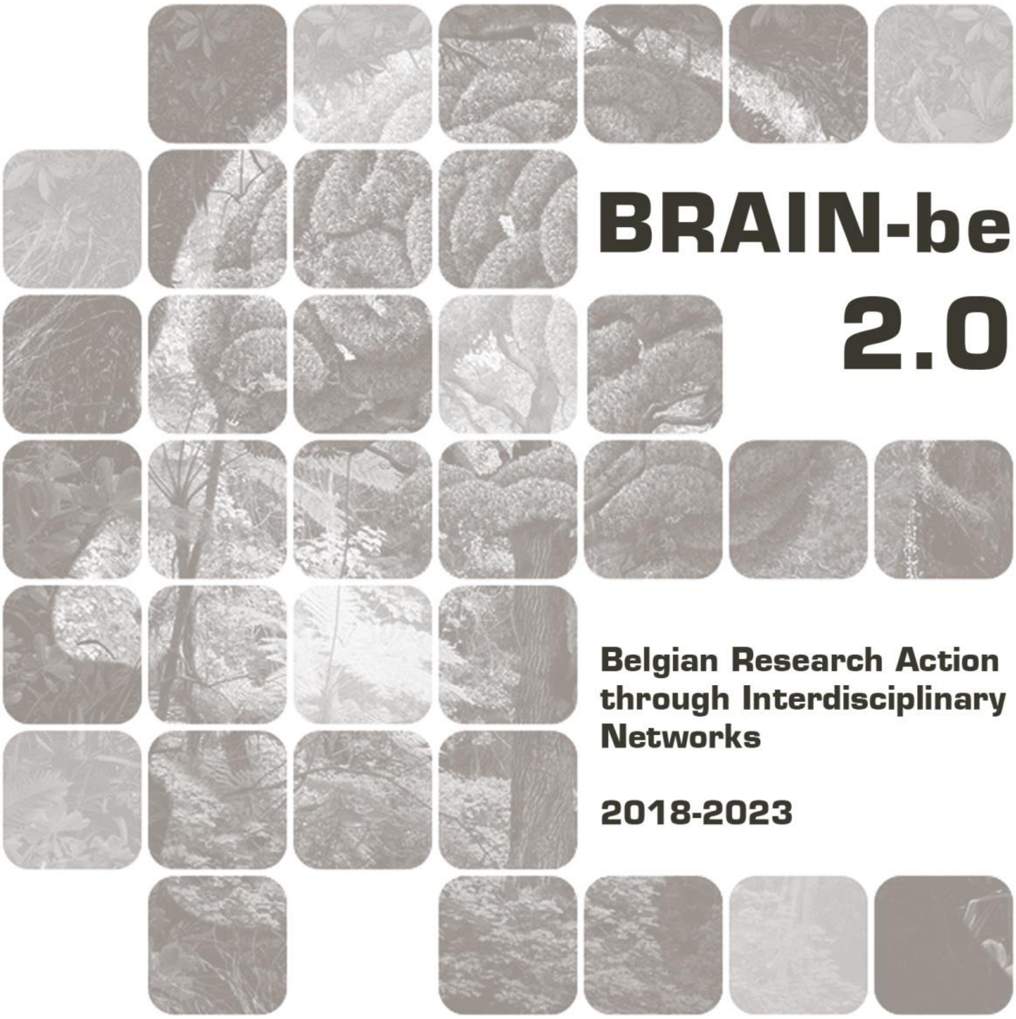

OART

Open Access Radio Telescope

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May 2024

Pillar 2: Heritage science

BRAIN-be 2.0

Belgian Research Action through Interdisciplinary Networks

2018-2023

NETWORK PROJECT

OART
Open Access Radio Telescope

Contract - B2/202/P2/OART

FINAL REPORT

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ABSTRACT

Context

The OART project deals with the renovation of a historical radio telescope on the site of the radio astronomy station of Humain, managed by the Royal Observatory of Belgium. As such, the project belongs to a large effort in several European countries, to maintain and bring back to life major scientific equipments of the past, once at the forefront in their categories, but which slowly lost their rank with the progress of technologies.

Objectives

The objectives of OART is not only to renovate and therefore maintain a telescope, but also to bring it back to a level of operation, compatible with simple observations that permits teaching fundamental radio astronomy to a large audience, ranging from the general public, enthusiast amateurs, pupils, to university students.

Conclusions

In the frame of the project, we brought a telescope that used to stand still for more than 50 years into one with full restored motion and pointing capabilities, new feed antenna support, a dedicated feed antenna and a modern and simple receiving chain. While the web interface and commissioning could not be fully completed before the end of the project, the team continues on its own funding to complete the last steps needed to open the instrument to the public use.

Keywords

Radio astronomy; scientific heritage; renovation; education; telescope

1. INTRODUCTION

The OART project is about the valorisation of a unique piece of scientific heritage from the Royal Observatory of Belgium. In 1953, the Observatory stepped in a field which was then very recent: solar radio astronomy. It did so by setting up a small radio astronomy station in Humain, near Marche en Famenne. Until the late 1960s, significant investments were made by the Belgian state, including a 48 antenna solar interferometer. In 1968, two 6-m dishes were set up on the station, one being in use today for solar radio observations. The other one had never really been actively used, but such an asset is still very valuable for science. In the frame of the Pilar 2 Historical Heritage from the BRAIN program, it was proposed to renovate the telescope to turn it into an instrument for educating the public and students to the field of radio astronomy.

2. STATE OF THE ART AND OBJECTIVES

Observatories world wide often host historical scientific infrastructures which, for many reasons, are not in use anymore: optical telescopes located in area where the light pollution is too strong, outdated historical instrumentation, decaying infrastructures or shift in research priorities to cite a few. These infrastructures are nonetheless evidences of past scientific and human enterprises that were at the forefront of research at the time they were in operation. In modern astronomy, the periods of practical observations with ground based instrumentations are very reduced, done remotely or done by scientists in remote places not accessible to the public. Space based observations are planned via what looks like regular office work, at a desk, behind a computer. Therefore, when research institutes or observatories open to the public, the only instruments to show are either mockup of satellites or often historical ones. Some institutes have had the opportunity to fully renovate their historical assets, and make them open to public for basic observations (e.g. Potsdam Observatory). In the radio astronomy field, the Astropeiler Stockert radio observatory has been fully renovated by a group of enthusiasts amateurs and the 25 m radio telescope on site is now operational.

The OART project is about the refurbishing of a relatively small radio telescope (6-m), once built for solar observations, to be used for the training of students, amateurs and the public. As such it will fulfil one of the *raisons d'être* of the Royal Observatory of Belgium, which is to educate the public with respect to astronomy. Despite its small size, several non solar radio astronomy studies can be performed with this class of instrument: pulsars, observation of the hydrogen distribution in our galaxy, or studies of star forming regions. It is the first attempt in Belgium to make operational again an historical instrument for a new usage, and to our knowledge, the very first time non solar radio observations will be performed on Belgian soil.

3. METHODOLOGY

The renovation of the telescope had several steps divided is as many work packages (WP): mechanical (WP1), control system (WP2), receiving chain (WP3), remote access (WP4) and commissioning (WP5).

Mechanical renovation

The original telescope on site was dismantled into 3 parts: the pilar, the parabolic dish (which both stayed on site), and the mount itself which was brought to the mechanical workshop at ROB for further disassembling. The main difficulty there, and it was known beforehand, has been the lack of accurate drawings and mechanical plans. A lot of information exists on the 4-m telescopes part of the old solar interferometer, but not on the 6-m ones. Both types were built by the same company "Établissements Gardier", a mechanical firm in Sclessin, near Liège, which does not exist anymore. From the outside, the mounts of the 4-m and 6-m telescopes look essentially the same, with some minor differences, but during the opening and disassembling, some deeper differences appeared: for example the main gear of the declination axis is nearly complete for the 6-m dish while it is only a third of a disc for the 4-m ones. Some "keys" insuring the mechanical junction between the main declination axes and the aforementioned gear were not documented and could not be removed preventing the axis to be fully extracted from the mount. New bearing were installed on all axes, gears where cleaned and greased, new adaptation pieces for modern motors were built and fit to the mount. Protective paint was applied.

On site, the pilar and the dish were sand blasted and repainted (the old reflective mesh was removed from the dish frame).

The observations foreseen with OART requires a finer mesh than the original one. After a rather long search, the appropriate mesh (mesh size, resistant to rust) was selected and purchased. To adjust the new mesh to the existing frame, new rings were built at ROB and tested and installed on site. A plywood parabolic template was used to insure the proper parabolic form could be achieved.

The original parabola had no feed support (it was instead meant to host a central tube supporting a dipole). A tripod was designed using a CAD software (FreeCad, open source), and a basic finite element analysis was performed to insure that no large deformation of the structure could happen.

The mount and the dish were installed back on site in the summer of 2023.

Control system

The core of the control system is derived from the modern control system of the 6-m solar telescope operational on site. It is made of several key components: step motors for the motion with variable speeds, absolute coders for measuring the position, safety switches to prevent mechanical damages, and a control rack with electronics boards to control the motors, read the coders, bring the meaningful information to a raspberry-Pi control computer. In addition, the rack encloses electrical transformers to power the different subsystems and various probes monitoring important parameters (some voltages, temperature etc…).

Post-pandemic recovery shortages of electronic components did have an impact on the progress of this part of the renovation. Some key components were delayed up to several months before being delivered and alternatives were looked for in some cases. The step motors that were chosen (based on our experience with the 6-m solar telescope) are controlled by an electronic driver that was discontinued by the manufacturer. The alternative that was proposed would have necessitated a large redesign of the power supply and its electronics of the control system, and instead we looked for generic electronic drivers that could match the motors. This has been a long process, as several drivers were tested. The best ones triggered some “freezing” of the motors at some speeds and new, more powerful motors were bought to solve this. This significantly delayed the progress of the control system completion.

As of today, there are still minor issues that need to be solved: the speed of the step motors is controlled by a frequency generator based on a micro controller. The original program meant for solar observations had to be rewritten but there remain bugs affecting the highest speeds. It appears also that the slow speeds used for tracking the Sun, celestial objects or the Moon are well within reach of the micro controller frequency generation capabilities in lab (i.e. in a controlled environment), but it may require thermostatisation in the field.

The software part of the control system is also mainly based on the one used for the current solar observations. After investigation it appears that it requires very little modification: adding extra sources in the ephemeris part (known pulsars, radio sources, formation star area…), and a very basic API for interfacing with an external program. A telescope simulator has been written to fine tune parameters of the control software (time it takes to reach a certain speed, or to switch from one source to another…).

Receiving chain

The receiving chain is made of: the feed antenna, at the focus of the parabola, the RF electronics next to it, and the receiver.

The feed antenna has been designed and built at the observatory. It is meant for observations in three bands and has a dual loop magnetic configuration (one of the loop allowing the observations of 2 bands). The design was chosen after a series of simulations performed at ROB (using an open source “method of moment” software library called NEC2++), optimizing at three frequencies the aperture efficiency when used with the OART parabola (a trade off between illumination of the parabola, spill over and aperture tapering). A prototype was built by the mechanical workshop. Field measurements have been made at ROB to characterize the beam pattern and the performances.

The RF electronic box contains the filters, a calibrating noise source, and amplifiers needed for the operations. For the first time, we used SMD components instead of “connector” ones, giving us access to a larger choice of components. Simulations were performed during the design phase with open-source software libraries (scikit-rf) to characterize the main performances of the system. The electronic laboratory of the Aeronomy Institute kindly agreed to turn our paper design into a real electronic board. The board was delivered in mid 2022. Unfortunately, during a testing session in lab a component was electrically damaged and repairs had to be performed in March 2023. The board itself is enclosed into a hexagonal box fitting the PVC tube were all the electronics and the temperature control systems sits, and incoming cables arrive.

From the focal plane, the signal is brought down in the telescope pillar were it is fed to a RF to optical converter and into an optic fibre. This is again a first in our practice and allow us to limit the loss in normal RF cables, since the laboratory is located about 110 m away. After a market study and the purchase of the fibre and the two converters, 3 pipes were buried in Humain, one carrying power cables, one an optic fibre for the network, and one for 2 optic fibres for OART observations (we put 2 to foresee future upgrades of the system).

Home made RF filters were designed in addition to the ones already existing in the RF box near the antenna feed. They are there to insure a proper delimitation of the RF bands under study, and are placed after the optic fibre, and before the receiver, in the laboratory. We have chosen “mechanical” filters based on the principle of resonant cavities and rods. A first batch of filters was designed using the interdigital concept, where resonant rods are electrically connected head-to-tail. The design method described in Hinshaw & Monemzadeh (1985) was implemented in Python and several filters were built for testing. They were assembled from individual panels of aluminium slabs, screwed together, with copper rods. Their performances were however deceiving in terms of insertion loss. We investigated at length the reasons for such poor results, and concluded that the electrical conductivity between the individual slabs could not be made sufficiently well. For the 611 MHz band, a new approach was tested using soldered copper plates and resonant rods, and this lead to an acceptable solution. For the 3 other bands, a slightly different design, called combline, where the rods are all electrically connected via the same end was chosen. We used open end cavities made from extruded aluminium profiles, with copper rods, following a design by Matjaz Vidmar.

Hinshaw & S. *Monemzadeh*, (1985) HAM RADIO, Jan. issue, pp 12-25

Matjaz Vidmar, Practical cavity filters for the frequency range 1GHz...4GHz,
http://s53mv.s5tech.net/cavity/cavity.html

Remote access

Part of the project relies on a remote-operation scheme where users can interact with the telescope. Several levels of interactions are foreseen depending on the public.

One is a direct operation of the telescope from a virtual paddle allowing live interaction. A prototype based on Python and Tk graphical interface has been developed and tested on actual telescopes in the station of Humain (prior to OART being fully operational). It integrates a live view of the telescope, a return on the telescope pointing (values of coders) and emergency break. The program has been shown to the public during open doors organised at the station in September 2023. This simple tool actually integrates all aspects that will appear on the OART website once operational.

Concerning the overall web interface, we made a thorough analysis of several web content management systems that could fit our needs: accessible to registered users, integration of php and python, interaction between web server and databases (storing instructions for the telescope and receiver). Out of the three main existing systems, Wordpress, Jumla and Drupal, the latter two were tested in mockup configurations. Despite Jumla being slightly more flexible and therefore probably more adapted to our needs, Drupal was finally chosen because there exists within ROB practical experience with that platform. This will help, in the future, the operation and maintenance of the system.

Several services at ROB require user registration for access to data products or services normally provided to ROB employees or close collaborators. With its registered users system, some of them having access to some resources (e.g. data falling within the frame of academical use are only accessible to the concerned students), OART is an extra service in needs of a robust registration system. After discussion with the IT service of ROB, a Single Sign-On service has been set up at the end of 2023 to give a single and manageable solution for all. At the time this report is finalised, the IT service is working on implementing an in house common mechanism to link this service to the different providers/users within our institute.

Commissioning

Due to the accumulated delays, it was not possible to perform the commissioning tasks on time.

The commissioning phase consists on testing and validating the main technical choices that have been made during the renovation of the instrument.

In terms of mechanics and control system, it consists on testing the performances of the telescope mount in real conditions: to give one example, the new support structure changes the balance of the telescope and one may need to adapt the maximum speeds in some situations to prevent oscillations to appear. Weather conditions also affects the observations: strong winds, depending on the direction can degrade the tracking quality while temperature variations can affect the frequency generators that are used to run the step motors.

Test observations will be made for each of the main targets of the instrument: hydrogen distribution in the galaxy, pulsars, star forming region... During these test observations, parameters of the receiving chain can be adjusted to optimise the scientific output: the position of the multi frequency feed antenna at the telescope focus, the level of attenuation to apply, the practical functioning temperature of the focal RF box (kept constant with our temperature control system), the gain applied in the optic fibre to minimize signal losses, to name a few.

Finally, the web interface will be fine tuned depending on user feedbacks to improve it and make it easier for non specialists to operate. Choices proposed by the IT service (centralised Single Sign On service), databases, authorisation to access certain storage can only validated by practical testings.

4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

In the following, we present the main results and practical realisations of the different activities described earlier.

Mechanical renovation:

The practical mechanical repair of the telescope has been performed by the technical service or the Observatory. This task was well within the competences of the team, and innovative solutions were found to circumvent unexpected issues like the blocking of the declination axis.

The tripod structure was designed in house using an open source CAD software (FreeCAD). Here, new technical competences were acquired during the project, since no mechanical design engineering capabilities exist at ROB. The software allows for 3D model of the structure to be designed, 2D technical drawings to be produced and even simple finite element structural computation to be performed. The software has been used in other tasks (e.g. mechanical filter designs, integration of the RF box), and is now commonly used in the team for basic developments.

The overall result is a renovated telescope that is again mechanically fit for operations. We provide here pictures of the different steps.

Before / After

Figure 1: Left initial state of the telescope. Middle and right: view of the telescope after reinstallation, with is new mesh, tripod and control rack

Dismantling

Figure 2 shows different steps in the dismantling of the telescope using a “manitou” (forklift vehicle). The parabola was deposited near the old interferometer control build and refurbished there. The mount (central picture) was brought by truck to ROB, the pillar remained in place.

Figure 2: Dismantling of the telescope at the start of the project

Mechanical refurbishment at ROB workshop

Figure 3: Renovation of the mount in the workshop at ROB

Figure 3 shows the mount in the ROB workshop (left). In the centre, the hour angle axis is repolished and checked. On the right is a view of the cast iron frame holding this axis and associated gears.

Parabola refurbishing and new feed support

Figure 4: Top: Early measurements on the parabola for new rings; bottom: the new rings, mesh and feed support being installed

Reinstallation on site

The different mechanical parts of the telescope: the mount, the parabola and the counterweights were reinstalled on the mount by the technical service of the Observatory in 2023. The large size and weights involved were tackled with the renting of a “manitou” (forklift).

Figure 5: Top: transportation of the refurbished parabola inside the station; bottom left: the mount is reinstalled, and the parabola is being fitted to it; bottom right: fastening of the counterweights

Control system

Figure 6: Top right: trenches carrying pipes for the power supply, one optic fibre for the network, and 2 optic fibres for RF over fibre; bottom left: motors and cabling on the mount; right: view of the control rack with its electronics and computer

Receiving chain

As described earlier, the design of the receiving chain went for SMD RF components that can be fitted on RF compatible electronic boards. The preliminary design was made using an open source software library, which can directly read and interpret calibration files provided by manufacturers.

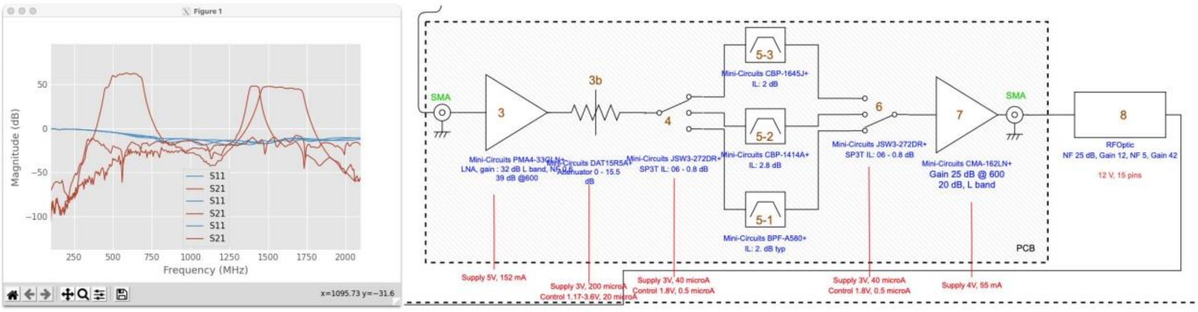

Figure 7: Left: Theoretical frequency response of the 3 filters and amplifiers shown on the right side

The actual implementation was made by the electronic laboratory of the Belgian Royal Institute for Space Aeronomy who kindly agreed to help us on that. The practical design evolved following several meetings and technical constrains on our side (space available near the feed antenna). This was our first collaboration with them on a radio astronomy project and we wish to repeat it in the future.

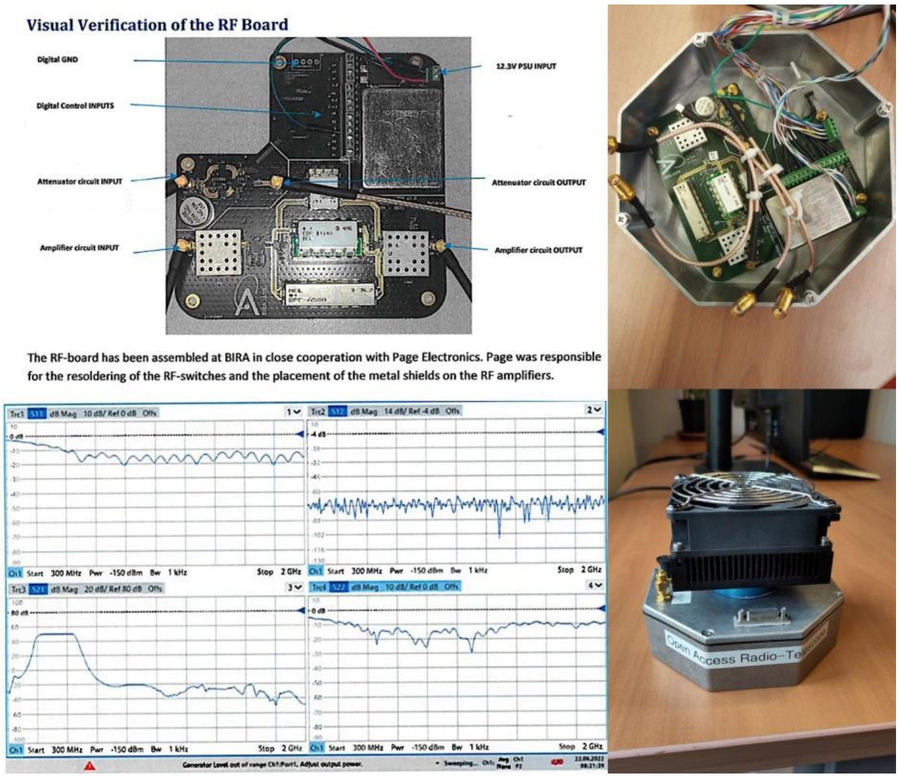

Figure 8: Top left: the board as produced by BIRA;, bottom left: performances curves from their technical report; top right: the board in its shielded box; bottom right: the box fitted with its temperature control system

Feed and filter design

As already said, the field antenna was designed in house following simulations performed by one of the OART team member. It's not the first time antenna simulations are performed within the team, but it had been made so far in the context of integrating commercial antenna into test devices, or in operational setups for the solar radio observations of the Observatory.

Based on the frequency band constrains, the simulations and the mechanical constrains at the focal point, a prototype antenna was built by the technical service and characterized in the field to evaluate its performances.

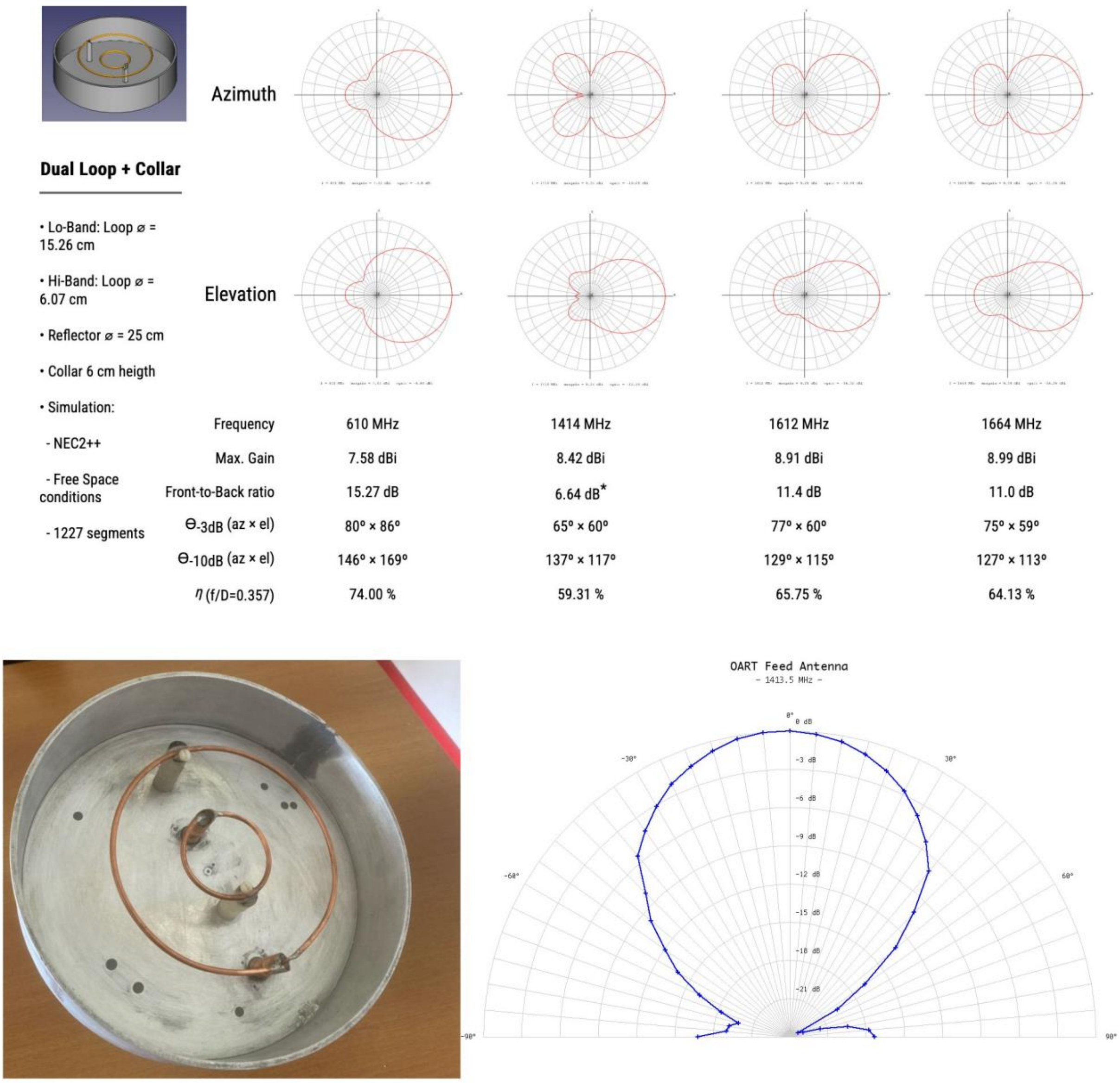

Figure 9: Top Simulation at different frequencies of the chosen feed antenna. Bottom left: feed antenna built by the workshop; bottom right: Beam measured at 1415 MHz

Filter designs

This was here also a first for the radio team. While several designs have been tested and fine tuned as already said before, the final choice was made to go for a copper based interdigital filter for the 611 MHz band and combline filters for the other ones. What has been gained here in terms of experience can readily be reused for the ongoing solar radio developments.

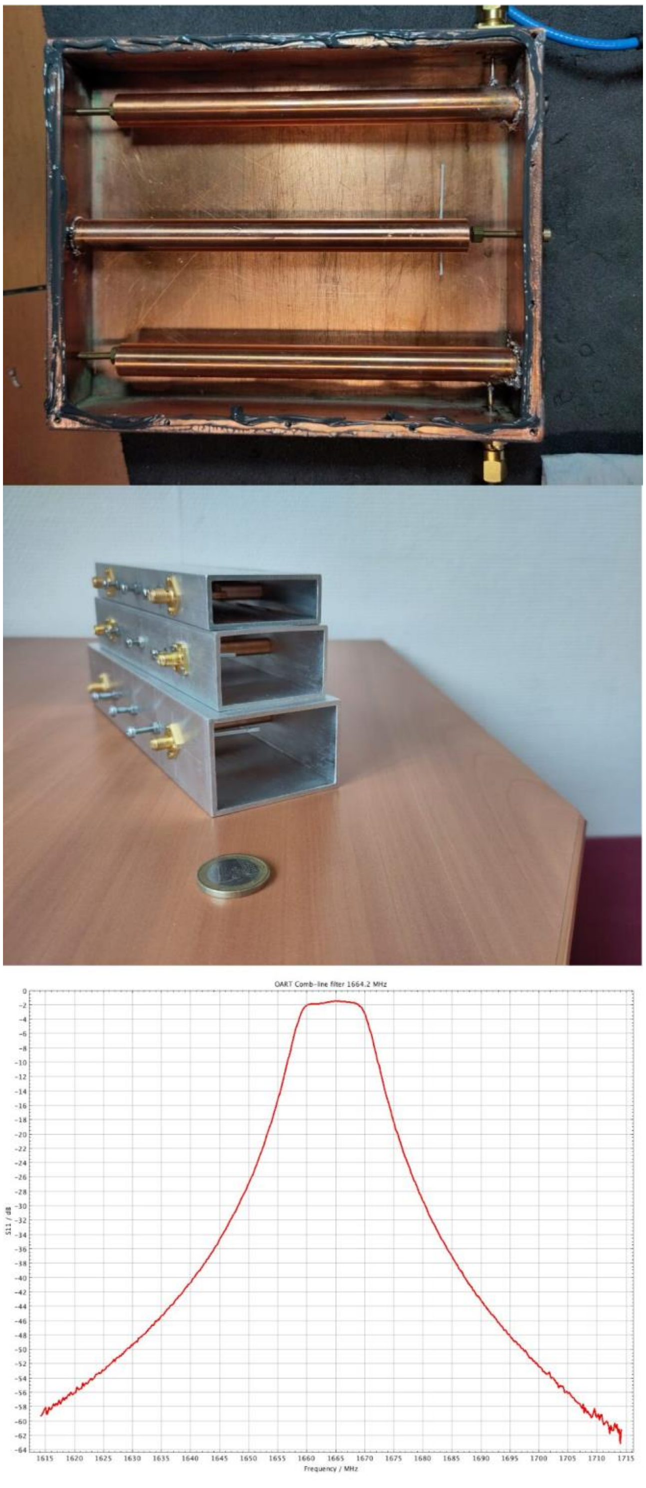

Figure 10: Top: interdigital filter (open) for the 611 MHz band;, middle: combline filters(higher bands); bottom: filter response at 1664 MHz

Remote access

Figure 11 shows, left, the actual remote controller compatible with all radio telescopes in Humain, including OART, that was shown during open doors organised in Humain in 2023. Two mockups of the OART website, one developed in Jumla (bottom), the other one in Drupal (top), our final choice.

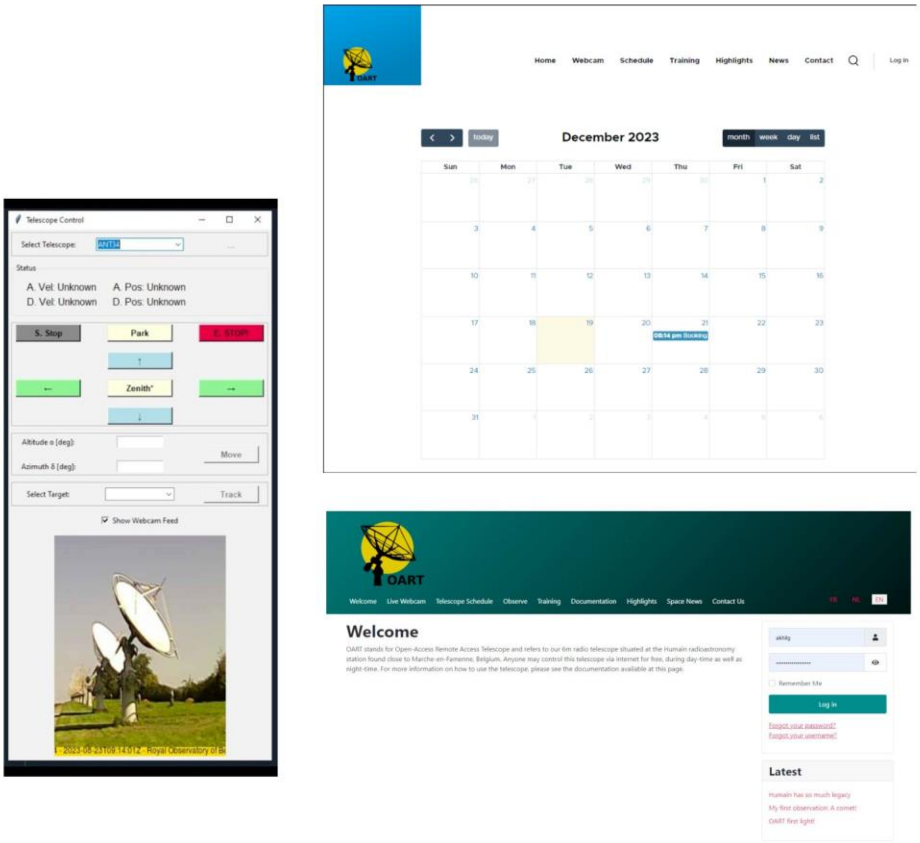

Figure 11: Parts of the remote access elements

Perspectives for the future

Completion of the project

Due to the delay in the hardware preparation and set up, it was impossible to complete the project as it was foreseen. Basically, the interface with the public and the commissioning work remain to be done. This will be carried on by the team already involved in the project on its own budget (ROB funded).

As said earlier in the report, the team and ICT department are actively working on integrating the different network and IT components of the web interface. With the return of good weather conditions, it will be possible to start the hardware commissioning (which requires access to the telescope and RF electronics in the field). We foresee support from engineering students in the frame of internships for some of the subtasks related to the testing and the first observations.

We target the fall of 2024 for the grand opening to the public, in time for the new academic year.

Medium and long term prospects

Interest of universities has been reiterated to use the instrument for training, i.e. for “exercises” during academic astronomy courses, but also for short scientific projects in the frame of master thesis.

As explained earlier in this report, the instrument has been renovated with “flexibility” in mind. For example a second optic fibre has been installed (in addition to the 2 others used for OART), for RF over fibre. This could be used for testing hardware prepared by students during special campaigns.

In 2026, the Observatory will celebrate its 200 years with a series of special events. An internal proposal has been made to obtain some funding to open the station to the public and schools for guided tours throughout the year. In this proposal, the laboratory hosting the equipment (and the receiver of the old interferometer) will be turned into a small museum, with a room serving as a small visitor centre. OART will certainly be put forward during this year-long event, with increased visibility from schools and local officials. The installation would also be used by students and (on a time basis to be agreed upon) by enthusiast amateurs using OART. We are confident that, if accepted, this activity would drive interest in the near and medium term: in September 2023, the station was for the first time in 70 years open to the public, gathering many visitors from the surroundings and the whole Belgium despite the site being fairly remote.

Recommendations and feedback from the project

On the practical side, several technical competences were acquired by the whole team:

- CAD software for mechanical design and basic structural stability (FreeCad)
- Simulation of radio circuits (scikit-rf) and first use of SMD radio components. Once again we acknowledge the support of our colleagues from BIRA in the practical stages leading to the completion of the RF board. Pending their availability in the future, we would certainly consider pursuing this collaboration for other radio projects in Humain
- RF-over-Fibre: this is again a first for our team, we certainly consider implementing it for the other solar radio telescopes in used in Humain. One is in particular remotely placed and for now the receiver is placed near the telescope, in a cabinet where the conditions are difficult

In terms of “lessons” learned, the short timing (2 years) in a post-pandemic recovery world was clearly a challenge for ordering and working with hardware (mechanical, electronics, electro-technics). Right after the pandemic, there were price hikes and shortages of basic material needed for completion of some of the mechanical tasks (finding an appropriate new mesh, resistant to rust for the parabola was particularly challenging). Some electronic components had months instead of days for delivery, forcing us to look for alternatives (this was the case for some RF SMD filters, and for the electronic drivers of the motors) or to adapt at minimum our design to integrate components in stock at ROB or at the merchant side. Delays in hardware subsystems readiness or completion made more difficult the planning of key tasks (e.g. the reinstallation on site) within the busy schedule of support teams.

5. DISSEMINATION AND VALORISATION

The renovated telescope was shown during the first ever open doors organised by the Observatory in the station of Humain on September 9-10 2023, in the frame of the European Heritage days. The event draw about 630 visitors over 2 days.

6. PUBLICATIONS

There is currently no publication linked to that project. Online technical documentation is available on the gitlab server of the Royal Observatory of Belgium. We plan, once operational to publish articles in amateur journals.

7. ACKNOWLEDGEMENTS

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- Aydin Ergen (electronic of the control system, soldering)
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- Jimmy Duquesne (dismantling and reassembling)
- Vincent Honet (dismantling and reassembling, logistic support in Humain)

From the central administration

- Philippe Motte (transportation and logistic support)

From the IT department

- Sarah Willems (IT support)

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- André Füzfa (Namur University)
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- Christian Steyaert (VVS)