First Deep Space Exploration Society (DSES) Pulsar Captured on the 60-ft Dish

Richard A. Russel, Ray Uberecken, Bob Haggart

Abstract

The Deep Space Exploration Society (DSES) has spent a year preparing their 60-foot dish system to capture pulsars. This preparation included: feed development, receiver selection, software design, pointing system design, and the integration of the processing software. On May 2, 2020, the first verified pulsar, B0329+54 was received and processed.

Introduction

The pulsar, B0329+54 (J0332+5434), was observed on the third try just before the team was ready to pack up for the day on Saturday, May 2, 2020. A final modification of the software defined radio settings was tried (all the gains were set to a minimum) did the trick.

The team used the 60-foot dish located at Haswell, Colorado with a 408 MHz feed. 408 MHz was selected because the pulsars have a higher signal strength at this frequency than 1420 MHz and the beamwidth is larger, which reduces the pointing precision requirement.

408 MHz Feed Antenna

The design of the 408 MHz feed was based on an Electronic Industries Association (EIA) Standard gain antenna (EIA/TIA-329-B) https://tiaonline.org/ scaled to 408 MHz. This antenna is comprised of two dipoles fed in phase ¼ wavelength above a reflector screen. The design center frequency was scaled to 408 MHz but can operate over an extended range. The feed mounted on the 60-ft dish is shown in figure 1.

Figure 1: 408 MHz Feed Mounted on DSES 60-ft Dish

A preamp mounted behind the antenna screen on the support post has two gain stages with a 365 to 455 MHz passband filter between the stages. The schematic for the antenna mounted feed system is shown in figure 2.

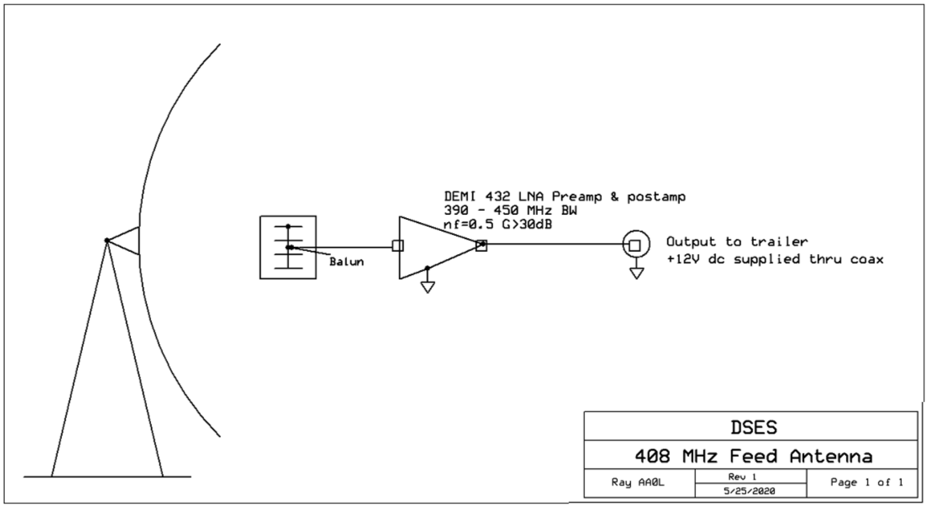


Figure 2: 408 MHz Feed at Antenna

The passband is relatively free of radio frequency interference (RFI) signals except for a few weak and one strong signal between 406 and 410 MHz. DSES has been running our pulsar detection tests above 410 MHz to minimize the effects of this RFI. The preamp noise figure is 0.5 dB and the cascade gain is >30 dB. An additional amplifier adds another >20 dB gain but is probably not required. Feedline loss is about 3 dB. The schematic for the extra amplifier and interface to the Ettus receiver is shown in figure 3.

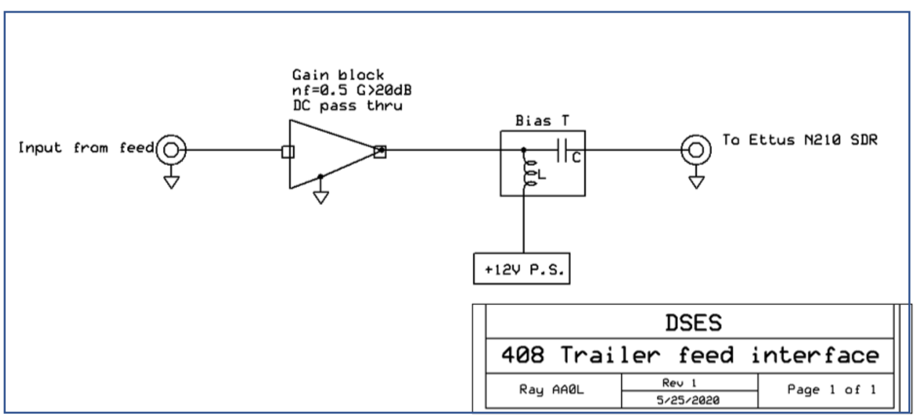


Figure 3: 408 MHz Feed Interface at the operations center in the operations center trailer

Ettus Research USRP N210 Software Defined Radio (SDR)

The Ettus N210 SDR was used because it was donated and was programmable using GNU software https://www.gnuradio.org . It contains an internal global positioning system receiver (GPS), which allowed for high precision time tagging of the signal samples. The Ettus N210 is shown in figure 4.

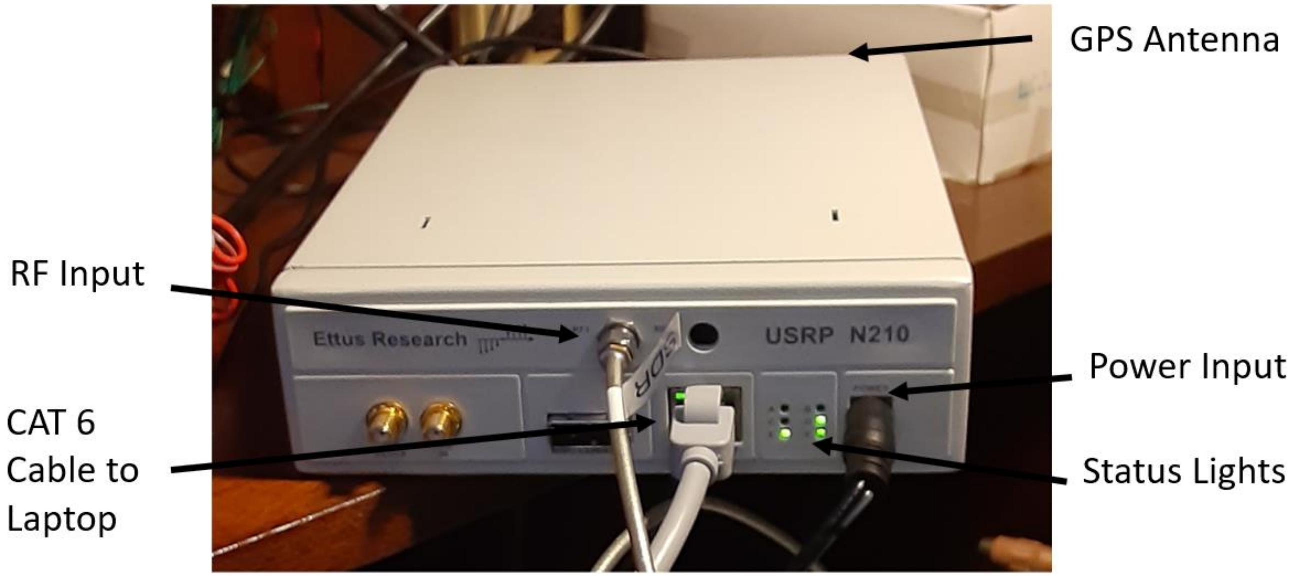


Figure 4: Ettus Research USRP N210

GNU Software SDR Radio Control

The Ettus N210 SDR pulsar acquisition software was developed by Dr. Joe Martin (K5SO) using the GNU open source software development environment. The program (figure 5) allows for the selection of gains, center frequency, bandwidth, and numerous other settings. It also conducts a Fast Fourier Transform (FFT) and converts the output into a (.FIL) file format https://www.reviversoft.com/file-extensions/fil . The (.FIL) format file is the input file required for the pulsar analysis software (PRESTO).

The laptop running this software had the following parameters:

Make Dell Precision M4800
Ubuntu 18.04.3 LTS
Memory 15.6 GiB
Processor Intel Core i7-4810MQ CPU X 8
OS Type 64 bit
Graphics Intel Haswell Mobile
GNOME 3.28.2
Disk 982. 4 GB
CAT 6 Interface port used to connect to SDR

A summary of the acquisition parameters as can be seen on figure 5 are:

Baseband center frequency: 420 MHz
CH 0, RF, IF, and Baseband Gains: 10
Sampling rate: 10 Mbs
Bandwidth: 10 MHz
FFT Size 64

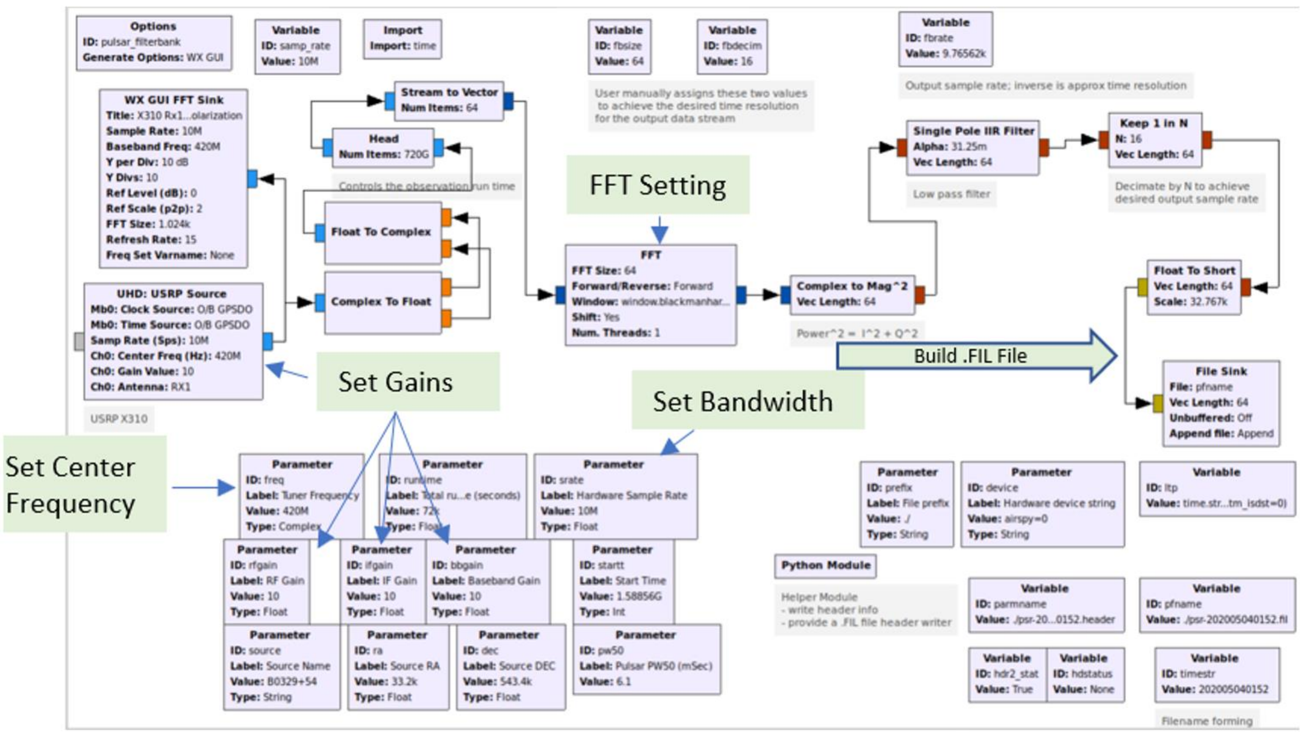


Figure 5: SDR Pulsar Acquisition Program

During acquisition, the program displays a real-time spectrum plot. This allows for observation of signal strength and any RFI (figure 6).

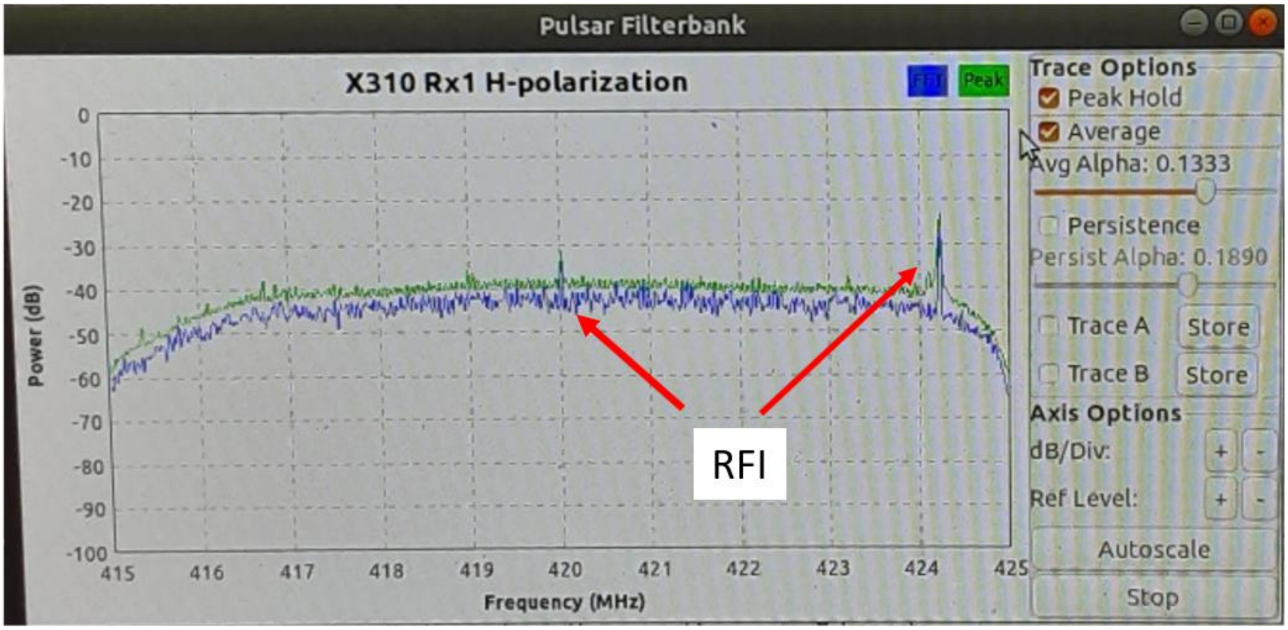


Figure 6: Real-Time Spectrum Plot During Acquisition

Tracking System

The 60-ft dish was setup to manually track the pulsar using the DSES "System 1" tracking program software developed by Glenn Davis, Phil Gage and Lewis Putnam. This program allowed DSES to track the pulsar's position by manually moving the antenna to keep the pulsar in the bullseye (figure 7).

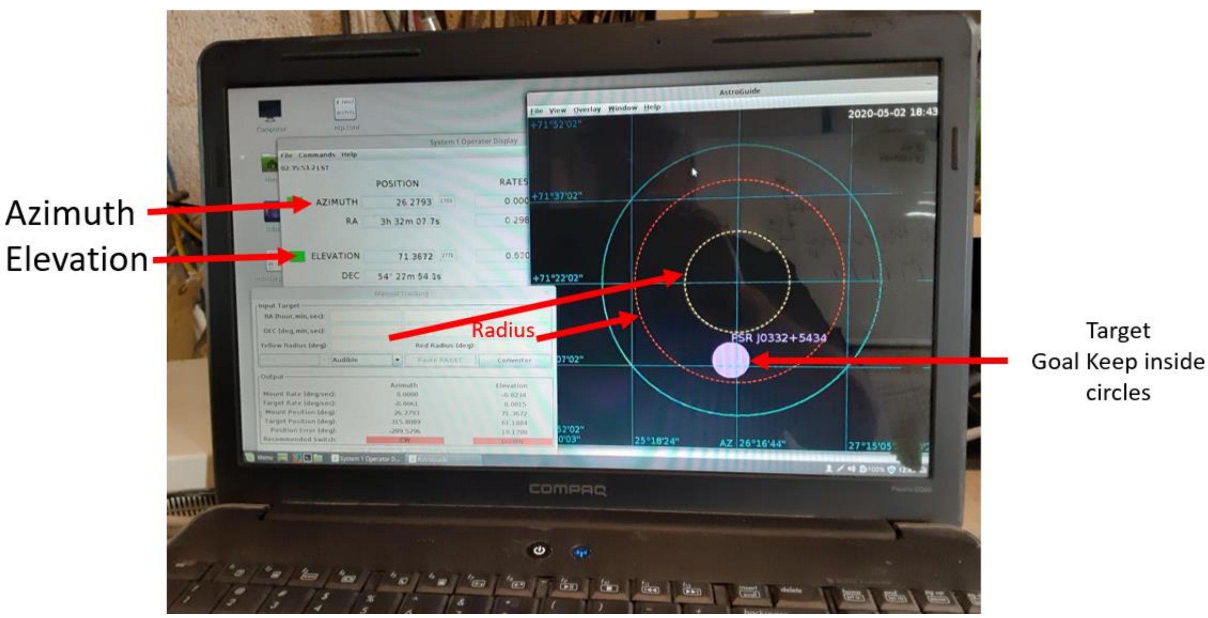


Figure 7: System 1 Pointing Capability

It should be noted that you cannot tell if you have the pulsar real-time because it is pulsing way below the noise level. After about 30 minutes, we stopped the acquisition and we moved the post-processing over to Bob’s new workbench (figure 8).

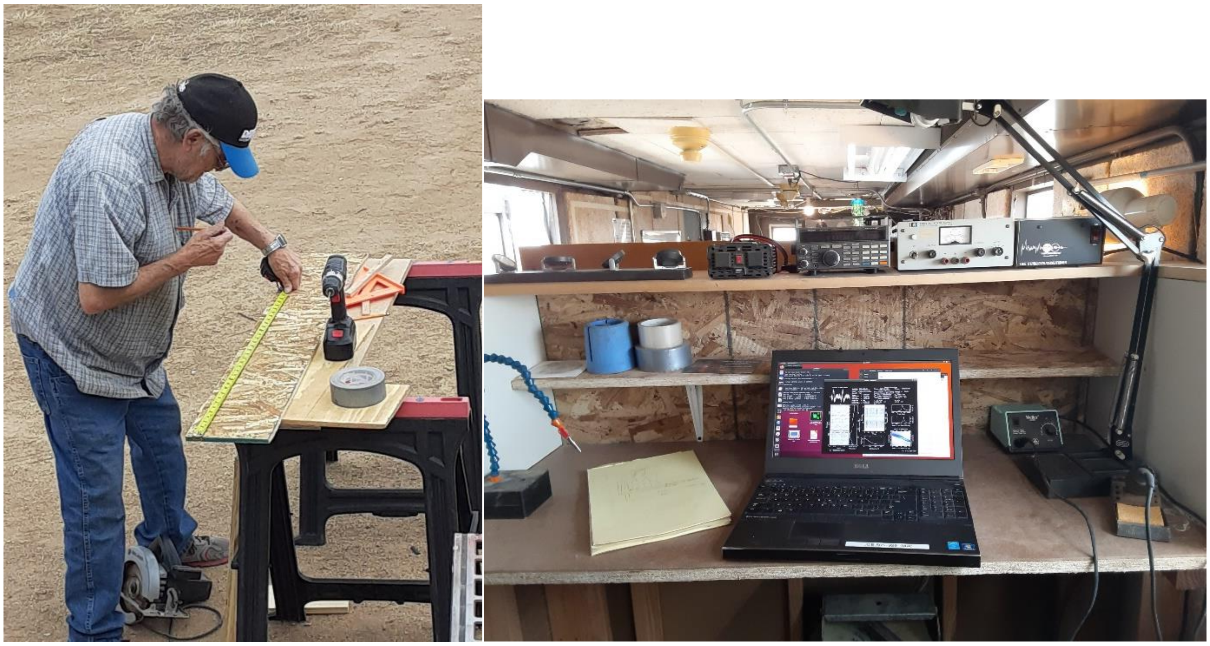


Figure 8: Bob's New Trailer Workbench

Operations Center Setup

Rich Russel and Ray Uberecken celebrate the first pulsar! (Bob Haggart is taking the picture) (figure 9). The 60-foot antenna is controlled manually with an analog motor control system.

Figure 9: First pulsar reaction

The operations center rack contains the manual antenna control system, the antenna rack preamp, plus a spectrum analyzer (figure 10). The spectrum analyzer is hooked to the antenna first in order to discover the presence of RFI. During the May 2nd run, there was a 408 MHz RFI signal. The acquisition center frequency was therefore moved to 420 MHz with a ± 5 MHz bandwidth.

Figure 10: Rack Equipment

Processing the Acquisition File

The acquisition (.FIL) file is processed using the PRESTO software developed by Scott Ransom from the National Radio Astronomy Observatory (NRAO). https://www.cv.nrao.edu/~sransom/presto/

The terminal command that was used for PRESTO:

prepfold -nsub -n 500 – topo -nopsearch – dm 26.7641 -p 0.7145 – fine psr-202005021839.fil

This is all you need assuming that you know the exact period of the pulsar at the time of acquisition and have minimum RFI. More commands are available such as using TEMPO and RFIFIND. These commands can be found in the PRESTO references previously noted.

The first iteration of post - processing required that the pulsar period be estimated with a program called TEMPO, http://tempo.sourceforge.net/ . The first iteration result is shown below (figure 11). It clearly shows a pulsar because of the prominent peaks and the lines tracing down the plots, however it is not quite set to an optimum period as can be seen by the wide pulses.

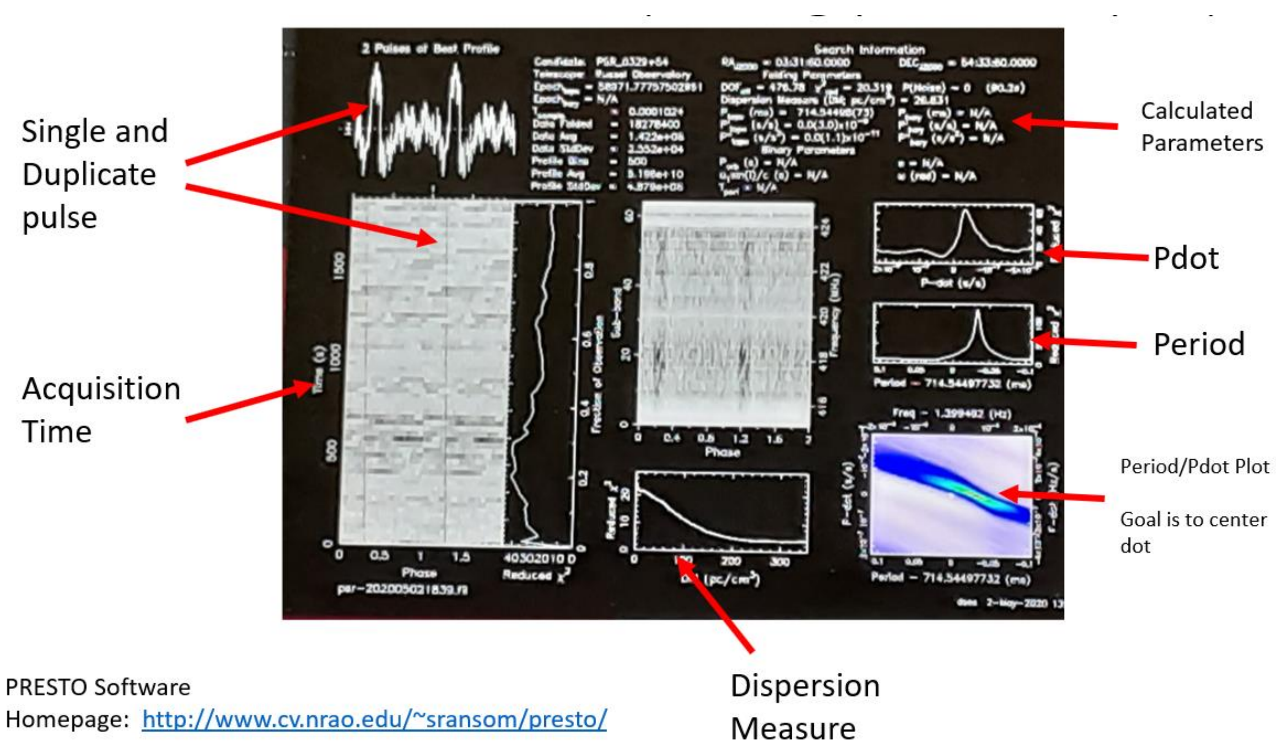


Figure 11: Raw output of pulsar using TEMPO input

After some more iterations of the input period of B0329+54, the final picture looks cleaner (figure 12).

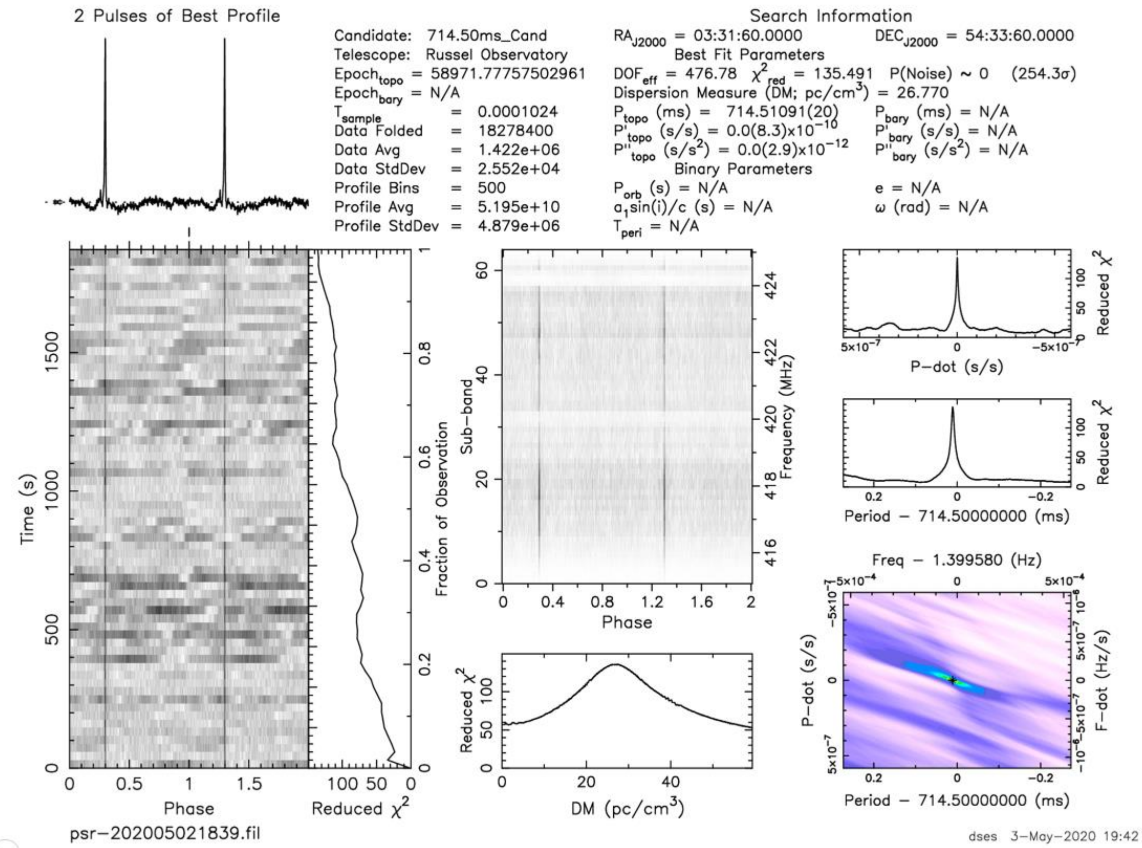


Figure12: Final Iteration of B0329+54 Post - processing

More analysis using the resultant data files allowed us to verify the pulsar as B0329+54 (J0332+5434) (figure 13).

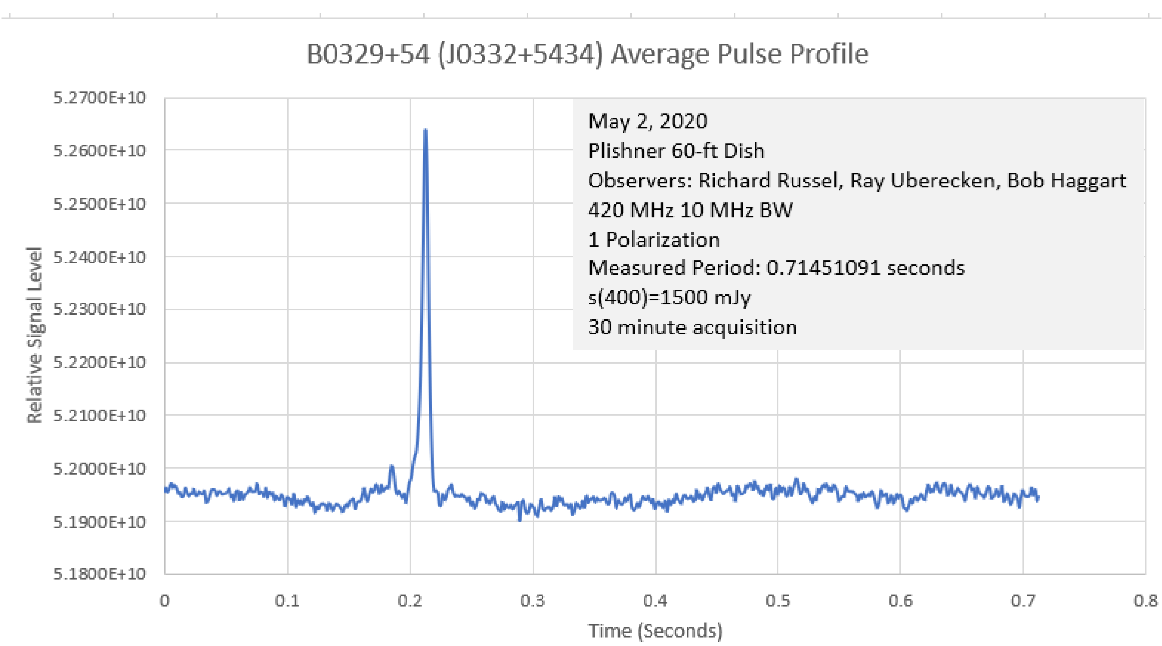


Figure 13: Pulse Analysis using PRESTO Data Output in EXCEL

Even the pulse width at the 50% height (W50) was estimated. The preliminary analysis below shows a measured W(50) of 6 ms. The current value in the Australia Telescope National Facility (ATNF) pulsar database is 6.6 ms https://www.atnf.csiro.au/ . The period, W(50), and right ascension/declination pointing provide a high probability that the pulsar received was B0329+54 (figure 14).

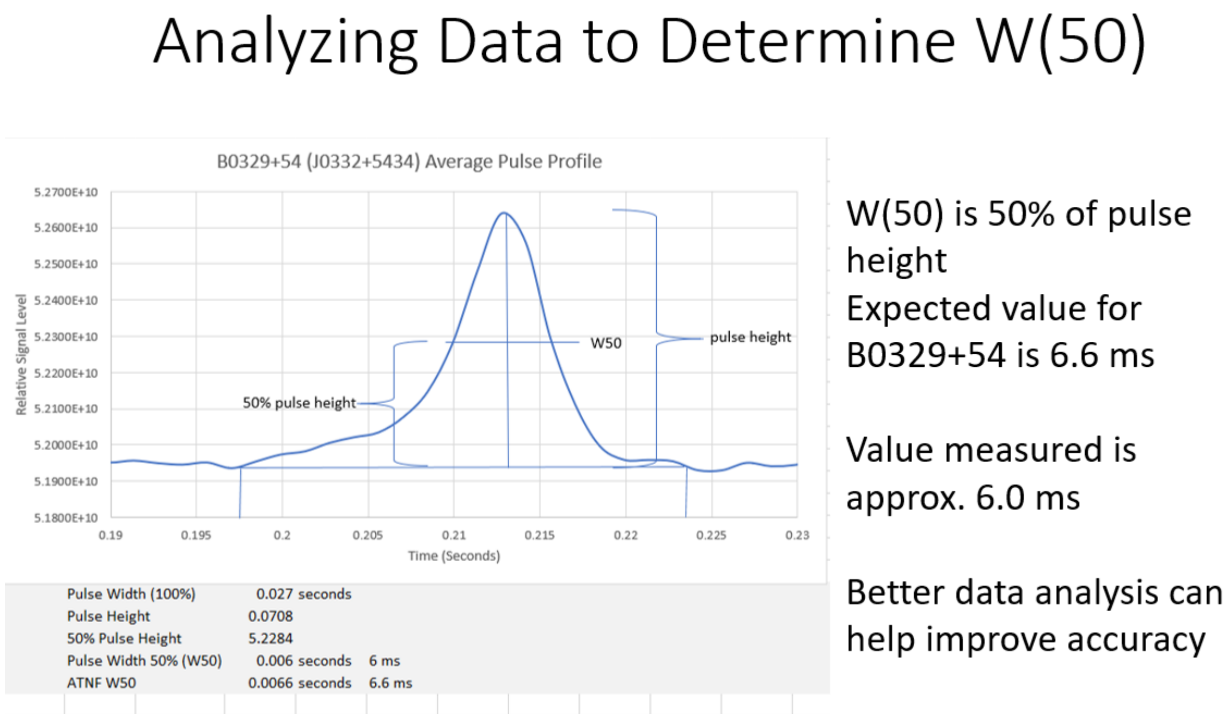


Figure 14: W(50) Analysis of the B0329+54 Received Pulse

Summary

Th 60-foot radio telescope feeds, pointing system and even electical power systems have been built from scratch by the volunteers of various trades and skills of the DSES organization (www.DSES.science). The acquisition of the first pulsar is a major milestone that the entire organization is proud to have accomplished.

More observation runs are planned and DSES is committed to providing future pulsar observation capability on the 60 ft. dish for professional and amateur astronomers alike.

Acknowledgements

Special thanks to Steve Plock and Dr. Joe Martin (K5SO) for their technical support, vision, and leadership that made this pulsar acquisition possible.

The DSES members have been working to restore this site since 2008. Congratulations for successfully getting the antenna converted to a radio astronomy asset!

Robert (Bob) A. Haggart (N0CTV)

Displayed interest in electricity beginning at about age 5

Automotive Shop, Arnold High School 1955 -1957

Twenty-three years USAF, Intricate Electronic Equipment Repair Technician 1957 – 1960, Cryogenic Fluids Production Plant Technician/Manager 1960 - 1980

Graduate of DeVRY INSTITUTE of TECHNOLOGY, Home Entertainment Electronics Systems 1975

Amateur Radio Operator, N0CTV, 1978

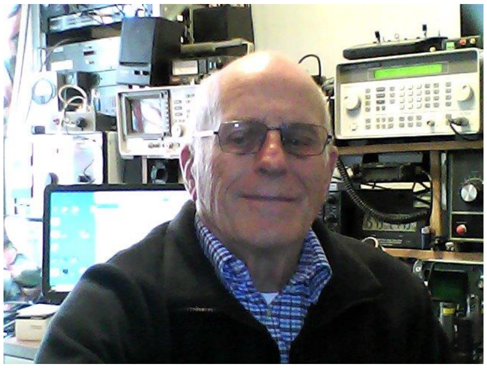
IGP, Maintenance Manager of Electronics Welding Equipment 1980 – 1983, welding robot design, build and installation.

Twenty years Owner Operator, Innovative Concepts, in computer technologies 1983 – 2003

Deep Space Exploration Society 2018 – present

Richard A. Russel (AC0UB)

Dr. Rich Russel is the acting vice president for SARA and the current science lead for the Deep Space Exploration Society. He is a retired Northrop Grumman Senior Systems Engineer and served as the Chief Architect for the Satellite Control Network Contract (SCNC). In this capacity he was charged with planning the future architecture of the Air Force Satellite Control Network (AFSCN) and extending the vision to the Integrated Satellite Control Network (ISCN). Dr. Russel has been the lead architect and integrator for the Space-Based Blue Force Tracking project for U.S Space Command, the Center for Y2K Strategic Stability, and CUBEL Peterson. Dr. Russel also has led the SPAWAR Factory team in the deployment of the UHF Follow-On Satellite system. He has a Doctorate in Computer Science, an Engineers Degree in Aeronautics and Astronautics, a Master’s in Astronautical Engineering, and a Bachelor’s in Electrical Engineering. He is also certified as a Navy Nuclear Engineer and he is a retired Navy nuclear fast attack submariner and Navy Space Systems Engineer.



Ray Uberecken (AA0L)

Ray's lifelong passions for astronomy and radio began in cub scouts. He became a licensed amateur radio operator in high school before entering the Navy in 1955 and has maintained his license ever since. Now licensed AA0L he obtained the class as Extra in 1978. He put ham radio and astronomy together as a hobby in the 1960's doing moon-bounce and measuring sun and galactic noise. He maintains radio and optical observatories at his home east of Colorado Springs, Colorado.

Ray is employed as a broadcast engineer babysitting two AM and four FM stations.

Ray is a long-time member of the Deep Space Exploration Society and enjoys building receiving equipment and feed antennas for their 18-meter dish in southeast Colorado. Ray is also a member of the Colorado Springs Astronomical Society, Society of Amateur Radio Astronomers, American Radio Relay League and life member of AMSAT.

Ray's current interest is in cosmology and proving the various theories of how the age of the universe is calculated. Ray's work on pulsars and the resultant measurement of dispersion measure (DM) is an excellent input into his work.