Publication Year	2021
Acceptance in OA@INAF	2023-07-28T09:30:53Z
Title	Status of the High-Frequency Upgrade of the Sardinia Radio Telescope
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DOI	10.46620/21-0026
Handle	http://hdl.handle.net/20.500.12386/34358
Journal	RADIO SCIENCE LETTERS
Number	3

Status of the High-Frequency Upgrade of the Sardinia Radio Telescope

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Abstract – The Sardinia Radio Telescope is going through a major upgrade aimed at observing the universe at up to 116 GHz. A budget of 18.700.000 € has been awarded to the Italian National Institute of Astrophysics to acquire new state-of-the-art receivers, back-end, and high-performance computing, to develop a sophisticated metrology system and to upgrade the infrastructure and laboratories. This contribution draws the status of the whole project at eight months from the end of the funding scheme planned for August 2022.

Manuscript received 23 December 2021.

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1. Introduction

A large team of radio astronomers, technicians, engineers, and administrative staff of the Italian National Institute of Astrophysics (INAF) is deeply involved in upgrading the 64 m Sardinia Radio Telescope (SRT) to increase the maximum observing frequency from 26.5 GHz to 116 GHz. The SRT is a fully steerable wheel and track radio telescope, equipped with active surface, shaped mirrors, beam waveguides, and microwave receivers, distributed across six focal positions remotely selectable. Technical details on the SRT and on its receiver fleet can be found in [1–3].

The SRT was regularly offered to the astronomical community since February 2018 for interferometric observations within the European VLBI Network and since January 2019 for single-dish observations. In the same year, in the framework of a "call for proposals for grants aimed to enhance research infrastructures located in Southern Italy" (National Operational Program [PON]), the INAF project "Enhancement of the SRT for the Study of the Universe at High Radio Frequencies" (hereafter PON-SRT) received 18.700.000 €.

The SRT upgrade will allow addressing the key science questions that emerged from a recently conducted survey in the national astronomical community [4]. The PON-SRT project is articulated in nine work packages (WPs) [5]. Four of them deal with new multibeam or multifrequency cryogenic receivers operating from 18 GHz on (the new receivers installed in the secondary focus [rotating turret] are shown in Figure 1):

- WP1: multibeam receiver in W band;
- WP2: multibeam receiver in Q band;
- WP3: millimeter camera in W band; and

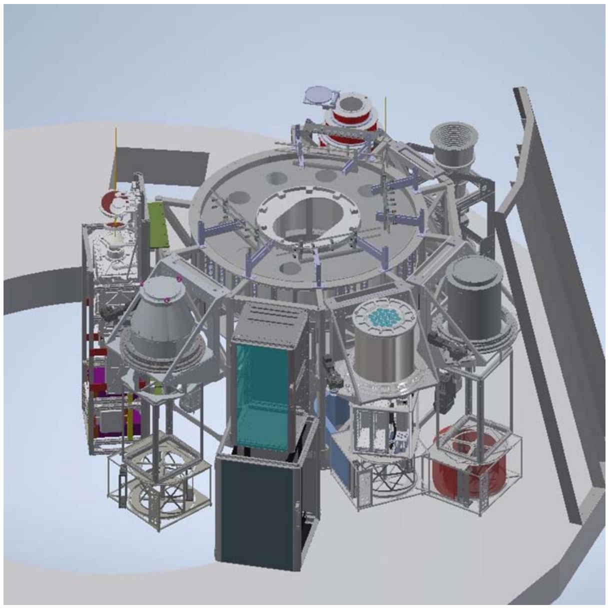

Figure 1. The 3D visualization of the receiver fleet at the SRT Gregorian focus. Starting from the left side and moving anticlockwise: three-band receiver (WP4), W-band multifeed (WP1), rack for auxiliary instruments, Q-band multifeed (WP2), K-band multifeed (already in operation), C-band single feed (developed outside the PON-SRT), and W-band camera (WP3).

- WP4: simultaneous three-band receiver for the three Italian radio telescopes.

The two WPs regard new backends and high-performance computing (HPC):

- WP6: backends; and
- WP8: HPC and storage systems for the archival and use of SRT data.

Finally, the upgrade of SRT with new interfaces, including a metrology system and laboratory equipment is addressed by three WPs:

- WP5: the metrology system;
- WP7: supply of electronic and mechanical interfaces for the integration of new systems; and
- WP9: upgrade of laboratories for the development of microwave technologies.

Updates on financial and on technical aspects are provided for each WP in Sections 2 and 3 respectively.

2. Status of Funding and Organization

Under the coordination of the principal investigator of the PON-SRT, a project office and an administrative office are in charge of project management, system engineering, funding, procurements, contracts, and documentation. The technical staff has 80 staff members with a wide variety of expertise, and science advisors contribute to the main astronomical require-

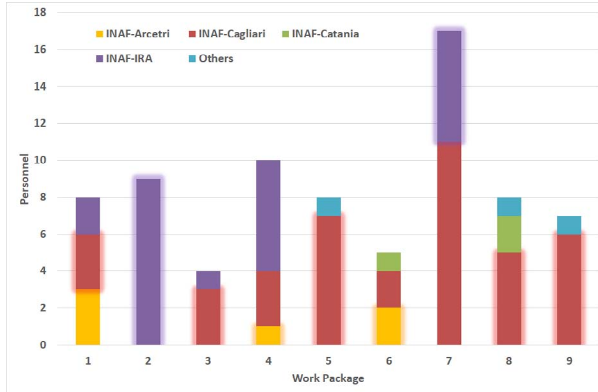

Figure 2. Histogram of the INAF technical staff involved in the PON-SRT for the nine WPs. The colors indicate the affiliation of the team. The shadowed color represents the affiliation of the WP coordinator.

ments. Almost half of the technologists and technicians involved in the PON-SRT are affiliated with the Astronomical Observatory of Cagliari, while 30% with the Institute of Radio Astronomy. The distribution of the team for different affiliations and different WPs is shown in Figure 2. The involvement of INAF technical personnel varies from four people in WP3 and up to 17 in WP7.

The allocated funds are not available for research and development activity and hiring new personnel but restricted to the purchase of components, instruments, and equipment from companies or research institutes. Several administrative procedures (open tenders above and below the European Union threshold and competitive dialogs) have been issued for the selection of the suppliers. As shown in Figure 3, the budget is not equally distributed across the nine WPs. More than half of the total budget is used for the new receivers, 20% for the backend and HPC, 20% for metrology and infrastructure, and the remaining for the laboratories. In particular, the budget ranges from 1.000.000 € for the

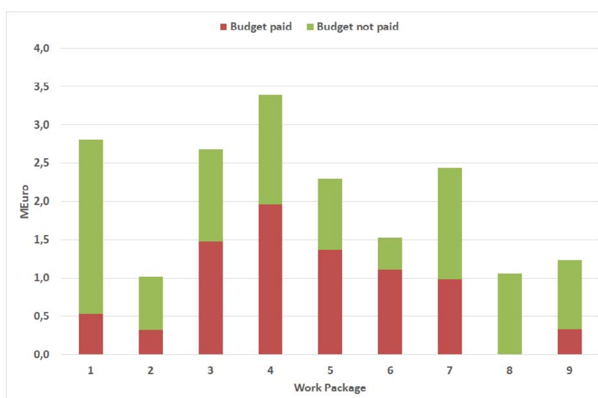

Figure 3. Histogram of the budget allocated to the PON-SRT for the nine WPs. The red and green colors indicate the amount of money spent and not yet spent, respectively, at the date of writing this article (December 2021).

Q-band multifeed and almost 3.500.000 € for the three-band receivers. At eight months from completion of the PON-SRT, almost 45% of the total budget has been paid to suppliers.

3. Technical Status

In this section, the technical characteristics of the main deliverables together with the status and the time line are given for each WP.

3.1 Work Package 1

The receiver is a 70 GHz to 116 GHz 4×4 focal plane heterodyne array of dual-linear polarization linear smooth-walled feed horns placed in cascade with waveguide orthomode transducers, low-noise amplifiers, and dual-sideband separation subharmonic image rejection mixers cryogenically cooled at $\approx$20 K with 4 GHz to 12 GHz intermediate frequency. The field of view covered by the 4×4 array is 2.15 arcmin $\times$ 2.15 arcmin, unfilled, with separation between contiguous elements of 43 arcsec. The receiver uses a mechanical derotator to track the parallactic angle, a single $\approx$293 K calibration target, and a solar attenuator for Sun observations. The instrument will offer a variety of observing modes, including dual-linear polarization and dual sideband, with expected receiver noise temperature $<$60 K. The INAF awarded the contract for the realization of the W-band receiver array to UK Research and Innovation after preselection and competitive dialogs with the applicants.

3.2 Work Package 2

The multibeam receiver operates in the band 33 GHz to 50 GHz and is made by 19 nominally identical receiving chains in dual-circular polarization, with an expected noise temperature $<$25 K. Each of the 38 outputs provides the full RF band, down converted to 1 GHz to 18 GHz. The design of the multibeam is such that both faint sources, as well as the quiet Sun can be observed, together with a compact and relatively lightweight solution. The receiver will be mainly devoted to continuum and spectral line observations. Spectropolarimetry is also possible. The 19 feed systems and 38 down-conversion units are available, as well as the cold head and the vacuum system. All parts for the construction of the cryostat and the cables to route the very large IF band will be delivered to INAF by the end of 2021. Multibeam assembly and tests will be conducted in the first half of 2022.

3.3 Work Package 3

The supply of a bolometric cryogenic W-band (78 GHz to 103 GHz) kinetic inductance detector (KID) camera has been assigned to the University Sapienza in Rome, Italy. The receiver, named Mistral, will consist of a compact cryostat hosting a set of radiation quasioptical filters anchored at different thermal stages, a reimaging optics system cooled at 4 K, and a 408 pixel array of photon noise-limited lumped element KIDs cooled at a base temperature lower than 250 mK. Two antireflection-coated silicon lenses will be used to image the Gregorian focus on the array. Because the detectors will be coupled to radiation through open space, a cryogenic cold stop will be placed in between the two lenses. The Mistral bolometric camera will enhance SRT by allowing high angular resolution continuum observations in W band in the elevation range from 37.5° to 77.5°. Mistral will provide a wide field of view of 4 arcmin in diameter, approximately Nyquist sampled at the diffraction limit of 12.2 arcsec.

3.4 Work Package 4

The tender for the supply of three simultaneous three-band (18 GHz to 26 GHz, 34 GHz to 50 GHz, and 80 to 116 GHz) receivers was awarded in February 2020 to the Korean Astronomy and Space Institute (KASI). These receivers are based on an original design developed by KASI [6]. This consists of a quasioptical system splitting the incoming EM waves toward three different dual-polarized feed-systems (one for each band) hosted in a compact Dewar-cooled assembly at 20 K. The requirement on the maximum receiver noise temperature is 60 K, 70 K, and 100 K in the three bands, respectively. The receivers will be installed on the three Italian radio telescopes (SRT, Medicina, and Noto), mainly for very long baseline interferometry (VLBI) observations. The receivers are currently along the characterization phase at the subassembly level before the final integration. The factory acceptance test is scheduled for March 2022.

3.5 Work Package 5

Structural deformations, mainly due to gravity or thermal gradients, could affect the SRT pointing accuracy and aperture efficiency. To compensate for such deformations, a metrological system consisting of a neural network-based model supervising a sensor network composed of inclinometers, temperature sensors, and a complex multilateration system has been designed. In addition, the metrological system includes a K-band holographic system and a laser scanner to characterize the SRT primary mirror. After a selection procedure, the INAF assigned the contract for the procurement of the system to the Leonardo Vitrociset Company.

3.6 Work Package 6

The new receivers require an upgrade of the back-end capabilities to support wideband multifeed observations. Three back-end systems, using different technologies, have been identified. A system uses the Xilinx Virtex-7 FPGA-based Square Kilometre Array reconfigurable application board, which is the major digital signal processor engine of the MeerKAT array. This takes advantage of the high-speed bandwidth of the hybrid memory cube technology for designing wide-band high-frequency resolution digital spectrometers. A second system explores the new RF system on chip technology for processing the whole gigahertz-wide bandwidth produced by the new receivers. Finally, an upgrade of the VLBI digital platform from the digital baseband converter, version 2, to the new version 3 will considerably widen the bandwidth to be recorded, with a remarkable leap forward for the related science. The system is complemented by a minicluster of GPU-based servers, which is needed for both data recording and postprocessing.

3.7 Work Package 7

This aims to integrate the new scientific instrumentation (receivers, backends, metrological systems, and computing resources) into the observing system of the SRT in coexistence with what is already present, as well as to maximize the efficiency and the reliability of the high-frequency observations. The WP7 focuses on different areas, ranging from the antenna and the infrastructure up to the technological plants. This translates into interventions on the mechanics of the prime focus positioner, on the servo systems that move the secondary mirrors, on the transmission of signals through coaxial cables and broadband optical fibers, on electrical and grounding components, air conditioning and cryogenic plants, on the distribution of the receivers RF bands, and on the monitoring and control software. Part of these activities are done internally by INAF staff, while the remaining part has been awarded as supply tender to the Leonardo Vitrociset Company. The contract was signed in December 2020. The Critical Design Review (milestone 2) package was delivered in July 2021, while the procurement (milestone 3) will close by the end of 2021. The integration phase of the supplies started in October 2021, and the contract is expected to be finalized by mid-June 2022.

3.8 Work Package 8

The acquisition of the new HPC and data storage capabilities was not formally finalized at the time of writing; thus, complete details cannot be reported. However, we expect that the data streaming from the SRT will be fully exploited thanks to more than 500 cores of last-generation CPUs, a dozen state-of-art GPUs, and more than 6 PByte of spinning disks. The refurbishment of the computational centers that will host the system will be completed by January 2022, and the implementation of the new equipment is expected in early spring 2022.

3.9 Work Package 9

Most of the instruments and machines planned in WP9 have been already purchased and tested. Some electromagnetic design software and small laboratory instruments are already being used in the electronic laboratory. The 3D digital microscope will be used in the microwave and mechanical laboratory for analyzing and measuring the assembly of electronic monolithic microwave integrated circuit components and the dimensions of boxes and circuits. Also, a micrometric lathe machine has been installed in the mechanical shop and is ready to be operated by expert technicians to build the mechanical parts for SRT receivers and for the metrology instruments. In the coming months, the most important instruments for upgrading the microwave laboratory will be delivered: a high-frequency signal generator, a high-frequency signal analyzer, a high-performance oscilloscope, and a portable spectrum analyzer with an integrated vector network analyzer.

4. Conclusions

A significant amount of money has been assigned to INAF for the upgrade of SRT. The 32 months (plus 6 months extension) life span of the PON-SRT project requires a very well-managed and structured team. Furthermore, the COVID-19 outbreak further increased this challenge due to lack of physical meetings with suppliers and delays in component deliveries. Almost all WPs are facing technical and management criticalities, but the overall project is expected to be completed in due time. Recently, a further contribution of 1.400.000 € has been assigned to INAF for 18 fellowships for young astronomers and engineers to exploit the new instrumentation developed within the PON-SRT.

5. Acknowledgments

"The Enhancement of the Sardinia Radio Telescope for the Study of the Universe at High Radio Frequencies" is financially supported by the "Programma Operativo Nazionale del Italian Ministry of Education, Universities and Research "Ricerca e Innovazione 2014–2020" Avviso D.D. n. 424 del 28/02/2018/ per la concessione di finanziamenti finalizzati al potenziamento di infrastrutture di ricerca, in attuazione dell'Azione II.1—Proposta Progettuale PIR01_00010".

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