RRAT TRAP: A Prototype Radio Transient Survey Instrument Using Piggyback DSN Tracking

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Project Objective

Recent discoveries [1-2] of strong, isolated radio pulses have invigorated interest in transient phenomena as probes of fundamental physics and astrophysics. The NASA/JPL Deep Space Network (DSN) has a unique unused capability: the DSN tracks continuously with several large antennas having low system temperature. Substantial bandwidth is collected, only a small fraction of which is processed for spacecraft tracking. This low-noise, wideband capability is ideal for studying the transient radio sky, especially for rare events requiring long observation times to give reasonable statistics. Examples of known signals are the recently discovered Rotating RAdio Transients (RRATs) [1] and the discovery of a strong, isolated apparently extragalactic pulse [2]. RRATs (galactic sources) challenge our understanding of pulsar astrophysics [3-5]. If extragalactic, a mechanism for the enormously strong pulse reported in reference [2] is unknown.

The objective was to develop a prototype instrument to search for radio transient events, taking advantage of existing but unused DSN capabilities: **RRAT TRAP** = **R**otating **RA**dio **T**ransien**T** **R**eceiver **A**nd **P**rocessor.

FY09 Results

FPGA Firmware

Pulses propagating through the interstellar medium (ISM) are dispersed due to the frequency-dependent refractive index of the ISM plasma [6]. The energy arrives first at higher radio frequency and later at lower radio frequency. RRAT TRAP uses this signature to search for pulses of astronomical origin. The hardware platform was the DSN's standard telecom receiver used operationally to track spacecraft. The receiver's core is the Digital Signal Processor Printed Wiring Assembly (DSP PWA) with a Xilinx Virtex-4 field-programmable gate array (FPGA). The input to the FPGA was an 8-bit 160 MHz sampled IF signal plus clock. The firmware was reprogrammed to create a filterbank [6], to produce real-time non-coherent dispersion corrections, and to output the filterbank's detected power to disc for post-processing. We focused on parameters appropriate for DSN center frequencies and moderate-to-large dispersion measure (DM = electron column density between the source and earth; conventional units: cm^{-3} pc) pulses. We produced two versions of the firmware: RRAT TRAP 1 (1 msec time resolution, search equally-spaced dispersions within | DM | < 2000 cm^{-3} pc), and RRAT TRAP 1.5 (100 microsecond time resolution and search for selected specific DMs). Each analyzed an 80 MHz RF band with frequency resolution 1.25 MHz. Search of non-physical negative DMs -- i.e. those associated with a pulse sweeping from lower-frequency, earlier time to higher-frequency, later time – is useful. In addition to giving a clean "off-source" to estimate noise-only statistics, any confirmed detection of a negative-DM pulse would be very interesting; if exotic radio frequency interference could be excluded it would suggest an intentional signal of extraterrestrial origin.

Field Test Results

We tested RRAT TRAP 1 and 1.5 at S- and X-bands (≈2.3 and 8.4 GHz) using DSS15 (a 34m antenna at the Goldstone tracking complex) on 2009 April 25 and June 2. We observed pulsars (B0531+21, B0329+54, B2351+61) as sources of low-dispersion pulses. We de-dispersed B0329+54 in real-time with the correct DM and observed the expected SNR improvement. We analyzed B0531+21 data to verify post-processing performance. **Figure 1** shows an individual "giant pulse" from B0531+21, clearly showing power arriving first at higher radio frequency and later at lower radio frequency. **Figure 2** shows a section of B0531+21 data where a pulse smeared by dispersion to within the noise is subsequently clearly detected after dispersion correction.

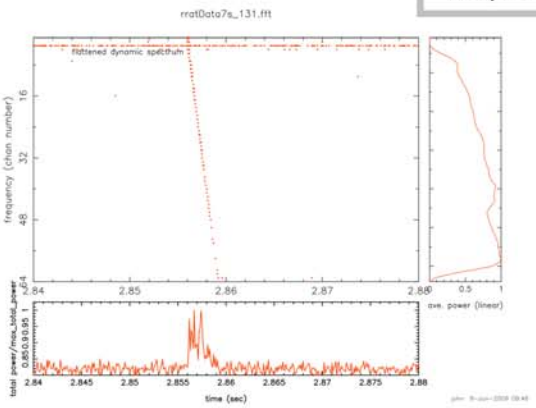

Figure 1. Dynamic spectrum (upper panel), total power time series (lower panel), and receiver passband (right panel) for a giant pulse from B0531+21 on 2009 June 2 (DSS15; S-band; RRAT TRAP 1.5). The power in the dynamic spectrum has been clipped to better show the dispersed pulse (power arriving first at high frequency and later at low frequency).

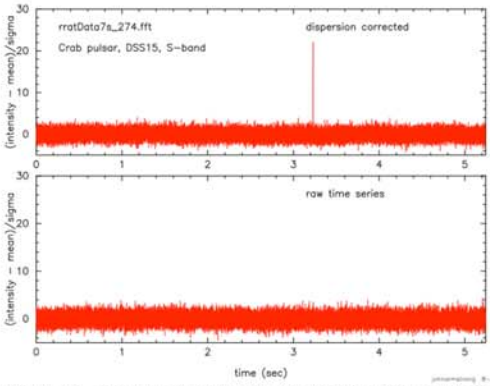

Figure 2. Example of a pulse recovered with SNR > 20 after de-dispersion (upper panel), but below the the noise in the raw time series (lower panel). Data taken 2009 June 2 on B0531+21 at S-band.

Benefits to NASA/JPL and Significance of Results

This task demonstrated that, via a different FPGA firmware load, an operational DSN hardware receiver could quickly be reconfigured as a filterbank/pulse searcher. RRAT TRAP could be used in parallel with any existing DSN spacecraft track to continuously monitor the background radio sky for dispersed pulses. This has impact on the scientific use of the DSN: because the DSN tracks continuously with low-noise, wide bandwidths, and many apertures, an operational RRAT TRAP would quickly and significantly increase the total observing time (thus the statistics) for rare radio events.

References

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