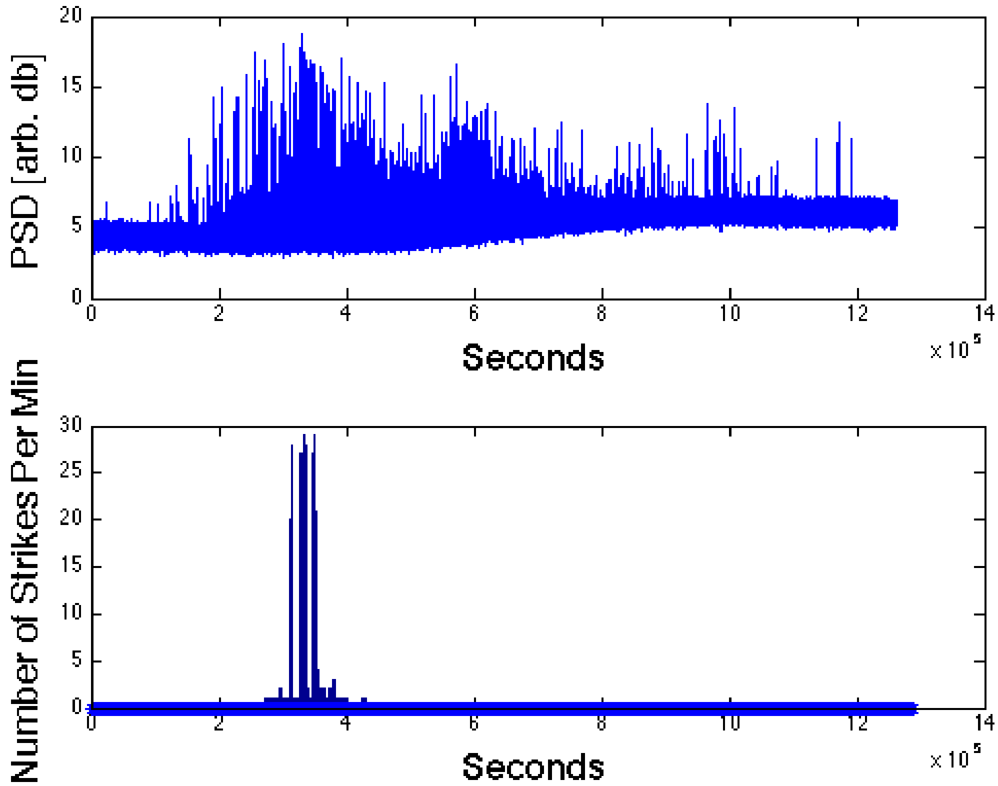


Figure 1. This is a plot showing the relation between antenna data (Top) and lightning detector (Bottom) data. As can be seen all of the strikes, recorded by the detector, occur during the strongest spikes in the antenna data.

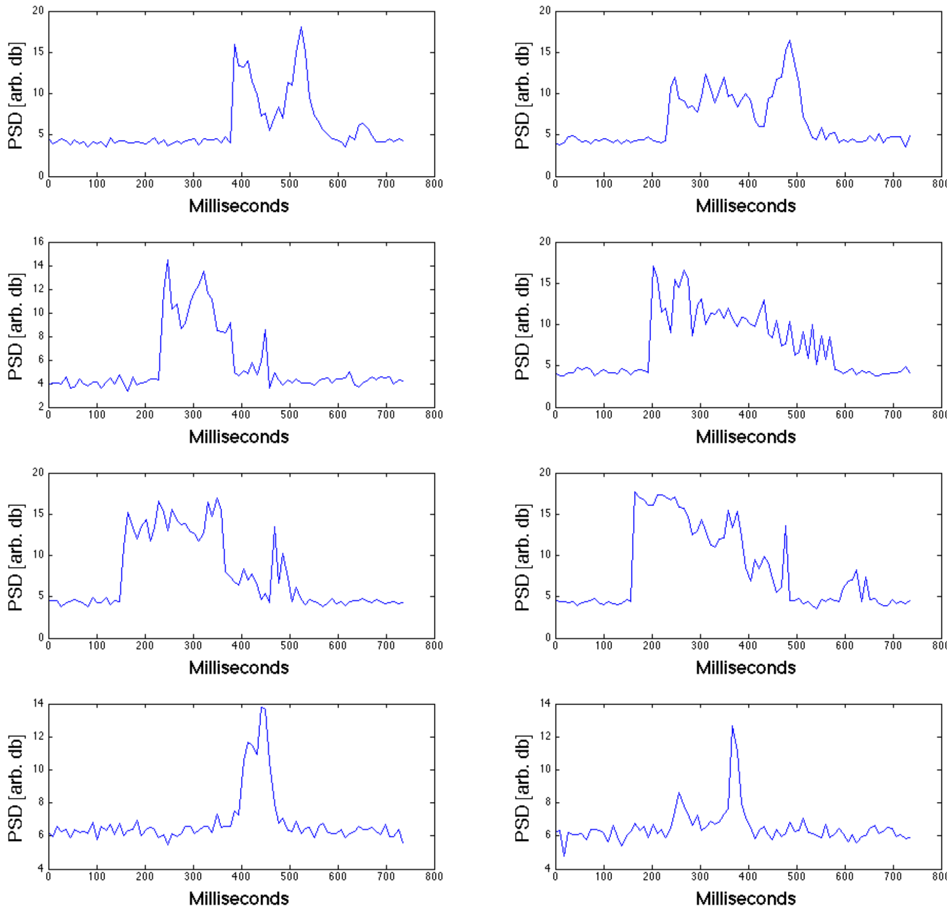


Figure 2. These are examples of x polarized lightning bursts at 70 MHz and averaged over 1.2 kHz.

3. Occupancy and Spectral Kurtosis

One can use spectral kurtosis as a means of identifying likely RFI candidates. Given a spectra we can step through time blocks of each frequency channel, 15 second steps in our case, and compute the spectral kurtosis of each block. Spectral kurtosis is a measurement of how Gaussian a distribution is, and for a perfectly gaussian distribution the value of the kurtosis is 1. We can then compare the kurtosis of each block with the expected distribution with a mean value of 1. Anything above a set threshold, 4σ in our case, is flagged as RFI. For further explanation see Nita et al. [1] and references therein.

As can be seen in Figure 3. The two waterfall plots show the entire bandwidth for the entire 24 hours. The white spaces are the areas identified as RFI by the spectral kurtosis. A large portion of what is blocked out are the broadband lightning strikes which appear in the top third of the plots. This creates a bias in the occupancy plots which show a minimum of about 20% occupancy for all the frequency channels.

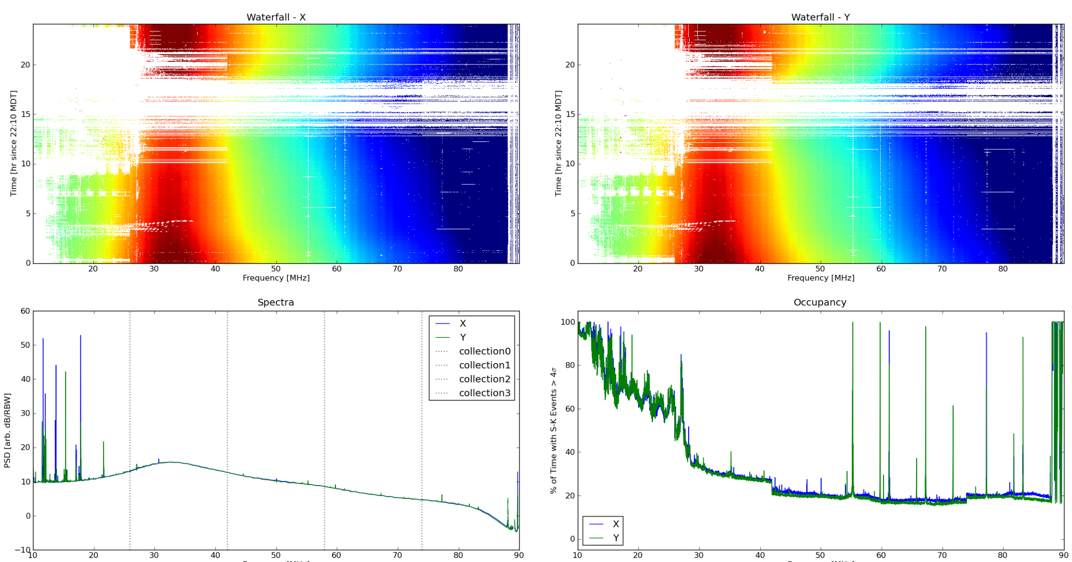


Figure 3. This figure includes the overall x and y waterfall plots (Top) showing the spectral kurtosis masking. An overall mean spectra (Bottom Left) and a occupancy plot (Bottom Right) showing the percentage of time each frequency is occupied by RFI as calculated using spectral kurtosis. The floor value of about 20% is due to the lighting storm in the later third of the data set.

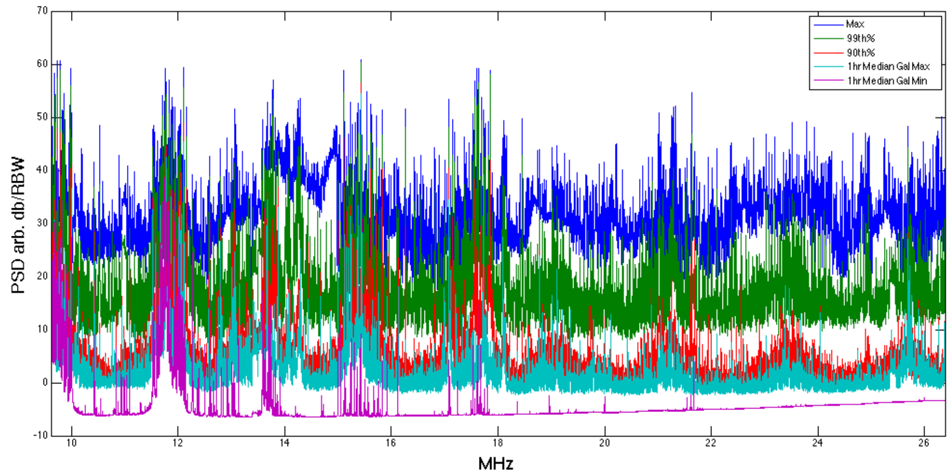
While we believe spectral kurtosis does a great job of finding the RFI, it is also useful to look at the percentages of how bad things get and how bad they usually are. Figures 4-8 each contain two sets of plots. On top are plots of the overall spectra during 5 different situations. The blue plot shows the maximum power for each frequency during the entire 24 hour run. The green shows the maximum power of each frequency excluding the top 1%. The red shows the same except it excludes the top 10%. The light blue shows the median power during the hour when the galactic center is it's highest in the sky. Finally, the purple shows the median power during the hour when the galactic plane is not in the sky.

On bottom are plots of the occupancy calculated using spectral kurtosis. As mentioned earlier the minimum of about 20% is due to the lightning storm seen in the afternoon. To show that this drops to nearly 0% during the night, when there wasn't a thunderstorm, Figures 4-8 are repeated in Figures 9-13 excluding the afternoon thunderstorm.

3.1. **Protected Bands.** Within the bandwidth of the LWA are 4 protected regions designated for radio astronomy. They include: 13.36 - 13.41, 25.55 - 25.67, 37.50 - 38.25, and 73.00 - 74.60 MHz. None of these were spared from RFI, however the later two were relatively clear. Table 1 gives occupancy percentages based on spectral kurtosis.

Frequency in MHz	Time Occupied by RFI	Night Only
13.36 - 13.41	90%	75%
25.55 - 25.67	66%	18%
37.50 - 38.25	27%	0.27%
73.00 - 74.60	21%	0.25%

Table 1. This is a table showing the occupancy percentages based on spectral kurtosis assessment of the data set



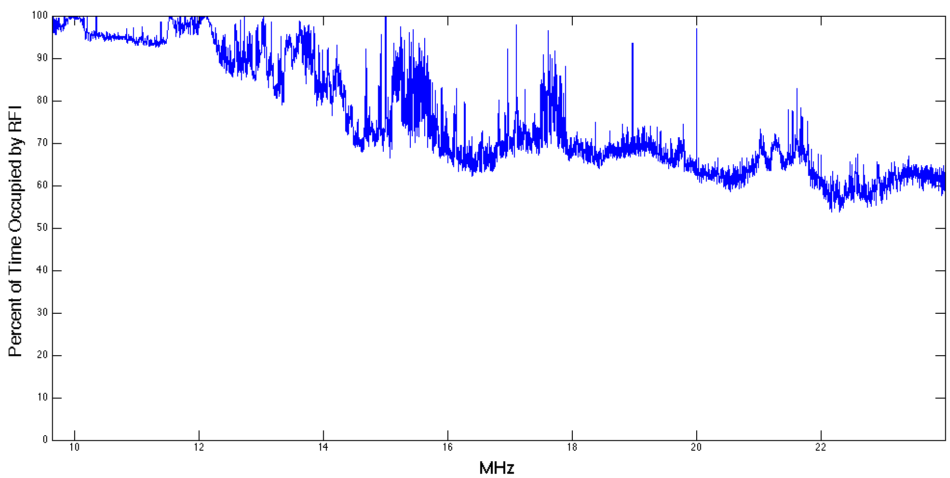
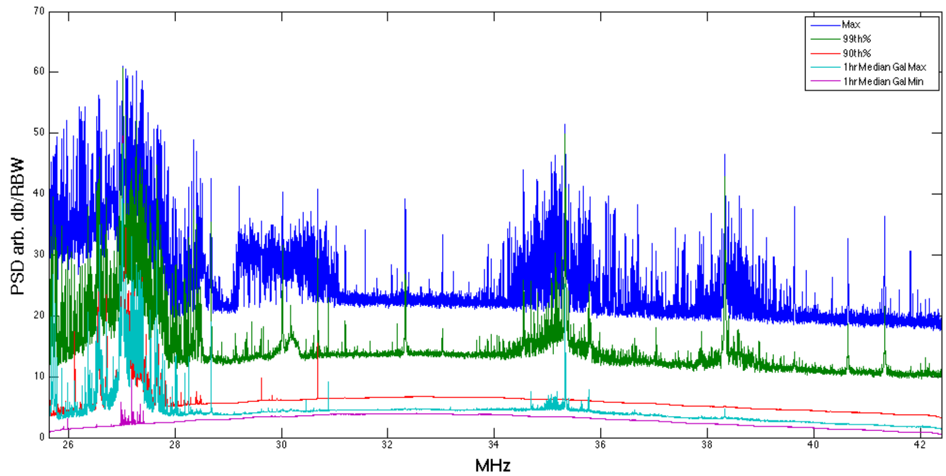


FIGURE 4. This is a figure showing plots of (Top) the power for each frequency at maximum, upper 1%, upper 10%, median when galaxy is up, and median when galaxy is down, centered at 18 MHz, and a plot of (Bottom) the percentage of time each frequency is occupied by RFI as found by spectral kurtosis.



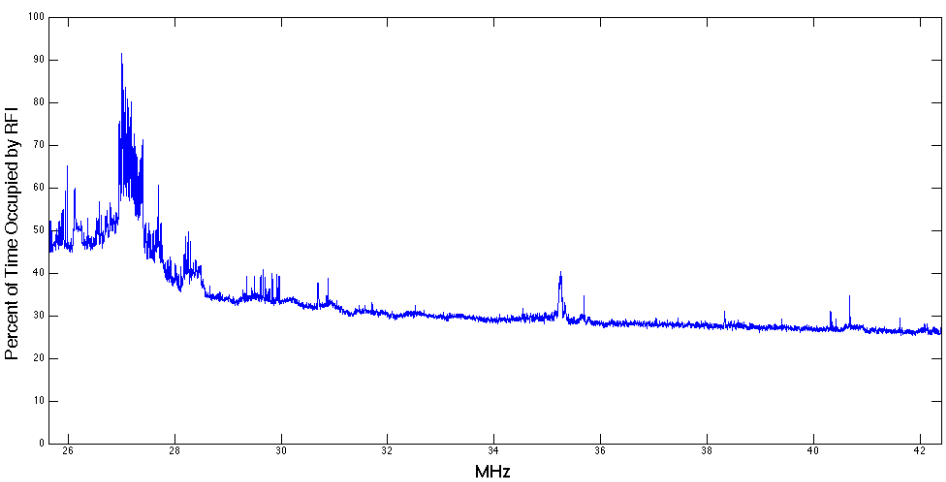


FIGURE 5. Similar to Figure 4, but centered at 34MHz. The labeling and layout are the same as Figure 4.

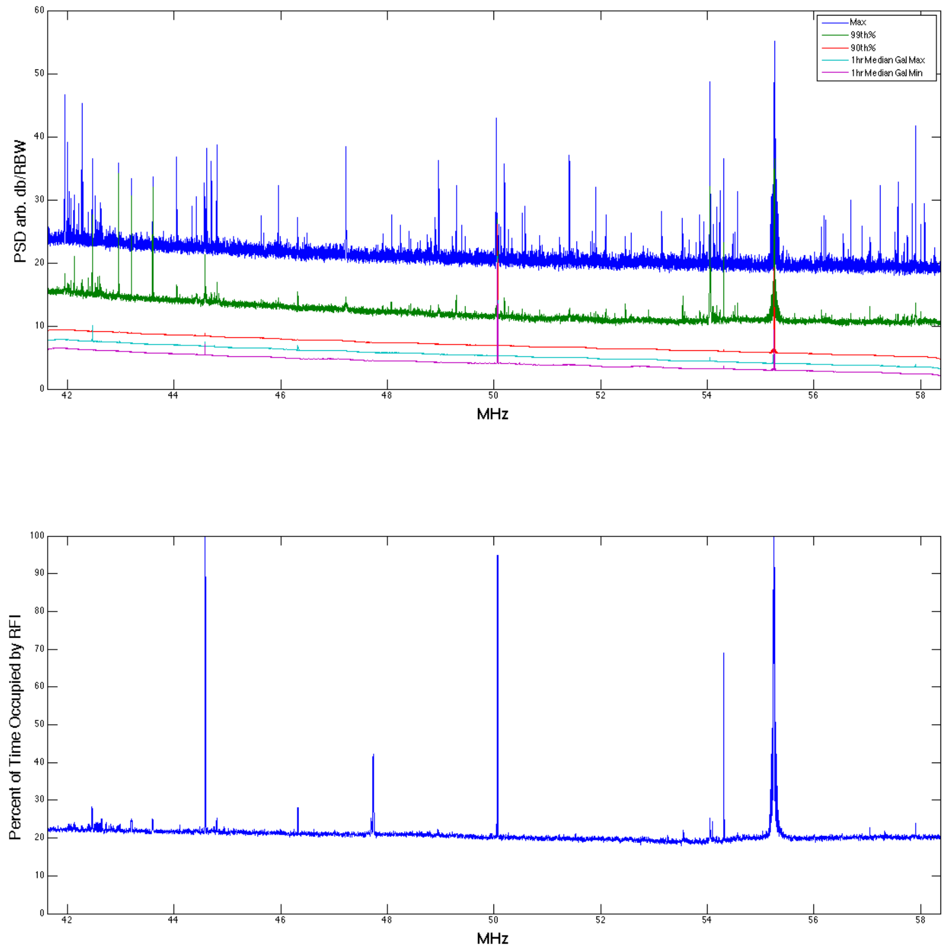
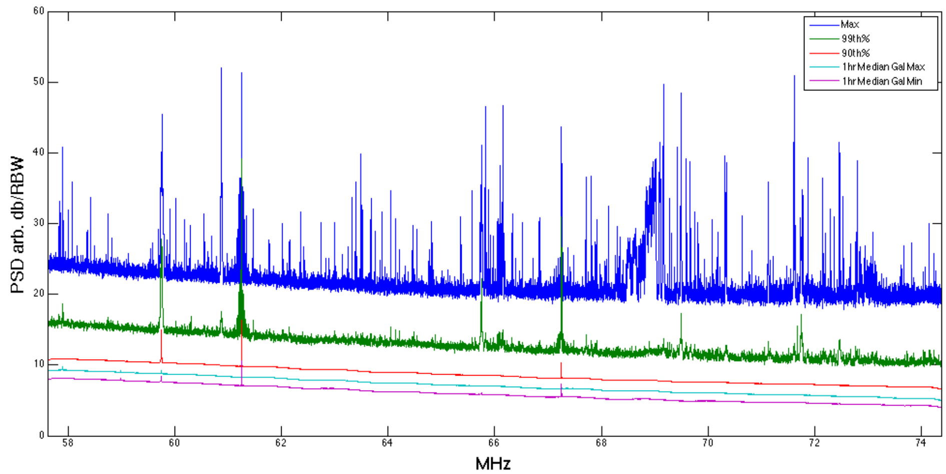


FIGURE 6. Similar to Figure 4, but centered at 50MHz. The labeling and layout are the same as Figure 4.



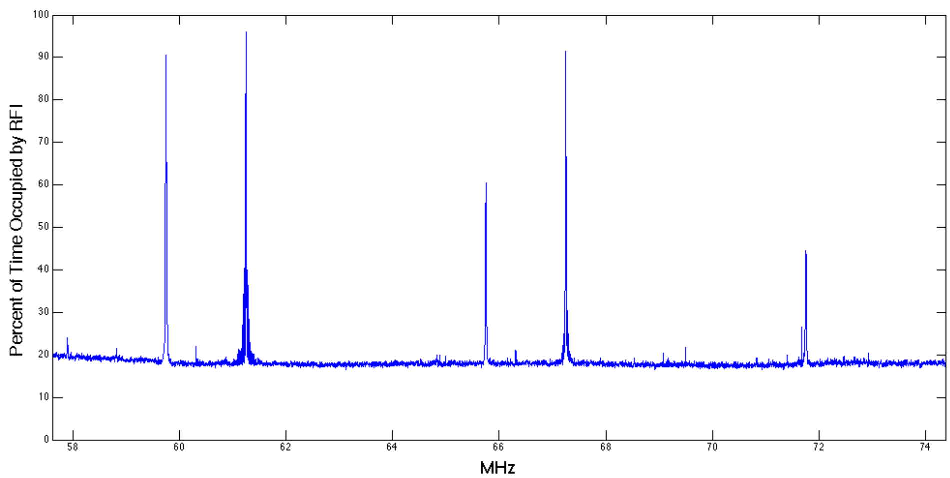


FIGURE 7. Similar to Figure 4, but centered at 66MHz. The labeling and layout are the same as Figure 4.

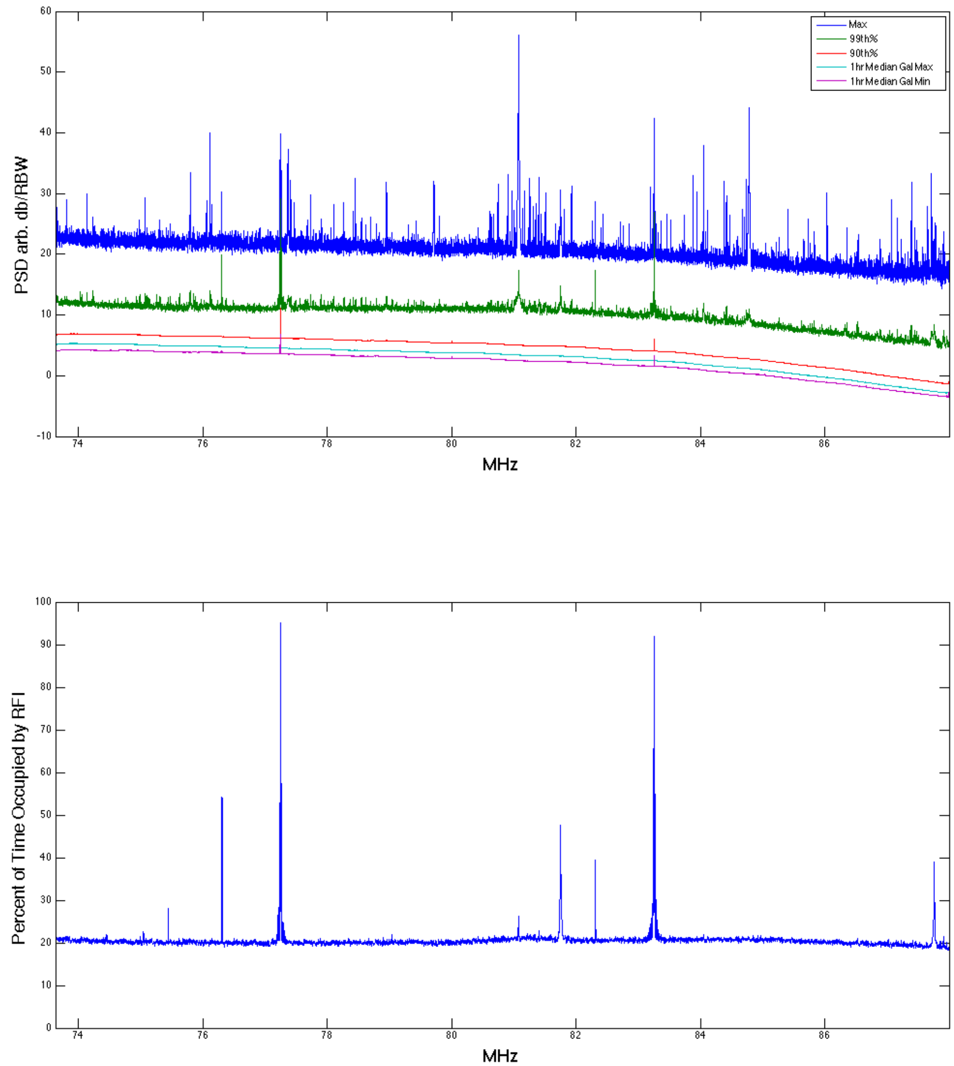


Figure 8. Similar to Figure 4, but centered at 82MHz. The labeling and layout are the same as Figure 4.

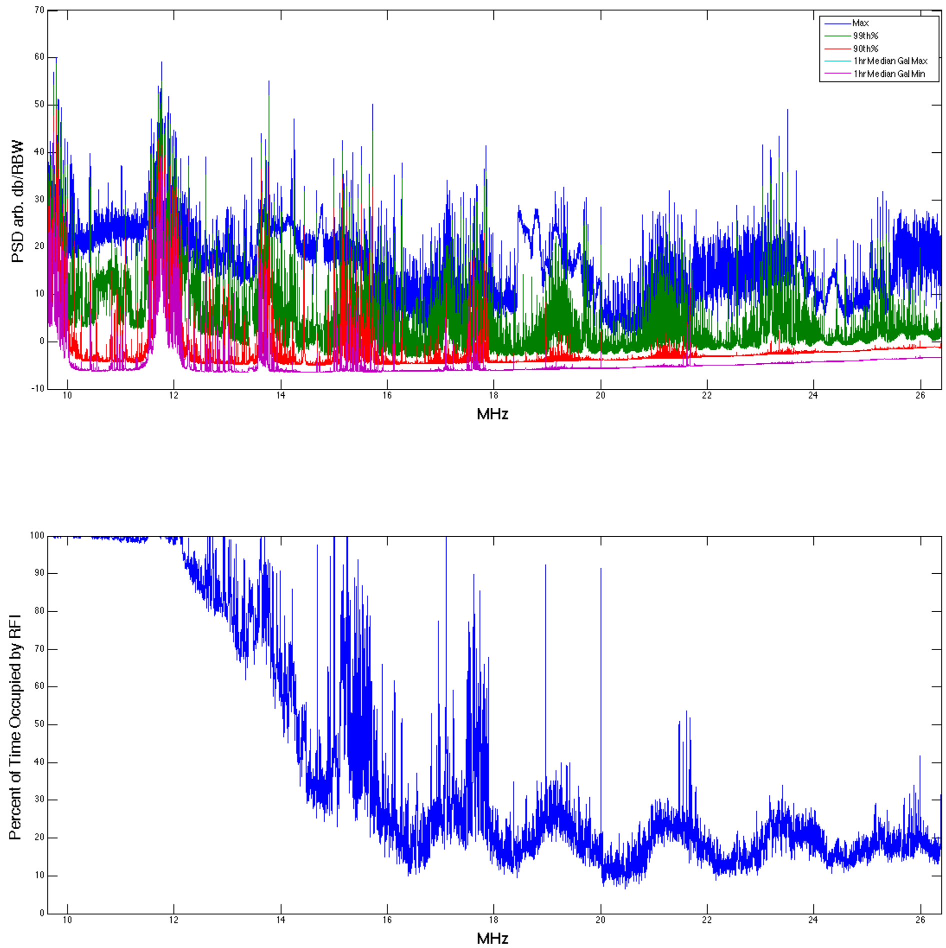


FIGURE 9. This is a figure showing plots of (Top) the power for each frequency at maximum, upper 1%, upper 10%, median when galaxy is up, and median when galaxy is down, centered at 18 MHz, and a plot of (Bottom) the percentage of time each frequency is occupied by RFI as found by spectral kurtosis. Both plots only include data from 10PM to 6AM to exclude the lightning storm.

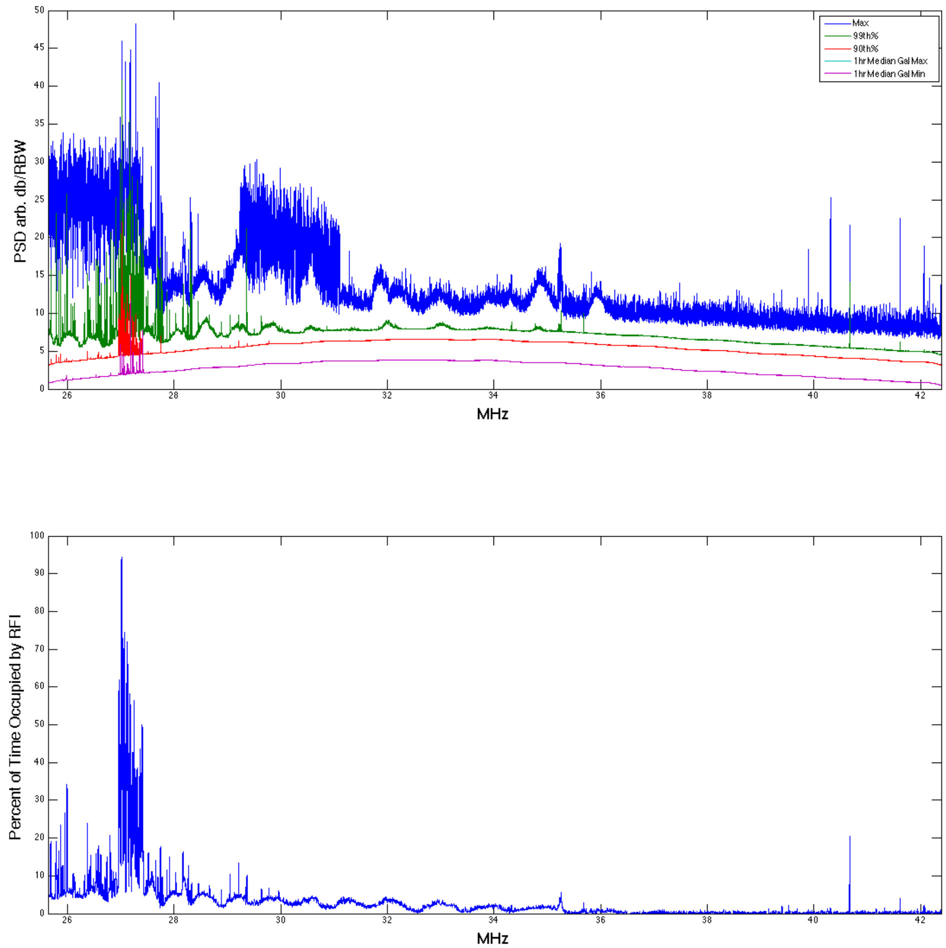


Figure 10. Similar to Figure 9, but centered at 34MHz. The labeling and layout are the same as Figure 9.

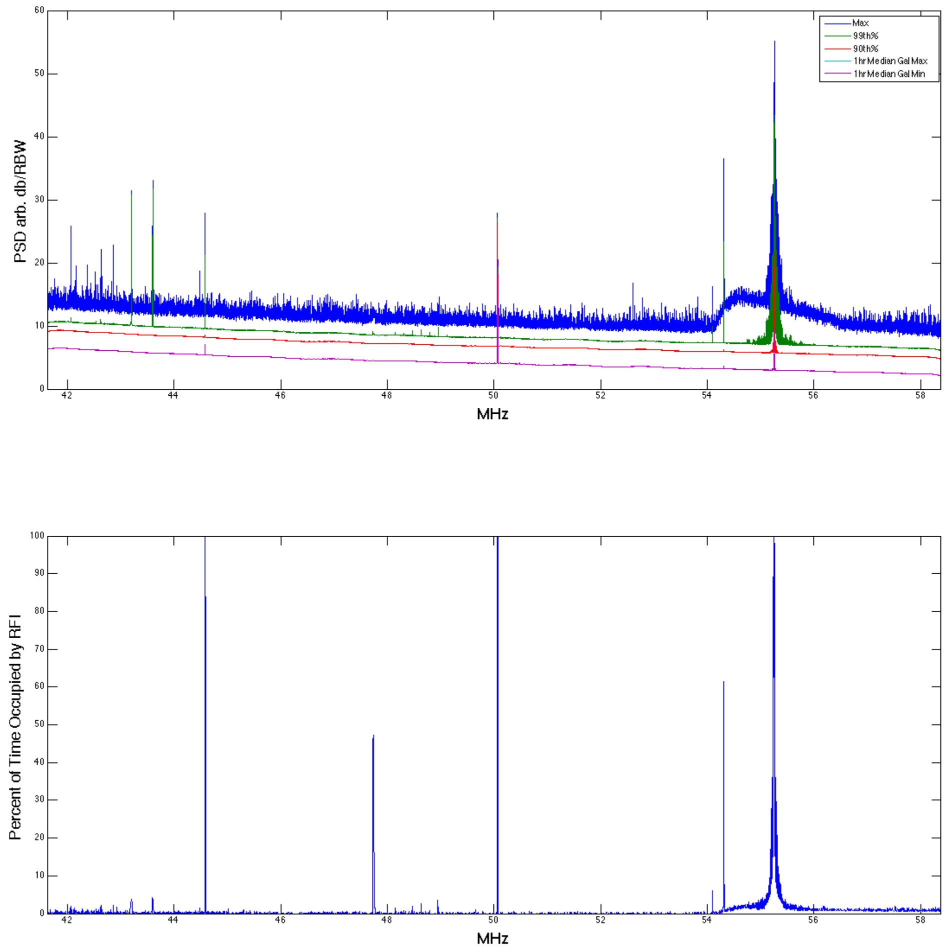


FIGURE 11. Similar to Figure 9, but centered at 50MHz. The labeling and layout are the same as Figure 9.

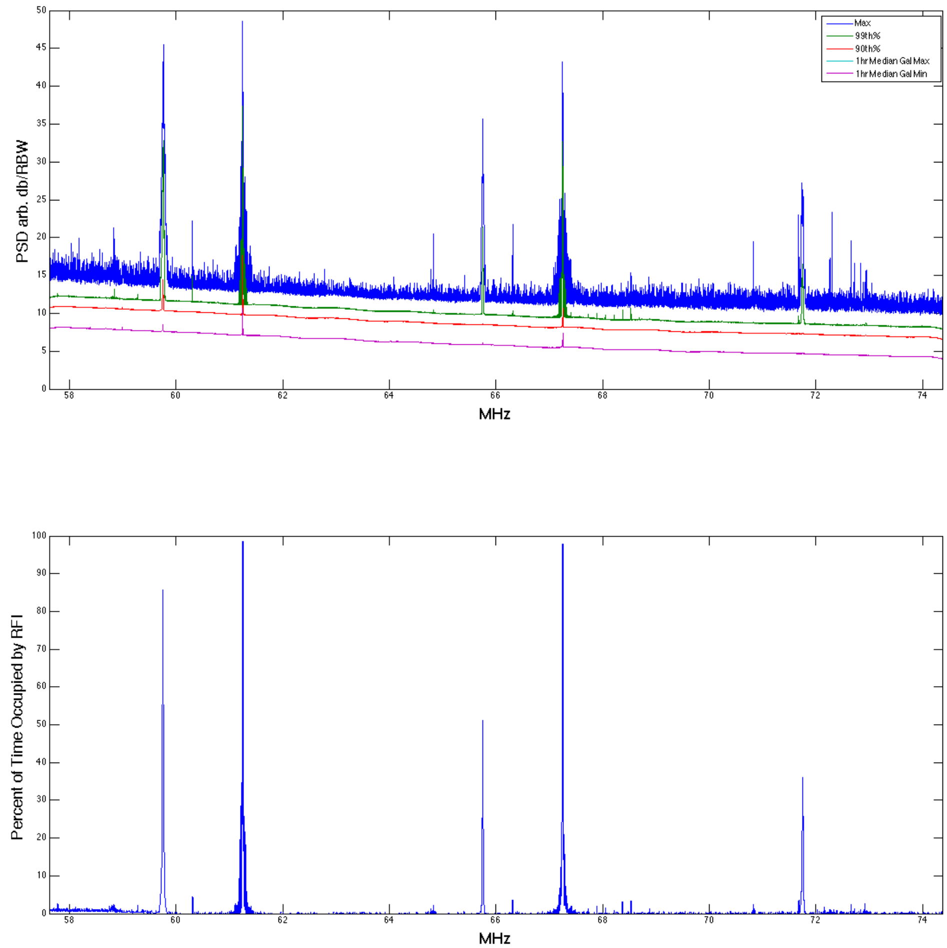


FIGURE 12. Similar to Figure 9, but centered at 66MHz. The labeling and layout are the same as Figure 9.

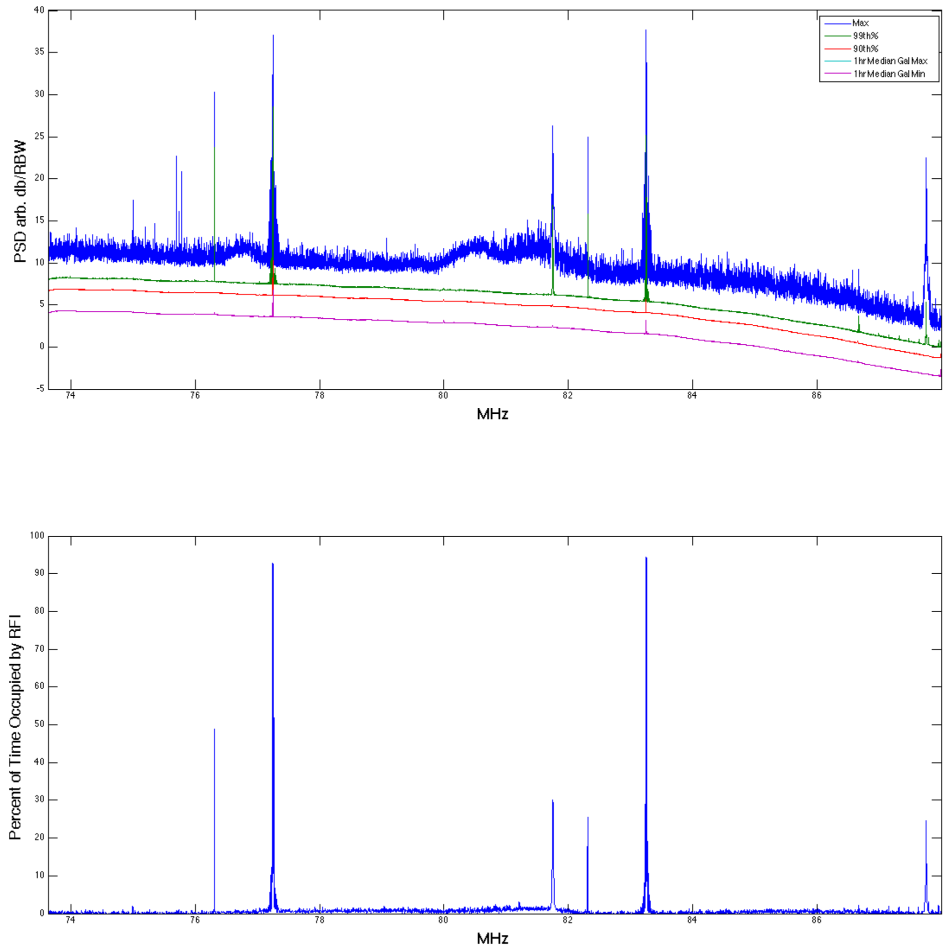


FIGURE 13. Similar to Figure 9, but centered at 82MHz. The labeling and layout are the same as Figure 9.

4. RFI Specifics

4.1. **Beam 1 Tuning 1.** Beam 1 Tuning 1 covers the band from 9 MHz to 25 MHz. Of all the bandwidth the LWA covers this is the most polluted with RFI. There are several transmitters which are on the entire day with variable intensity. most notably from 9.4-10.2, 11.6-12.4, 13.1-14.3, 15-16, and 17-18 MHz. The only area of this band that was not flooded with RFI during the entire run was from about 18-27 MHz from 11PM-9AM. This area of the band was fairly clear during these hours, but far from ideal. There was almost no difference between the x and y polarizations.

4.2. **Beam 1 Tuning 2.** Beam 1 Tuning 2 covers the band from 25 MHz to 43 MHz. This was much clearer than tuning 1. There were a few transmitters around 27 ± 2 MHz. This is exactly where the Citizens' Band (CB) is, which is no doubt what we are seeing. We were also hit by RFI in the Land Mobile throughout the afternoon, and part of the morning. Land Mobile bands are used by emergency vehicles, the military, large corporations, and civilian mobile devices. The particular offending frequencies were at 30, 35.3, and 38.3 During the strongest RFI bursts of the Land Mobile signals, our data was saturated across the entire observed bandwidth of Beam 1 Tuning 2, for both polarizations. The Land Mobile RFI was stronger in the x polarization however, reaching nearly 50 db, while the y polarization only reached 25 db.

4.3. **Beam 2 Tuning 1.** Beam 2 Tuning 1 covers the band from 42 MHz to 58 MHz. It contains steady transmitters at 55.25 and 44.6 MHz and several small blinking transmitters between 42.5 - 44 MHz, and at 54 ± 0.1 MHz. The transmitter at 55.25 was identified as an analog TV station (See Table 2). There were some RFI bursts in intermittent frequencies corresponding to times in Beam 1 Tuning 2 where the Land Mobile signals were present. However, the sources in Beam 2 Tuning 1 were much weaker and more narrow. There was no saturation. Both polarizations were similar and rather clear, except that in the x polarization there a was a broadband sawtooth like RFI source just above the noise level. It did not appear in the y polarization.

4.4. **Beam 2 Tuning 2.** Beam 2 Tuning 2 covers the band from 57 MHz to 74 MHz. There were two strong and steady transmitters. One at 59.75 MHz (more y polarized) and one at 61.25 MHz (more x polarized). There were also weaker transmitters at 65.75, 67.25, and 71.75 MHz. They have all been identified as analog TV channels (See Table 2). Also there were again RFI bursts in intermittent frequencies corresponding to times in Beam 1 Tuning 2 where the Land Mobile signals were present.

4.5. **Beam 3 Tuning 1.** Beam 2 Tuning 2 covers the band from 73 MHz to 91 MHz. There were analog TV transmitters at 76.31, 77.25, 81.75, 82.31, 83.25, and 87.75 MHz (See Table 2). Again there were RFI bursts in intermittent frequencies corresponding to times in Beam 1 Tuning 2 where the Land Mobile signals were present. As expected there we saw the lower FM band starting at 88 MHz, the strongest of which was 89.9 KUNM.

Frequency in MHz	Channel	Channel Use
55.25	2	Video Carrier
59.75	2	Audio Carrier
61.25	3	Video Carrier
65.75	3	Audio Carrier
67.25	4	Video Carrier
71.75	4	Audio Carrier
76.31	5	ATSC Carrier
77.25	5	Video Carrier
81.75	5	Audio Carrier
82.31	6	ATSC Carrier
83.25	6	Video Carrier
87.75	6	Audio Carrier

TABLE 2. This is a table showing the analog TV stations that can be seen by the LWA1

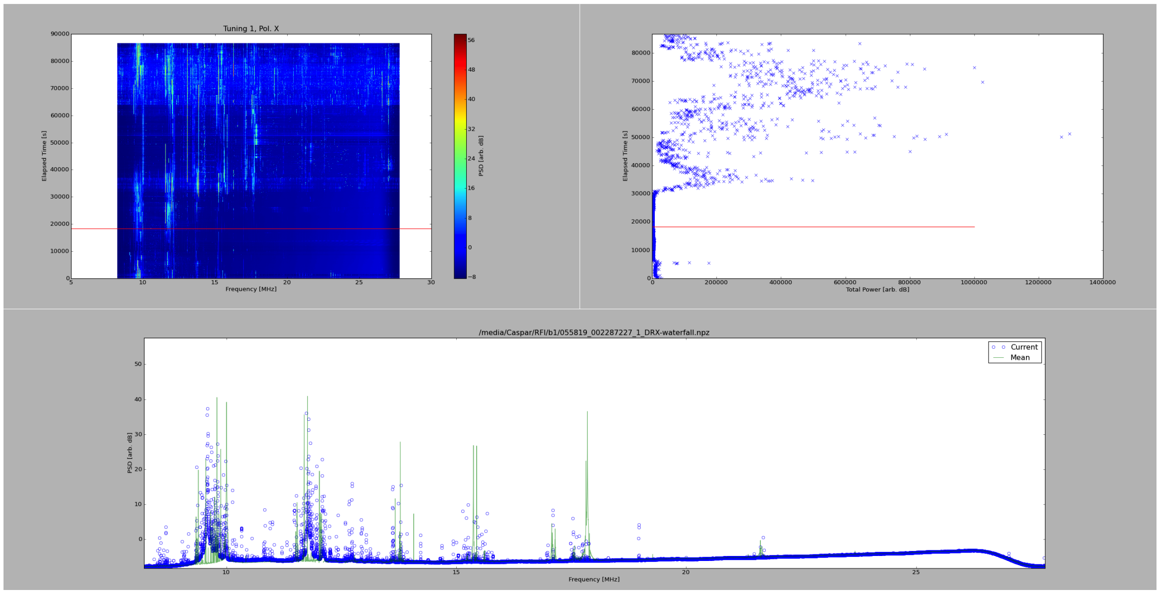


FIGURE 14. Beam 1, Tuning 1, x polarization

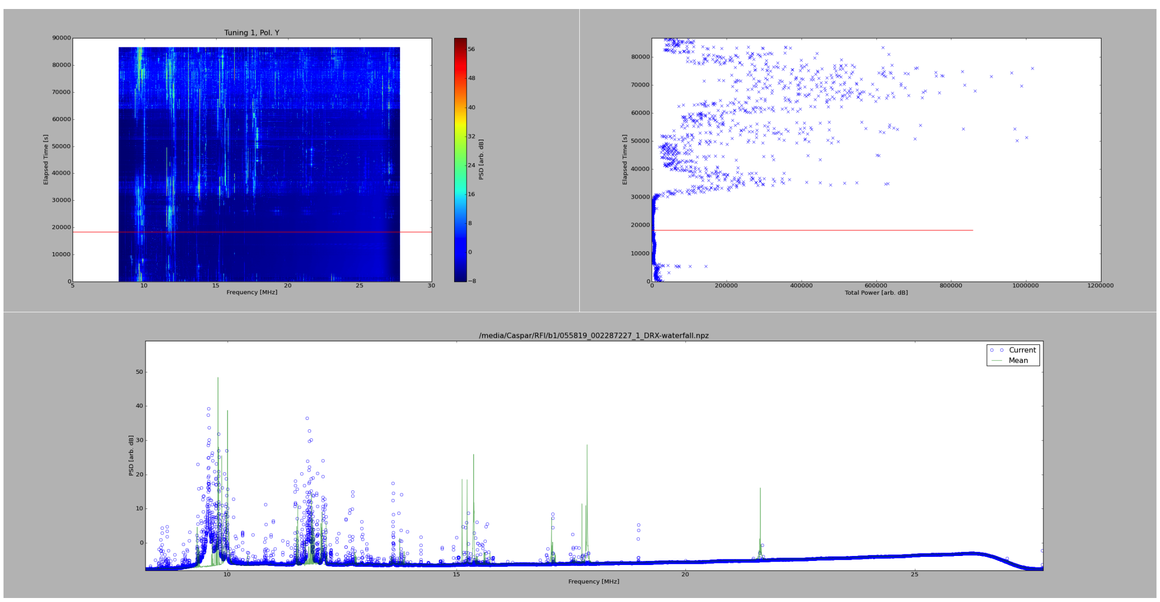


FIGURE 15. Beam 1, Tuning 1, y polarization

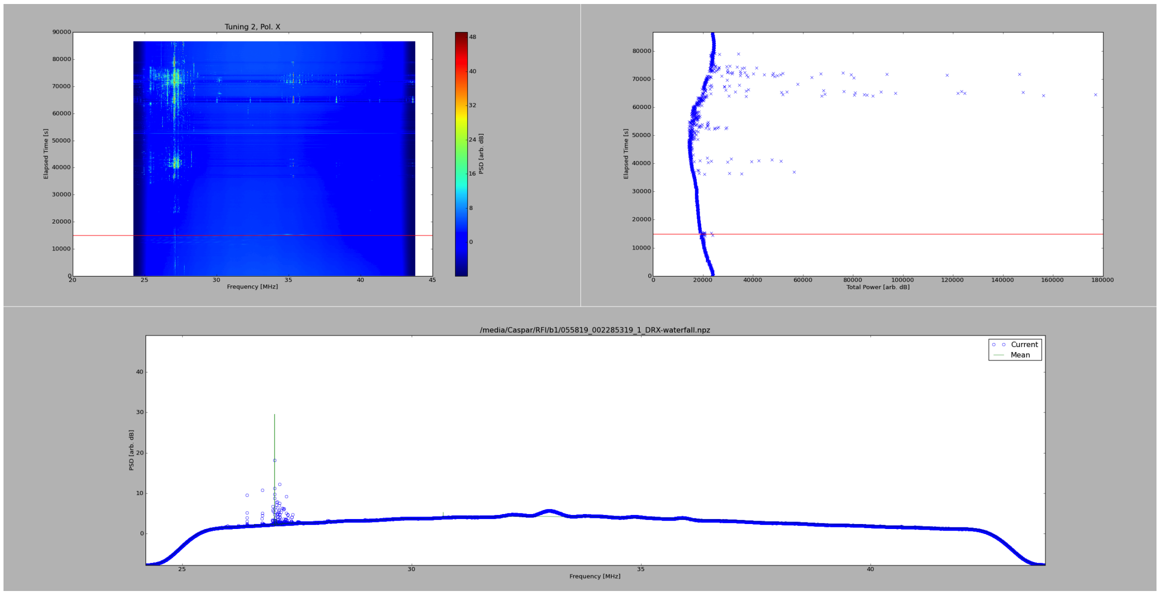


FIGURE 16. Beam 1, Tuning 2, x polarization

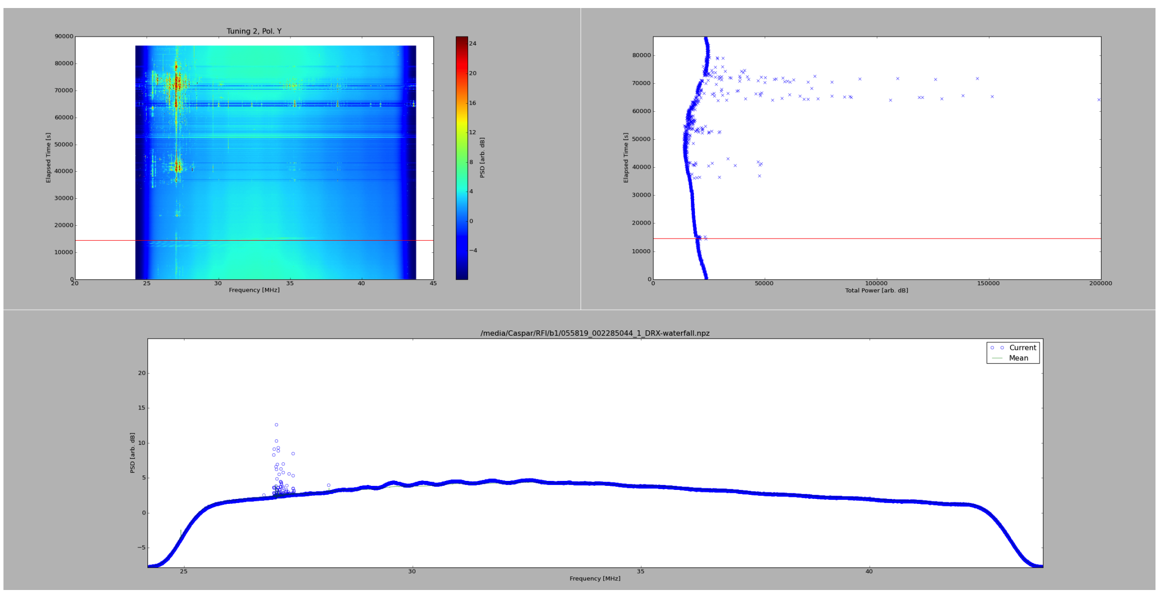


FIGURE 17. Beam 1, Tuning 2, y polarization

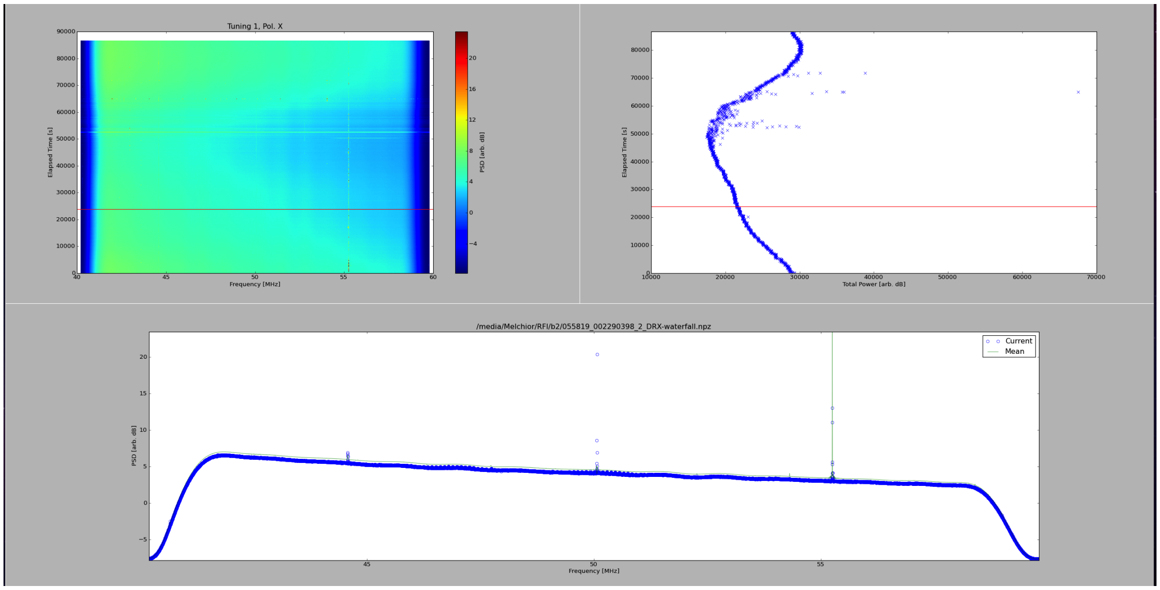


FIGURE 18. Beam 2, Tuning 1, x polarization

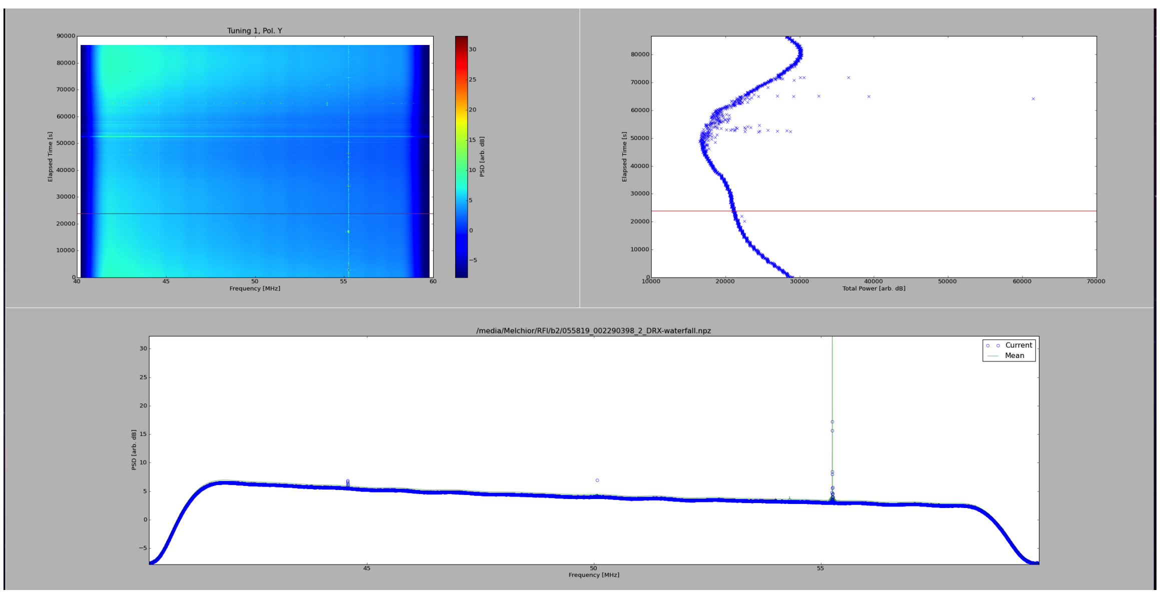


FIGURE 19. Beam 2, Tuning 1, y polarization

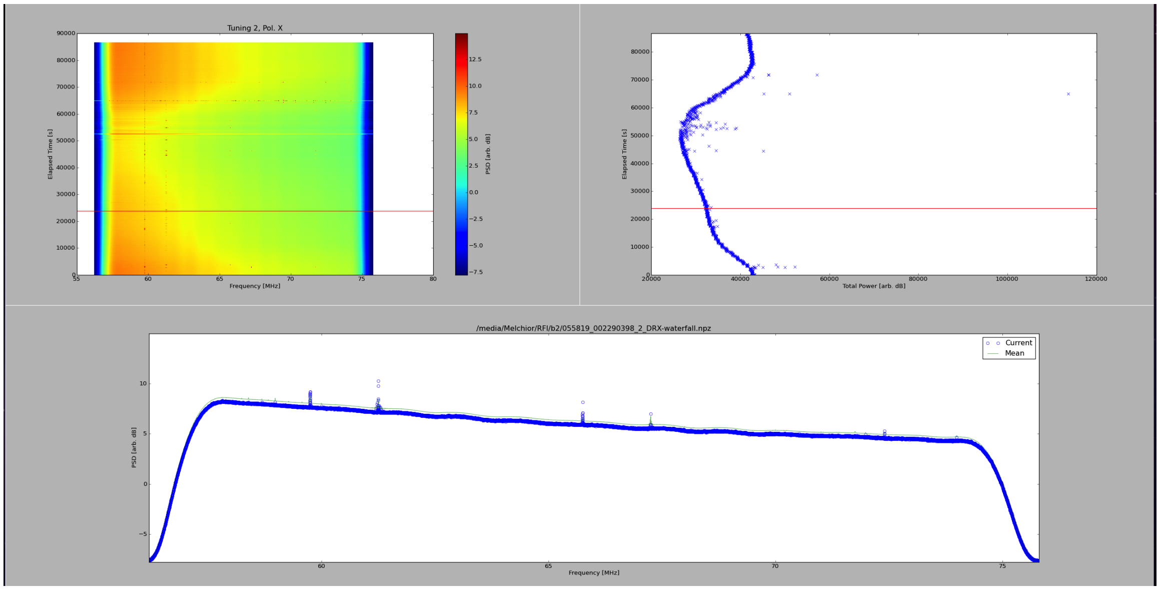


Figure 20. Beam 2, Tuning 2, x polarization

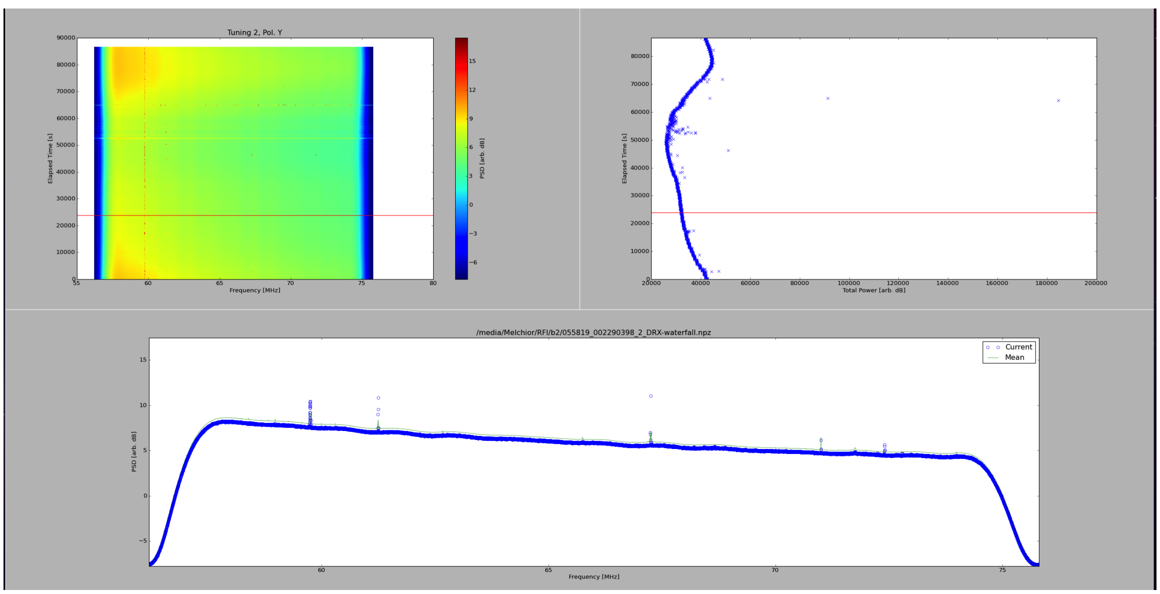


Figure 21. Beam 2, Tuning 2, y polarization

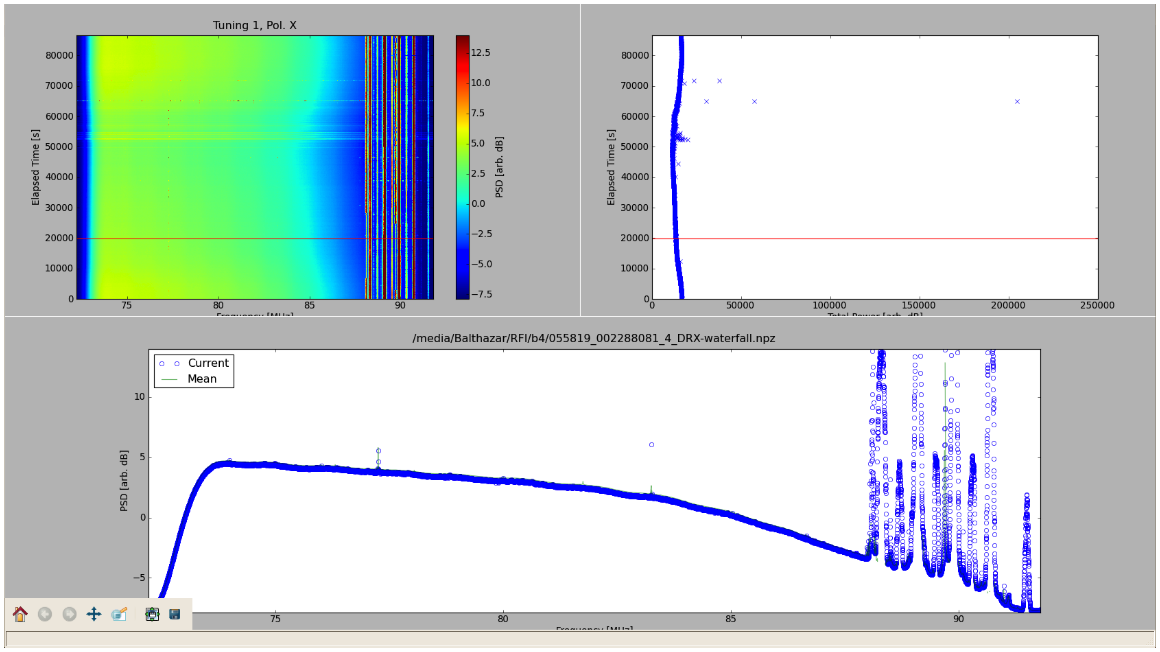


FIGURE 22. Beam 3, Tuning 1, x polarization

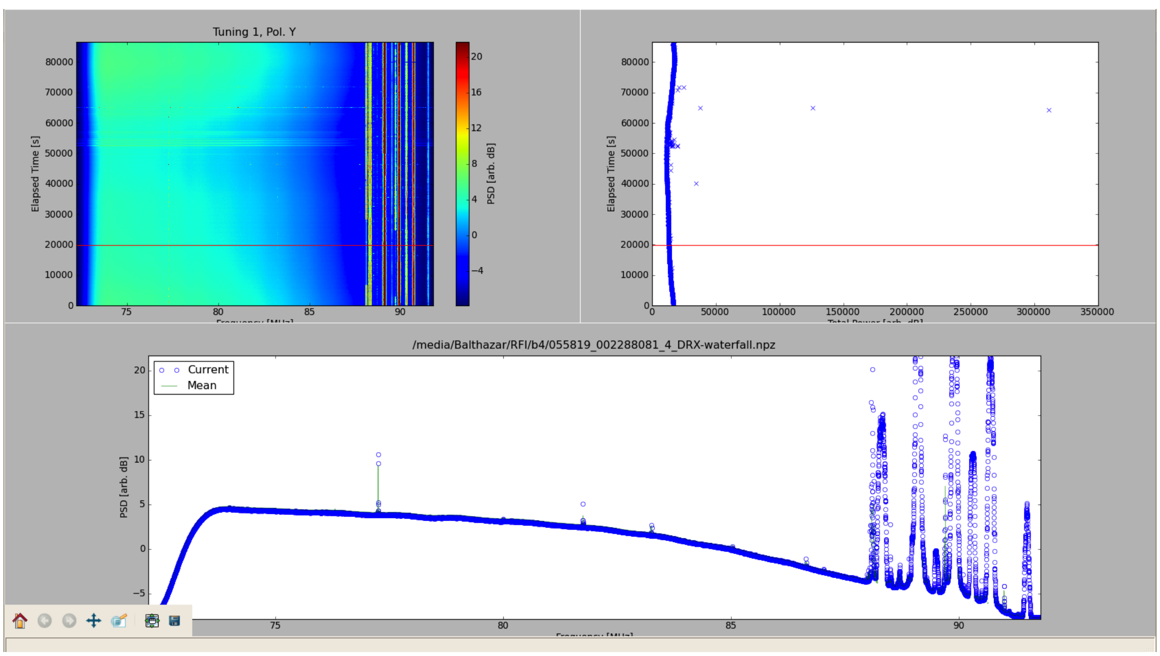


FIGURE 23. Beam 3, Tuning 1, y polarization

References

[1] G. M. Nita & D. E. Gary, Statistics of the Spectral Kurtosis Estimator, Publications of the Astronomical Society of the Pacific, Volume 122, pp. 595-607, May, 2010.