Design Concept of W-band Multibeam Receiver for the SRT

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***Abstract*—We describe the preliminary design concept of a W-band multibeam receiver for the Gregorian focus of the Sardinia Radio Telescope (SRT), a new general purpose fully steerable 64-m diameter antenna located on the Sardinia island, Italy, managed by the Italian National Institute for Astrophysics (INAF).**

The goal specifications of the W-band receiver foresee a 4×4 array of dual-polarization feed-systems utilizing waveguide Orthomode Transducers (OMTs) and low-noise amplifiers (LNAs) cryogenically cooled at ≈20 K, all designed to cover the 70-116 GHz RF band. The instrument concept utilizes a dual sideband separation (2SB) downconversion mixing scheme delivering two 8 GHz-wide Intermediate Frequency (IF) bandwidths (across 4-12 GHz), the USB and the LSB, for each of the two polarization channels of each of the pixels.

The instrument is being procured by INAF through an international call for bid. In support of such procurement, we set the instrument minimum requirements and selected few possible architectures. Then, we conducted an advanced feasibility study of the receiver that allowed us to define a preliminary design of the full receiver for its minimum and goal requirements. In particular, we studied the following receiver subsystems: the optics, the cryogenic modules, the cryostat, the down-conversion and calibration systems, the mechanical derotator (to track the parallactic angle), and all of its essential subsystems. Here, we present the main requirements and the preliminary design of the W-band multibeam receiver, which is set to deliver state-of-the-art performance and will allow to conduct single-dish high-sensitivity large-scale surveys radio astronomy observations with the SRT.

***Index Terms*—Low-Noise Amplifiers, Mixers, Radio astronomy, Receivers, Telescope.**

I. Introduction

THE Sardinia Radio Telescope (SRT, www.srt.inaf.it) is a new general purpose fully steerable 64-m diameter radio telescope designed to operate with high efficiency across the 0.3-116 GHz frequency range [1]. Since December 2018 the telescope, shown in Fig. 1, has been opened to the international community to carry out radio astronomy observing programs using an initial set of receivers covering four RF bands across 0.3-26.5 GHz [2]-[6]. The SRT operates in single-dish (continuum, full Stokes and spectroscopy), Very Long Baseline Interferometry (VLBI) and Space Science modes and it has been successfully used also for space-debris detection and Sun observations.

The telescope optical design is based on a quasi-Gregorian configuration with shaped 64-m diameter primary (M1) and shaped 7.9-m diameter secondary (M2) reflectors to minimize spillover and standing waves (Fig. 2). The primary mirror utilizes an active surface with 1116 electromechanical actuators to compensate the gravitational deformation in real-time. The actuators are also used to convert the shaped surface of the primary mirror to a parabolic profile during primary focus observation.

To extend the current capabilities of the telescope to high frequencies, INAF aims at upgrading the metrology system and at developing and/or procuring a new set of Front-Ends to be installed at its Gregorian focus (Fig. 3).
One of such new instruments is a W-band multibeam heterodyne receiver, whose specifications and design concept are described in the following sections.

Fig. 1. The 64-m diameter Sardinia Radio Telescope (SRT), Sardinia island, Italy.

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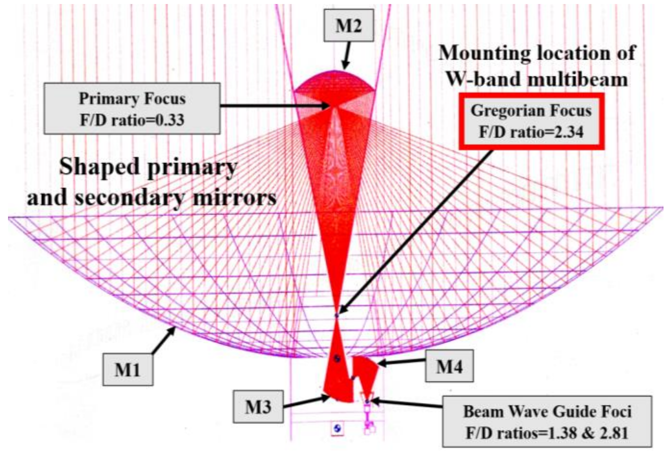

Fig. 2. Optical configuration and ray tracing of the SRT showing the 64-m diameter primary (M1), the 7.9-m diameter secondary (M2), and two additional Beam Waveguide (BWG) mirrors (M3 and M4). The primary and secondary mirrors are shaped. The W-band multibeam receiver will be installed at the Gregorian focus (F/D=2.34).

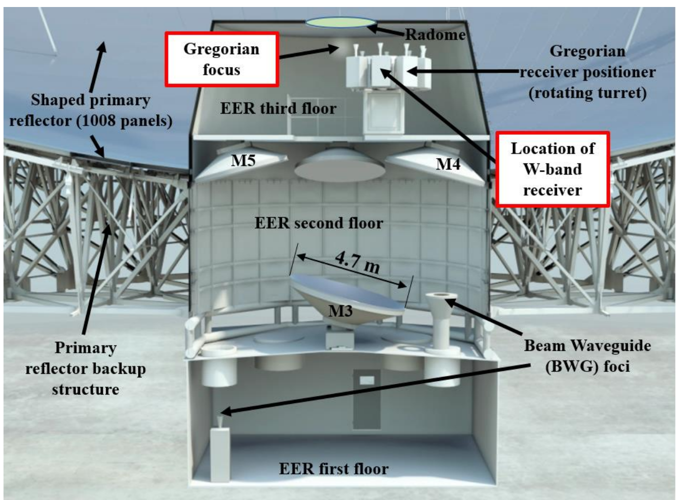

Fig. 3. Cross-cut of the SRT telescope showing details of the three-floor Elevation Equipment Room (EER). The W-band multibeam receiver will be installed on the Gregorian receiver positioner at the Gregorian focus, located on the EER third floor. The image also shows four of the Beam Waveguide (BWG) mirrors on the EER second floor as well as the BWG foci, one of which on the EER first floor.

II. W-BAND MULTIBEAM RECEIVER SPECIFICATIONS

The receiver will be installed at the Gregorian focus of the SRT and must be designed to provide high-efficiency illuminations of the antenna shaped optics for all of its pixels across the 75-116 GHz band, with goal band 70-116 GHz. The minimum requirements and the goal requirements of the W-band receiver are listed in Table I. The instrument must be capable to observe weak radio astronomy sources with high-sensitivity (receiver noise of less than 60 K) but also the strong signals from the Sun without saturating the receiver chains. The array receiver shall be based on a minimum of nine dual linear polarization feeds in a square 3×3 configuration. The goal is an array of 16 feeds in a square 4×4 configuration for the 70-116 GHz band. The receiver must be designed to provide high mapping efficiency by optimizing the geometry and the separation between the projected beams on the sky. The aperture efficiency η_{eff} of the SRT antenna illuminated by all feeds, including the ones with the largest offset from the optical axis, shall be no less than 0.50 (50%) at all frequencies across the full RF band, i.e. $\eta_{eff}=\eta_t\,\eta_s\,\eta_p \geq 0.50$, where η_{eff} is the product of taper efficiency η_t, spillover efficiency η_s and polarization efficiency η_p, (the other contributions to the aperture efficiency, e.g. Ruze, focus, radiation efficiency and blockage, are considered to be unitary, see also [7]-[8] for definitions).

TABLE I
MINIMUM AND GOAL REQUIREMENTS OF THE W-BAND MULTIBEAM RECEIVER

RF band	75-116 GHz (goal 70-116 GHz)
Polarization properties	Two orthogonal linear with OMTs
Number of pixels and array configuration	Square or alternative formats. Minimum 9. Goal 16
Antenna aperture efficiency	$\eta_{eff}=\eta_t\,\eta_s\,\eta_p \geq 0.50$ across the RF band for all feeds
Technology	HEMT LNAs
Downconversion scheme and IF band	2x6GHz SB (USB+LSB), IF band 4-10GHz. Goal 2x8GHz SB, IF band 4-12 GHz
Maximum IF outputs	38 for any number of pixels. A 4x4 array must have a maximum of 32xIF outputs.
Mechanical derotator	Yes, to track the parallactic angle
Array calibration	Single ≈293 K calibration load
Solar observations	Yes, with switchable filter/attenuator placed in front of vacuum window
Noise temperature	$T_{SSB} \leq 60$ K over 80% of RF band
Image band suppression	Ri ≥ 10 dB
Local Oscillator signal	Tunable via high phase stability synthesizers or YIG oscillator
Cryocooler	Two cryogenic stages: S1<80 K; S2<20 K
Overall diameter (mm)	< 800
Height (mm)	≤ 2465
Weight (kg)	< 250

The receiver shall include a calibration system with at least one room temperature (≈293 K) calibration load.

III. RECEIVER ARCHITECTURE

A possible architecture of the receiver is shown in Fig. 4.

The dual linear polarization shall be achieved by means of dual-polarization feed systems where each array element

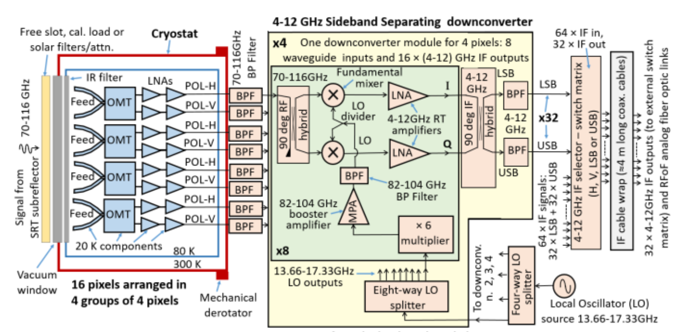

Fig. 4. Possible W-band multibeam receiver architecture in 4×4 configuration covering 70-116 GHz. It shows the calibration load and solar filters/attenuator at its input, the cryostat with the cryogenic components, the room temperature sideband separating down converters, the LO distribution system and the "internal" IF switch matrix to select the IF signals to deliver to the backend. The receiver includes a derotator mechanically attached to the cryostat.

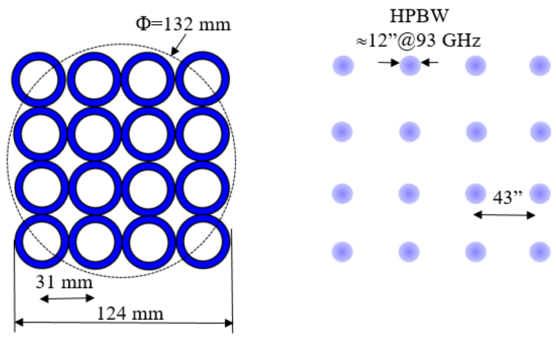

Fig. 5. Array feed configuration and spacing on the Gregorian focal plane (left) and projected beams on the sky (right) for a 4x4 square format solution.

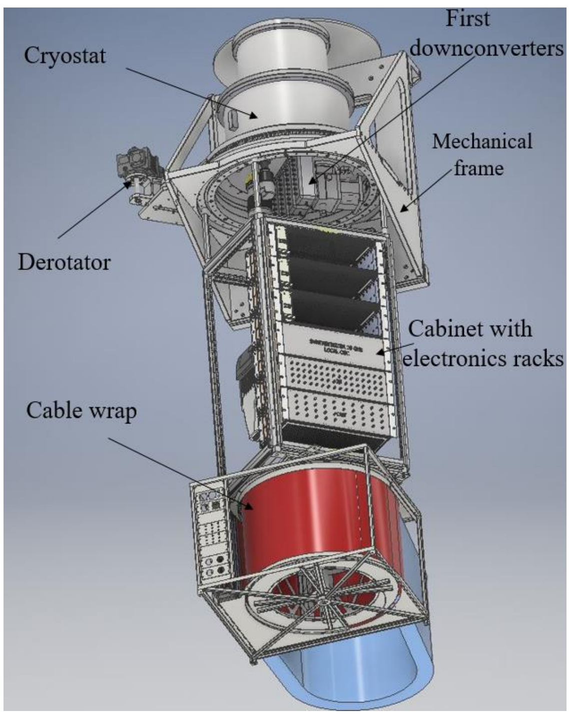

Fig. 6. 3D sketch of the W-band multibeam receiver for the Gregorian focus of the SRT. View of the full instrument showing the cryostat, the downconverters, the mechanical derotator, the cabinet with electronics rack and the mechanical frame for mounting on the Gregorian receiver positioner.

employs a cascade of corrugated feed horn, OMTs and High Electron Mobility Transistor (HEMT) LNAs cryogenically cooled at ≈20 K inside a cryostat. The downconverters for each of the receiving chains, utilizing a tunable Local Oscillator (LO) signal distributed to each of the elements, can be located at cryogenic temperature or at room temperature, inside or outside the cryostat.

The downconverter shall provide a minimum of 12 GHz band of Radio Frequency (RF) sky coverage for each polarization of each of the pixels (goal 16 GHz) and can utilize either a Single Side Band (SSB) or a dual Sideband Separation (2SB) mixing scheme. Fig. 4 shows a possible example of receiver architecture based on 2SB scheme delivering an IF band of 4-12 GHz per sideband (goal specification).

Due to the shaped configuration of the SRT the usable focal plane area at the Gregorian focus is limited to feed horns whose axis are placed within a radius of ≈65 mm from the telescope optical axis. To be confined within a ≈130 mm diameter, a 9 element dual polarization focal plane array in 3×3 configuration can adopt a feed spacing of ≈45 mm, although shorter spacing would be desirable. Instead, a dual polarization array in 4×4 configuration necessarily requires to design cryogenic modules with smaller footprint size where the feed spacing is ≈31 mm. The module would have to adopt OMT waveguide outputs and LNA inputs with non-standard miniaturized waveguide flanges. A possible configuration of the array with 4×4 feeds on the SRT Gregorian focal plane and the corresponding beams projected on the sky are shown in Fig. 5. The example refers to an array of feeds placed on the Gregorian focus without reimaging optics.

We made a preliminary 3D design concept of the full receiver, illustrated in Fig. 6, corresponding to the receiver architecture shown in Fig. 4. The 3D sketch includes the cryostat with commercial cryocooler and first downconverters attached to its backplate, the mechanical frame to mount the instrument on the Gregorian receiver positioner (see Fig. 3), a cabinet with electronics racks for biasing the LNAs and for monitoring and control of the receiver subsystems, a mechanical derotator to maintain the parallactic angle during source tracking with associated cable wrap, a vacuum pump with remotely controlled vacuum valve, the switching mechanism for selecting the calibrator or the solar filter/attenuator in front the vacuum windows and all other minor but necessary accessories.

IV. Conclusions

We presented the specifications and a preliminary design concept for a W-band multibeam receiver to be installed at the Gregorian focus of the SRT. The instrument is being procured by INAF through a call for bid.

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