# Radio Transient Signals De-dispersion: Design, Implementation and Operation for the Deep Space Antenna 3

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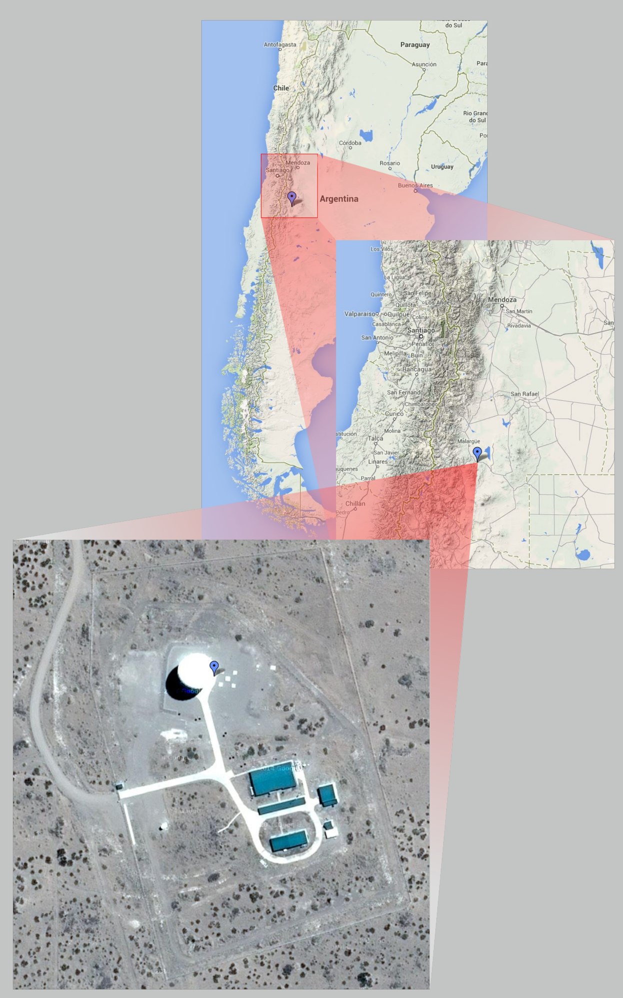
## ABSTRACT

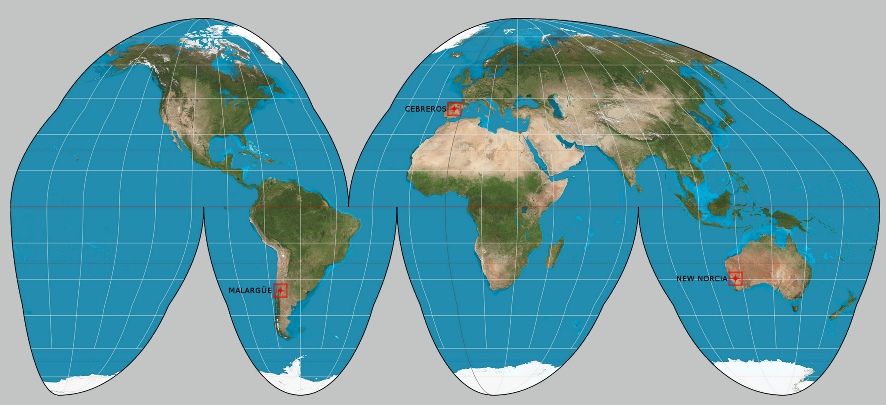
This work intends the use of a Deep Space Antenna (DSA) designed for telecommunications in the detection of individual radio signals, such as transient signals.
The focus of the presented solution to the use of the DSA 3 in transient detection of radio signals, within astronomical purposes, intents to be the least disruptive as possible for the terrestrial main mission, which is telecommunications.
The proposed uses commercially available equipment (Commercial Off-The-Shelf or COTS), avoiding the development of a made-to-measure hardware, in order to mitigate risks. Most of the remaining parts of the tool to implement is done by developing a processing software.

## JUSTIFICATION

In 2012, the European Space Agency (ESA) inaugurates the third Deep Space Antenna (DSA 3), in Argentina (Malargüe, Mendoza). The instrument is mainly engaged in communications with interplanetary missions. However, it allows observations and radio signals processing in radiometric frequencies (8-32 GHz), with considerable angular resolution (1-5 arc-sec), thanks to the transmitters and receivers in X-band and receivers in Ka-band. Data can be obtained with very low noise level in much shorter time than with other instruments.



Location and Facilities of DSA-3. Malargüe, Argentina



Three 35-metre diameter antennas (New Norcia, Cebreros and Malargüe).

DSA-3 (MGUE-1), Facilities Opening December 2012.

- Research interests for Argentinean groups:
  1. Identification of gamma rays sources.
  2. Study of the radio galaxy Centaurus A.
  3. Studies of variations in active galactic nuclei.
  4. Studies of supernova remnants (SNR) and ionized regions (HII regions).
  5. Physicochemical studies of protoplanetary clouds.
  6. Study of the interstellar medium (ISM) through scintillation of extra galactic punctual sources.
  7. **Characterization of radio transient phenomena.**

## GOALS

- General Goals
  1. Design, develop and implement a prototype hardware and the associated data acquisition software using GPU-based parallel computing.
  2. Study the performance of this telecommunications antenna as radio telescope, in order to detect transient signals, using part of the observing time available for Argentina in the DS3
- Specific Goals
  1. Employ commercially available equipment (COTS) in order to avoid made to measure hardware for mitigating risks.
  2. Develop the first stage of processing software.
  3. Equip ESA with instrumental to search for rotating radio transients (RRATs).
  4. Take advantage from DSA-3 facilities as a radioastronomy observatory.
  5. Process data at a rate equal to the rate of receipt thereof, avoiding spurious data storage.
  6. Develop the necessary software using parallel programming GPUs.

## SCIENTIFIC CASE

- The called RRATs, recently discovered [1] [2], and their physical description is proving to be an opportunity for the development of astrophysics associated with sporadic phenomena, which require extensive time base observation [3].
- This project involves the design, construction and operation of a prototype equipment and the associated data acquisition technique that will be implemented as software, permitting the observation of these radio transients events.
- The approach of this solution for the use of DSA 3 for radio transient signals detection with radio astronomical purposes, attempts to be as least disruptive as possible to the main mission of the ground station, which is telecommunications. The use of commercially available kits (COTS) avoids the development of custom hardware, in order to mitigate risks. Most of the remaining part of the instrument is performed implementing software development.

## DEVELOPMENT

As a result of the dispersion of the pulse, the power received by a receiver arrives distributed in time. In order to detect a scattered pulse, it is convenient to counteract the effect by adding the low power pulses spread across time and frequency.
The accurate dispersion compensation returns a pulse equal to the original and of maximum width (assuming that the envelope is the same throughout the frequency spectrum). A sub or over compensated pulse will have smaller amplitude but a greater one than the dispersed pulse.
A wideband pulse moves through the plasma slowlier at lower frequencies than at higher frequencies. If the distance to the source is $z$, the dispersion delay $t$ with frequency $\nu$ is

$$t = \int_0^z v_g^{-1} dl - \frac{z}{c} = \frac{1}{c}\int_0^z \left(1 + \frac{\nu_p^2}{2\nu^2}\right) dl - \frac{z}{c} = \frac{e^2}{2\pi m_e c} \frac{\int_0^z n_e dl}{\nu^2}$$

In astronomically convenient units, this becomes

$$\left(\frac{t}{\mathrm{sec}}\right) \approx 4.149 \times 10^3 \left(\frac{DM}{\mathrm{pc\ cm}^{-3}}\right)\left(\frac{\nu}{\mathrm{MHz}}\right)^{-2}$$

where $DM \equiv \int_0^z n_e dl$ in units of $\mathrm{pc\ cm}^{-3}$ its called **Dispersion Measure**.

The pulse width increases with distance $z$. Also, the pulse amplitude decreases with distance. The effect of the extra length of the pulse and the amplitude reduction refers to the dispersion of the group velocity or chromatic dispersion.

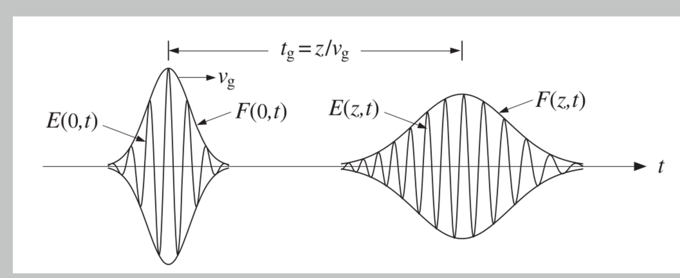
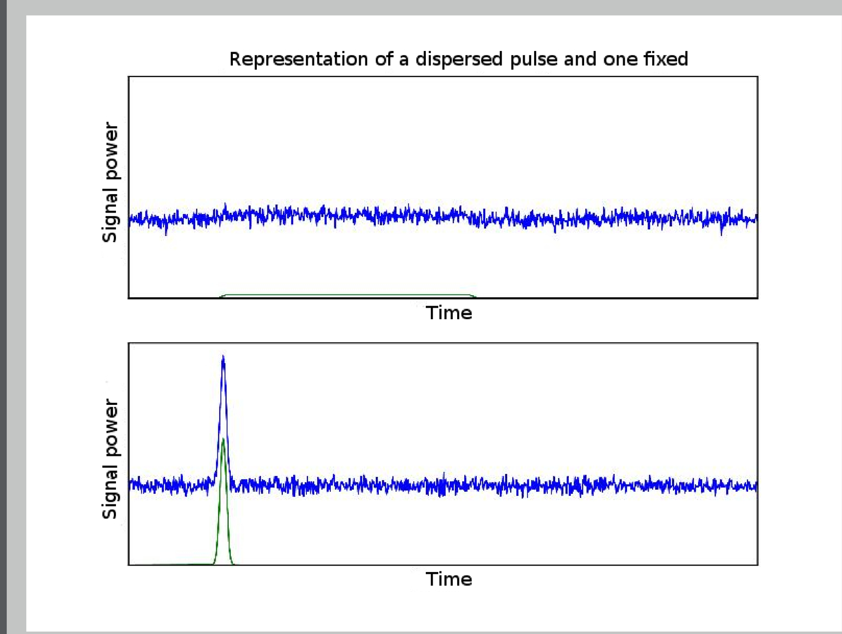
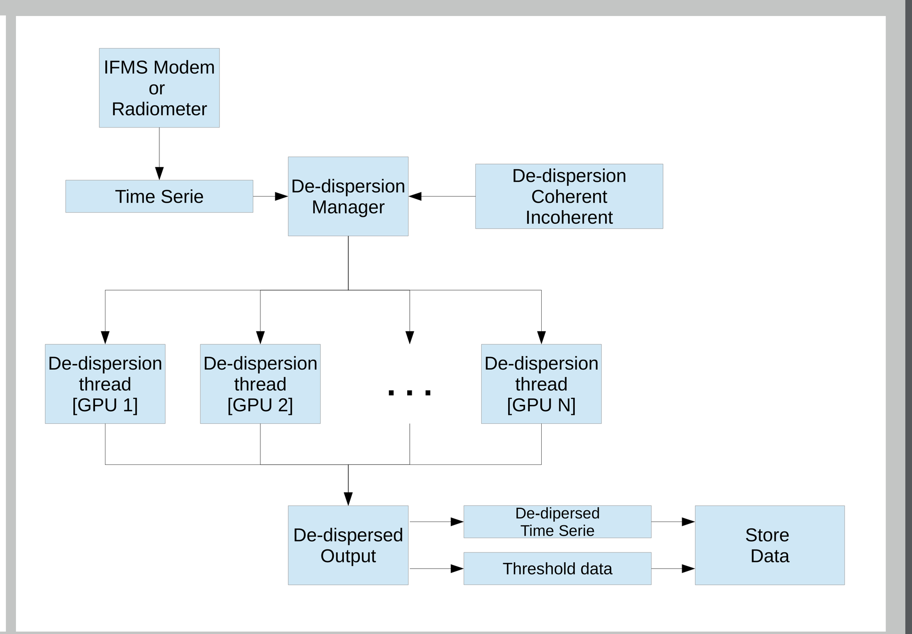



Figure : Group Velocity, the pulse has extra length and the amplitude decreases with distance.




Pulse shape dispersed and de-dispersed in time.




Functional Diagram of Proposed Design

To search for pulsars, DM is unknown and becomes a search parameter like the pulsar rotation frequency. This searching of additional dimension is one of the main reasons whereby pulsar searches require computationally intensive processes.
Finding transient consists of two main steps:

1. De-dispersion to eliminate the effects of interstellar medium.
   1.1 Coherent De-dispersion
   1.2 Incoherent De-dispersion

   This always requires some prior knowledge of the dispersion measure (DM). Generally, this information about DM is not available in the search for radio transients. Therefore, tests should be performed with several values of DM, which is equivalent to intensive computational requirements of computing power.
2. Appropriate duration of transients.
   For the possible highest signal-to-noise relationship, which is necessary for reliable detection, filtering should be adapted and the "signal strength" must be correlated to a template of the expected transient.
   Both cases, DM and iterative testing matched filtering, require considerable computational effort, especially considering other searching parameters: frequency, sky observation and celestial coordinates.

## WORK IN PROGRESS

- Synthesis of data format used by ESA.
- Conversion of the raw data to FITS format.

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## PARTICIPATING INSTITUTIONS

Argentina has an 8% annual operation time of the antenna (480 hs./year), for using with scientific and research purposes. The institutions that manage the time available are:

- ITeDA
- CONICET
- CONAE

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