Testing Argus using a Spectrum Analyzer Mode

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Contents

1 Introduction **2**

2 Argus System Configuration **2**

3 DCR Input Tests **4**

4 On-The-Air Tests **6**

List of Figures

1 Frequency response of the DDC. 3
2 *Top:* DCR input terminated. *Bottom:* Single tone at 1420.8 MHz applied to the input of the DCR. *Both panels:* Integration over 100 sweeps. 5
3 GPS L1 observation, 1000 sweeps. *Top:* Sky. *Bottom Left:* Sky (zooming in). *Bottom Right:* Absorber. 7
4 Hydrogen line vicinity, 1000 sweeps. *Left:* Sky. *Right:* Absorber. . . . 9
5 Hydrogen line vicinity, $\sim$ 39450 sweeps. *Top:* Sky, *Bottom:* Zooming in to show more detail. The downward spikes every $\sim$ 80 kHz are due to the roll off in the DDC filter response for each DDC tuning. 11
6 The 1331 MHz air traffic control radar based in London, OH. 1000 sweeps. 12

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1 Introduction

This report describes some tests of the current generation of Argus hardware. In these tests, the system was programmed to behave as a spectrum analyzer, digitally sweeping the 14 MHz passband of the direct conversion receiver (DCR) while the tuning of the DCR itself was held fixed. This allowed us to evaluate 14 MHz of digitized spectrum simultaneously while using exactly the same hardware required for the anticipated routine (relatively narrowband) operation of the system.

We made observations of the GPS L1 signal at $\sim$ 1575 MHz, the hydrogen line region $\sim$ 1420 MHz, and an air traffic control radar at 1331 MHz. The GPS L1 and radar signals were unambiguously detected. The 1420 MHz and 1331 MHz observations were affected by significant levels of "spectral garbage", which appears to be generated by the DCR in response to strong, pulsed, out-of-band signals. The 1575 MHz results do not show this problem, suggesting that the culprit is likely to be signals at the low end of the DCR tuning range and below. It is believed that additional filtering for the current DCRs or planned design changes for future DCRs may alleviate this problem. It is also possible that the problem may rectify itself as a result of the move from the ESL roof (height $\sim$ 10 m) to the SCF roof (height $\sim$ 2 m). In the worst case, it appears that about 20% of the available spectrum for any given DCR tuning is corrupted due to this problem.

On the bright side, we confirm that the sensitivity of the system is quite acceptable using some simple tests with absorber panels as calibration sources, and we also confirm that the image rejection (associated with the I-Q balance at the output of the DCR) is also quite good; about -40 dBc.

2 Argus System Configuration

For this testing, a single spiral antenna unit was used on the roof of ESL. The antenna unit contained an MCL SHP-1000 high pass filter and an Argus LNA [1]. The antenna unit used here was one of those recently constructed by the NAAPO volunteer group. A 6-foot section of RG-58 from the antenna unit was threaded through an opening

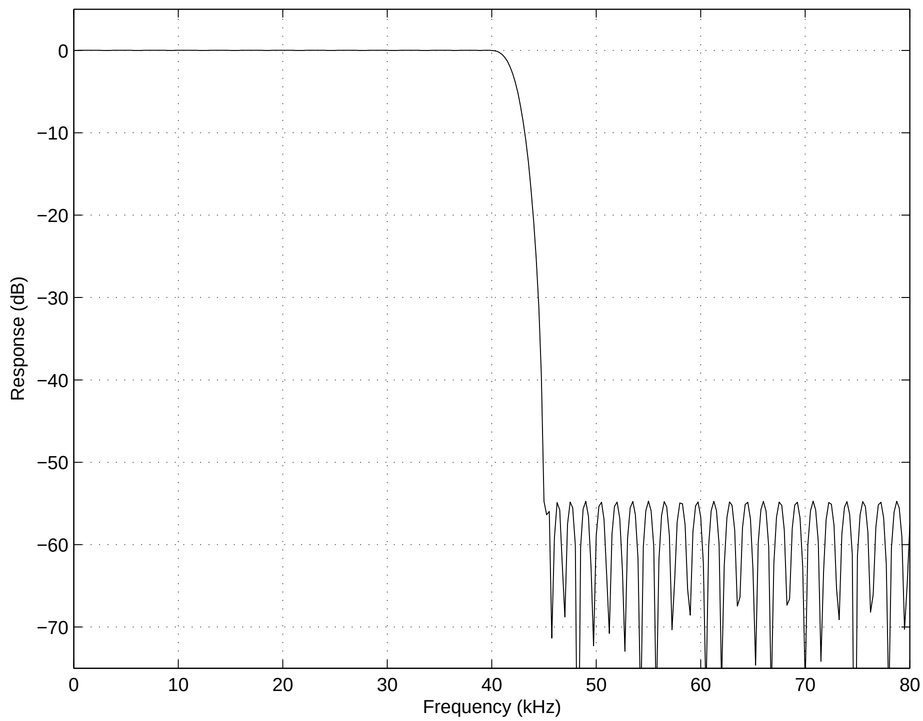

Figure 1: Frequency response of the DDC.

in the roof to an Argus line amplifier [2] in the lab below. The line amplifier also provided power to the antenna through a bias-tee arrangement. The line amplifier was connected to the input of a DCR through 100 ft of Belden 9913 coaxial cable.

The DCR used in this experiment was one of eight functioning in the current Argus system rack [3, 4]. It downconverts the input signal to baseband I and Q signals, lowpasses each to 7 MHz, and digitizes at 20 MSPS. The resulting samples are transferred at 320 Mb/s using LVDS over CAT-5 networking cable to one of eight digital channel processor (DCP) cards. The DCP recovers the data from the LVDS link and passes it through a AD6620 digital downconverter (DDC) chip. The DDC tunes within the DCR's 14 MHz digital passband by shifting the desired frequency to baseband. The DDC then bandlimits the signal to 80 kHz (40 kHz lowpass) and reduces the sample rate by a factor of 200, to 100 kSPS. The DDC passband response is shown in Figure 1.

The output of the DDC is routed onto the Argus Narrowband Processor's (ANP) LVDS daisy chain at 320 Mb/s. The data from the other DCP cards is multiplexed as the data travels along the daisy chain, until the array controller card is reached. The array controller passes the data recovered from the DCPs to a PC via a high-speed parallel digital I/O card, the National Instruments PCI-DIO-32HS. The acquisition of data is controlled from the PC side using a C language program running on Windows 98.

The PC is also able to tune the 8 DDCs using the same data paths: The PC passes the instructions to the array controller card, which distributes them to the DDCs using the ANP's LVDS daisy chain. Because these data paths are very fast, it is possible to rapidly tune the DDCs from the PC. This allows the current Argus hardware to operate as a very high-resolution spectrum analyzer with 14-MHz span, despite the 80 kHz span of the DDC.

To assemble a 14 MHz-wide spectrum, the DCR passband was divided into 173 DDC tunings spaced 81.25 kHz apart. At each DDC tuning, 64 samples were collected and immediately transformed using the FFT into 64 frequency channels, each 1.5625 kHz wide. Only the central 52 channels are used to mitigate the effect of the roll off near the DDC band edges. After completing all 173 DDC tunings, a single spectrum of 9000 1.5625 kHz channels, covering 14.062 MHz, is obtained. The DCR tuning is held fixed during this process.

Using this procedure, spectra were collected during the afternoon hours of Feb 5, 2003.

3 DCR Input Tests

As an initial check and diagnostic, spectra were first obtained with the DCR tuned to 1418 MHz and with the DCR input terminated using a matched load. The top panel in Figure 2 shows the resulting power spectral density (PSD). The tone at 1418 MHz is the LO breakthrough, which is an unavoidable attribute of direct conversion receivers. The tone at 1420 MHz is spurious; it is known to be associated with the LO but it's exact nature has not been determined. All other tones are spurious products.

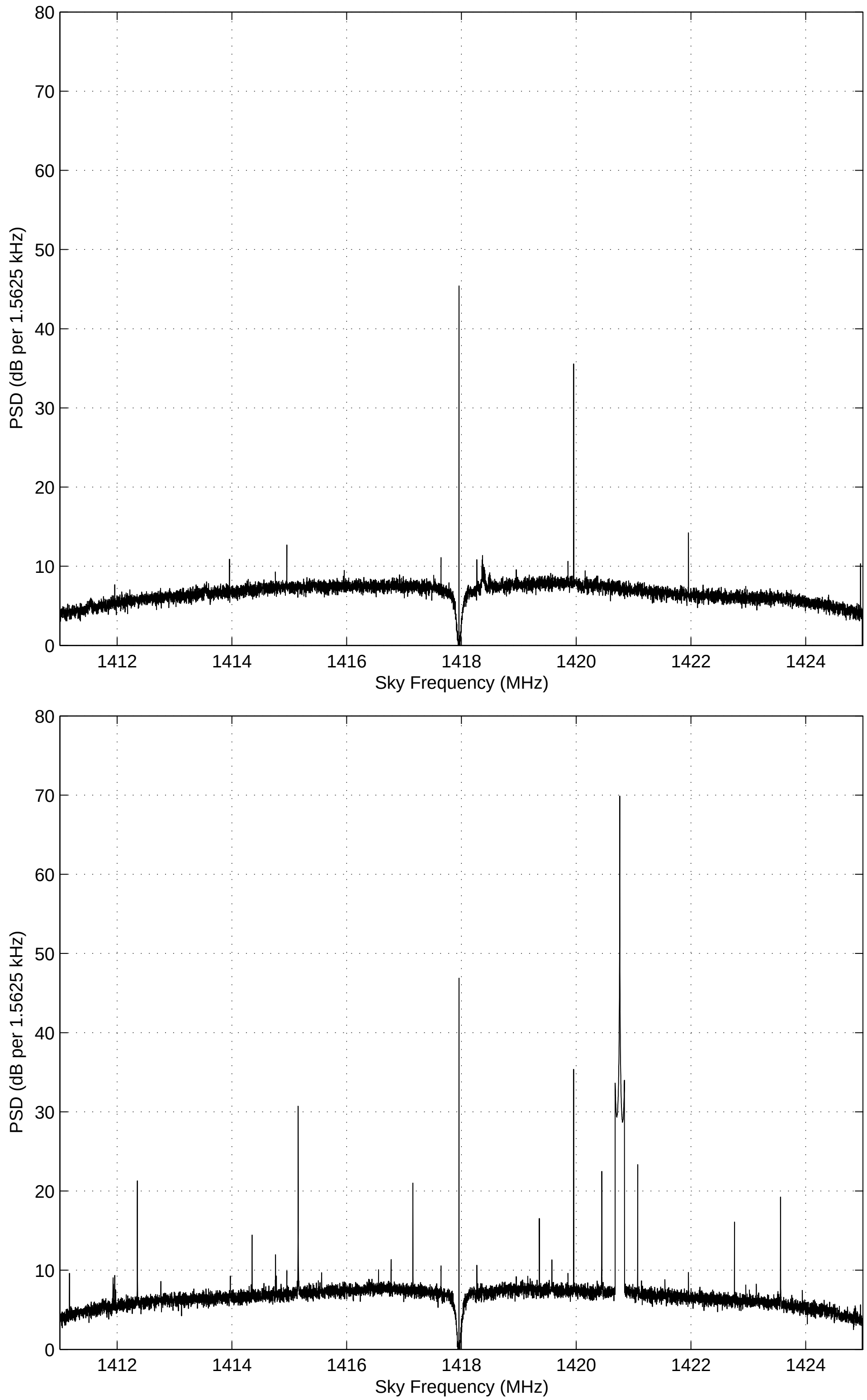

Figure 2: *Top:* DCR input terminated. *Bottom:* Single tone at 1420.8 MHz applied to the input of the DCR. *Both panels:* Integration over 100 sweeps.

Next, a tone at 1420.8 MHz was applied to the input of the DCR. It was determined that A/D clipping occurred when the level of this tone was -47 dBm at the input of the DCR. This level corresponds to +80 dB in the units used in the plots in this report. Next, this tone was reduced in power by 10 dB and the resulting spectrum is shown in the bottom panel of Figure 2. Note that the tone is clearly visible, as is it's image at 1415.2 MHz. This image results from a subtle imbalance between the analog I and Q signal paths internal to the DCR. However, this level of performance – -40 dB relative to the true signal – is much better than required, and thus planned efforts to correct I-Q imbalance on the fly are probably not warranted.

In addition to the true tone and it's image, the LO breakthrough, and the 1420 MHz LO spurious, there are quite a few other low-level spurious products. The low-level spurious is generated by the A/Ds, but is not of much concern since (as we will see shortly) they will be buried in the system noise when an antenna is used.

4 On-The-Air Tests

Next, the input of the DCR is reconnected to an antenna such that the complete system is configured as described in Section 2. For the first on-the-air observation, the DCR was tuned to 1572.4 MHz in order to observe the GPS L1 signal at 1575.42 MHz. GPS makes an excellent function check for this system because it is very weak (-30 dB SNR referenced to it's $\sim$ 1 MHz occupied bandwidth), yet is much stronger than astronomical sources. The result is shown in Figure 3; note that the GPS L1 signal is clearly visible. In fact, although Figure 3 shows the result after integration over 1000 sweeps, the GPS L1 signal was apparent after the first sweep.

Also worth noting is that the noise floor has increased by about 10 dB relative to the DCR input tests of the previous section. Thus, the "sky noise" truly is dominating the measured system noise. A small amount of additional gain (perhaps 6 dB or so) would be desirable to increase the margin over the A/D spurious observed in the DCR input tests, however the current configuration is acceptable.

As an additional check, a thick panel of RF absorbing material (typically used in anechoic measurement chambers to mitigate scattering) was placed over the spiral

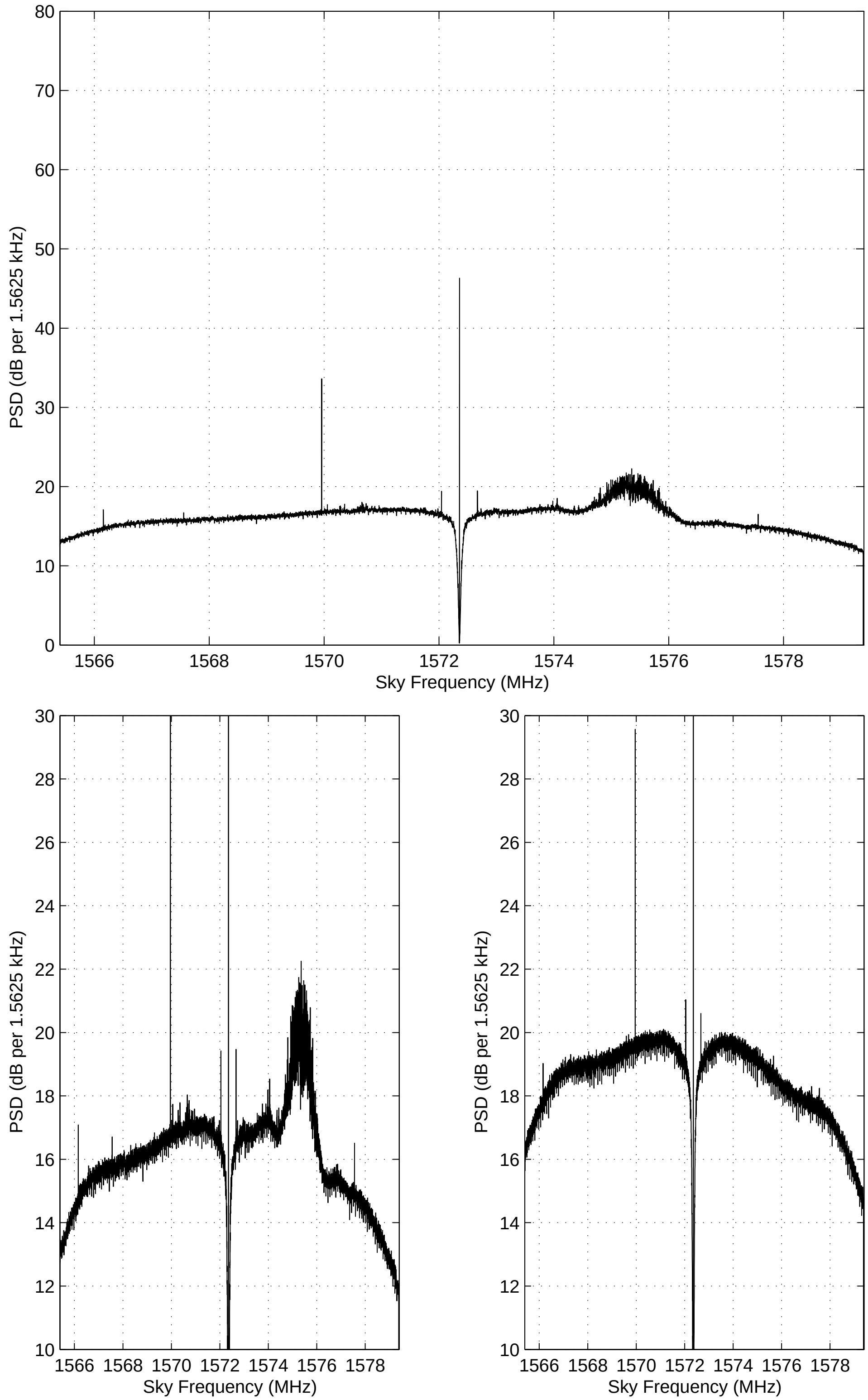

Figure 3: GPS L1 observation, 1000 sweeps. *Top:* Sky. *Bottom Left:* Sky (zooming in). *Bottom Right:* Absorber.

antenna unit. The resulting spectrum in this case is shown in the bottom right panel of Figure 3. Note that the noise floor goes up by about 2.5 dB. Thus, the system perceives the sky as being significantly "colder" than ambient-temperature absorber. This confirms that the sensitivity of the receiver is reasonable.

Next, the DCR was tuned to 1418.0 MHz to observe in the vicinity of the hydrogen line. The result is shown in Figure 4. Note that some form of interference is clearly visible. We are fairly certain that this interference is not actually present at these frequencies, but rather is the result of the DCR reacting to strong interference outside the 14 MHz passband, most likely below it's tuned frequency. Our reasons for believing this is based on two previous experiments, where a *bona fide* spectrum analyzer was used in lieu of the signal path from the DCR onward. In one of these experiments [5], the signal path was antenna, SHP-1000 highpass filter, Argus LNA, Argus line amp, long cable, and spectrum analyzer. In this case, the 1420 MHz region seemed to be free of interference. In a second experiment [6], the signal path was antenna, a tighter (1200-1800 MHz) coaxial bandpass filter, Argus LNA, Argus line amp, long cable, and spectrum analyzer; also, additional integration was used to increase sensitivity. In this case, the 1420 MHz region still appeared to be free of interference, and also the hydrogen line was detected as a $\sim$ 0.1 dB deflection from the noise baseline, about $\sim$ 100 kHz wide. Although these experiments were performed from the rooftop of SCF (about 2 m above ground), as opposed to ESL (about 10 m above ground), it seems clear that there is no significant interference in this band. On the other hand, we have observed in other experiments that the DCR seems to produce transient I-Q imbalances in response to intermittent strong out-of-band signals (probably radar) for tunings below 1400 MHz or so. This is the most likely explanation for the spectral garbage seen in Figure 4, and is also consistent with the relatively good result shown in Figure 3, obtained at a higher frequency.

If the problem remains when the present experiment is repeated at SCF, it may be necessary to employ additional bandlimiting filters for observations around the hydrogen line and lower frequencies using the current generation of Argus hardware. As suggested by Figure 3, observations at frequencies of 1575 MHz and above appear

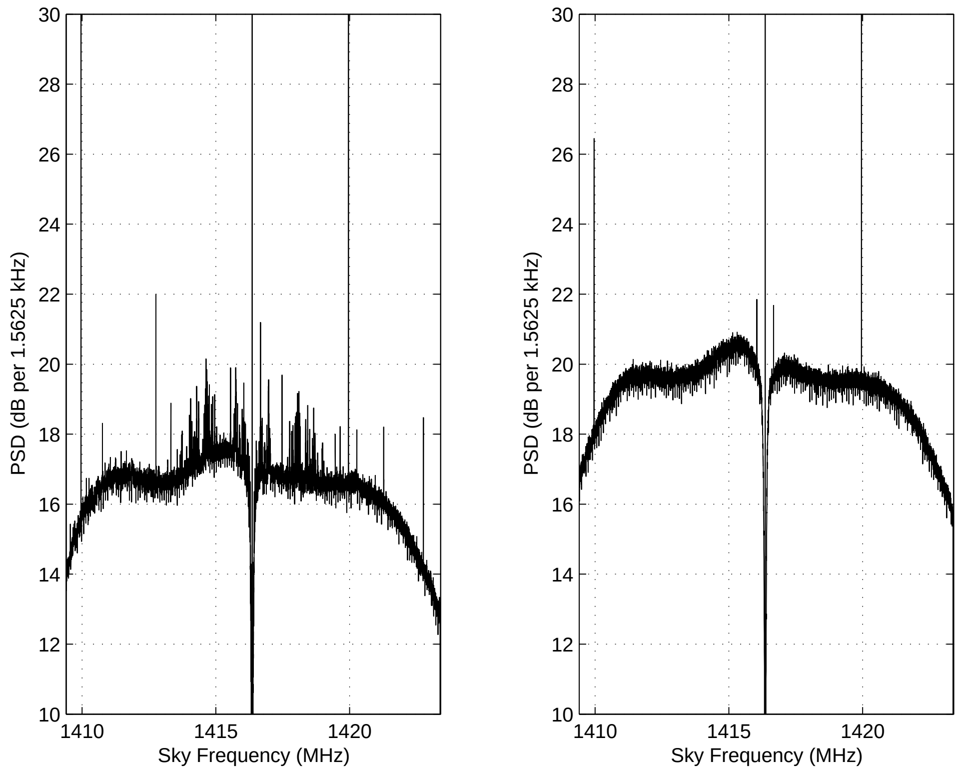

Figure 4: Hydrogen line vicinity, 1000 sweeps. *Left:* Sky. *Right:* Absorber.

to be satisfactory with no additional filtering. Nevertheless, new DCRs (serial numbers 9 and above) will include a few design changes in an attempt to mitigate this problem over the full tuning range.

As an additional check, we repeated the hydrogen line observations at night integrating over a much greater number ($\sim$ 39450) sweeps. The result is shown in Figure 5. Note that the noise variance is now on the order of $\sim$ 0.1 dB, and thus the hydrogen line should be just barely detectable in this result. Although there is a spectral feature near 1420.3 MHz, the spectral garbage throughout the passband makes it is impossible to say whether it is real or not. On the bright side, the system seems to be extraordinarily stable: where there is no spectral garbage, the noise integrates very nicely to a smoothly varying baseline. We estimate that less than 20% of the 9000 channels shown here are significantly affected by this problem. Since the affected channels do not appear to change over time, in the worst case we can simply “blacklist” (ignore) these channels and still observe effectively over 80% of the bandwidth.

Finally, we made observations of another of our favorite diagnostic signals, the 1331 MHz air traffic control radar based in London, OH. This radar transmits relatively strong pulses of length ~ 3 μs every ~ 3 ms. So, despite it’s instantaneous high power, it is often difficult to detect in average spectra due to the low ($\sim 0.1\%$) duty cycle. Nevertheless, the signal is clearly visible in our result, shown in Figure 6. Unfortunately, so is quite a bit of the spectral garbage noted previously.

References

[1] 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; also in the Ohio State University ElectroScience Laboratory Technical Report 531393-4 (Jan 2003).

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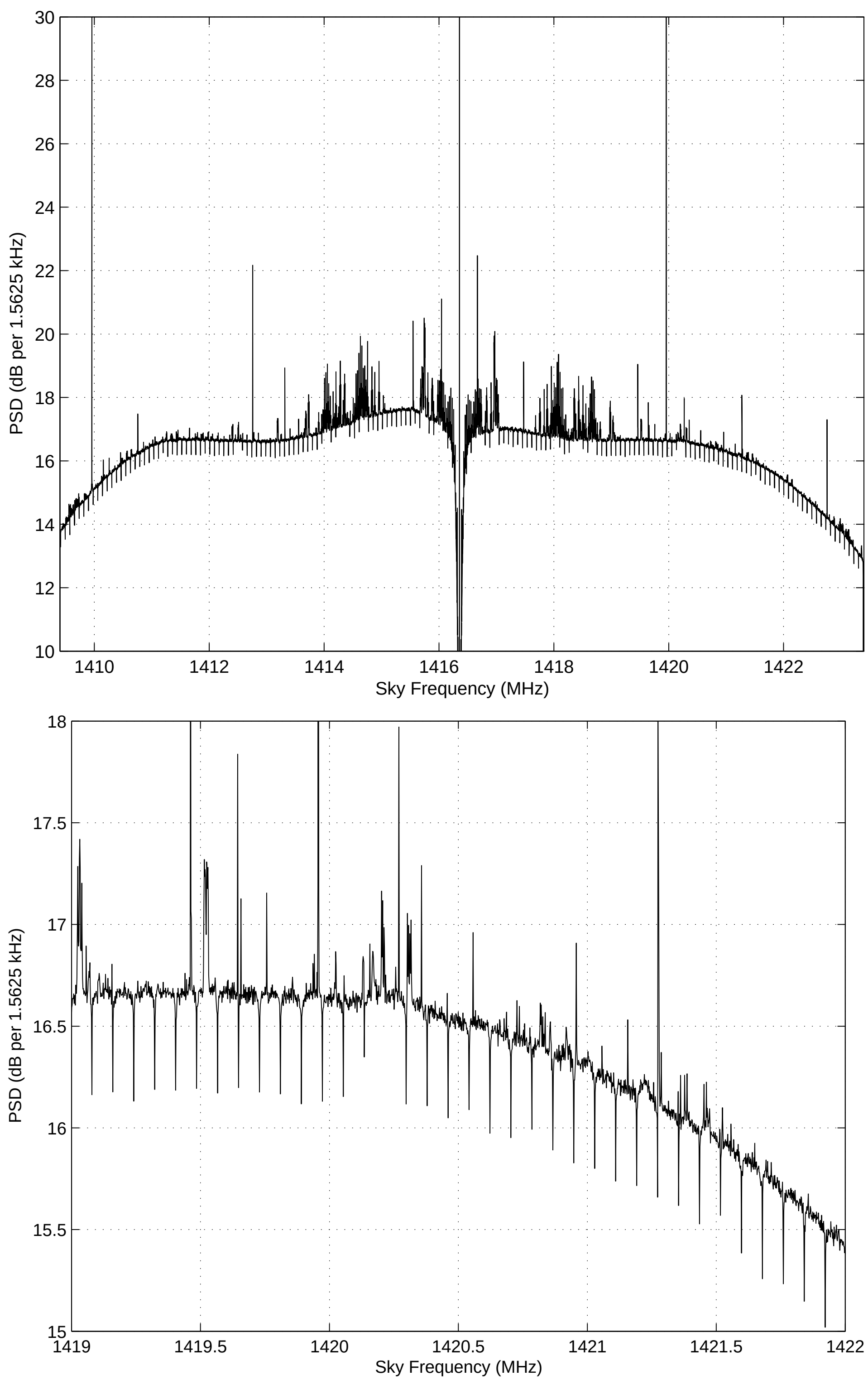

Figure 5: Hydrogen line vicinity, ~ 39450 sweeps. *Top:* Sky, *Bottom:* Zooming in to show more detail. The downward spikes every ~ 80 kHz are due to the roll off in the DDC filter response for each DDC tuning.

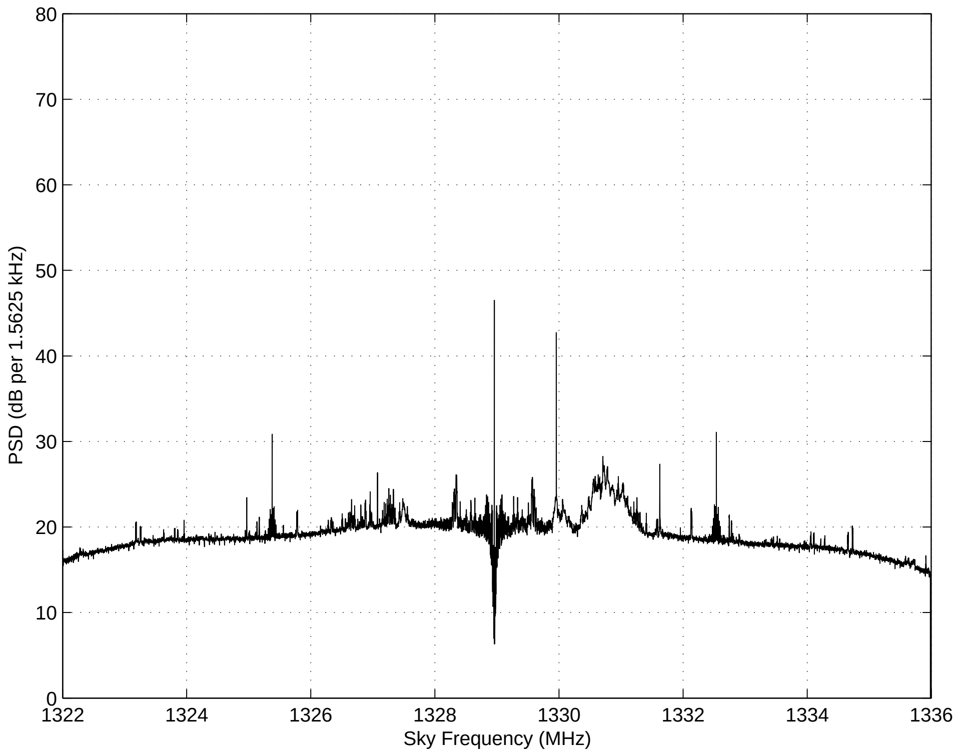

Figure 6: The 1331 MHz air traffic control radar based in London, OH. 1000 sweeps.

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