The Portable Radio Science Receiver (RSR)

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The radio science receiver (RSR) is an open-loop receiver that has been used in NASA's Deep Space Network (DSN) facilities for almost a decade and is a valuable resource used to record data for radio science experiments, radio astronomy observations, and very long baseline interferometry. In the last few years, NASA has needed to send RSRs to non-DSN facilities such as the Greenbank Telescope and Australia's Parkes and Narrabri antenna array for special events such as the Mars Exploration Rover entry, descent, and landing maneuver and the Huygens probe landing on Titan. The need to quickly and cost effectively ship and set up an RSR without taking away valuable existing DSN resources has led to the development of a prototype portable RSR (PRSR). The PRSR maintains most of the capabilities of a full RSR and greatly exceeds it in many ways while only a fraction of the cost and weight.

I. Overview

Several recent NASA missions required data recording for mission-critical maneuvers or science experiments that were not supported by the Deep Space Network (DSN), typically due to incompatibility. These included entry, descent, and landing (EDL) for Pathfinder, Mars Exploration Rover (MER), Huygens, and Phoenix [1]. In addition, radio science experiments have occasionally been supported by non-DSN facilities. To meet these requirements, the missions made use of radio telescopes worldwide, including the Parkes Australia 64-m telescope, the Narrabri Australia six-antenna array, and the Green Bank Telescope (GBT). A radio science receiver (RSR) was shipped to each of these facilities and used to record data, which greatly augmented the data captured at the DSN facilities.

The DSN's RSRs are full-spectrum, open-loop receivers that were primarily developed for radio science investigations. An RSR provides filtering and digital recording of analog signals, which do not include hardware real-time tracking or signal acquisition. Instead, signal detection is done via software and performed by the user. Designed specifically for phase stability, an RSR detects multipath reflected signals and spurs for science (surface scattering) or mission anomaly support. While hugely successful, sending and installing this receiver,

consisting of a large DSN rack, proved to be a daunting and expensive task and took away valuable resources from the DSN stations. To meet the requirements of future missions, a portable version of the RSR needed to be developed.

II. Approach

JPL's Advanced Tracking and Observational Techniques (ATOT) office funded a two-year development of a prototype portable RSR (PRSR). The PRSR hardware was based on the wideband very long baseline interferometry (VLBI) science receiver (WVSR), rather than the older RSR. The WVSR is also an open-loop receiver, which has the full capability of an RSR, but was developed after the RSR specifically for differential one-way ranging (DOR) measurements, which are used in spacecraft navigation. Since the PRSR is based on WVSR hardware, it had the potential to greatly exceed the performance of the original RSR unit. To create the PRSR, hardware for the WVSR was repacked into a smaller form factor. A new chassis, RF cabling, and developmental field-programmable gate array (FPGA) firmware and software were developed. The PRSR supported only one intermediate frequency (IF) input instead of the two used on the full RSR and WVSR racks.

The PRSR implemented a limited set of FPGA firmware and software to fit budget and schedule constraints. More specifically, the prototype had limited frequency predict handling, only a subset of recording bandwidths, and recorded only discontinuous blocks of data samples instead of a continuous stream. The prototype included a stand-alone, simplified user interface and did not contain software that could interface with the existing DSN network monitor and control (NMC) infrastructure. Tests of the unit were performed in a development laboratory at JPL, at the GBT facility, and at the DSN's Goldstone Deep Space Station 13 (DSS-13) in California.

III. Requirements

The PRSR team was tasked with delivering a prototype receiver that could fit in a standard travel suitcase and be carried or checked as luggage by one person traveling to the required destination. In addition, a fully operational PRSR would need to maintain all the requirements of the RSR, such as performance and interface.

IV. Prototype Development

A. Hardware

Packaging a subset of the WVSR hardware into the required size called for the development of a custom-built chassis. To reduce cost and development time, the Canadian company Protocase was selected as the supplier. A 2.5U, 19-inch rack mount steel chassis was designed and purchased from Protocase to accommodate the existing WVSR analog and digital hardware boards. A shielding plate was developed to separate the analog and digital components to reduce spurs. Also, an interface plate was developed to maintain RSR-like external connectors, such as the IF input and the Ethernet interface.

The hardware borrowed from the WVSR included the advanced telecommunications communications architecture (ATCA) processor engine (APE) board, the intermediate frequency digitizer (IFD) VLBI sampler module (VSM), and the IFD common module (CM). The IFD modules provided the digitization of an IF signal from 0 to 640 MHz and the APE board contained Xilinx FPGA chips where firmware could be loaded that provided downconversion and channel filtering.

To act as the controlling computer and data storage medium, a Dell laptop PC was purchased with high-performance features such as gigabit (Gb) Ethernet, dual-core processor, and a relatively large-capacity hard drive. This computer would record data sent across the Gb Ethernet from the PRSR, provide real-time models for predicts tracking, and provide the user interface. In the PRSR prototype, this computer is referred to as the data processor and controller (DPC). A block diagram of the PRSR prototype is shown in Figure 1.
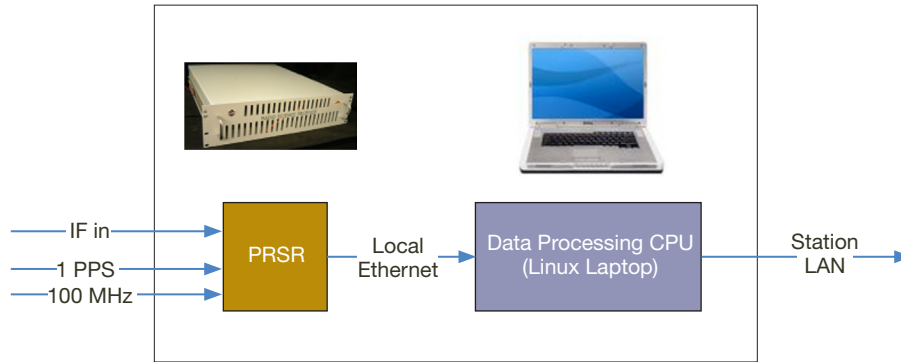
Figure 1. PRSR prototype block diagram.

B. Firmware

Digital downconversion and channel filtering was accomplished using the APE board FPGA chips. To provide a demonstration of the PRSR hardware's suitability to function as an RSR, a set of firmware was borrowed from a research project using the same APE board and modified to give a basic set of parameters for signal detection and data capture.

C. Software

Driver and command software was also borrowed and modified for use on the APE board embedded Power PC processor for the purpose of configuring the firmware. A simple set of commands allowed configuration of the front-end attenuation, the downconversion oscillator frequency, filter gain, filter bandwidth, number of bits, and capture of samples.

The DPC was loaded with the Redhat Enterprise 5.1 Linux operating system and configured to establish a Gb Ethernet connection to the PRSR. A separate 100-Mb Ethernet card on the DPC was used as the interface for external login and downloading recorded samples. To

demonstrate the PRSR receiver, software written in C was written and compiled for running on the DPC. This demonstration software consisted of a GTK graphical user interface (GUI) — see Figure 2 — and a set of functions to monitor and control the PRSR APE and IFD hardware. Data samples were captured to disk as discontinuous blocks of hexadecimal samples that could be processed and viewed on plots in real time or later.
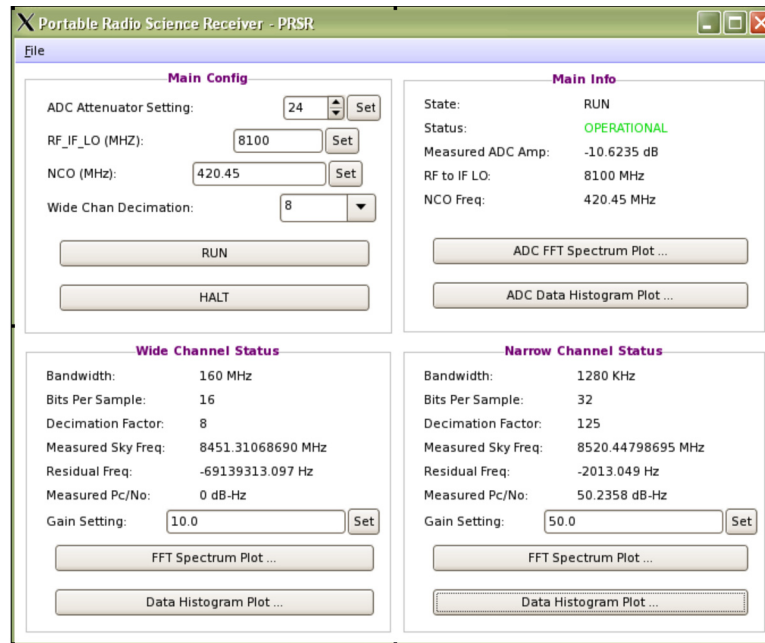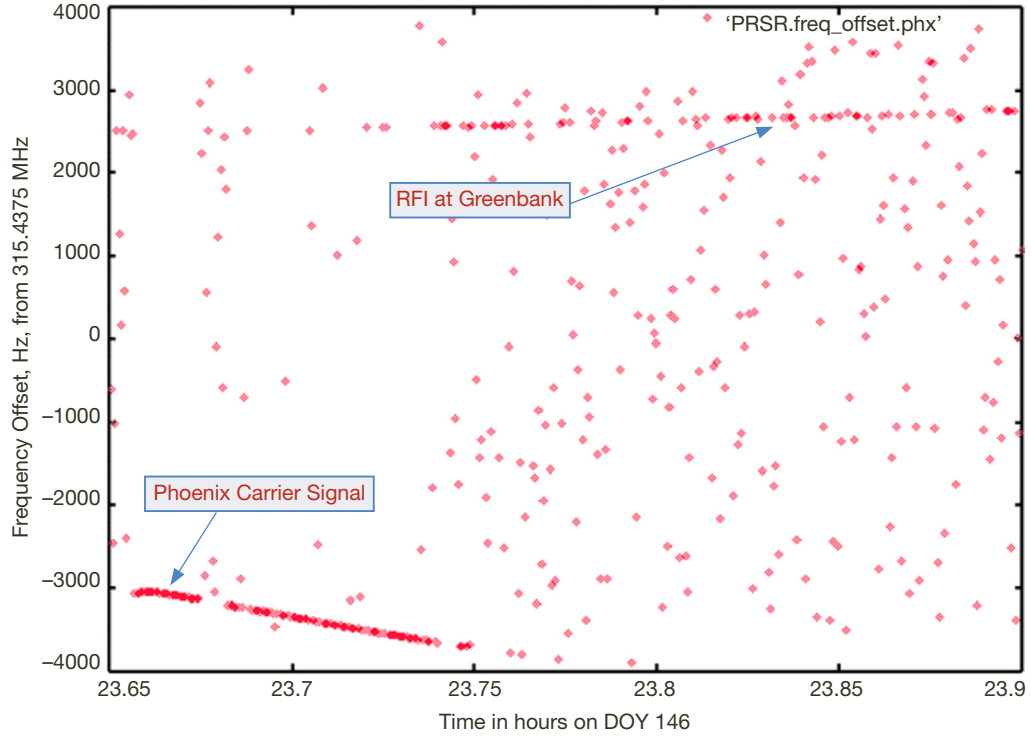

Figure 2. PRSR demonstration GUI.

V. Demonstrations

A. GBT for Phoenix Landing

On May 25, 2008, the Phoenix spacecraft landed on Mars. An RSR unit was shipped from the DSN test facility in Monrovia, California, to support this event. The PRSR prototype was also shipped a few days before to demonstrate its capability alongside the RSR. Figure 3 shows a frequency time history plot of the Phoenix signal detected on the PRSR as Phoenix approached and went through EDL.

The plot in Figure 3 shows the peak frequency detected by the PRSR inside a 10-kHz window centered at 315.4375 MHz. The Phoenix carrier was tracked during the carrier-only stage of EDL. The signal was lost by the PRSR once telemetry was turned on due to about a 6 dB decrease in signal-to-noise ratio. Later in the pass, a noticeable radio frequency interference (RFI) signal was detected by both the PRSR and the RSR, which is visible in the upper right of the plot.

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Figure 3. PRSR frequency history of Phoenix entering EDL.

B. Cassini Radio Science at Goldstone

Figure 4 shows the results of a PRSR demonstration using a signal transmitted from the Cassini spacecraft, which took place in September 2008. The data were captured using IF input from the Goldstone DSS-13 antenna. The prime operational RSR was simultaneously capturing data for a standard radio science pass. The results from the PRSR plots were closely comparable to the RSR plots. More specifically, the analog-to-digital converter (ADC) histogram and spectrum plots looked nearly identical on the RSR and PRSR. Also, a narrowband channel of 10 kHz was configured identically on both. Spectrum plots for these looked nearly identical. The signal power to noise density ratio (P_c/N_0) measurement taken from the narrowband spectrum on both receivers was comparable, but differed slightly due to the use of a modified algorithm on the PRSR.

VI. Future Development

The GBT and DSS-13 demonstrations showed that the PRSR has the potential to function as an operational RSR. However, to accomplish this, the PRSR needs more development. The firmware must be expanded to include capturing continuous data samples at a bandwidth up to at least 100 kHz. Software must be written that can take DSN-generated downlink frequency (DLF) predict files and provide millisecond-level signal tracking as well as taking data samples from firmware and encapsulating them in RSR-compatible data packets. It would also be very advantageous to provide a user interface that is similar to the operational RSR and to improve the real-time monitoring tools for better signal detection.
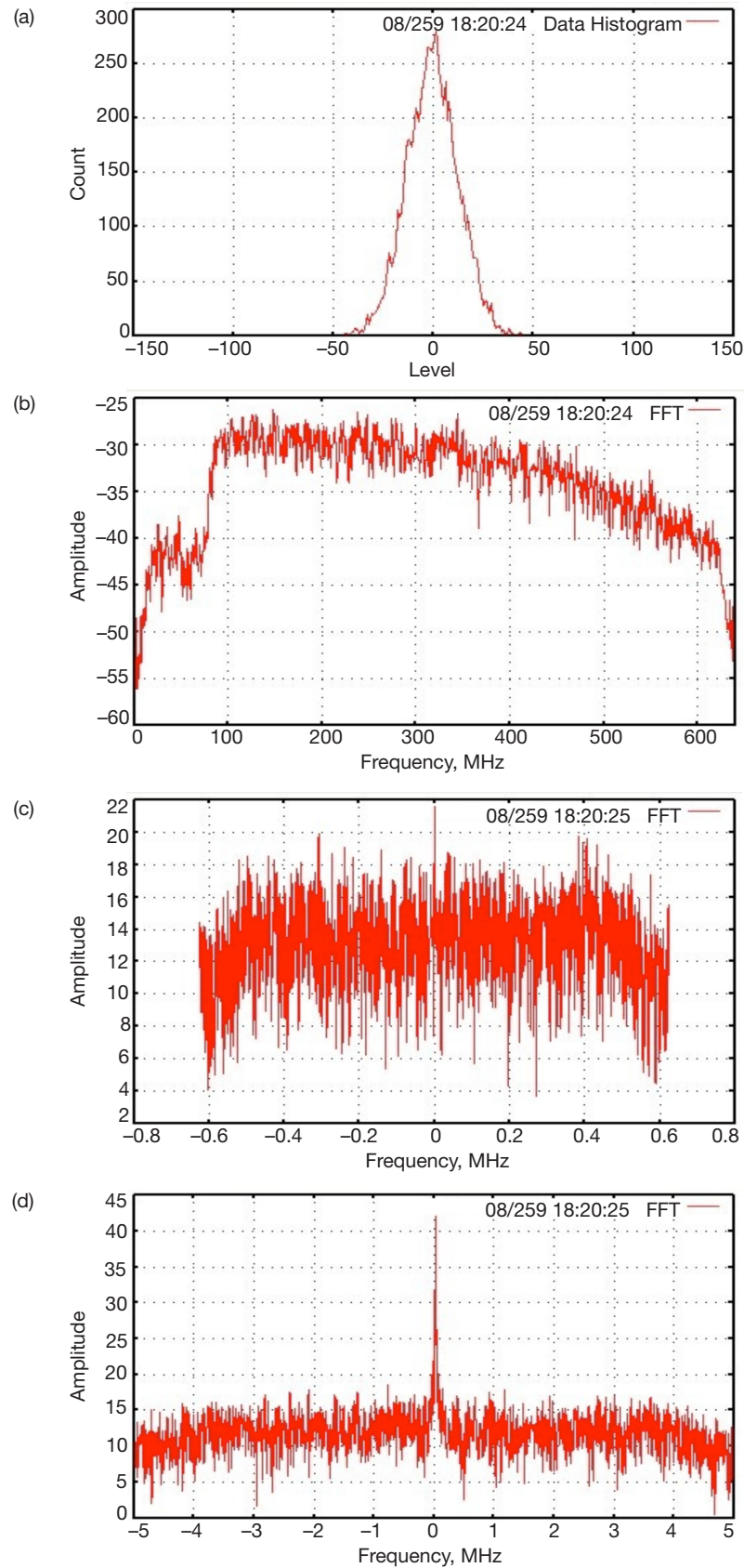
Figure 4. PRSR frequency history of Phoenix entering EDL: (a) ADC data histogram; (b) ADC fast Fourier transform (FFT) spectrum; (c) wide-channel FFT spectrum; (d) narrow-channel FFT spectrum.

VII. Summary

In the next few years, a PRSR is envisioned to be used to supplement radio science experiments as well as mission-critical maneuver support (e.g., Mars Science Laboratory EDL and Juno Jupiter orbit insertion) at both the DSN and various radio telescopes. Further-out missions that could use a PRSR include Grail, Kepler, BepiColombo, and the Mars Atmosphere and Volatile Evolution Mission (MAVEN). It has been proven that an RSR (or a functionally equivalent receiver) presence at these radio telescopes — Usuda, Japan; Parkes, Australia; Narrabri, Australia; GBT, U.S.; and Very Long Baseline Array (VLBA), U.S. — has made significant contributions to radio science investigations. Having a PRSR can also open a window for new science opportunities. Doing data acquisition at telescopes with good view periods has previously been ruled out due to logistics and cost of shipping. Within the DSN, some experiments use all available RSRs, leaving no more options. A PRSR can be shipped to a complex lacking in receivers for a specific investigation. It may also be used to record telemetry from a spacecraft for postprocessing demodulation and decoding.

Reference

[1] Timothy Pham, Christine Chang, David Fort, Edgar Satorius, Susan Finley, Leslie White, and Polly Estabrook, "Tracking Capability for Entry, Descent, and Landing and Its Support to NASA Mars Exploration Rovers," ESA 3rd Workshop on Tracking, Telemetry, and Command Systems for Space Applications, Darmstadt, Germany, September 23, 2003. http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/39045/1/04-2430.pdf