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# The Sardinia Radio Telescope Front-Ends

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**Abstract**— The 64 m diameter Sardinia Radio Telescope (SRT) has recently started an early science program using three cryogenic front-ends covering four bands: P-band (305-410 MHz), L-band (1.3-1.8 GHz), high C-band (5.7-7.7 GHz), K-band (18-26.5 GHz). The L- and the P-bands can be observed simultaneously with a single coaxial receiver installed at the primary focus, while a seven-beam K-band receiver and a mono-feed high C-band receiver are installed, respectively at the secondary and beam waveguide focus. Additional front-ends are under construction to further expand the telescope observing capabilities. We report on design and performance of the front-ends already installed on SRT and give an overview of the new ones to be completed in the near future.

## INTRODUCTION

The Sardinia Radio Telescope (SRT, [www.srt.inaf.it](http://www.srt.inaf.it)), a challenging scientific project of the Italian National Institute for Astrophysics (INAF), 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]-[2]. The telescope is located 35 km North of Cagliari, Sardinia, Italy, at about 600 m above the sea level. The technical and scientific commissioning of the telescope was completed and an early science program has started in February 2016.

The SRT optical design is based on a quasi-Gregorian configuration (Fig. 1) with shaped 64 m diameter primary (M1) and 7.9 m diameter secondary (M2) reflectors to minimize spillover and standing waves. The primary active surface consists of 1008 aluminium panels (with a panel manufacturing RMS < 70  $\mu\text{m}$ ) and of 1116 electromechanical actuators under computer control that compensate the gravitational deformation of the backup structure. The primary reflector was aligned to an RMS of  $\sim 290 \mu\text{m}$  using photogrammetry. Work is in progress to improve the total optics surface accuracy down to an RMS of  $\sim 150 \mu\text{m}$  using microwave holography that will allow high efficiency observations up to the highest frequencies ( $\sim 100 \text{ GHz}$ , 3 mm band).

SRT has been designed to host up to twenty receivers installed in six focal positions: Primary focus (F1), Gregorian focus (F2) and Beam-Wave Guide foci (F3&F4 and F5&F6), respectively with focal length to diameter ratio (F/D) and frequency ranges equal to 0.33 (0.3-20 GHz), 2.34 (7.5-115 GHz), and 1.38 & 2.81 (1.4- 35 GHz).

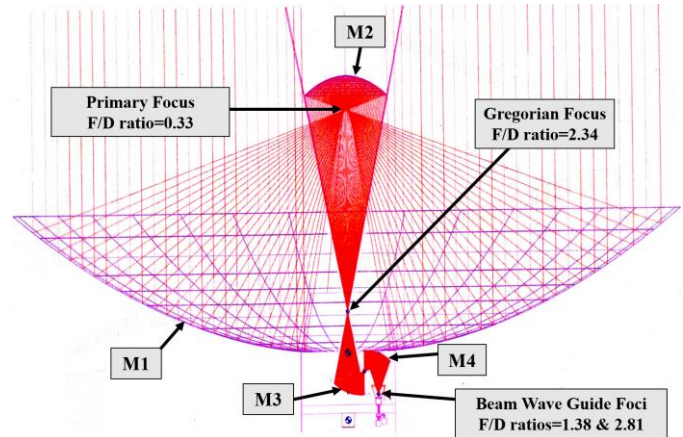


Fig. 1 Optical configuration and ray tracing of the Sardinia Radio Telescope showing the 64-m diameter primary (M1), the 7.9-m secondary (M2), and two additional Beam Waveguide (BWG) mirrors (M3 and M4). Three out of six possible focal positions (primary, Gregorian and BWG) are shown together with corresponding focal ratios.

Table I gives a summary of the receivers installed, under test and under construction for SRT.

## FRONT-ENDS INSTALLED ON SRT

Currently, four receivers developed by INAF are installed on SRT: *a*) a primary focus dual linear polarization cryogenic coaxial receiver, which simultaneously covers the 305-410 MHz (P-band) and the 1.3-1.8 GHz (L-band), and is mostly used for Pulsars observations; *b*) a secondary focus dual circular polarization seven-beam cryogenic receiver operating in 18-26.5 GHz (K-band); *c*) a Beam-Wave Guide dual circular polarization mono-feed cryogenic receiver for 5.7-7.7 GHz (High-C-band); *d*) a primary focus X-Ka room temperature coaxial receiver, which simultaneously cover the 8.2-8.6 GHz (X band) and the 31.85-32.25 GHz (Ka band). While the P-, L-, C- and K-band receivers are permanently installed on SRT and used for radioastronomy science, the X-Ka band receiver is temporarily installed and used for testing the spacecraft downlink capabilities of the SRT.

The K-band and C-band use a heterodyne down-conversion to the final 0.1-2.1 GHz IF bands that are delivered to the various backends. The results of commissioning of such front-ends on the SRT antenna are described in dedicated SRT

TABLE I: RECEIVERS INSTALLED, UNDER TEST AND UNDER CONSTRUCTION FOR SRT

Front-End	Freq. range [GHz]	Focal position, F/D	Feeds $\times$ pols	Measured / Expected* receiver noise temp. [K]	Measured / Expected* antenna gain [K/Jy]	Measured / Expected* system temperature at zenith [K]	Derived / Expected* SEFD [Jy]	Status
L- and P- band coaxial feed	P: 0.305-0.410	Primary, 0.33	$1 \times 2$	17-22	0.47-0.59	50-80	123	Commissioned
	L: 1.3-1.8		$1 \times 2$	10-13	0.50-0.60	17-23	36	Commissioned
High C-band	5.7-7.7	BWG I, 1.38	$1 \times 2$	6.5-9	0.64-0.70	24-28	39	Commissioned
K-band	18-26.5	Gregorian, 2.34	$7 \times 2$	20-40 <sup>a</sup>	0.60-0.66	40-70	89	Commissioned
S-band	3-4.5	Primary, 0.33	$7 \times 2$	15*	0.76*	54*	71*	Under construction
Low C-band	4.2-5.6	BWG II, 2.81	$1 \times 2$	8*	0.62-0.70*	30-35*	49*	Under construction
Q-band	33-50	Gregorian, 2.34	$19 \times 2$	25*	0.45-0.56*	45-120*	163*	Under construction
W-band	84-116	Gregorian, 2.34	$1 \times 1$	30-45	0.34 <sup>a, b</sup>	115*	338*	Under construction
X- and Ka-band coaxial feed	8.2-8.6	Primary, 0.33	$1 \times 1$	150	0.64	180	281	Under testing
	31.8-32.3		$1 \times 1$	130	0.57	190	333	Under testing

Summary of the receivers installed, under test and under construction for the Sardinia Radio Telescope. The measured receiver noise temperatures are obtained in the laboratory using the Y-factor method. <sup>a</sup>The noise temperature of the  $2 \times 7$  channels of the K-band receiver refers to the measured value across  $\approx 18$ -24 GHz. <sup>b</sup>With a surface accuracy of  $\approx 180 \mu\text{m}$  and the metrological systems in operation.

technical reports as well as in [3].

#### *L-P Band cryogenic coaxial receiver for primary focus*

Fig. 2 shows a cross-section of the L-P band cryogenic coaxial front-end. Details of the receiver design and performance are described in [4]-[5]-[6]-[7].

The room temperature illuminators are arranged in coaxial configuration with an inner circular waveguide for L-band (diameter of 19 cm) and an outer coaxial waveguide for P-band (diameter of 65 cm). Choke flanges are used outside the coaxial section for improving the cross-polarization performance and the back-scattering of the P-band feed. The geometry was optimized for compactness and high antenna efficiency in both bands. Four probes arranged in symmetrical configuration are used in both the P- and the L-band feeds to extract dual-linearly polarized signals and to combine them, through phase-matched

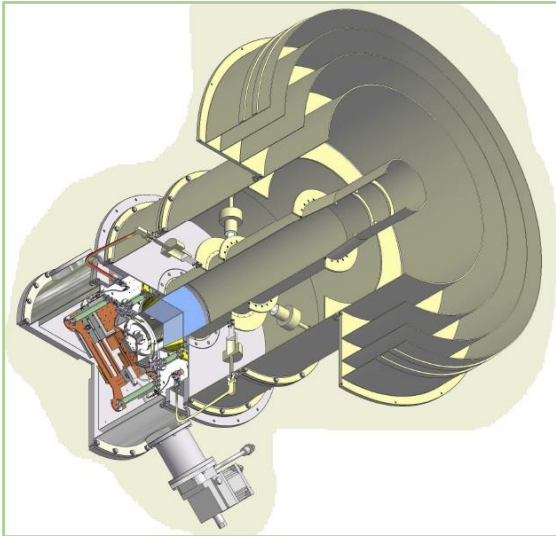


Fig. 2. Cross-section view of the L-P band coaxial receiver.

coaxial cables, into 180 deg hybrid couplers. A vacuum vessel encloses the two P-band hybrids and the two L-band hybrids that are cooled respectively at 15 K and 77 K by a commercial closed-cycle cryocooler. For the P-Band, four low loss coaxial feedthroughs are used to cross the vacuum vessel, while for the L-Band a very low loss large window is employed. The RF signals are amplified by coaxial low noise amplifiers (LNAs) thermalized at 15 K inside the cryostat. Two High Temperature Superconductor (HTS) band-pass filters [8], one per polarization channel, are located in front of the LNAs to mitigate the Radio Frequency Interference (RFI) in P-band. Room temperature noise calibration sources can be injected, under remote control, through coaxial cables and coupled into the RF signal paths, also located in front of the LNAs. The noise temperatures at the input flanges of the receiver measured in the laboratory (see [9] for details) are in the range 17-22 K in P-Band and in the range 10-13 K in L-Band for both linear polarization channels. The receiver was installed on the SRT primary focus in May 2013. It is mounted on the primary focus positioner (PFP), a robotic arm that brings that front-end at its focal position during primary focus observations (see also Fig. 5).

#### *High C-band cryogenic monofeeder receiver for BWG focus*

SRT detected its first radio source in the summer 2012 using the high C-band (5.7-7.7 GHz) receiver that was temporarily mounted in the Gregorian focus at the time. Later, that receiver was moved to the beam waveguide focus, where is now permanently installed. The desired feed-horn illumination of the SRT antenna from the two different F/D ratios of 2.34 and 1.38, available respectively at the Gregorian and BWG foci, was obtained by adding a corrugated adapter to the front-end feed-horn when the instrument was used at the Gregorian focus. Details on the design and characterization of the high C-band

corrugated monofeed receiver are given in [10]-[11]-[12]. The passive waveguide chain cascaded to the feed-horn consists of a calibration noise injector connected to a DPS (Differential Phase Shifter) and OMT (Orthomode Transducer). The DPS

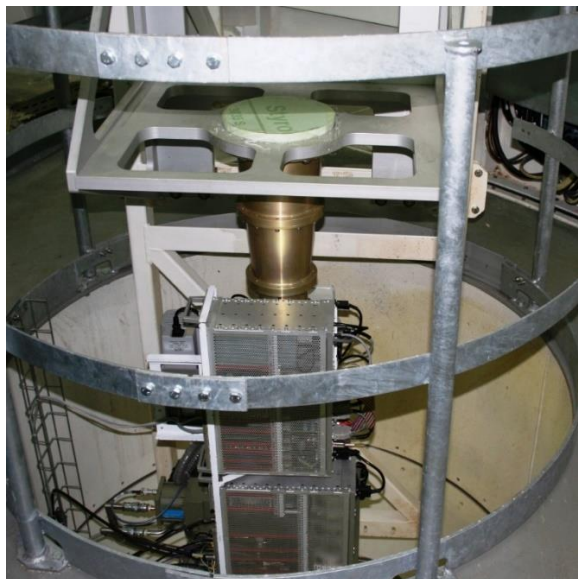


Fig. 3. Fully assembled high C-band front-end installed on the BWG focus.

and OMT are thermalized at 15 K inside a cryostat. A photo of the high C-band front-end installed at the BWG, given in Fig. 3, shows the room temperature (corrugated) feed horn, the remotely controlled vacuum pump as well as the front-end downconversion and electronics control modules arranged in racks. The front-end is held in place inside the antenna receiver cabin, which moves in elevation (and azimuth) as the antenna tracks the astronomical sources, through a mechanical frame. The frame is aligned inside the antenna receiver cabin by means of internal mechanical references. Laboratory measurements of the front-end, followed by tests in open-air, allowed accurate determination of the noise temperature of the receiver before its installation in SRT. The receiver noise was derived by the Y-factor method, which utilized room temperature and cold loads respectively given by microwave absorber and cold sky (the method also allowed to characterize the noise calibration source). The measured receiver noise temperature at the feed-horn input was below 9 K for both circular polarization channels (RHCP and LHCP).

#### *K-Band multifeed cryogenic receiver for Gregorian Focus*

A detailed description of the K-band (18-26.5 GHz) seven-beam multibeam receiver is given in [13]. The seven beam system allows to increase by a factor of seven the mapping speed of extended radio astronomy sources when compared to a monofeed. The feed-horns are arranged in hexagonal configuration plus a central one. The cryogenic part of each of the seven receiving chains includes a corrugated feed-horn, a circular waveguide directional coupler for noise calibration injection, a differential phase shifter, an orthomode transducer and an InP MMIC (Monolithic Microwave Integrated Circuit) low noise amplifier, all cooled at a physical temperature of  $\approx 20$  K. A photo of the instrument showing the inner part of the cryostat is given in Fig. 4.

The room temperature parts of the receiver include down-conversion and local oscillator (LO) distribution chains. Two down-conversions are used. The first LO is variable from 12 to 18.5 GHz to allow selecting a 2 GHz band across the 18-26.5 GHz RF range from each polarization channel. The input band of the second down-conversion is 6-8 GHz and utilizes a fixed local oscillator at 5.9 GHz to downconvert to the final 0.1-2.1 GHz IF band. The receiver delivers a total IF bandwidth of 28 GHz (7 feeds x 2 pols x 2 GHz).

A mechanical rotator is used in the receiver to compensate for the Earth's rotation and maintain the parallactic angle thus avoiding the astronomical field derotation caused by the SRT altitude-azimuth movement when tracking sources in the sky. The cryostat is attached to a rack cabinet containing the down-conversion modules, the local oscillator distribution chains, the bias electronics for the LNAs, and the monitoring and control electronics for the valve of the vacuum pump of the cold head, of the calibration noise source as well as of the LNAs. The noise temperature at the vacuum window of the receiver measured in the laboratory for the 14 channels (seven dual polarization beams) is in the range 20-40 K across most of the 18-24 GHz band. The noise increases at frequencies above 24 GHz to values in the range 40-80 K.



Fig. 4. Photo of the K-band seven-beam front-end showing the assembly of the components inside the cryostat (external shields removed).

#### *X-Ka band coaxial receiver for Primary Focus*

A coaxial dual-frequency X-Ka band (X: 8.2-8.6 GHz, Ka: 31.85-32.25 GHz) room temperature receiver was installed on the primary focus of the SRT to perform an experimental verification of the antenna potential capabilities in Space Science [14]-[15]. The single circular polarization receiver was originally developed for the INAF 32-m diameter Noto radiotelescope (Italy) in order to track the Cassini spacecraft. The receiver delivers two 400 MHz wide IF bandwidths (one per band) using two internal local oscillators. The measured noise temperatures are 150 K for the X-band receiver and 131 K for the Ka-band receiver. The huge collecting area of SRT

compensates the relatively high system temperatures of these two uncooled receiver with respect to other Deep Space antennas.

A view of the X-Ka band receiver installed at the SRT primary focus is visible in Fig. 5.

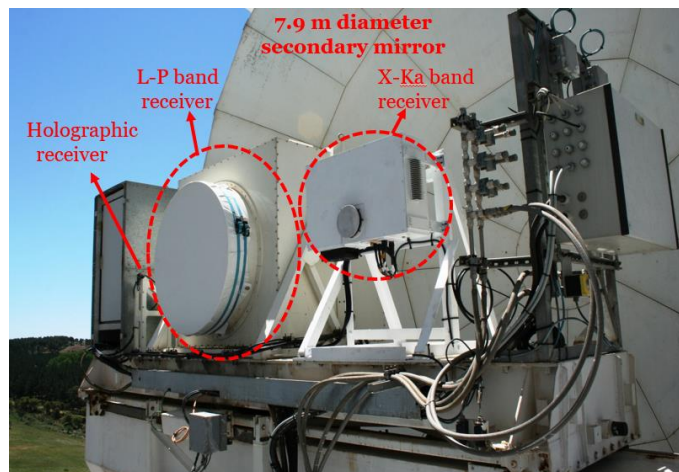


Fig. 5. Photo of the front-ends installed at the primary focus of SRT. The L-P band receiver is located between the X-Ka band and the holographic receivers. All front-ends are mounted on the primary focus positioner (PFP). The 7.9-m diameter ellipsoidal secondary mirror is visible in the back.

#### FRONT-ENDS UNDER CONSTRUCTION FOR SRT

Four additional cryogenic front-ends for radio astronomy application are currently being constructed for SRT (see also Table I): an S-band (3.0-4.5 GHz) seven-beam dual-linear polarization receiver for primary focus [16]-[17]-[18]; a Q-band (33-50 GHz) 19-element dual-circular polarization receiver for Gregorian focus [19]; a low C-band (4.2-5.6 GHz) monofeed receiver for the BWG focus at  $F/D=2.81$ ; a W-band (84-116 GHz) monofeed receiver for the Gregorian focus [20].

#### CONCLUSIONS

We described the design and performance of the front-ends installed on the 64-m diameter Sardinia Radio Telescope and gave a short overview of the ones under construction. The SRT has started an early science program in February 2016 and is currently producing remarkable scientific results.

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