BAAA, Vol. 64, 2023
R.D. Rohrmann, C.H. Mandrini, C.E. Boeris & M.A. Sgró, eds.

Asociación Argentina de Astronomía
Boletín de artículos científicos

Development of a technological demonstrator for a radio astronomy receiver

S. Ruppel[1], A. Venere[1], J. Cogo[1], J. Areta[1,2], N. Maffione[1,2], M. Orellana[1,2], A. Granada[1,2] & G.M. Gancio[3]

[1] *Universidad Nacional de Río Negro, Sede Andina, Argentina*
[2] *Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina*
[3] *Instituto Argentino de Radioastronomía, CONICET–CICPBA–UNLP, Argentina*

Contact / sruppel33@gmail.com

Resumen / En la presente colaboración entre la Universidad Nacional de Río Negro y el Instituto Argentino de Radioastronomía estamos trabajando en el diseño y desarrollo (a partir de la evaluación numérica de sus componentes) de las etapas de adquisición y post-procesamiento de un receptor radioastronómico integrado a una antena para radioastronomía amateur. Con esta presentación queremos mostrar los avances realizados hasta el momento.

Abstract / In the present collaboration between the Universidad Nacional de Río Negro and the Instituto Argentino de Radioastronomía, we are working on the design and development (by numerical analysis of its components) of the acquisition and post-processing stages of a radio astronomical receiver for amateur radio astronomy. In this presentation we want to show our results on this work in progress.

Keywords / instrumentation: detectors — methods: observational — radio continuum: general

1. Introduction

We present here some results concerning the assembly of an amateur radio telescope centered at $\lambda \simeq 21$ cm (the line of the neutral hydrogen transition between the two hyperfine levels of the 1s ground state).

This is a follow-up work of the project initially reported in Lopez Cabrera et al. (2020), where the authors developed a back end with Commercial Off-the-Shelf (COTS) equipment. From that experience a commercial feeder is available (VE4MA), but unfortunately, it required a large dish that was not finally granted to complete the initially conceived project. Therefore, we decided to carry out the necessary tests on a smaller antenna in order to characterize the equipment. Now we are working on the radio antenna once again, recovering the know-how gained in such previous research. We intend to advance in the integration of a fully operational basic system to be used by students of electronic engineering who show interest in radio astronomy, and to promote the collaboration between our institutions.

The particular goals set for this stage of the project continuation are the following:

- Manufacture and assembly of a prototype antenna, to be tested autonomously,
- full chain integration: Low Noise Amplifier (LNA), Filter, Antenna and Software Defined Radio (SDR),
- software development in GNU Radio to validate the spectrometer,
- alternative software validation of the entire Radio Frequency (RF) chain.

2. Equipment

For the RF front end, the following MiniCircuits commercial components were used:

- LNA: ZX60-1614LN-S,
- band Pass Filter: VBF-1445+,
- semi-rigid cables,
- SMA male-male connectors.

An ADALM SDR was used for the acquisition stage. The ADALM Pluto is mainly used for educational purposes but showed a good performance for the task. The SDR is accompanied by a Raspberry Pi model 3b+ running GNU Radio on Linux.

2.1. Antenna

A patch antenna (the element that mediates with the electronics) made of FR4 (a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant) was designed to be used with a parabolic of small diameter. We also evaluated a cardboard type feeder: a small parabolic dish made of aluminized cardboard, with a diameter of 62 cm and a depth of 14 cm. The later follows the project guidelines given by Digital Signal Processing in Radio Astronomy (DSPira) from the University of West Virginia (WVU). See `https://wvurail.org/dspira/` for further details.

Assuming the handmade antenna reached an acceptable parabolic shape, the resultant focal distance is 17 cm, and an effective aperture area of around 0.18 m^2. With these values, we estimated a gain $G \sim 17$ dB

Poster contribution

using publicly available software that can be found at `https://www.rfwireless-world.com/calculators/parabolic-dish-antenna-calculator.html`

The patch antenna (Zhang, 2007) was designed and simulated using the electromagnetic moment tools provided by Keysight's ADS 2021. We estimated its response in frequency and gain. Figure 1 shows that the patch antenna has a good theoretical reflection coefficient for the desired frequency. Notice that the closer to the 0 dB, the higher the reflection and consequently, less signal would be captured by the antenna.

The option of dumping the measurements to a file for storage was included in order to allow a post analysis.

3. Methodology and results

We studied a simple RF chain using a single LNA as initial approach. Then, the full acquisition chain was assembled using two LNA units. In order to reduce the noise figure as much as possible, we decided to place the bandpass filter in the middle and use short connections.

Besides, GNU Radio Companion was chosen for the development of the spectrometer. We started from the simplest possible arrangement given by the DSPiRA project guidelines, and build up from that. The full acquisition chain is presented in Figure 2 where we show the blocks used to transform the acquired electrical signals by the receiver into those related to the desired spectral line of the neutral hydrogen. In order to achieve this goal, the signal is treated as follows: the first step corresponds to the signal going through a polyphase filter bank (PFB) giving out a flat response across the channel, then the application of the Fast Fourier Transform (FFT) which allows the system to obtain the different frequency components of the raw signal, suppress the signals out of the band and avoid scalloping the noise. Then, the system obtains the power spectral density, PSD (by computing the square modulus of the FFT) to show the energy linked to each frequency. In order to achieve a better PSD estimate (to further cancel noise), we proceed to average 4096 consecutive PSD estimations. Finally it is dumped for visualization and stored for posterior analysis.

Eventually, we decided to use the spectrometer proposed by the WVU: their system already includes not only the tools necessary to perform the system calibration, but also those for the observation itself and furthermore, it has the ability to save measurements for later analysis, meeting the stated requirements.

We pointed in the west direction with the star Antares as our guide. However, note that the pointing system of our instrument is not precise. The theoretical angular resolution is estimated: 4.15×10^{-1} rad, and therefore, some of the emission from the Galactic plane neutral hydrogen was detected. The integration of the signal was done by periods of 30 minutes after the system reached (thermal) stability (around and hour).

The Raspberry initially used with the SDR was left aside due to its low performance (especially foreseeing future projects). We connected the SDR directly to a PC and the data was saved in the same format as it was

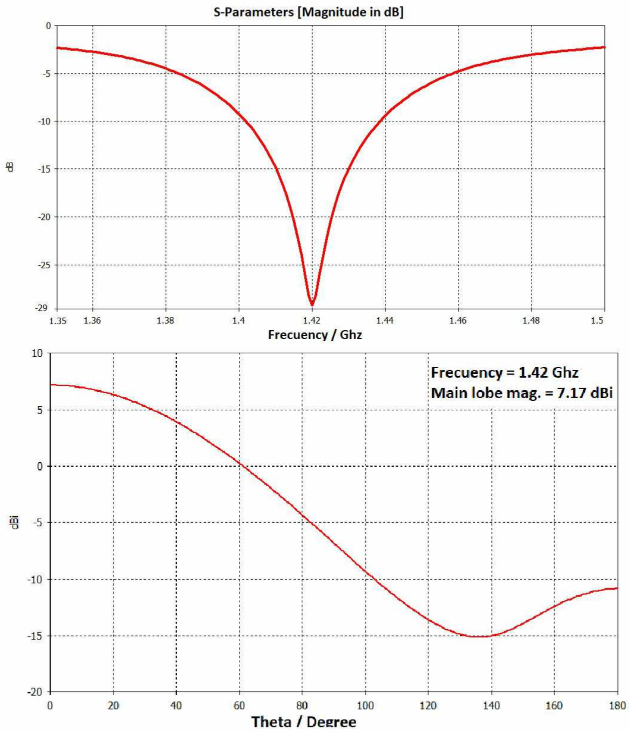

Figure 1: The reflection coefficient of the antenna (S11). *Top panel:* Response of the patch antenna as a function of the frequency. *Bottom panel:* Gain as a function of direction.

loaded by the receiver for the sake of simplicity (a 32 bit floating point number sequence).

The most relevant result is shown in Figure 3 that illustrate the testing observation. There, we show that the largest peak corresponds to the desired operational frequency, that is validating the configuration established for the SDR and the capacity of the antenna to work tightly to the line of the neutral hydrogen, as expected. The first case, illustrated with a solid blue line corresponds to the patch antenna alone. The second case, depicted with a solid red line, corresponds to an arrangement made of a LNA plus the bandpass filter. The secondary peaks correspond to interference in the measurements. At 1415 Mhz this might be due to the noise of the system because of using OTS electronics.

4. Conclusions and future work

The methodology applied for the experiments allowed us to learn about the design and assembly of an acquisition and post-processing unit as well as the writing of the companion software (the spectrometer on GNU Radio Companion) to perform some basic but efficient measurements.

However, some caveats should be mentioned:

- it is necessary to improve the antenna, using a disk with a larger diameter;
- improvements on the mount system will be further explored, as well as performing observations in several directions.

Regarding the first point, we are in communication

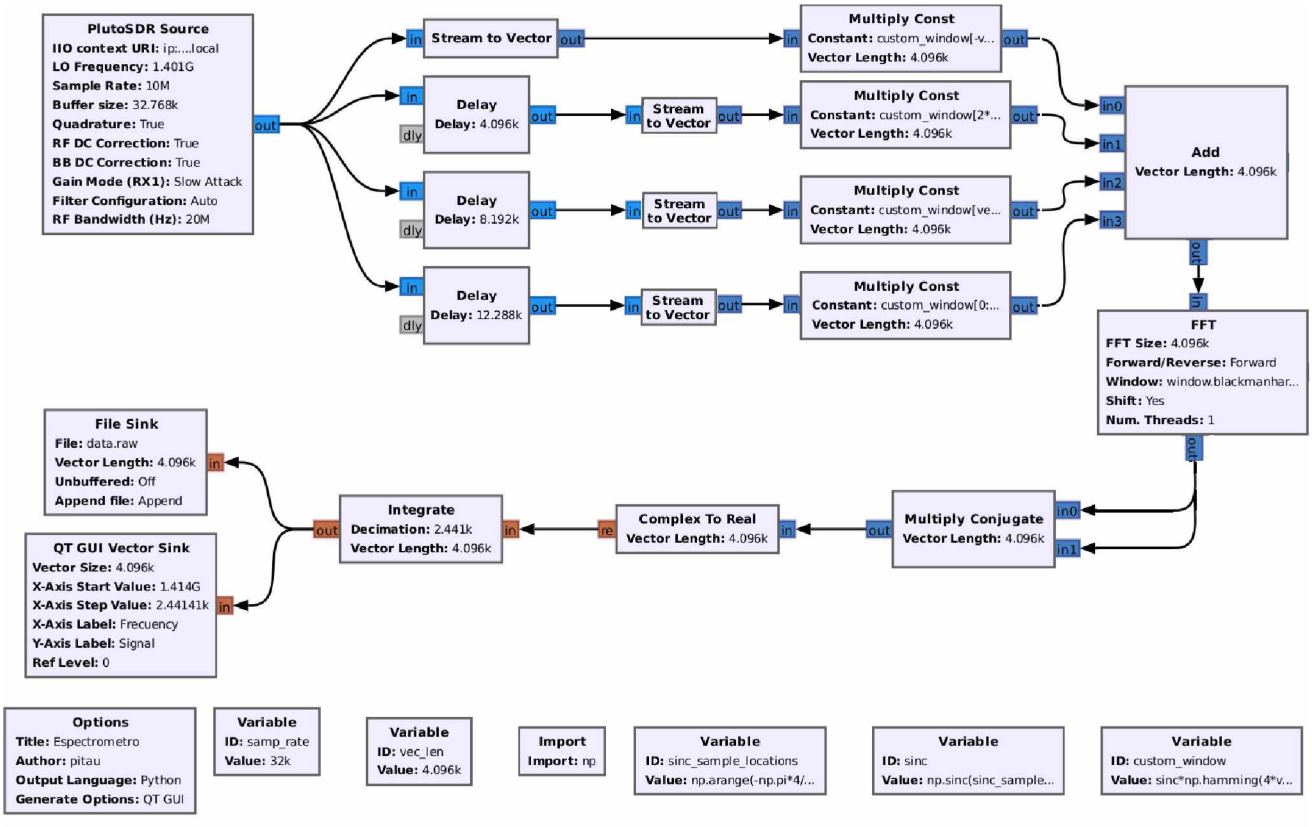

Figure 2: Acquisition chain of the spectrometer with polyphase filter. See text for details.

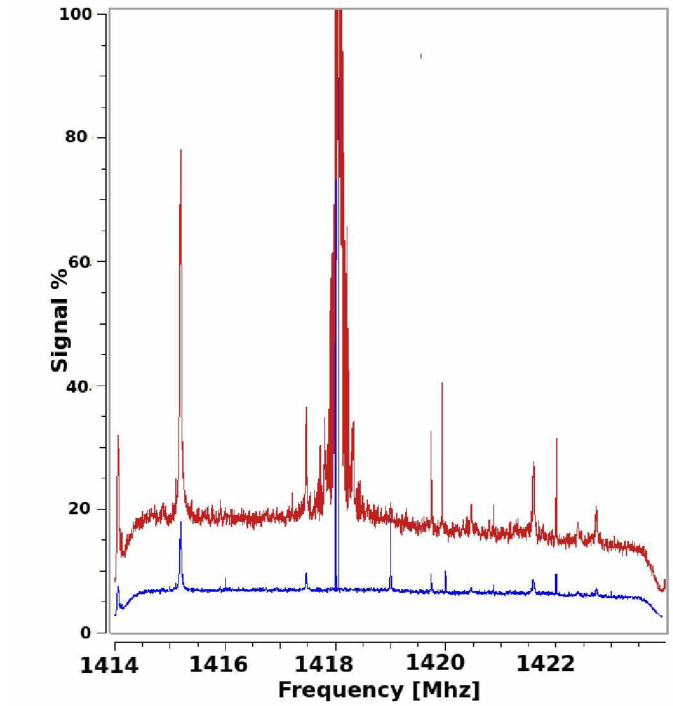

Figure 3: Test observations centered at 1420Mhz. See text for details.

with an institution that might provide us with an antenna of a larger size (3 m diameter), which would also allow us to use another feed of better quality and continue with the experiments. Finally, according to the second point we plan to follow the guidance and experience of the Instituto Argentino de Radioastronomía staff (we are in close collaboration in other projects too) as well as published surveys, for instance HI4PI Collaboration et al. (2016).

It is worth mentioning that with this project we put together a team that works with professors and advanced students of Electronics Engineering of the Universidad Nacional de Río Negro who are willing to collaborate in an interdisciplinary way.

Acknowledgements: We thank PI 40B885 UNRN for partial funding support.

References

HI4PI Collaboration, et al., 2016, A&A, 594, A116
Lopez Cabrera O.V., et al., 2020, BAAA, 61B, 225
Zhang Y., 2007, *Patch Antenna for 1420MHz Radio Telescope*, Master's thesis, School of Information Science, Computer and Electrical Engineering Halmstad University, Box 823, S-301 18 Halmstad, Sweden