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Electromagnetic Characterization of the S-band Feedhorn for the SRT Multibeam Cryogenic Receiver

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Abstract

This paper describes the measurements conducted to characterize the feed-horn of the new under-development S-band multi-beam receiver for the Sardinia Radio Telescope (SRT). The receiver is designed to observe the sky in the 3-4.5 GHz frequency range and will be composed by seven feed-horns arranged in a regular hexagonal layout with a central one. The feed-horns are optimized to illuminate the 64-m dish of SRT from the primary focus. The electromagnetic characterization of the single feed-horn is crucial to verify the receiver's performance; for this reason, we manufactured one of them in order to measure the reflection coefficient and the radiated far-field. For the measurement setup, we designed and fabricated two adapters: a circular-to-rectangular waveguide and a coax-to-rectangular waveguide. All the devices have been designed using the CST© Studio Suite and Ansys HFSS© electro-magnetic software. The test performed in the anechoic chamber are in a very good agreement with the simulated results.

1. Introduction

The Sardinia Radio Telescope (SRT) (Figure 1) is a fully steerable 64-m diameter radio telescope with an active surface, developed by the Italian National Institute for Astrophysics (INAF) [1]. The telescope was designed to operate with high performances from 300 MHz up to 116 GHz and it is located 35 Km North of Cagliari (Sardinia, Italy) at an altitude of around 600 meters above sea level. The Astronomical Observatory of Cagliari (OAC) manages the SRT for general astronomical research, space weather and space situational awareness activities [2-4] using at present P, L, C and K band receivers. Furthermore, the Italian Space Agency (ASI) manages the space configuration of the antenna, namely the Sardinia Deep Space Antenna, which is implemented since 2017 with an X-band mono-feed cryogenic receiver [5] operating in the band 8.4-8.5 GHz.
The optical design of the telescope follows a quasi-optical Gregorian configuration, with a 64 m diameter quasi-parabolic primary mirror (M1) and a 7.9 m diameter quasi-elliptical secondary reflector (M2). The shapes of both mirrors are designed to minimize spillover and the standing waves between M1 and M2.

Figure 1: The Sardinia Radio Telescope.

The radio telescope has been designed to be equipped with up to twenty receivers [6]: in addition to the two focal positions corresponding to the primary and secondary mirrors (F1 and F2 respectively), there are two other additional focal positions in the BWG – Beam Waveguide F3 and F4, as shown in Figure 2.

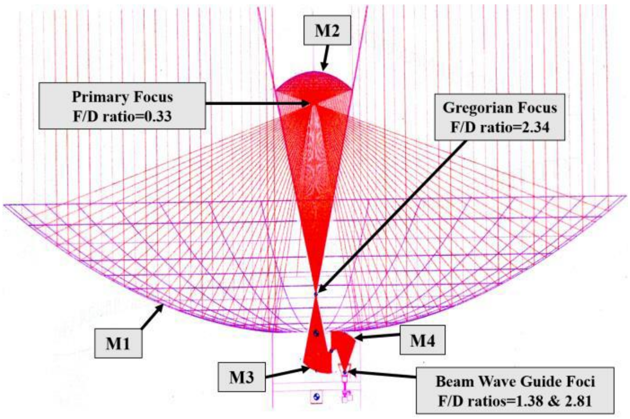

Figure 2: Optical configuration, ray tracing, mirrors and foci position of the Sardinia Radio Telescope [6].

In the next few months, ASI will install two other mirrors in the BWG, to create two other focal positions, F5 and F6 [7].

In Table 1 we show the operational frequencies of the SRT related to the actual four focal positions and the corresponding F/D ratio.

F/D ratio	Minimum Frequency	Maximum Frequency	Focus
0.33	300 MHz	20 GHz	Primary Focus F1
2.34	7.5 GHz	116 GHz	Gregorian Focus F2
1.38	1.4 GHz	35 GHz	BWG I, F3
2.81	1.4 GHz	35 GHz	BWG II, F4

Table 1: Operational frequencies of the four focal positions and the corresponding F/D ratio.

The under-development S-Band multi-feed receiver will be one of the upcoming SRT new generation receivers. It will be placed in the SRT Primary Focus Positioner (PFP) [8] for operation at the F1 primary focal position from which the feed-horn should illuminate the primary mirror at full angle of 148 degrees with a designed edge taper of ≈ -15 dB. Designed to observe the sky within the 3-4.5 GHz frequency band, this receiver will significantly expand the observational capabilities to the radio astronomical community. As detailed in [9], the new S-band receiver will enable exciting scientific investigations, including discovery of new pulsars in the galactic center, evaluation of pulsar dispersion measures, detailed mapping of galactic supernova remnants and much more.
A first design of the S-band receiver is presented in [9]: this work presented the S-Band RFI spectrum in the SRT site and the electromagnetic study of the feed-horn for an optimal aperture efficiency; the spatial configuration and the maximum number of feed-horns for the SRT optical configuration was also investigated.
In [9] and [10] a detailed description of the receiver's front-end design, including its electromagnetic, electronic, cryogenic and thermal aspects, along with laboratory measurements has been shown. To avoid strong radio frequency interference (RFI) in the lower portion of the original 2.3-4.3 GHz band, we shifted the operating frequency range of the receiver to 3.0-4.5 GHz. An alternative design of a wideband quadruple-ridged horn for the S-band receiver is described in [11] and the latest updates and the progress status regarding the receiver's development are explained in [12].
In this paper we report the characterization of the single feed-horn using a modified configuration of the single radiating component of the multibeam receiver. This modified configuration has been designed and optimized using ANSYS HFSS© and CST Studio Suite©, two general purpose software packages for the 3-D electromagnetic simulations of microwave components.
The fabricated feed-horn was then fully characterized, demonstrating good agreement between the simulated and measured results.

2. The RF single feedhorn measurement

The S-band feed-horns are arranged in a regular hexagonal layout with a central one and optimized to be placed, as described in [9], in the primary focus (F1 focal position) of the Sardinia Radio Telescope.
This way, the sky beams result mirrored, as shown in Figure 3.

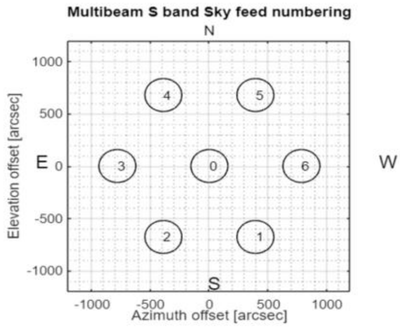

Figure 3: In the sky beam position of the multi-beam receiver.

The center-to-center spacing between feedhorns is 91 mm resulting in a very compact array with a 1.1 λc at the central frequency of the RF band (3.75 GHz) and less than 1 wavelength at the lowest frequency [12].
The focal plane of the multi-feed receiver consists of seven radiating feedhorns consisting of two separate parts. A first part is a homogeneous circular waveguide of 64 mm in diameter and 100.5 mm in length.
To achieve a reduction in sidelobes, to extend the operative bandwidth and to improve uniformity of the primary reflector illumination with a low level of cross-polarization, we added a cylindrical choke to the truncated waveguide. This part is visible in the cross-section view (Figure 4), with an internal diameter of 72 mm and a length of 63 mm. This choke plays a crucial role in optimizing the receiver's performance in terms of antenna efficiency, cross-polarization and spillover, thereby reducing unwanted signal components that could degrade system performance.

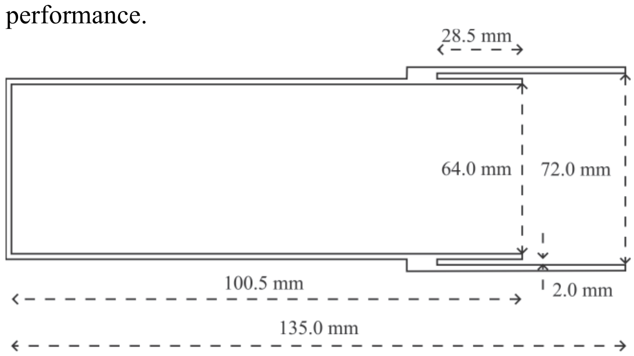

Figure 4: Sketched cross-section S-Band feedhorn

We extensively described the design of the entire receiving chain in [8-12]. In this paper we focus on the measurement characterization of the single feed-horn element's radiated field (in one polarization).
To characterize the single feed-horn is not necessary to use the entire passive feed system, but the "test chain" (Figure 5) can be limited to a quarter-wavelength section in circular waveguide and two custom-designed adapters: a circular-

to-rectangular waveguide and a rectangular waveguide-to-coaxial cable.

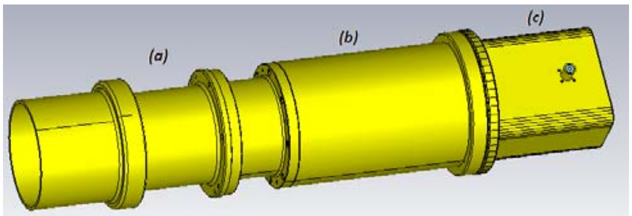

Figure 5: 3D CST model of the modified front-end: (a) circular feed horn, (b) rectangular-to-circular adapter, (c) waveguide-to-coaxial cable adapter.

The waveguide-to-coaxial cable adapter consists of a 90 mm long rectangular waveguide (RW) having a section of 64x32 mm. We chose these specific dimensions to optimize the performances with the desired operating frequency range (3.0-4.5 GHz) of the receiver. To connect the waveguide to a coaxial cable (CZ), a commercial coaxial connector with a designed probe is used. This connector provides a seamless interface between the waveguide and the coaxial cable, allowing an efficient signal transfer. A metallic probe 13.85 mm long is positioned to convert the RW TE_{10} mode into the CX TEM fundamental mode. The distance between the probe and the back-short of the waveguide is important for achieving the desired characteristics and impedance matching: in this case this distance is equal to 13.85 mm.

3. Measurement of radiation pattern

We characterized the S-band single feed-horn front-end in the anechoic chamber at the INAF Arcetri Astrophysical Observatory (INAF-OAA) with the setup sketched in Figure 6. The chamber (Figure 7) has a dimension of 2.5x3.5x2.4 meters (width x length x height) and its facilities allow to perform both near and far-field measurements of devices not excessively bulky, compared to the size of the chamber itself.
In our case, we present the results of the far-field measurements and consisting of the Device Under Test (DUT) and a double ridge wideband horn with 12.5 dBi of gain in the 3-4.5 GHz range (Figure 6).

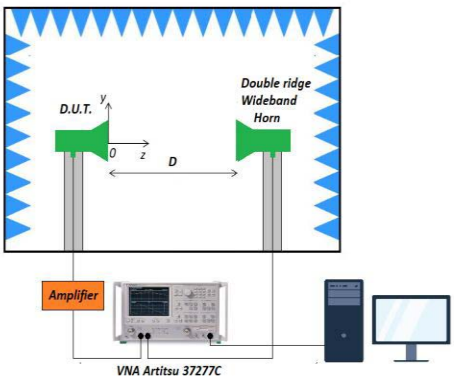

Figure 6: Measurement setup in the anechoic chamber.

A vector analyzer Anritsu VNA 37277C has been used for the measurements. In the far-field setup an amplifier between the VNA output and the DUT input has been used to increase the dynamic range of about 10 dB: this helps to overcome losses in the measurements setup and ensures improved accuracy at angles far from on-axis, where the signal level of the field measurement is lower.

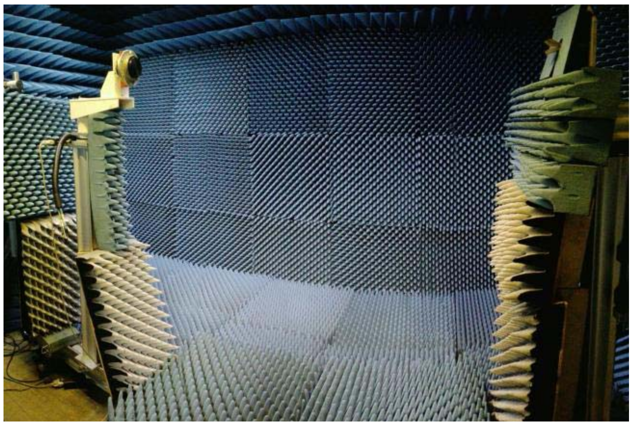

Figure 7: Anechoic chamber of Arcetri Astronomical Observatory

The scans of radiated far field are evaluated at three frequency points (3, 3.75, 4.5 GHz) while the distance D between the DUT and the transmitter was 900 mm. The DUT and the transmitter are mutually oriented to directly measure the field over the E-plane, the H-plane and the 45°-plane cuts ranging from -90 deg to 90 deg with sample points taken every 1 deg of rotation: copolar and cross-polar field scans are this way obtained, the cross-polar field scan is obtained on the 45 deg plane with DUT and transmitter cross-coupled in polarization, that is rotated 90 deg off with respect to each other around the z-axis (Figure 6).
The results obtained are compared with the simulated radiated fields in the following Figures 7, 8 and 9.

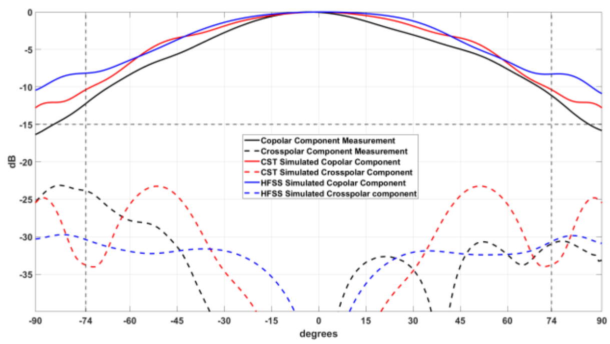

Figure 8: 3.0 GHz normalized far field.

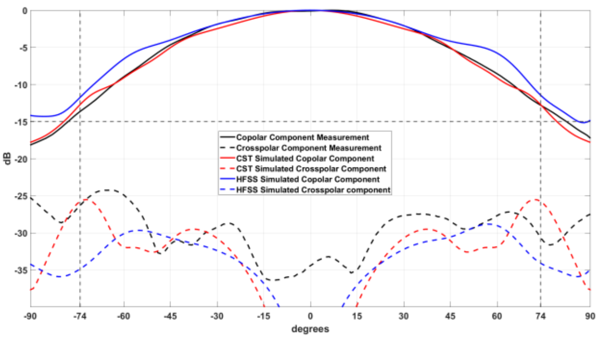

Figure 9: 3.75 GHz normalized far field

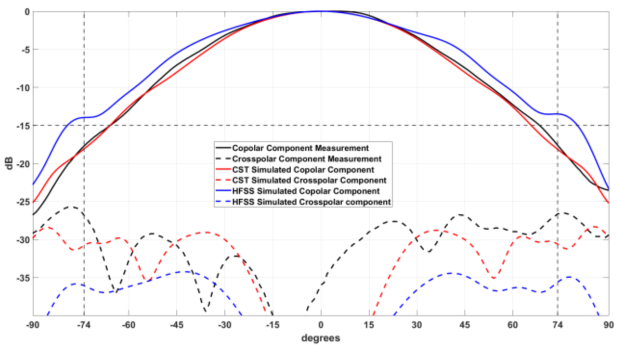

Figure 10: 4.5 GHz normalized far field

The measured far field co-polar patterns are in very good agreement with the CST Studio Suite© and Ansys HFSS© simulated data; there are slight differences between the measured and simulated data in the cross-polar component not affecting the characteristics of the feedhorn, both highlighting cross-polar levels of order of -25 dB.

4. Conclusions

The electromagnetic characterization of the single radiation element of the SRT multi-feed S-band receiver has been presented. The feedhorn covers the band from 3 to 4.5 GHz and consists of a cylindrical truncated waveguide with a cylindrical choke for side lobe reduction and improvement of the operative bandwidth.
The device is part of a seven-element Focal Plane Array to be placed in the primary focus of the Sardinia Radio Telescope. In this work, the single feedhorn has been connected to a dedicated chain composed by two adapters in order to make the electromagnetic characterization more feasible. The feedhorn has been fully characterized (in single polarization) in the anechoic chamber of the Arcetri Astrophysical Observatory.
The measurement results show a very good agreement between simulated and measured data.

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