RFI at SCF as Seen by Argus

Steven W. Ellingson*

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

1 Introduction

The Argus [1] array is currently located on the roof of the Ohio State University (OSU) ElectroScience Laboratory's Satellite Communication Facility (SCF), located on OSU's West Campus. This report documents the radio frequency interference (RFI) environment at this site, as seen by the Argus antennas and front end electronics. A survey of the band 0-3000 MHz is done with 1 MHz resolution. First, a low-sensitivity survey is done using only the antenna (no front end electronics) in order to see what signals appear at the antenna terminals. Then, the survey is repeated with the front end electronics installed. In the 1200-1800 MHz passband of the front end, a system temperature of $\sim 290°K$ is acheived, resulting in a detection limit of $\sim 5°K$ (-132 dBm/MHz) for stationary signals after 4200 sweeps. Many signals are detected and indentified.

2 Instrumentation

The instrumentation consisted of an Argus antenna unit, a long cable from the SCF roof to a room within SCF, a spectrum analyzer, and a PC for experiment control and data collection. Initially, none of the Argus front end electronics were used, because we want to see what is present at the antenna terminals. Next, the Argus front end was added and the experiment was repeated. The various components are explained in more detail below.

The Argus antenna unit is a custom design developed at ESL. The antenna is shown in Figure 1. In it's design range of 1000-2000 MHz, this antenna has a pattern which is uniform in azimuth, with maximum gain at the zenith and very low gain toward the horizon. At lower frequencies, it's small size leads to nearly isotropic patterns, although with spurious pattern nulls. At higher frequencies, it tends to become somewhat more directional toward the zenith.

The front end, when used in this study, consisted of a coaxial high-pass filter, an Argus LNA [2], and an Argus line amplifier [3]. The high-pass filter was a Mini-Circuits Model SHP-1000, which rolls off at about 950 MHz. The length of the cable

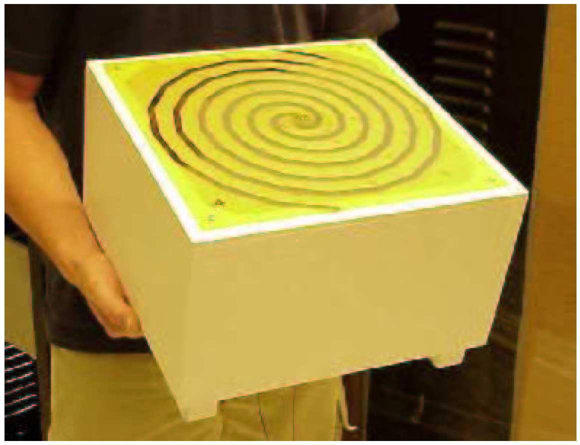


Figure 1: Spiral antenna. The antenna consists of a planar spiral printed on a circuit board substrate, above a system of three ground planes, enclosed in the box.

connecting the front end on the roof to the spectrum analyzer below was not measured but was on the order of 30 m. The spectrum analyzer was an Agilent Model E4407B. When the front end is used, the gain from the antenna terminals to the input of the spectrum analyzer was about 20 dB. When the front end was not used, this becomes a loss which is frequency-dependent; about 15 dB at 1500 MHz.

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 over the desired frequency span are taken. Each sweep samples the spectrum 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 22 s for a frequency span of 0-3000 MHz.

2. *Power Average.* Same as max hold, except the 100 sweeps are linearly averaged. This procedure takes about 22 s for a frequency span of 0-3000 MHz.

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 during the afternoon hours of Oct 16, 2002. Unless indicated otherwise, all data presented in the following sections were calibrated to remove the seperately-measured transfer function of the front end and long cable. Thus, the indicated power spectral density (PSD) is that observed at the terminals of the antenna; except of course for the noise floor, which determined by system temperature.

3 Antenna-Only (Without Front End) Results

In the first set of measurements, the antenna is connected directly to the long cable, with no front end. The results are summarized in Figure 2. In this figure, as in all the figures to follow, we show the average result twice, once with the antenna replaced by an ambient-temperture matched load. Without a low-noise front end, the receiver temperature is dominated by cable loss, which increases with frequency. Thus, the noise PSD in these measurements increases with frequency, with the result that the measurement is less sensitive at high frequencies than at low frequencies. (For reference, a perfect radiometer would measure the matched load PSD as frequency-independent at about -114 dBm/MHz.)

Therefore, the measurements in this section are useful to the extent that the *strongest* signals are characterized. This is important because it impacts the filtering and linearity requirements for the front end electronics. Figure 2 shows that the antenna captures many strong signals, including a few exceeding -40 dBm/MHz. A few spans are shown in more detail in Figures 3–7.

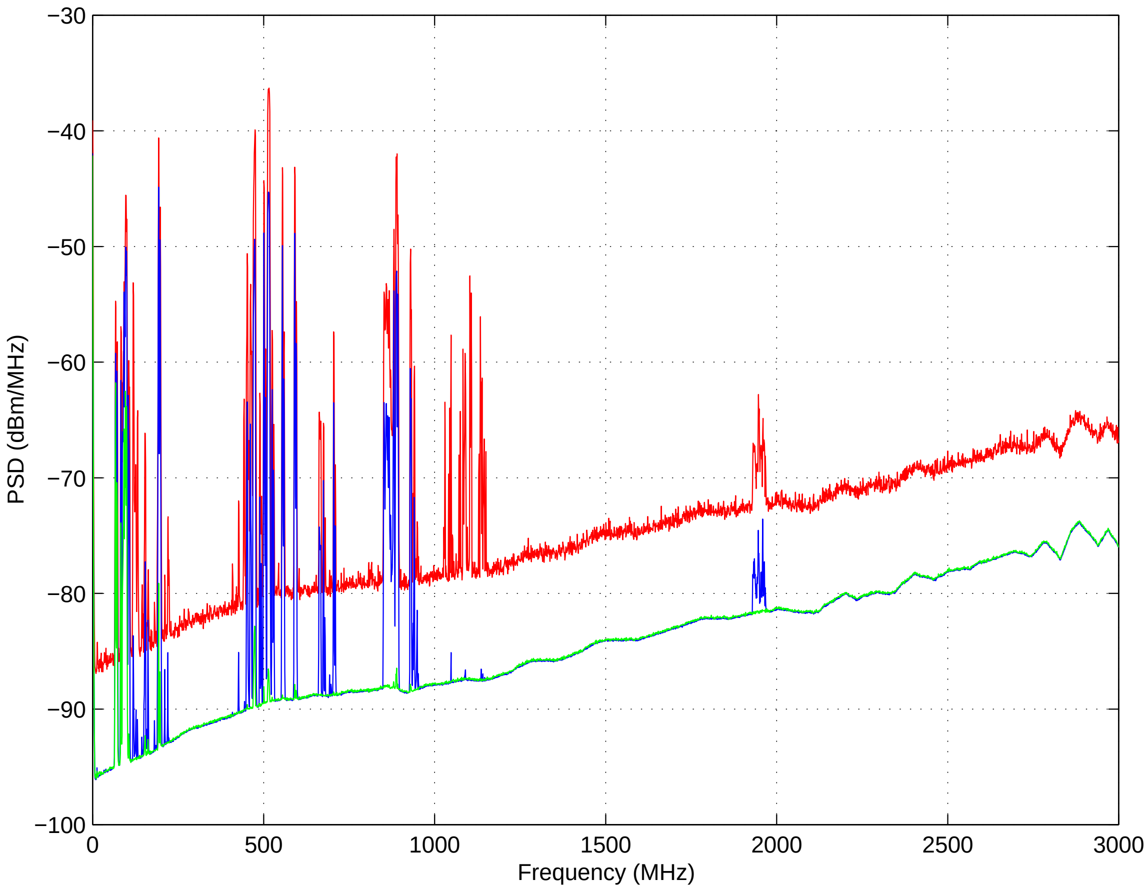
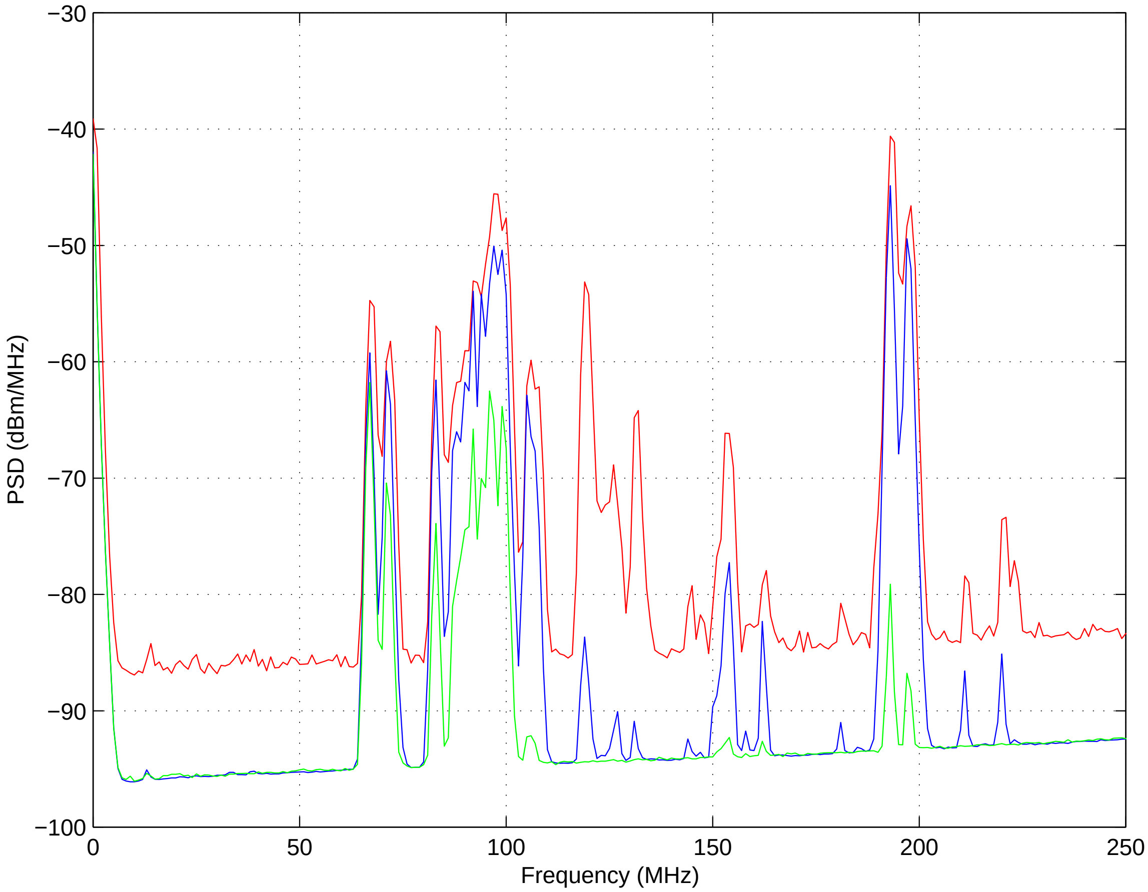
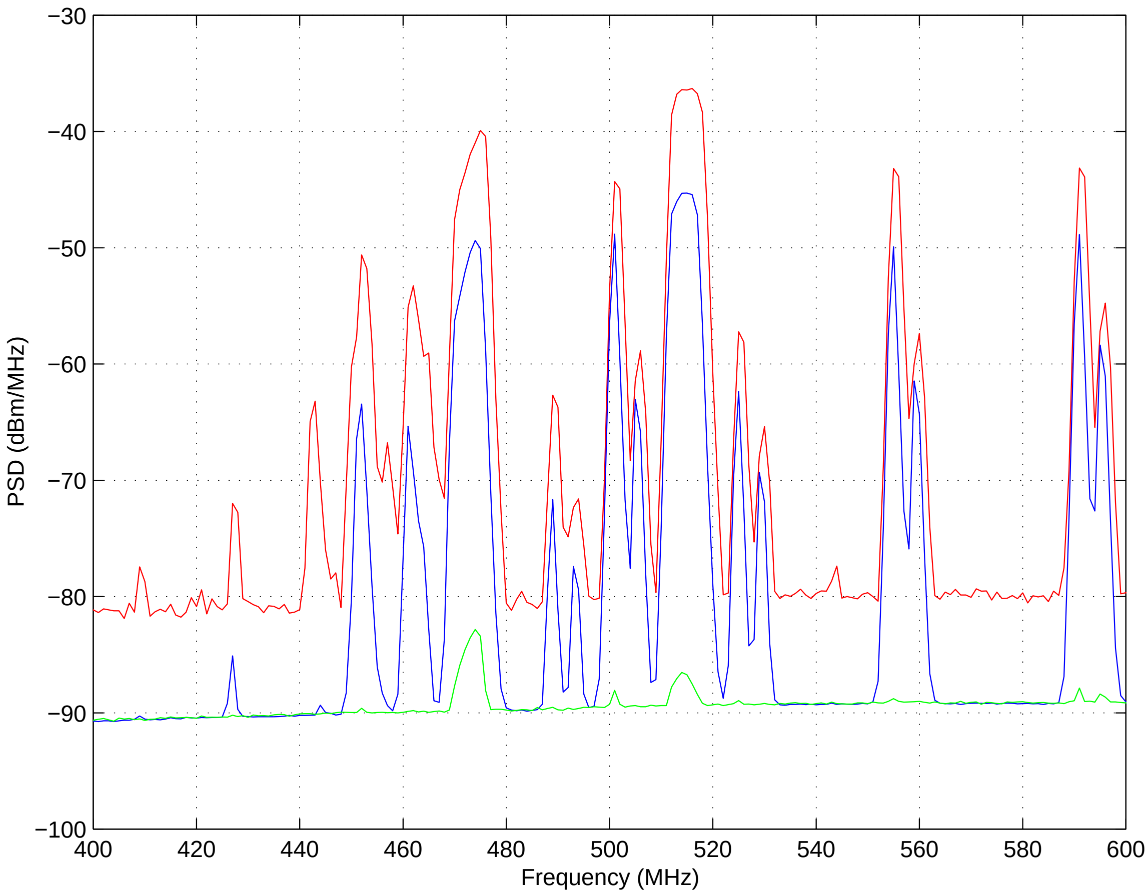


Figure 2: Antenna only, 0-3000 MHz. *Top/Red:* Antenna/Max hold, *Blue:* Antenna/Average, *Green:* Matched Load/Average.



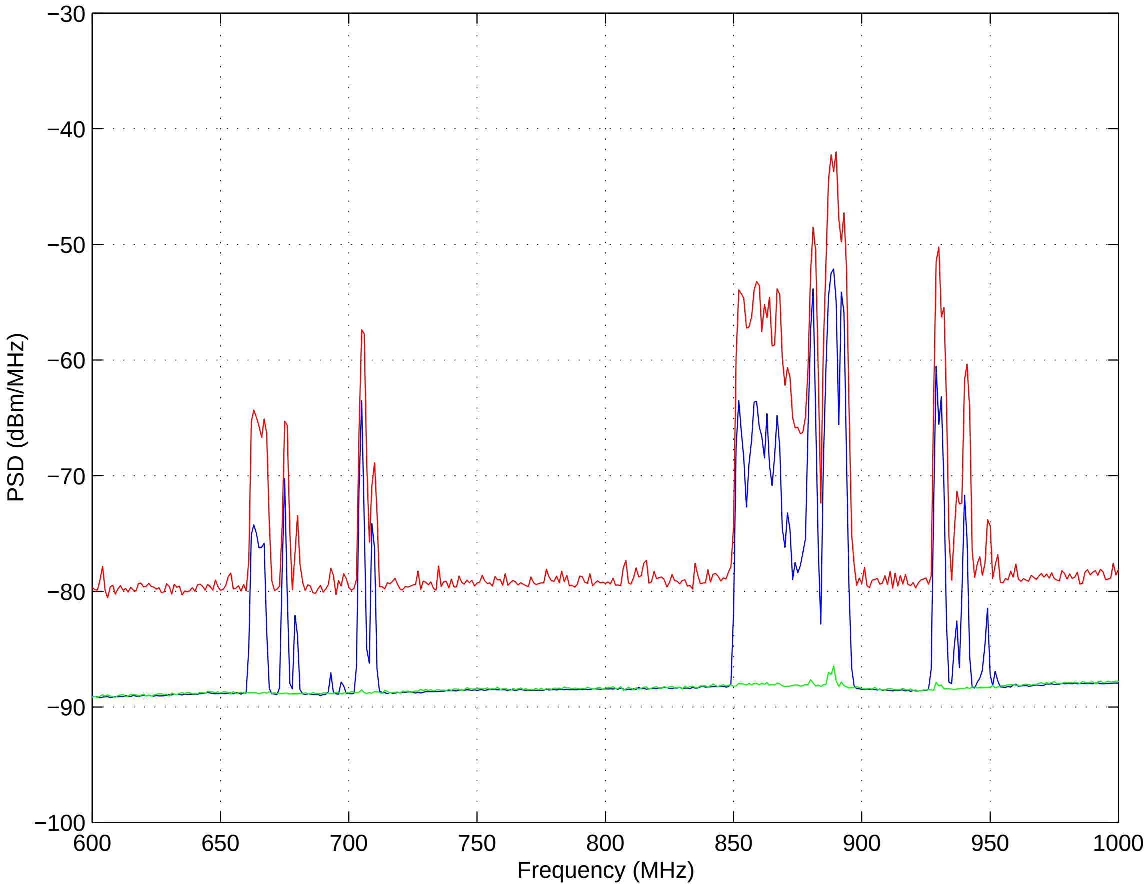
- 67.25 MHz (Video)/70.83 MHz (Color)/71.75 MHz (Audio): TV Channel 4
- 83.25 MHz (Video)/86.83 MHz (Color)/87.75 MHz (Audio): TV Channel 6
- 88-108 MHz: Broadcast FM stations
- 193.25 MHz (Video)/196.83 MHz (Color)/197.75 MHz (Audio): TV Channel 10

Figure 3: Antenna only, 0-250 MHz. See Fig. 2 for legend.



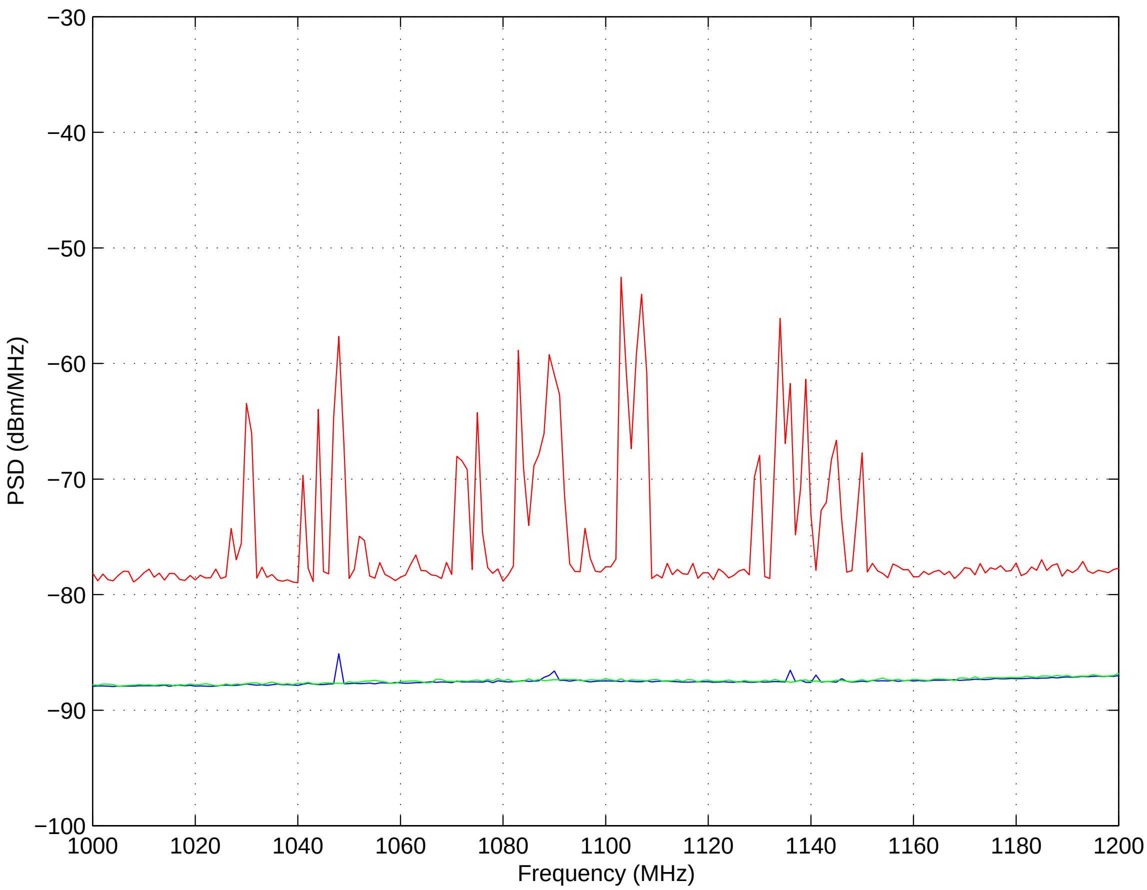
- 489.25 MHz (Video)/492.83 MHz (Color)/493.75 MHz (Audio): TV Channel 17
- 507.25 MHz (Video)/510.83 MHz (Color)/511.75 MHz (Audio): TV Channel 20
- Vicinity 515 MHz: HDTV broadcast (TV Channel 21)
- 525.25 MHz (Video)/528.83 MHz (Color)/529.75 MHz (Audio): TV Channel 23
- 555.25 MHz (Video)/558.83 MHz (Color)/559.75 MHz (Audio): TV Channel 28
- 591.25 MHz (Video)/594.83 MHz (Color)/595.75 MHz (Audio): TV Channel 34

Figure 4: Antenna only, 400-600 MHz. See Fig. 2 for legend.



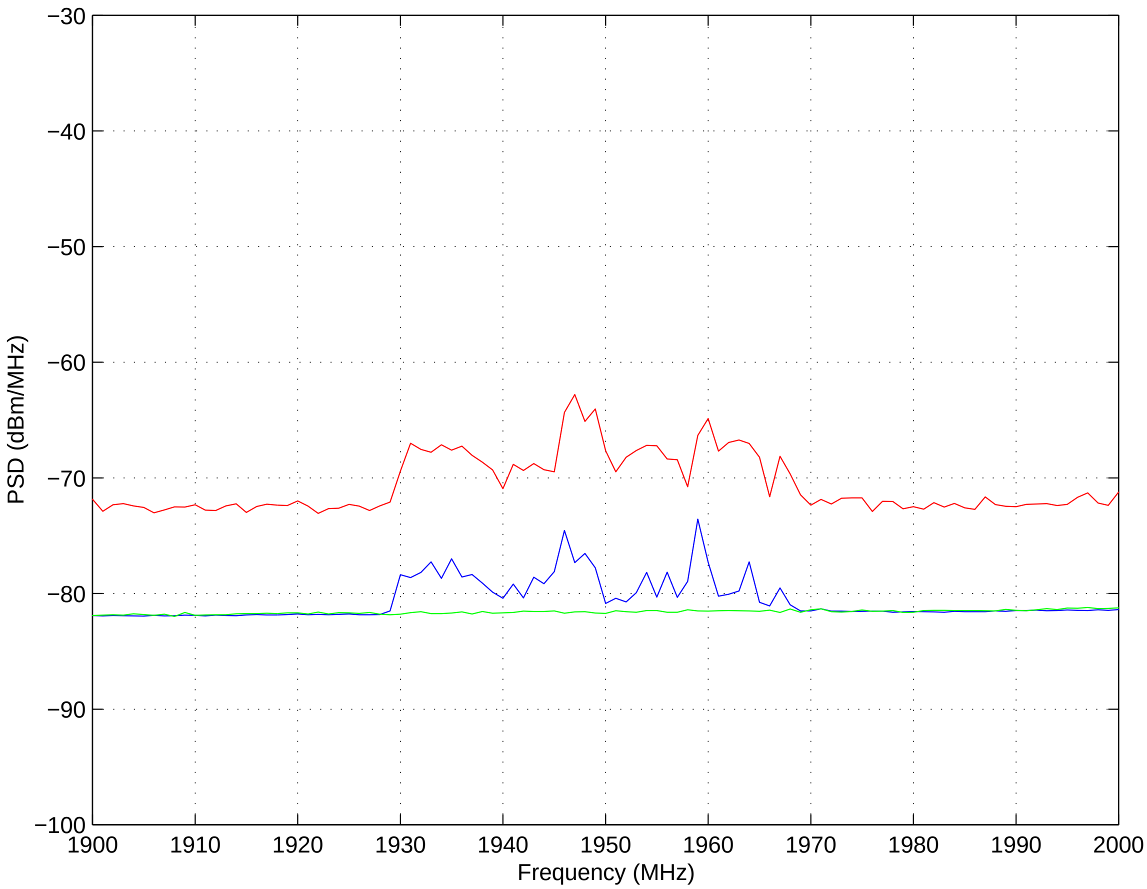
- 705.25 MHz (Video)/708.83 MHz (Color)/709.75 MHz (Audio): TV Channel 53
- 851-894 MHz: Land Mobile & Cellular Base Station → Mobile [5]

Figure 5: Antenna only, 600-1000 MHz. See Fig. 2 for legend.



- The entire band 960-1215 MHz is allocated to “Aeronautical Radionavigation”[5].
- 1030 MHz: Air Traffic Control Radar Beacon System (ATCRBS), Ground→Air [5].
- 1090 MHz: Air Traffic Control Radar Beacon System (ATCRBS), Air→Ground [5].
- *Various:* Secondary Surveillance Radar (SSR), Traffic Alert and Collision Avoidance System (TCAS), and Distance Measuring Equipment (DME) [5].

Figure 6: Antenna only, 1000-1200 MHz. See Fig. 2 for legend.



- 1930-1945 MHz: PCS Block A Base Station → Mobile [5]
- 1945-1950 MHz: PCS Block D Base Station → Mobile [5]
- 1950-1965 MHz: PCS Block B Base Station → Mobile [5]
- 1965-1970 MHz: PCS Block E Base Station → Mobile [5]

Figure 7: Antenna only, 1900-2000 MHz. See Fig. 2 for legend.

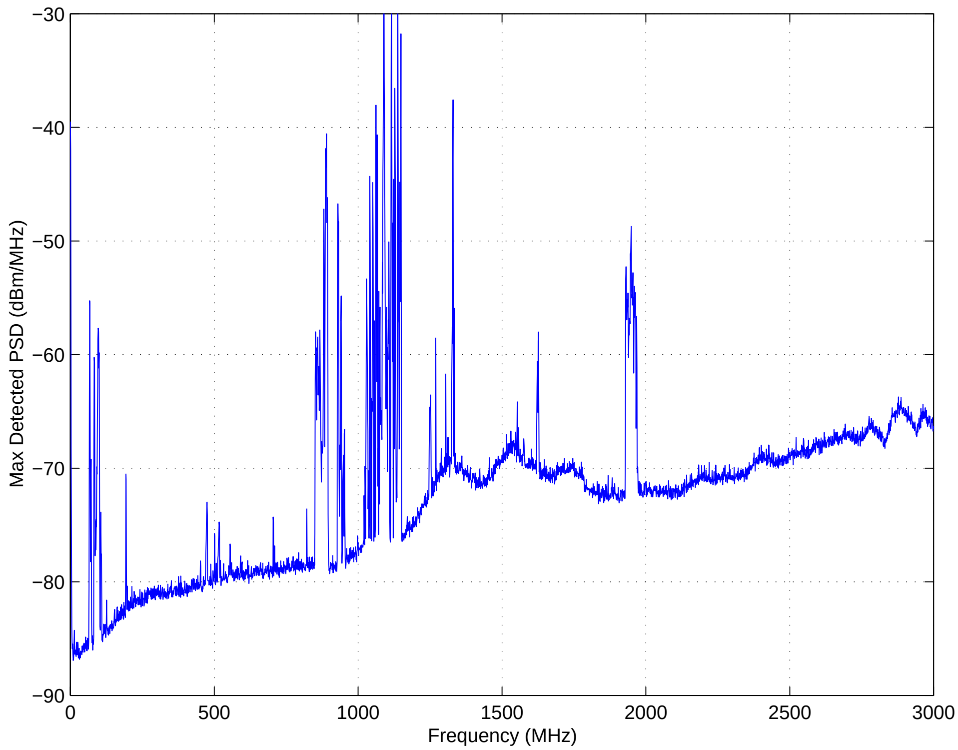


Figure 8: Antenna + Front End, 0-3000 MHz, *uncalibrated* (only the response of the long cable is compensated) max hold measurement.

4 Antenna + Front End Results

In this section we repeat the measurements of the previous section, now including the Argus front end electronics. This adds about 30 dB of low-noise gain at the antenna (before the long cable), and filtering outside the 1200-1800 MHz passband set by the Argus line amplifier. An *uncalibrated* result (in which the response of the long cable, but not the front end, is removed) is shown in Figure 8. It is interesting to note that the pulsed signals of the 960-1215 MHz Aeronautical Radionavigation band are now the strongest signals present at the output of the front end electronics, although broadcast FM remains strong.

Figure 9 includes a complete calibration, including removal of the front end frequency response, and is analogous to Figure 2. In other words, this plot shows the PSD of signals as they appear at the antenna terminals, and the noise PSD represents the system temperature. Since the front end includes a very selective 1200-1800 MHz

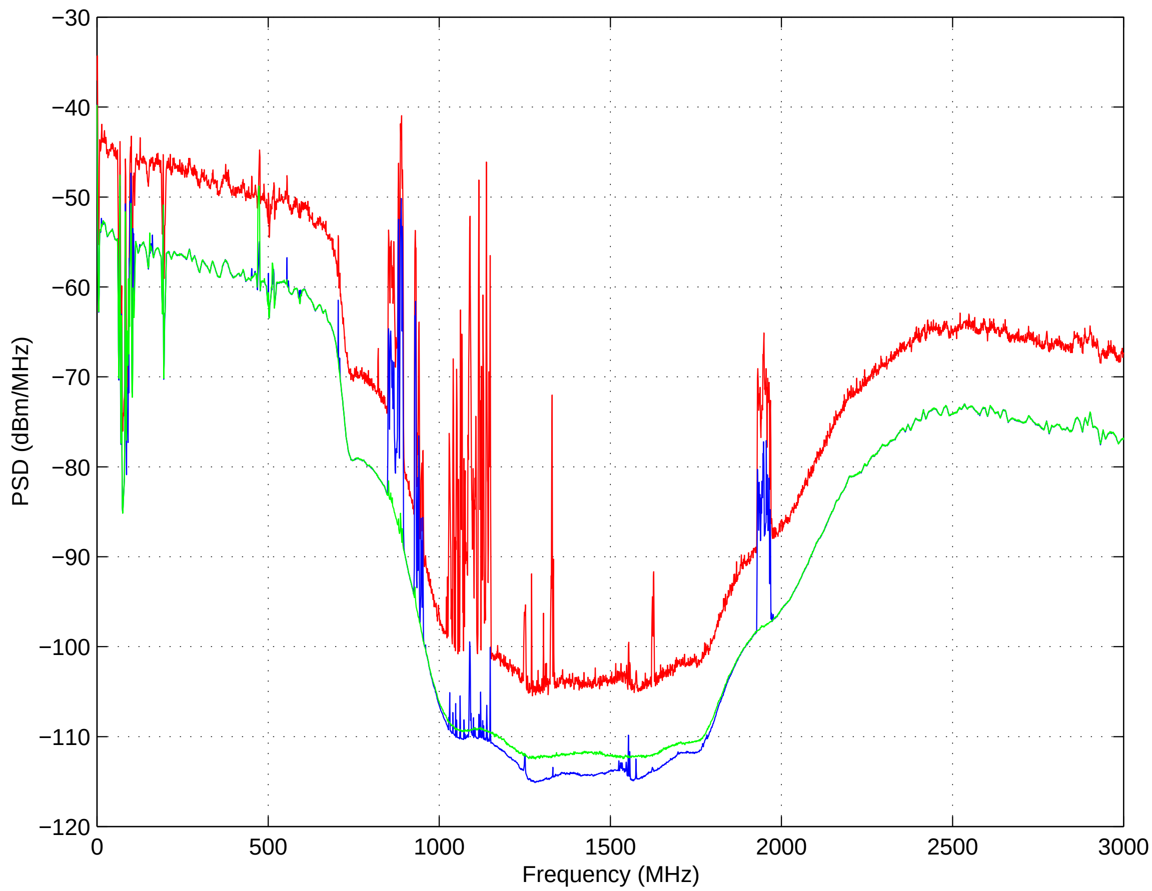


Figure 9: Antenna + Front End, 0-3000 MHz. *Top/Red:* Antenna/Max hold, *Blue:* Antenna/Average, *Green:* Matched Load/Average. (Analogous to Fig. 2.)

bandpass filter, the sensitivity of the measurement outside this range is very poor. On the other hand, the use of a low-noise front end makes the sensitivity within the 1200-1800 MHz quite good. In fact, we now observe a significantly lower in-band PSD for the antenna than we do for the matched load; i.e., we can sense that the sky is "colder" than the ambient temperature ($\sim 290°$K) matched load. Figure 9 represents 4200 sweeps through the measurement span, collected over a period of about 30 min.

In Figure 10, we zoom in to the passband region of Figure 9. The ambient temperature matched load is measured at about -112 dBm/MHz, which suggests a noise figure of 2 dB, or, equivalently, a receiver temperature T_R of about 170°K. Subse-

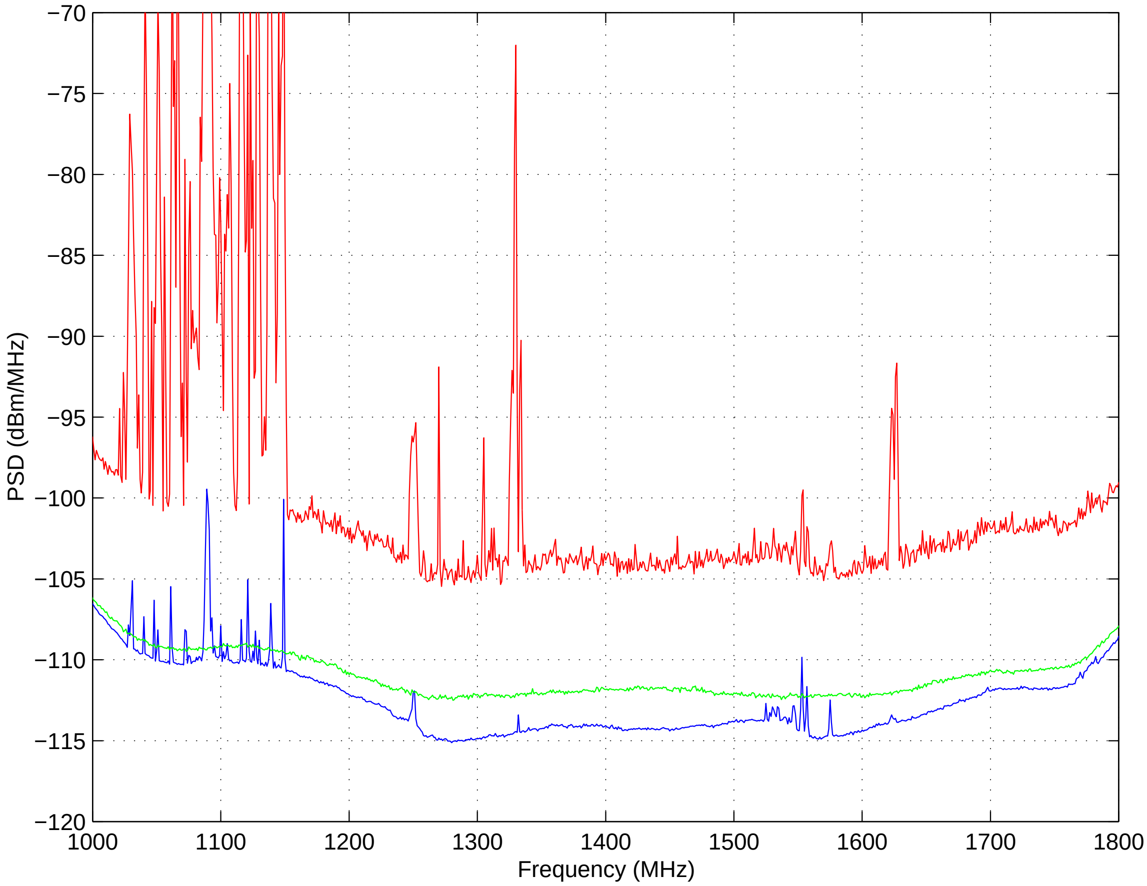


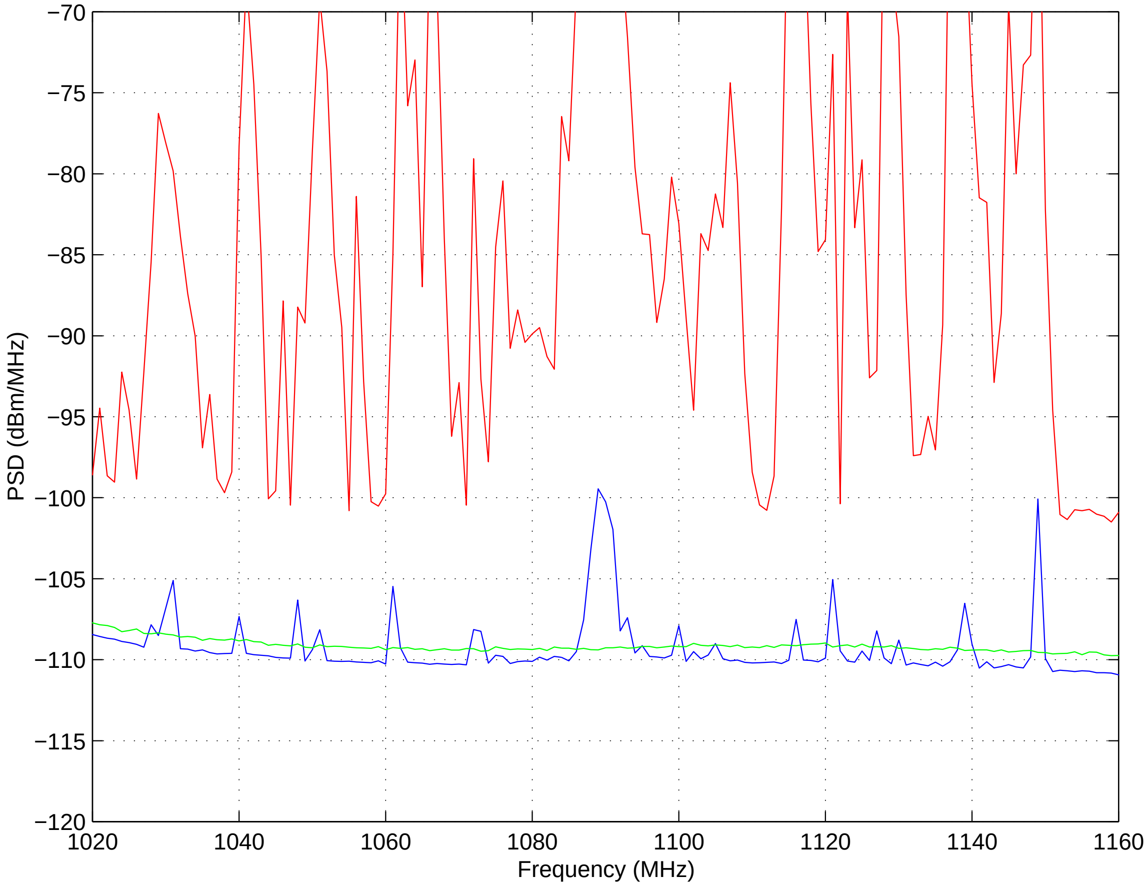
Figure 10: Antenna + Front End, 1000-1800 MHz. See Fig. 9 for legend.

quently, we can estimate the antenna temperature T_{sky} using the relationship:

$$\frac{T_{sky} + T_R}{290°\text{K} + T_R} \approx 10^{((-114 \text{ dB})-(-112 \text{ dB}))/10} \tag{1}$$

giving $T_{sky} \sim 120°$K. For the purposes of sensing RFI, the system measurement noise temperature $T_{sys} = T_r + T_{sky}$ is thus $\sim 290°$K. Since the averaging in Figure 9 is over 4200 sweeps, the detection sensitivity $\Delta T \approx 290°\text{K}/\sqrt{4200} \approx 5°$K, or, equivalently, -132 dBm/MHz. In other words, signals at -132 dBm/MHz or better should be visible as a 1σ deflection from the baseline in Figure 10.

A few spans are shown in more detail in Figures 11–13.



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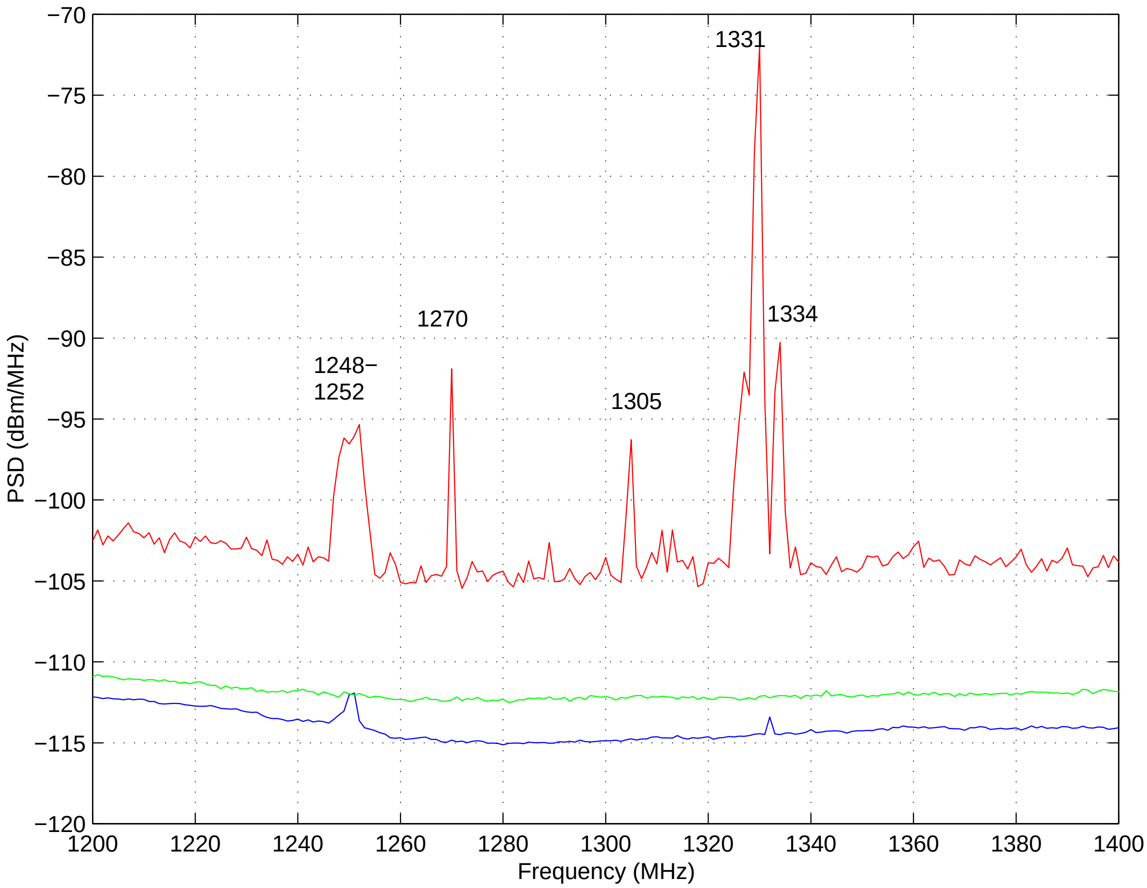
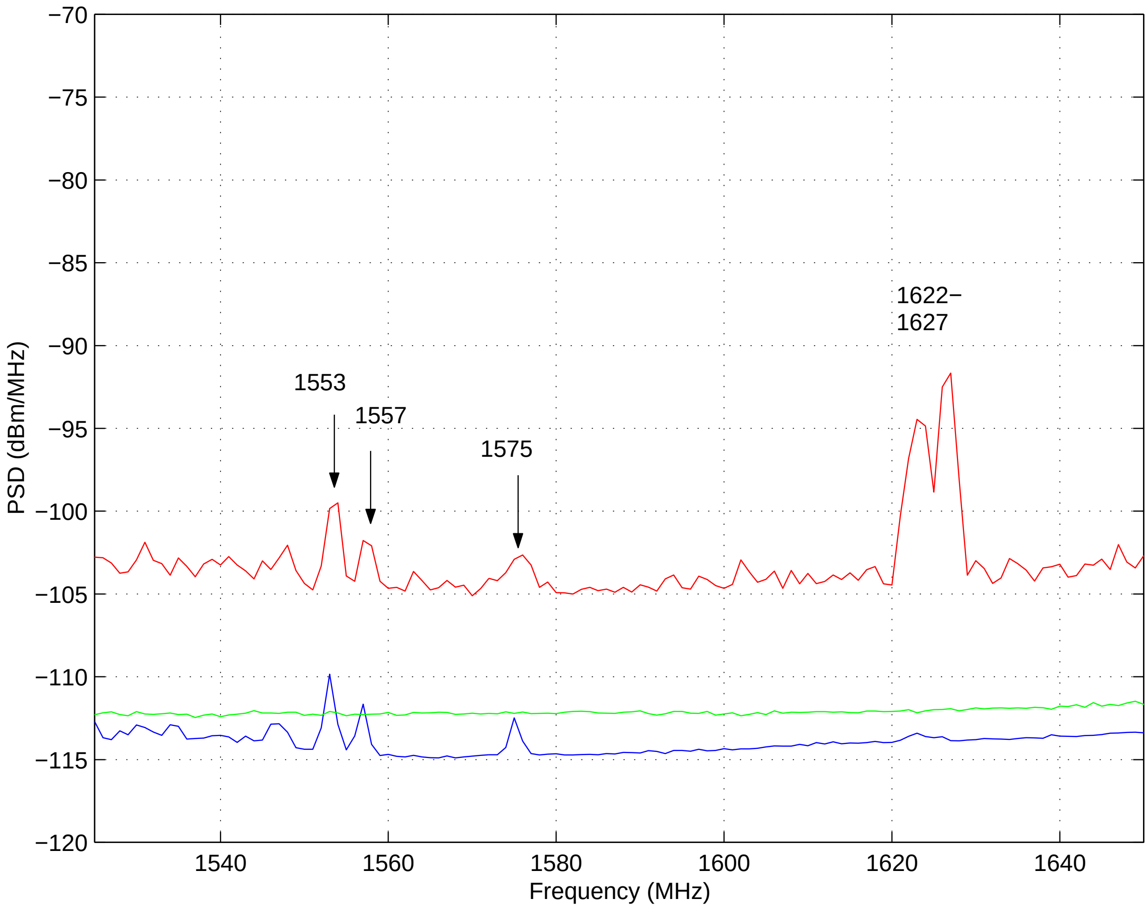
- *Various:* Secondary Surveillance Radar (SSR), Traffic Alert and Collision Avoidance System (TCAS), and Distance Measuring Equipment (DME) [5].

Figure 11: Antenna + Front End, 1020-1160 MHz. See Fig. 9 for legend.



- Vicinity of 1250 MHz: Local Amateur Television (ATV) station.
- 1270 MHz: Suspected to be a radar.
- 1305 MHz: Suspected to be a radar.
- 1331 MHz: Air traffic control radar located in London, OH.
- 1334 MHz: Possible radar.

Figure 12: Antenna + Front End, 1200-1400 MHz. See Fig. 9 for legend.



- Vicinity of 1250 MHz: Local Amateur Television (ATV) station.
- 1553 MHz: Suspected to be a downlink from a geostationary satellite.
- 1557 MHz: Suspected to be a downlink from a geostationary satellite.
- 1575 MHz: GPS.
- 1622-1627 MHz: Downlinks from Iridium satellites.

Figure 13: Antenna + Front End, 1530-1650 MHz. See Fig. 9 for legend..

References

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[5] B.Z. Kobb, *Wireless Spectrum Finder*, McGraw-Hill, 2001.