A Survey of 1200-1800 MHz using a Discone and a Spiral with the Argus Front End

Steven W. Ellingson*

October 12, 2002

1 Summary

This document reports on a survey of radio frequency interference (RFI) in the band 1200-1800 MHz. The survey was conducted during business hours from the roof of the Ohio State University ElectroScience Laboratory (ESL), using two antennas. One antenna was a commercially available wideband discone antenna, which is weakly directive along the horizon, and has directivity $\ll 1$ toward the sky. The other antenna was a planar spiral, which has a complementary pattern (directivity $\ll 1$ toward the horizon, weakly directive toward the sky). The resolution of the survey is 1 MHz and the system temperature $T_{sys} \sim 360°$K, resulting in a nominal "snapshot" sensitivity of about -110 dBm/MHz against an antenna temperature $T_A \sim 290°$K (i.e., $\Delta T \sim 650°$K). After 1 hr, ΔT is reduced to about 5.3°K, allowing detection of signals as weak as -131 dBm/MHz provided that they are stationary. A "max hold" technique is also used to enhance sensitivity to strong, low-duty cycle signals, such as pulsed-CW radars.

The results presented here represent the best characterization of the RFI environment in the ESL area obtained so far. A number of known RFI sources – both strong and weak – are identified, and the presence of weak, impulsive spurious RFI is identified. Fortunately, the latter is found to be predominately terrestrial in origin;

*The Ohio State University, ElectroScience Laboratory, 1320 Kinnear Road, Columbus, OH 43210, USA. Email: ellingson.1@osu.edu.

thus, significant mitigation is possible simply by using antennas that have low directivity at or below the horizon. Also, this study represents the first field use of the new Argus front end electronics [2, 3], along with the existing spiral antenna design, with very satisfactory results.

2 Instrumentation

The instrumentation consisted of an antenna (either a discone or spiral), a single channel LNA + line amplifier borrowed from the Argus project [1], a long cable from the roof to a room within ESL, a spectrum analyzer, and a PC for experiment control and data collection. These components are explained in more detail below.

The discone antenna used for this study was an AOR Model DA3000, which is intended for use primarily as a scanner radio antenna, and claimed by the manufacturer to be useable from 25 MHz to 2000 MHz. The discone has a pattern which is uniform in azimuth, with maximum gain slightly below the horizon and nulls toward the zenith and nadir. The discone was mounted on a temporary mast about 2.5 m above the main roof of ESL, as shown in Figure 1, such that the antenna was about 12 m above the ground. A utility structure exists on the roof to the north of the antenna, which may have attenuated signals arriving from that direction.

The planar spiral antenna used for this study was a custom design developed for our omnidirectional radio telescope project, Argus [1]. The antenna is shown in Figure 2. This antenna has a pattern which is uniform in azimuth, with maximum gain at the zenith and very low gain toward the horizon. In other words, the patterns of the discone and spiral are complementary. When used, the spiral was located about 5 m from the discone antenna setup shown in Figure 1.

The output of the antenna (either the discone or the spiral) was connected via a short cable to a front end consisting of a bandpass filter, an Argus LNA [2], and an Argus line amplifier [3]. The bandpass filter was K&L Model 4B120-1500/600-0/0 (1200-1800 MHz), and was added to ensure that strong VHF-band signals present at

Figure 1: Discone antenna setup.

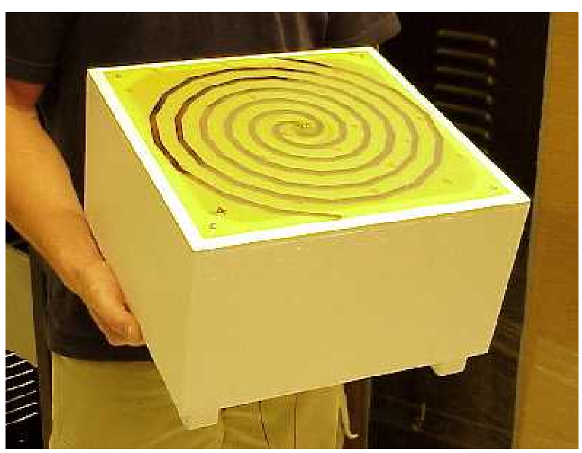


Figure 2: Spiral antenna. The antenna consists of a planar spiral printed on a circuit board substrate, above a system of three ground planes, enclosed in the box.

the ESL roof could not create linearity problems for the front end.* The frequency response of the front end is shown in Figure 3. Note that the bottom panel shows the frequency response including the long section of RG-58† cable connecting the front end to the spectrum analyzer. The length of the cable was not measured but was on the order of 30 m. Note that the frequency response in the 1400-1800 MHz range seems to oscillate; this was later determined to be associated with the long cable, which seemed to have only a marginally-good match to 50Ω. However the resulting variation was stable over time and the data were easily corrected after the experiment. Also, since the cable follows about 30 dB of low-noise gain, the measurement sensitivity was probably not significantly compromized.

In a laboratory within ESL, the other end of the long cable is connected to an Agilent Model E4407B spectrum analyzer. Neglecting the antenna, the gain in front of the spectrum analyzer was about +20 dB (as shown in Figure 3). The spectrum analyzer was interfaced to a PC via RS-232 at 115.2 kb/s. A C-language program controls the spectrum analyzer and collects data using the techniques described in [4]. For this work, the following spectrum analyzer settings are held constant throughout the experiment: Input attenuation: 5 dB; Internal preamp: ON; Resolution bandwidth (RBW): 1 MHz; Detection method: SAMPLE (as opposed to PEAK (the default for this spectrum analyzer)). The PC directs the spectrum analyzer to take measurements in the following sequence:

1. *Max Hold.* 100 sweeps from 1200-1800 MHz are taken. Each sweep samples the spectrum at 601 points (that is, every 1 MHz). The output is a "max hold" over the 100 sweeps; that is, the result is a power spectrum where each bin indicates the maximum value observed in that bin. This procedure takes about 6 seconds.

*At ESL, the incident power of VHF-band FM and TV broadcast signals increases dramatically with increasing antenna height. At 10 m height, some FM broadcast signals increase as much as 20 dB to above 0 dBm at the terminals of a low-gain antenna. Thus, while the front end can tolerate these signals at ground level, additional VHF-band rejection is usually required when operating from the roof.

†O.K., this was dumb. Sometimes, you just have to use what's at arm's reach!

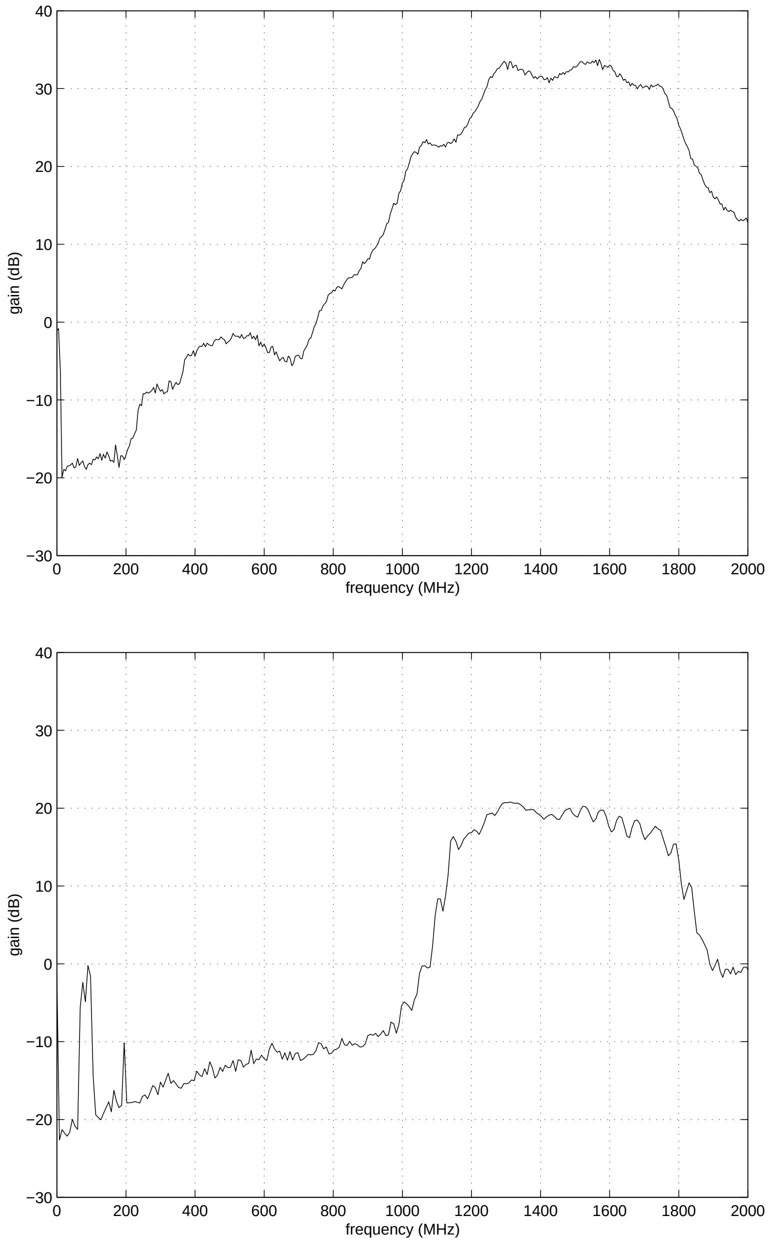


Figure 3: *Top:* Frequency response of the LNA + Line Amplifier chain (from [3]). *Bottom:* Frequency response of the filter + LNA + line amplifier + long cable chain, measured *in situ*. Note the break-through of broadcast FM in the lower panel, which gives some indication as to how strong these signals are at the ESL rool test location.

2. *Power Average.* Same as max hold, except the 100 sweeps are linearly averaged. This procedure takes about 6 seconds.

3. Go to Step 1.

The max hold and power average measurements are different, but complementary measurements. Power averaging is most effective for characterizing weak, stationary signals. Max hold, on the other hand, is essential for detecting low-duty cycle signals, such as radar pulses or irregularly-timed (possibly one-time) bursts.

Using this procedure, data were collected for about 1 hr from each antenna during the afternoon hours of Oct 10, 2002. In each case, a total of about 15,000 sweeps were performed. All data presented in the following section were calibrated to remove the seperately-measured transfer function of the front end. Thus, the indicated power spectral density (PSD) is that measured at the terminals of the antenna.

3 Results

The results of the 1-hour surveys are most concisely summarized by Figure 4. This figure shows the max hold and power average results computed for the entire observation time. In other words, the max hold result is the max hold over all ∼15,000 sweeps; similarly the power average result is the average over all sweeps. This summary result reveals a number of interesting features.

Quite a few already-known (to us) RFI signals are immediately apparent in Figure 4.

- The strong RFI at 1250 MHz is a local amateur television (ATV) transmitter.

- 1331 MHz: This is an air traffic control radar located in London, OH (about 40 km away). Note that the signal is clearly revealed in the max hold curve, but barely visible in the power average: indicating a strong, low-duty cycle (in this case, pulsed) signal. We have examined this signal in detail in previous experiments. We know that this radar emits pulses about 2 μs long every 3 ms,

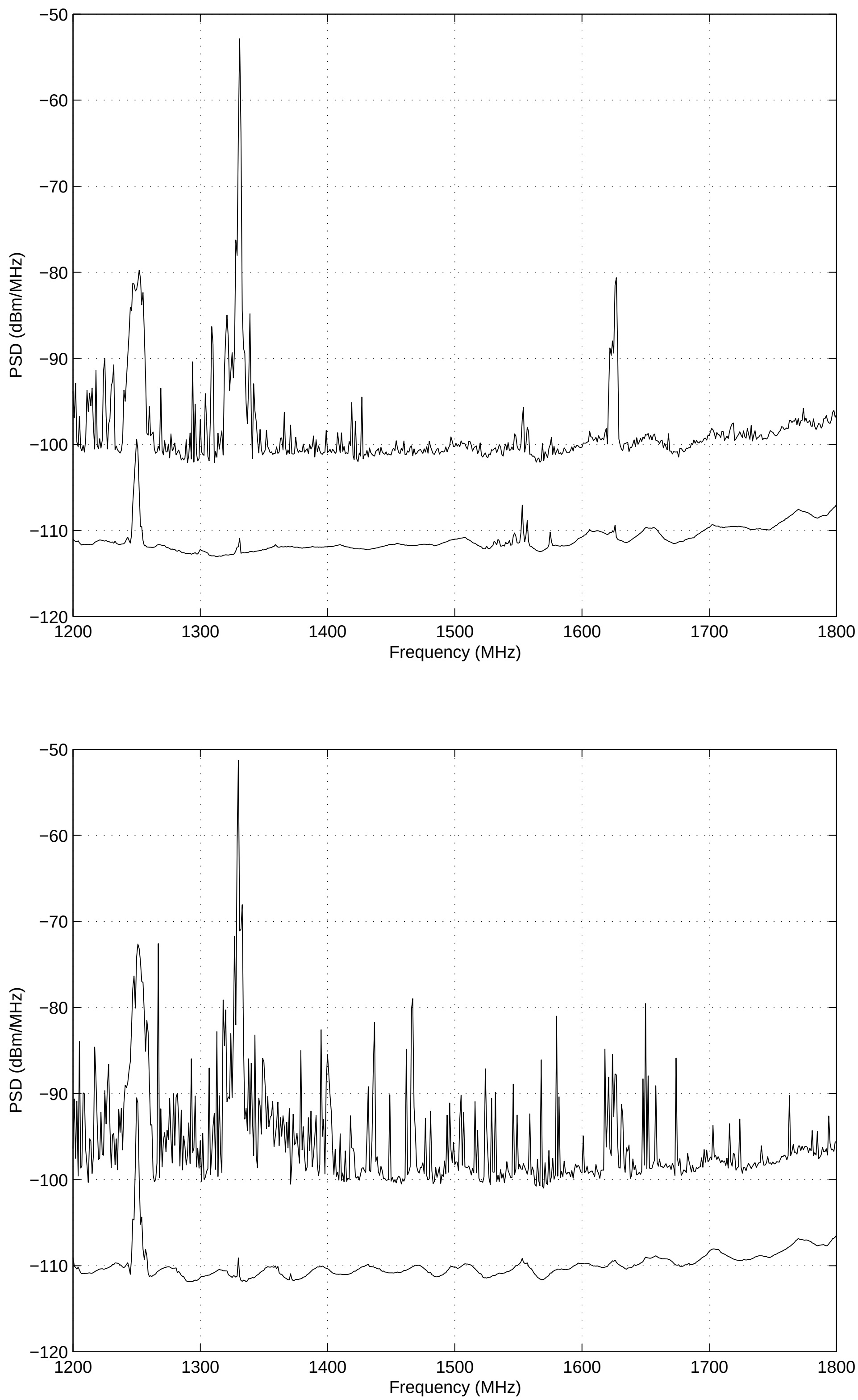


Figure 4: *Top:* Spiral, *Bottom:* Discone. In each panel, the top curve is max hold and the bottom curve is power average.

and transmits using a highly-directional antenna that rotates in azimuth every 10 s. See [5] for additional information.

- 1575 MHz: This is combined emission of whichever GPS satellites were above the horizon at the time of the measurmement. Note that the signal is clearly revealed in the spiral/power average curve, but not in the spiral/max hold curve: clearly indicating a weak, but stationary signal. Also note that the signal is not visible in the discone/power average curve, since that antenna is not very sensitive to the sky.

- 1624 MHz vicinity: This is the downlink from various Iridium satellites. Iridium is bursty (like the 1331 MHz radar), and thus is most easily detected using max hold. However, like GPS, it originates from the sky and so is not quite as prominent in the discone/max hold curve.

Another stunning feature of Figure 4 is that the majority of spurious L-band RFI seems to originate from very low elevations (probably, terrestrial). This is evident in the dramatic reduction of spurious signals (noted in the max hold spectra) between 1400 MHz and 1600 MHz when the spiral is used, as opposed to the discone. The spiral seems to be suppressing these signals by 10-20 dB at least, and seems to confirm that the spiral does in fact have very low gain at the horizon and below.

A third feature noted in Figure 4 is that the spiral seems to be a somewhat better matched antenna than the discone, as evident in the absense of baseline ripple in the 1300-1600 MHz band. Of course, the discone is designed to cover a much larger bandwidth; nevertheless, it is comforting to see that the Argus spiral is better in this respect.

The aggregate power average data can also be used to confirm the sensitivity of the measurement system. In Figure 5, the power average is compared to the result of a similar observation in which the antenna is replaced by a matched load at ambient temperature. Considering first the matched load, we estimate the associated power density to be between -111 dBm/MHz and -110 dBm/MHz, or equivalently, between 576°K and 724°K. Subtracting 290°K leaves an estimated system temperature between 286°K and 434°K (In the summary, the average value of 360°K is used). Next, consider the spiral: note that the apparent temperature is less than that of the load, as we would expect for an antenna whose field of view is limited to "cold" sky. The discone, in contrast, sees primarily "hot" ground, which manifests itself as an antenna temperature comparable to the ambient physical temperature.

Finally, Figures 6 through 10 show the results of the survey as a series of time-frequency representations (TFRs) covering the spectrum in 100 MHz swaths. For each band, the result from the spiral and the discone are shown side-by-side. When studying these TFRs, keep in mind that the spiral and discone data are taken at different times, and thus bursty RFI does not appear synchronized between the two TFRs. However, the axes and gray scale assignments are identical in all the TFRs, in order to facilitate comparisons.

References

[1] http://esl.eng.ohio-state.edu/rfse/argus/rfse-argus.html.

[2] S.W. Ellingson, "A 1-GHz Highpass PHEMT Low-Noise Amplifier (Rev. 1)," Design Report, Oct 6, 2002. Available via http://esl.eng.ohio-state.edu/∼swe/argus/docserv.html.

[3] S.W. Ellingson, "A Low-Cost L-Band Line Amplifier (Rev. 1)," Design Report, October 9, 2002. Available via http://esl.eng.ohio-state.edu/∼swe/argus/docserv.html.

[4] S.W. Ellingson, "Agilent Spectrum Analyzer Computer Control Demo", IIP Memo 20, June 6, 2002. (see [5])

[5] ESL's NASA IIP Project Document Server, http://esl.eng.ohio-state.edu/∼swe/iip/docserv.html.

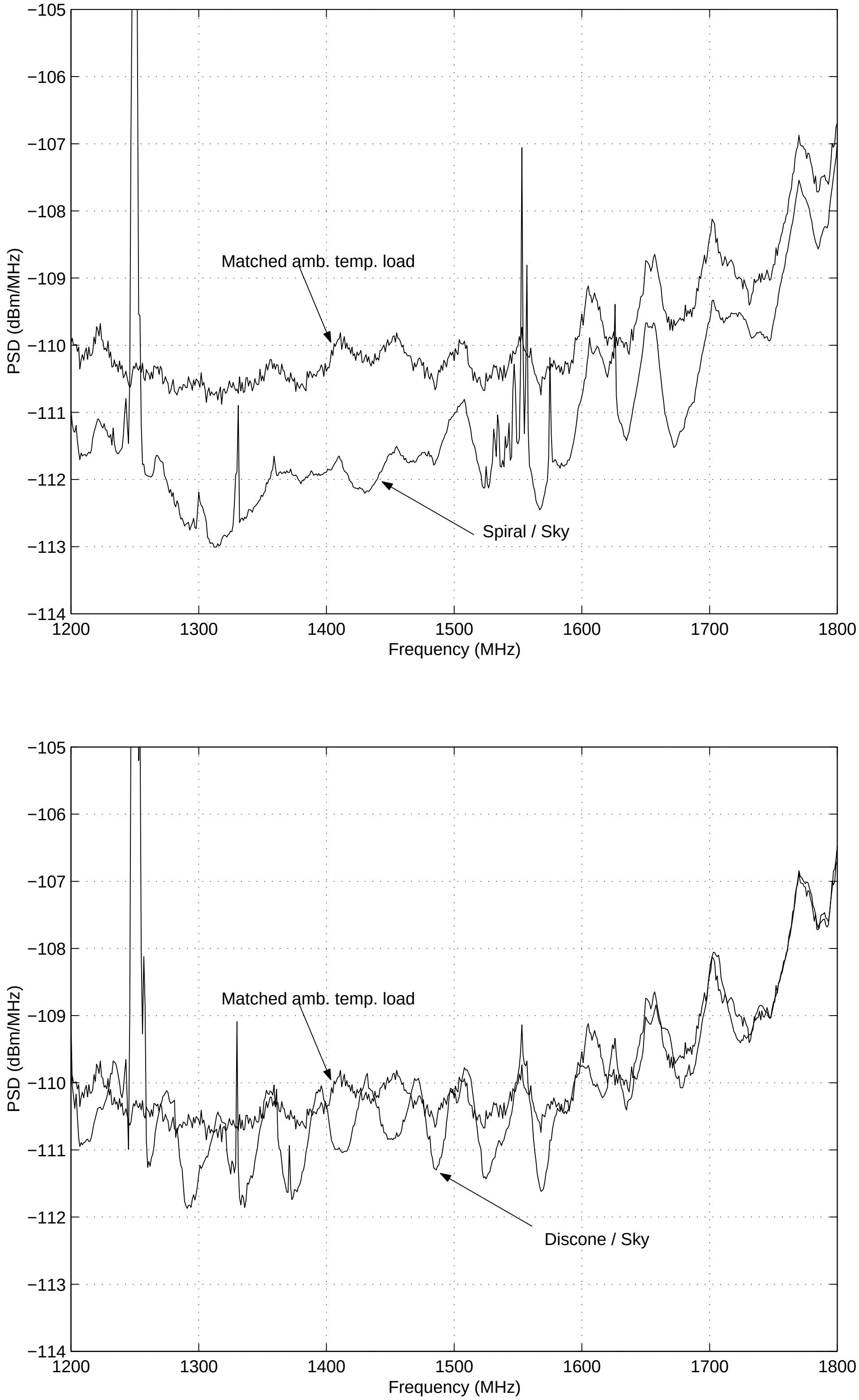


Figure 5: Power average results compared to a matched ambient-temperature load. *Top:* Spiral, *Bottom:* Discone. Note: The observation time for the matched load measurement was only a few minutes, compared to 1 hr for the antenna measurements.

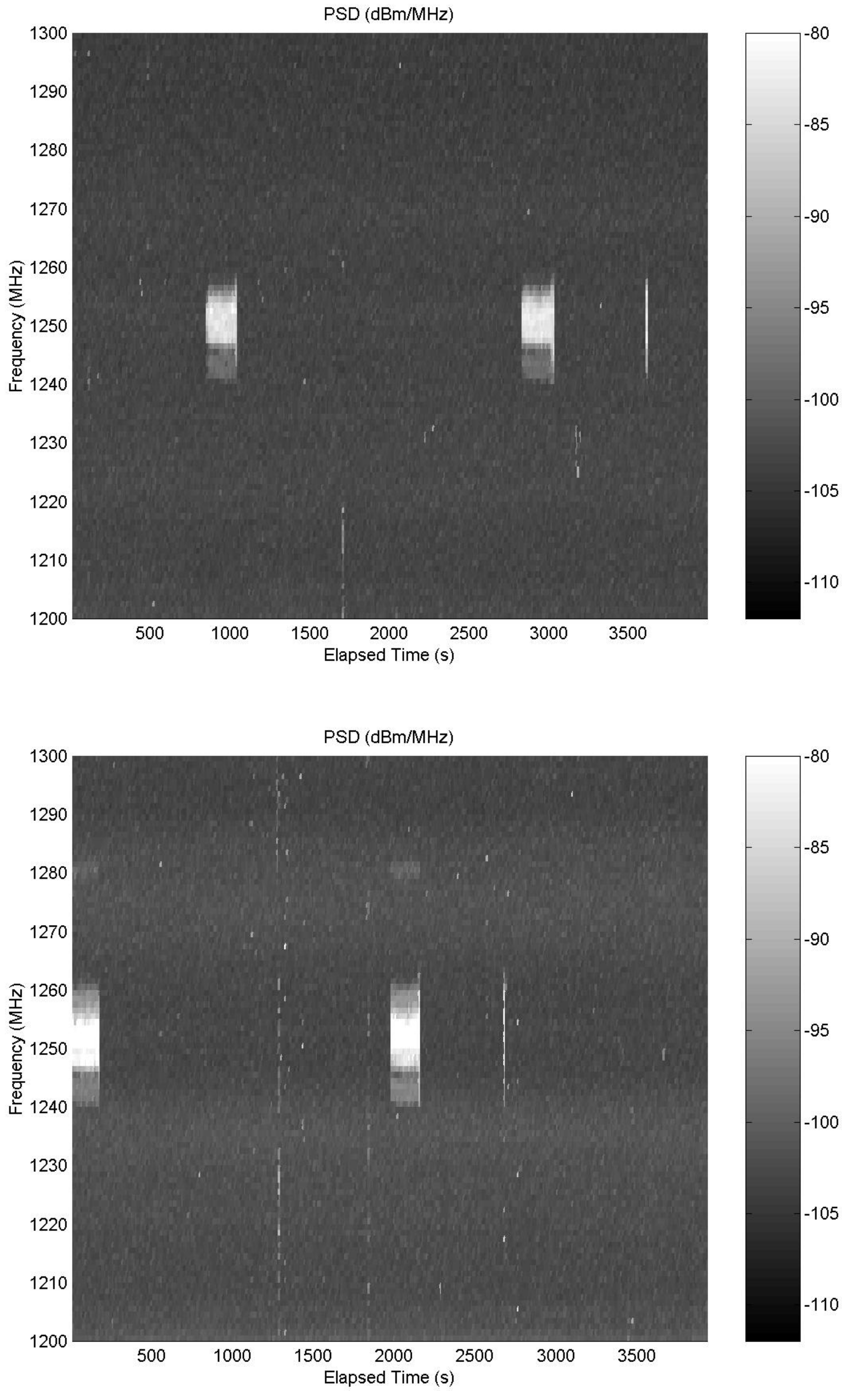


Figure 6: Max-hold TFR for 1200-1300 MHz. *Top:* Spiral, *Bottom:* Discone. Note the 1250 MHz ATV signal.

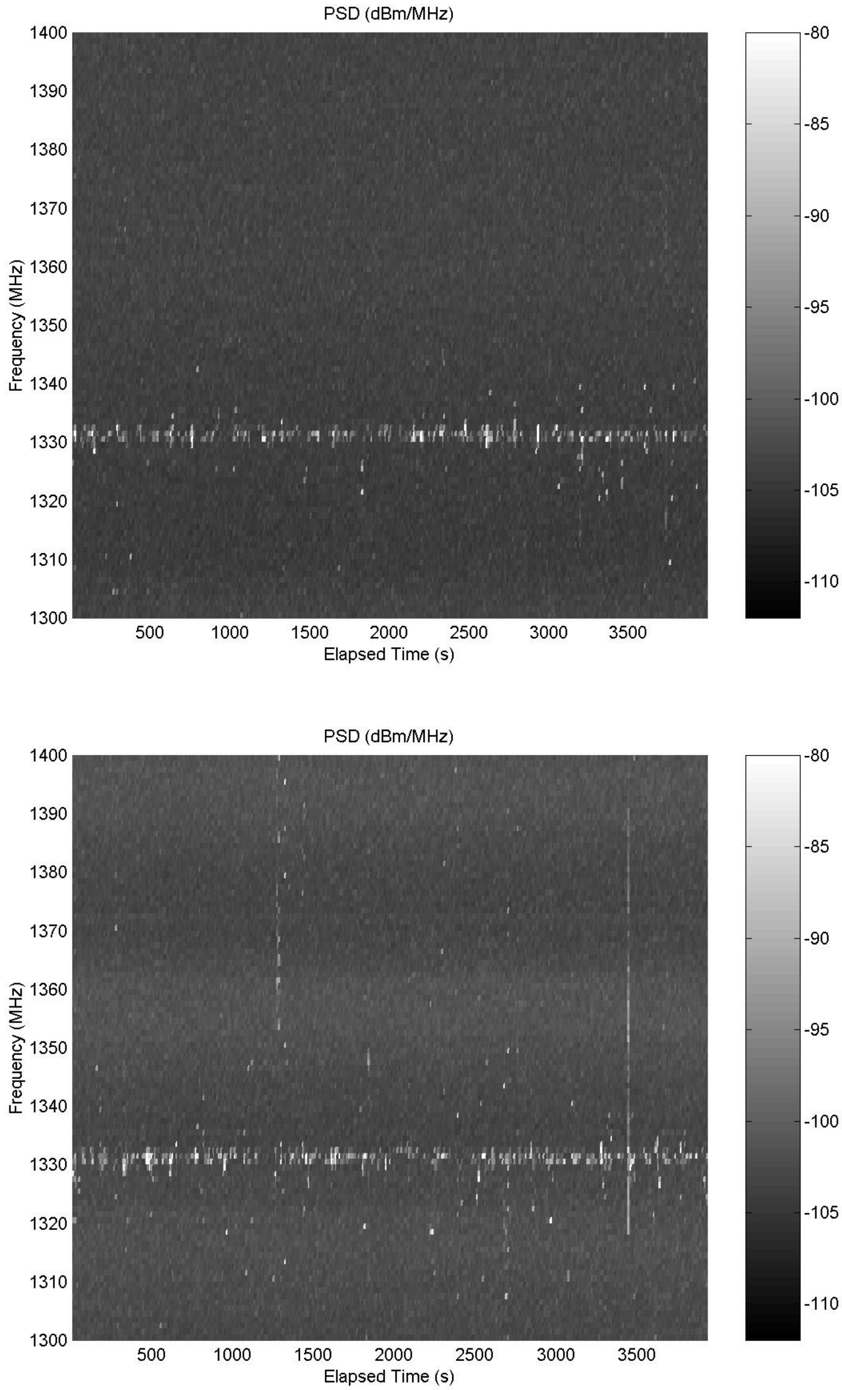


Figure 7: Max-hold TFR for 1300-1400 MHz. *Top:* Spiral, *Bottom:* Discone. Note that the 1331 MHz radar is equally strong in both antennas, suggesting that this signal arrives from a range of elevations over which the spiral and discone have roughly equal sensitivity; i.e., a few degrees above the horizon.

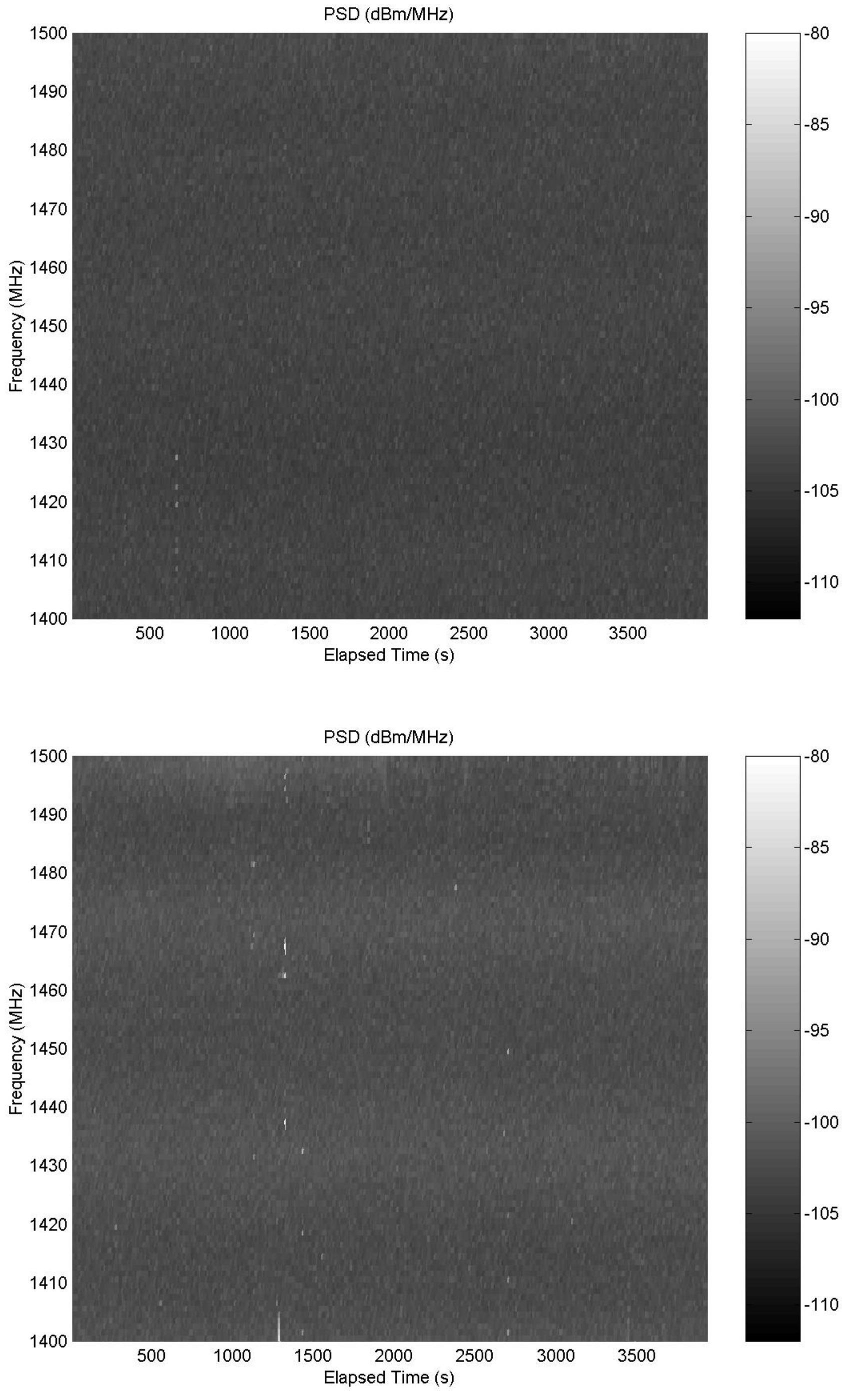
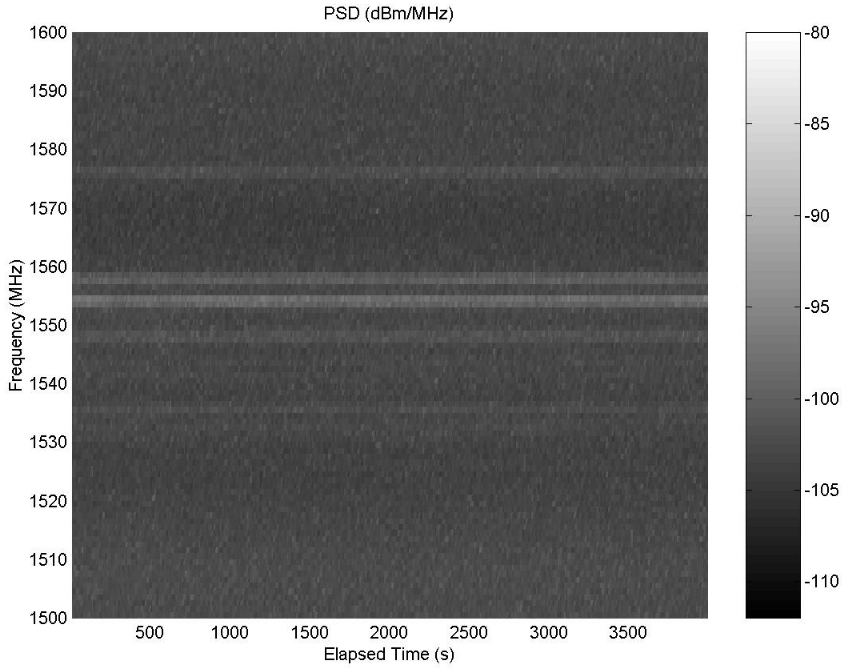


Figure 8: Max-hold TFR for 1400-1500 MHz. *Top:* Spiral, *Bottom:* Discone. Note that this band is relatively clean.



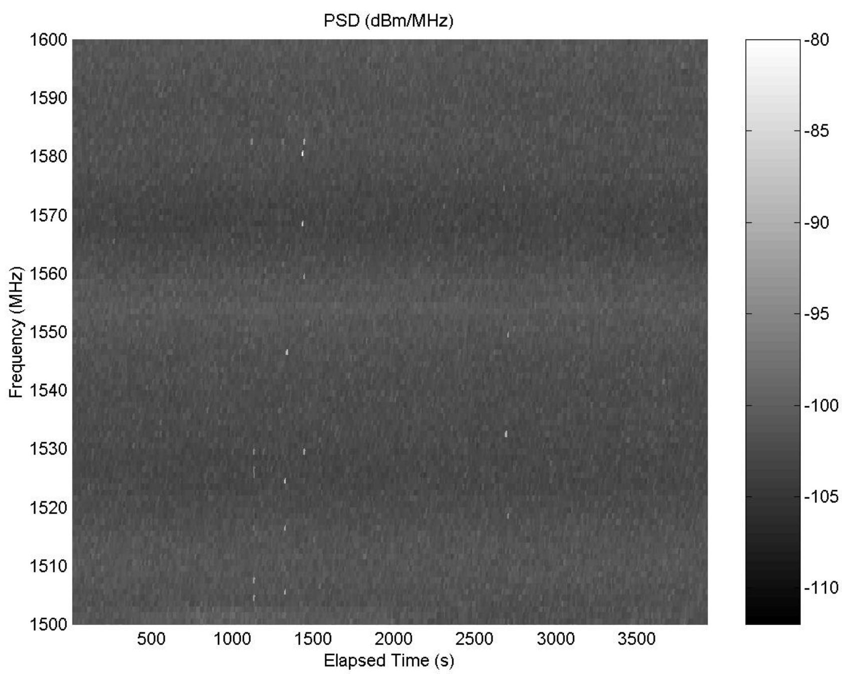


Figure 9: Max-hold TFR for 1500-1600 MHz. *Top:* Spiral, *Bottom:* Discone. Note the 1575 MHz GPS signal visible in the spiral (but not the discone) output. The other signals visible between 1530 MHz and 1560 MHz in the spiral output are also believed to originate from satellites.

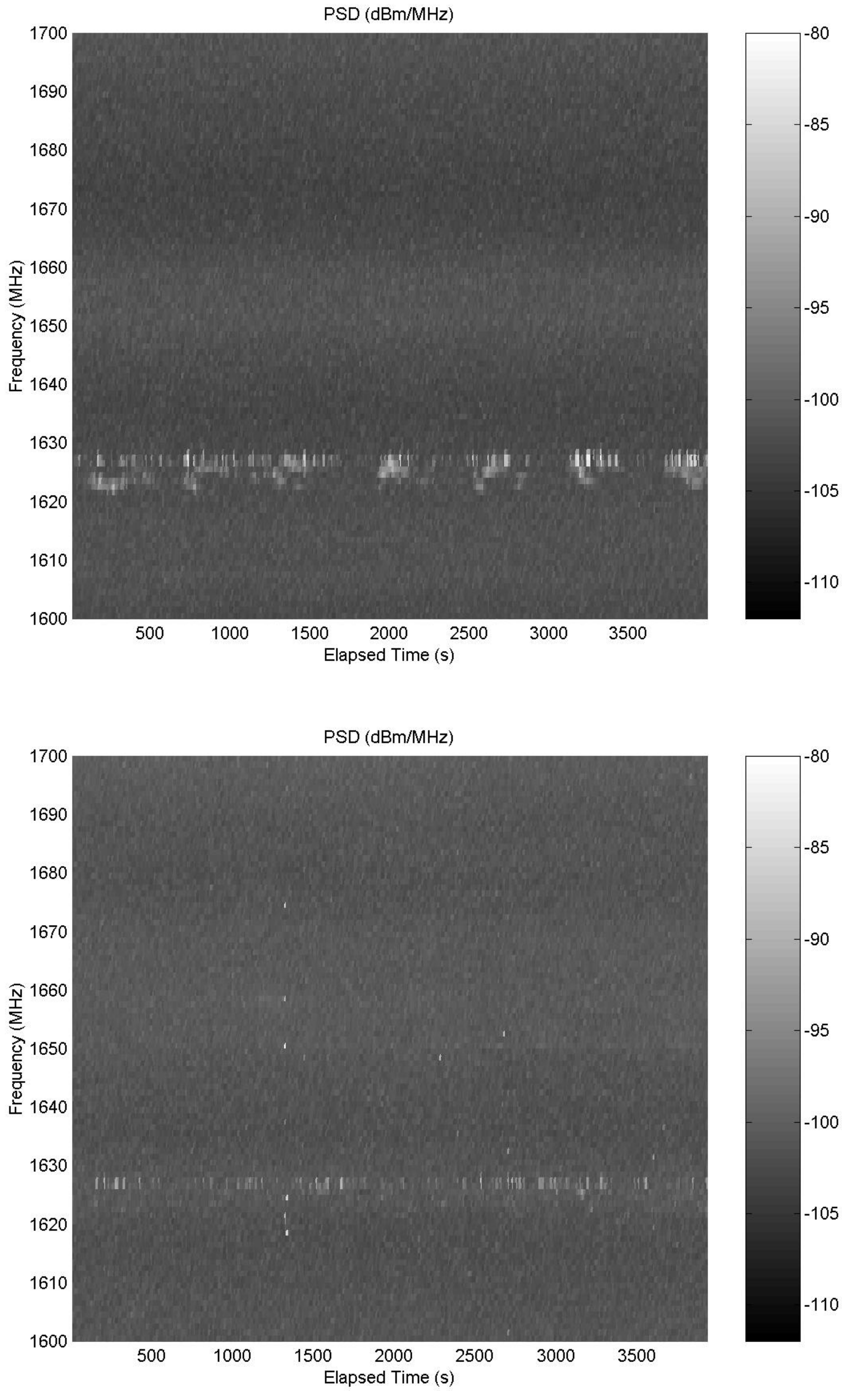


Figure 10: Max-hold TFR for 1600-1700 MHz. *Top:* Spiral, *Bottom:* Discone. Iridium is clearly visible around 1626 MHz in the spiral output, and less so in the spiral output.