# Characterization of High-Speed IF Digitizers For Use by NASA Deep Space Network

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**Abstract.** Digitizers are a key component of deep space communications. We must know they function well and understand their limitations in order to use them to their highest potential and interpret the results they give us. One way of testing that functionality is through a spur test, which can show how well the internal components of the receiver are working. We ran several spur tests on two kinds of analog-to-digital converters, the Intermediate Frequency Digitizer (IFD) for the Wideband VLBI Science Receiver (WVSR) and the IFD for the Portable Radio Science Receiver (PRSR). We found that the PRSR had slightly better spurs than the WVSR.

**Text.** The NASA Deep Space Network provides services for navigation and telemetry of spacecraft beyond Earth orbit. Currently, NASA is trying to move more of the processing from the analog to digital domain, in order to take advantage of modern signal processing techniques and improve accuracy. In one such effort, NASA is starting work on the DSCC Downlink Array (DDA). The basic idea of the DDA is to eventually replace the current 70-m antenna with a more cost-effective and robust array of 34-m antennas no more than 10 km apart from each other[1].

While the signal processing hardware required to support several antennas is much more complicated than for a single antenna, the proposed technology could make it possible to array up to 8 antennas in one geographically close cluster. The signals received from the antenna are down-converted from very high frequencies (the X and Ka bands) to a convenient intermediate frequency (IF) at the antenna and sent to the Array Signal Processing Subsystem (ASPS), which is the focus of the work at JPL (2). The IF signal has a bandwidth of 500 MHz and is centered at 950MHz. A key part of the design of the ASPS is the analog-to-digital converters (ADC) that convert the analog IF signals to digital data streams that can be processed by the digital signal processors (DSP).

My project primarily focused on the evaluation of several candidate converters to determine which provides the best overall performance for the needs of the DDA. Of particular concern was the flatness of the gain and group delay of the converter over the IF bandwidth, as excessive variation interferes with the beam forming that occurs when combining the signals from many antennas. In addition, converter nonlinearity and noise were evaluated as these could limit the DDA's ability to resolve weak signals, particularly in the presence of large interferers. The sensitivity of the noise at the output of the converters due to noise in the power supplies and jitter in the ADC and the reference clock were also evaluated[2]. Specifically, I worked with various high speed (1280 to 2000 MHz sampling clock) ADCs.

The ADCs we targeted include:

- The Intermediate Freqency Digitizer (IFD) for the Portable Radio Science Receiver (PRSR) featuring an Atmel 10-bit 2.2 Gsps ADC (E2V AT84AS008)
- The IFD for the Wideband VLBI Science Receiver (WVSR) also featuring an E2V AT84AS008
- The CASPER Berkeley ADC2x1000-8[3] used with a CASPER ROACH board[4]

The main test I ran on these candidates was the spur test, though I had to develop appropriate testing environments and conditions on most of the candidates. We started working with the ROACH board in the last couple of weeks I was there, so we weren't able to make much headway on the testing process. Initial tests showed that the ROACH performed reasonably well. However, the majority of my time was spent working with the PRSR and the WVSR.

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by Caltech's Summer Undergraduate Research Fellowships program and the National Aeronautics and Space Administration.

The WVSR is a well-established piece of equipment – we already know where it's spurs are and its general performance level. However, the PRSR is just finishing being developed now, so the data we gathered was brand new. In order to understand the performance of the PRSR, we compared the data to that of the WVSR.

The PRSR is designed to be portable – the entire system fits in about the space of two suitcases. As such, all of its equipment is very close together. Our group was expecting to see results that were much worse than that of the WVSR. We expected to see several spurs at high powers, due to crosstalk and feedback amongst components. However, out results showed that the PRSR generally outperformed the WVSR. We saw few total spurs, which had slightly lower powers on average. We also noticed that the 100 MHz reference signal leaked much less in the PRSR, with a drop of almost 15 dbHz in power.

These results may lead the group to hone the design of the PRSR, or even reconsider the WVSR design. Currently, making repairs to the PRSR would not be very easy to do as half of the components are unable to be accessed inside the chassis. The growing popularity and the excellent performance of the PRSR may help to spur some design changes which would make it easier to use.

## Methods.

**SPUR TEST:** The spur test is the best way to check the health of a receiver's IF stream. We input a random noise source that spans the entire band of observed frequencies. We then take data across the band at several frequencies on several channels using a script that resides on each receiver, called spur_test.scrpt[5]. This script runs for approximately 14 hours on the receivers collecting data into a log file. The script is designed to only see spurs, and only records a point into the log file if there are two similar readings in a row on a given frequency. After the observation, we plot a spectrum of all these points recorded in the log file. We can then see what the amplitude of the signal is at each of these frequencies. Since the signal source is just random noise, we would expect to just see a series of points close to the noise floor. However, we had some issues with leaking from the reference signal, and harmonics can be seen in the case of the WVSR. Spurs are not related to the observed signal. They can be caused by leaks from any number of components, and unrelated frequencies getting mixed into the observable range. Both the PRSR and the WVSR show examples of spurs, though the PRSR has significantly fewer.

**Figures.**

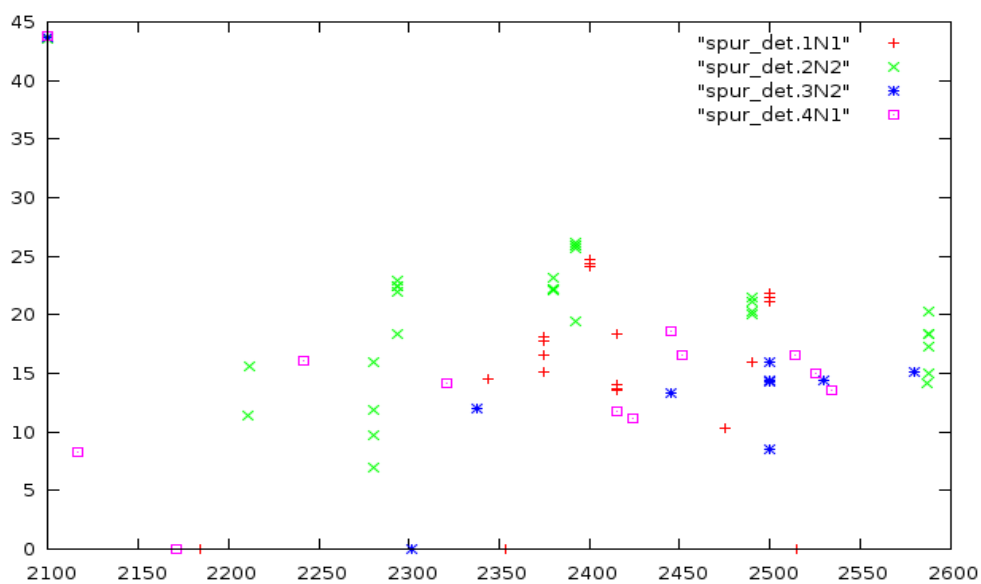

Figure 1: This plot shows the results of the spur test for a WVSR. The x axis of this plot is the RF frequency of the receiver in MHz. For our analysis, we converted the RF to IF by subtracting 2000 MHz from all numbers along the x axis, as that's what it's actually measuring. The y axis is the power of the signal at that point. The estimated the noise floor to be around 20 dbHz - so our definition of spur is anything that was plotted that has a power greater than that. As mentioned in the main text, there is strong leakage from the 100 MHz reference signal at around 44 dBHz. Spurs can also be seen at around 300 MHz, 380 MHz, 400 MHz, 490 MHz, 500 MHz, and 590 MHz.

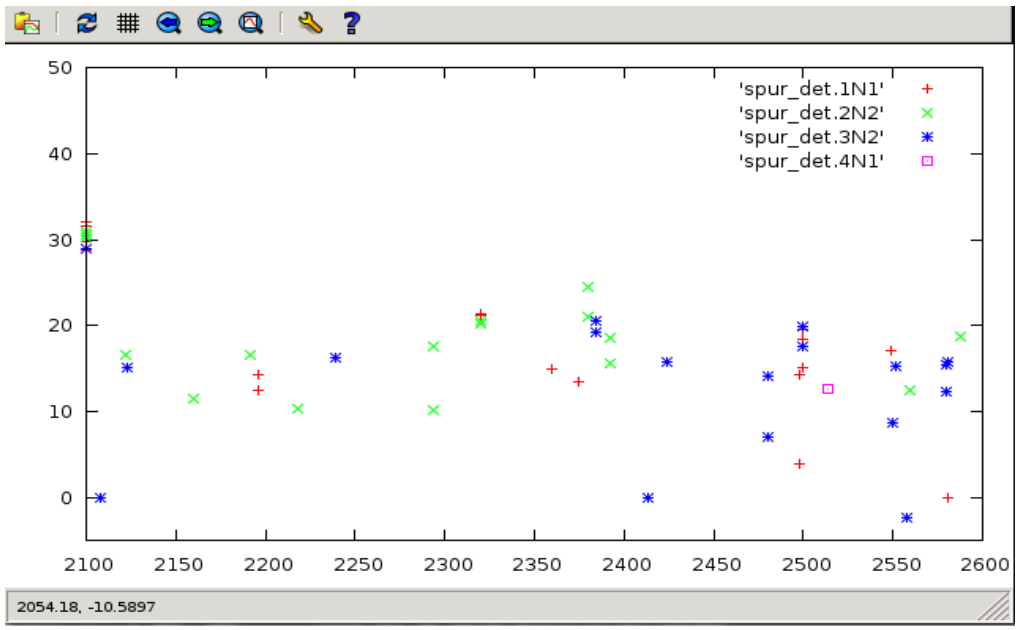


Figure 2: This plot shows the results of the spur test for a PRSR. As with the WVSR, the x-axis is plotting the RF frequency of the receiver in MHz, and the power at each sampled frequency in dBHz. The conversion factor from RF to IF is also subtracting 2000 MHz from the frequency. Noise floor is again estimated at 20 dbHz. This plot shows that the leakage from the 100 MHz reference source is not nearly as significant as with the WVSR, with it's power being around 32 dbHz. The only powers that lie above the noise floor are at around 320 MHz, 380 MHz, and 500 MHz. The number of spurs decreased, as did their power levels.

## References.


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<http://announcements.surf.caltech.edu/index.cfm?event=ViewAODetail>.

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Acknowledgments. I would like to thank the SURF program and my mentor Robert Navarro for offering me this opportunity this summer. I would also like to thank Dan Stinebring, my advisor back at Oberlin College. Without him, I certainly wouldn't have found my way here this summer. Finally, of course, I want to thank the entire team I worked with for the duration of my stay at JPL.