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Optical design of S-band multifeed for the Sardinia Radio Telescope primary focus

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***Abstract*—We present the optical design of an S-band seven-feed cryogenic radio astronomy receiver for illuminating the 64-m diameter Sardinia Radio Telescope (SRT) dish from the primary focus. The feeds are arranged in a compact hexagonal configuration with a central one and are cryogenically cooled at 20 K inside a cryostat. Each feed accepts two linear polarizations and use a circular waveguide with a single outer corrugated section to achieve a nearly constant beam width and low cross polarization across the 3.0-4.5 GHz band. The simulated radiation pattern of the SRT telescope is obtained by coupling the array of feed-horn beam patterns (optimized with the electromagnetic software CST) with the 64-m parabolic dish (through a physical optics analysis carried out with GRASP). We compare the simulated beam pattern of an isolated feed with those of the same feed embedded in the dense array and analyze the effects of an absorber located inside the cryostat around the cryogenic feeds. We found that the absorber improves the overall system performance by decreasing the cross-coupling effects between the feeds while adding negligible noise to the system.**

Keywords—Radio astronomy; receivers; optics; Sardinia Radio Telescope; electromagnetic modeling; feeds.

I. INTRODUCTION

The Sardinia Radio Telescope (SRT, 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]-[3]. The telescope is located 35 km North of Cagliari, Sardinia, Italy, at about 600 m above the sea level. The SRT optical design is based on a quasi-Gregorian configuration 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 μm) and of 1116 electromechanical actuators under computer control that compensate the gravitational deformation of the backup structure. 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). The technical and scientific commissioning of the telescope was carried out [4] and a six-month early science program successfully completed in August 2016 using three cryogenically cooled Front-Ends: a dual-frequency L-P band coaxial receiver (P-band 305-410 MHz and L-band 1.3-1.8 GHz), a C-band (5.7-7.7 GHz) monofeed receiver, and a K-band (18-26.5 GHz) multibeam receiver with seven feeds. A photo of the telescope is shown in Fig. 1. Here, we describe the design and electromagnetic simulation results of the optical design of an S-band (3.0-4.5 GHz) cryogenically cooled multibeam receiver that is being built for the SRT primary focus F1. The array is based on a cluster of seven identical feeds with a single external corrugation. The primary goal in the design of this feed array was to produce beam patterns that minimize the ratio of system noise and antenna aperture efficiency T_{sys}/A_{eff} of SRT and obtain high performance for on-axis and off-axis feeds over the 3.0-4.5 GHz range. This new instrument will offer large science capabilities for mapping extended radio astronomy sources.

Fig. 1. Photo of the Sardinia Radio Telescope at the opening ceremony on Sep. 30th, 2013.

II. SPECIFICATIONS OF S-BAND MULTIBEAM RECEIVER

The S-band multi-feed receiver [5] will be placed at the SRT primary focus F1, where the F/D ratio is 0.33 and the half-angle from boreside to the dish edge is approximately 74 deg.

TABLE I TOP-LEVEL SPECIFICATIONS OF S-BAND RECEIVER.

Parameter	Goal
Frequency Range	3-4.5 GHz (BW: 40%)
Focal Plane Array	Seven Feeds
Polarization	double linear polarization
Intermediate frequency (IF)	range 0.1-2.1 GHz
Receiver noise temperature	< 20 K
Return loss of each passive component	< 20 dB
Cross-pol. of each passive component	< -35 dB

The design of the waveguide passive components, (feed, OMT and directional coupler) were constrained by the available space along the direction of the optical axis (1 m) at the primary focus. Table 1 summarizes the top-level specification of the receiver. The seven feeds are located inside a cryogenic dewar and thermalized at the physical temperature of 20 K.

III. FEED-HORN DESIGN

The design of the passive part of one of the feed-horn chains, including the orthomode transducer, is shown in Fig. 2. The dual-polarization feed is based on a circular waveguide (diameter 64 mm) with a single outer corrugated section with approximately quarter-wavelength electrical length (the metal thickness and separations are 2 mm). First, the geometry was optimized for an isolated feed (not embedded in the array) in order to provide the desired return loss and beam pattern performance. Later we found that the relatively strong coupling between the array elements, due to their vicinity in the focal plane, had an impact on the feed performance. The electromagnetic simulation program CST Microwave Studio was used for the feed design.

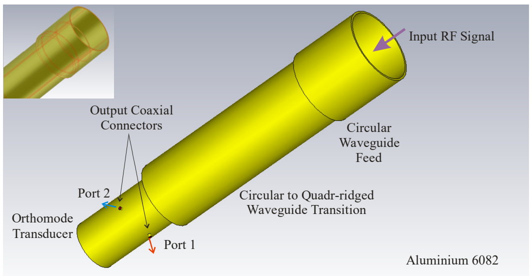

Fig. 2. Design of a dual-polarization feed-horn system with circular waveguide feed and orthomode transducer. The single external corrugation is shown in the inset on th eupper left corner.

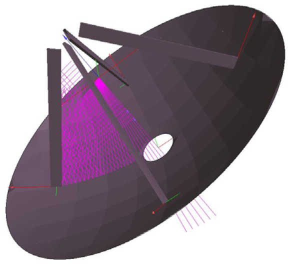

Fig. 3. GRASP model of the SRT dish.

The commercial software GRASP based on Physical Optics was used to simulate the coupling of the feed with the 64-m SRT dish and generate the radiation beam patterns of the antenna. Fig. 3 shows a 3D view of the GRASP model of the SRT primary. In this simulation we have taken into account the blocking effects of the subreflector (simulated with a hole on the primary mirror reflector, equivalent to the secondary mirror aperture) and of the quadrupod. The far-field beam patterns of the isolated feed and of the isolated feed coupled with the SRT optics at 3.75 GHz are given in Figs. 4 and 5, respectively. The edge taper at the 74 deg half angle from boreside is ≈15 dB.

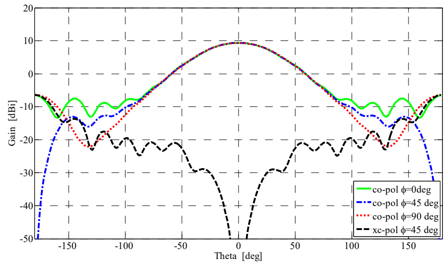

Fig. 4. Radiation pattern of isolated feed at 3.75 GHz.

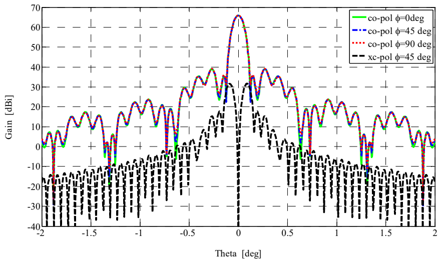

Fig. 5. Radiation pattern of isolated feed coupled with the SRT 64-m optics at 3.75 GHz.

IV. ARRAY DESIGN

The arrangement of the array with seven feed is shown in Fig. 6. The separation between two feeds is 88 mm, thus making the array very compact in electrical terms, i.e. 1.1 λ_c at the central frequency of the RF band (3.75 GHz) and less than one wavelength at the lowest frequency.

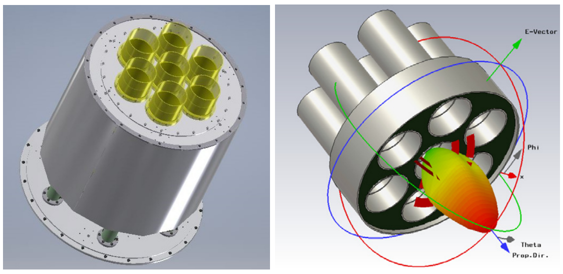

Fig. 6. Left: Arrangement of the array inside the cryostat showing the seven feeds. Right: 3D view of the S-band seven-beam receiver with absorbers surrounding the feeds (in dark colour), showing the radiation pattern from the central feed.

The 3D CST model of the feeding system in Fig. 6 (right panel) is represented to look downward from the primary focus towards the telescope primary dish (as when in operation). We optimized two different array models, one with empty space between the feed-horns and one with an absorber (Eccosorb MSF-124) surrounding the feed (as shown in Fig. 6). The CST model of the array without absorber has a background ground plane at approximately a quarter wavelength behind the feed horn apertures. The radiation patterns of the central feed of the array with and without absorber at 3.75 GHz and at 4.50 GHz are shown in Figs. 7, 8 and 9. The radiation patterns of the array central feed and of one of the lateral feeds with and without absorber coupled with the antenna optics at 3.75 GHz are shown in Figs. 10, 11, 12 and 13.

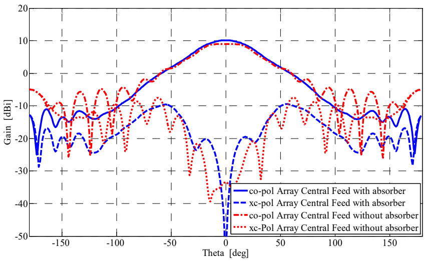

Fig. 7. Radiation pattern of the array central feed with and without absorber at 3.75 GHz.

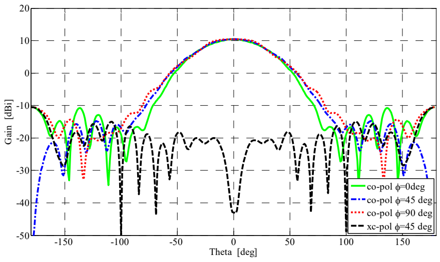

Fig. 8. Radiation pattern of array central feed without absorber at 4.50 GHz.

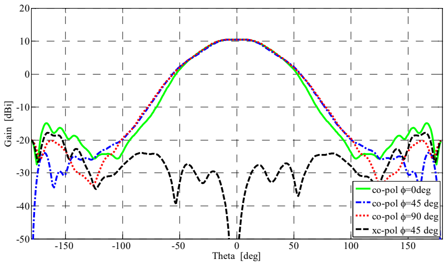

Fig. 9. Radiation pattern of array central feed with absorber at 4.50 GHz.

The simulations show that the overall performance of the array are improved when the cryogenic feeds are surrounded with absorber. The thermal emission injected by the absorber into the feeds is negligible as this is thermalized at the cryogenic temperature of 20 K. The simulated array feed antenna gain is of order 10 dBi and of order 66 dBi when coupled with the 64-telescope at 3.75 GHz. The antenna efficiency is of order 60%. The simulated HPBW (half power beam width) of the radiated far-field pattern of the SRT telescope is 2.64 arcmin at 3.75 GHz. The return loss of the feeds are greater than 25 dB in all configurations across the 3.0-4.5 GHz frequency band. Table 1 summarize the main simulation results.

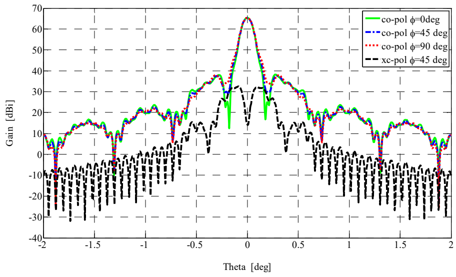

Fig. 10. Radiation pattern of array central feed without absorber coupled with the SRT 64-m optics at 3.75 GHz.

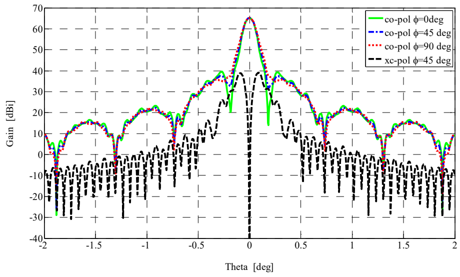

Fig. 11. Radiation pattern of array central feed with absorber coupled with the SRT 64-m optics at 3.75 GHz.

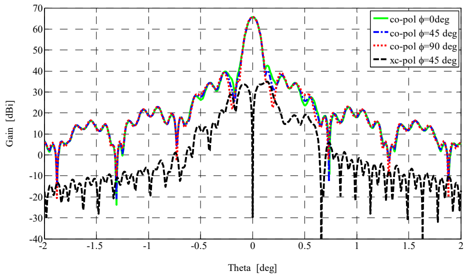

Fig. 12. Radiation pattern of array lateral feed without absorber coupled with the SRT 64-m optics at 3.75 GHz.

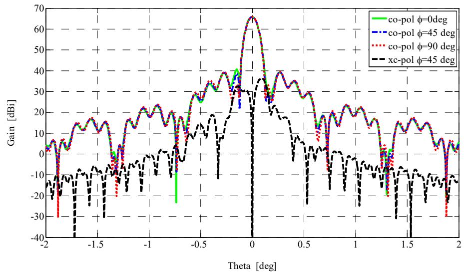

Fig. 13. Radiation pattern of array lateral feed with absorber coupled with the SRT 64-m optics at 3.75 GHz.

TABLE II COMPUTED PERFORMANCE OF THE SRT ANTENNA WITH VARIOUS S-BAND SEVEN-BEAM RECEIVER CONFIGURATIONS.

SRT radiation performance at 3.75 GHz (central frequency)			
Configuration	***Gain [dBi]***	***Sidelobe level [dB]***	***Cross-pol level [dB]***
Isolated feed	65.9	27.0	34.2
Central array feed without absorber	65.4	28.4	32.9
Central array feed with absorber	65.2	26.0	26.0
Lateral array feed without absorber	65.7	23	30
Lateral array feed with absorber	65.8	26	30

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