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Simulations of Angular Super-Resolution with the Active Surface of the Sardinia Radio Telescope

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Abstract

We are currently carrying out a project devoted to the implementation of *super-resolution* (SR) on single-dish radio telescopes, which should result in an angular resolution better than the classical diffraction limit. A feasible method to achieve this goal consists of using variable transmittance pupils. The simplest transmittance pupils are binary phase shift masks, also known as *Toraldo Pupils*, consisting of finite-width concentric coronae which modify the phase of the incident wavefront. In previous works we have suggested that the active primary surface of a telescope could be used to simulate a Toraldo Pupil placed at the entrance pupil. In this paper we present new electromagnetic simulations whose goal is to assess the feasibility of this method using the shaped active surface of the 64-m Sardinia Radio Telescope.

1. Introduction

One of the fundamental properties of filled-aperture telescopes is their angular resolution, i.e., their ability to separate points of an object that are located at a small angular distance. Apart from other effects which can be either cancelled or mitigated (e.g., aberrations and atmospheric "seeing"), the diffraction of electromagnetic (EM) waves is generally considered to be a fundamental limit for any imaging device. The concept of *super-resolution* (SR) refers to various methods for improving the angular resolution of an optical imaging system beyond the classical diffraction limit. Variable transmittance pupils, such as *Toraldo Pupils* (TP) [1], represent one viable approach to achieve SR in Radio Astronomy [2].

In a previous work [3] we have shown that it is in principle possible to implement the SR effect on a radio telescope at the entrance pupil level, if an active surface is available. In fact, in this case one can use the active panels of the primary reflector to approximately mimic the behaviour of an ideal TP placed at the aperture plane. Such method would present several advantages compared to the option of modifying the incoming wavefront at the exit pupil of the telescope.

2. Previous results

In ref. [3] we have described several procedures that were implemented to test the modifications applied to the primary reflector of the telescope, by moving specified sections of the antenna surface. These EM simulations were carried out using the commercial software GRASP[1], in reception mode, assuming an incident plane wave, and they have initially concentrated on the Noto 32-m antenna. In fact, among the three radio telescopes operated by the Italian National Institute for Astrophysics (INAF), the Noto telescope and the 64-m Sardinia Radio Telescope (SRT) are currently the only ones with an active primary surface. The Noto antenna has a classical Cassegrain design, whereas the SRT has a more complex shaped Gregorian design, which is also the reason why we have initiated this analysis with the simpler Noto telescope.

Our previous results suggest that while an ideal reflector with fully independent active panels (of the same size and shape as those of the Noto antenna) would be able to achieve the SR effect, the real Noto active surface, where each actuator is connected to four distinct panels, adversely affects the operation of the simulated Toraldo Pupil. In ref. [3] we speculated that this problem was likely caused by the limited "spatial resolution" of the active surface of the Noto antenna, where the active panels are organized in a series of 48 radial lines and four rings.

The situation is quite different with the SRT. Its active surface consists of 1116 actuators and the active panels are distributed according to 96 radial lines and 15 rings, with the number of actuators per ring increasing from the inner to the outer rings [4, 5] (see Fig. 1). Compared to the Noto antenna, the SRT has a slightly higher number of panel rings per unit length (0.5 m^{-1}, compared to 0.4 m^{-1} for Noto). However, the major advantage of the active

[1] https://www.ticra.com/software/grasp/

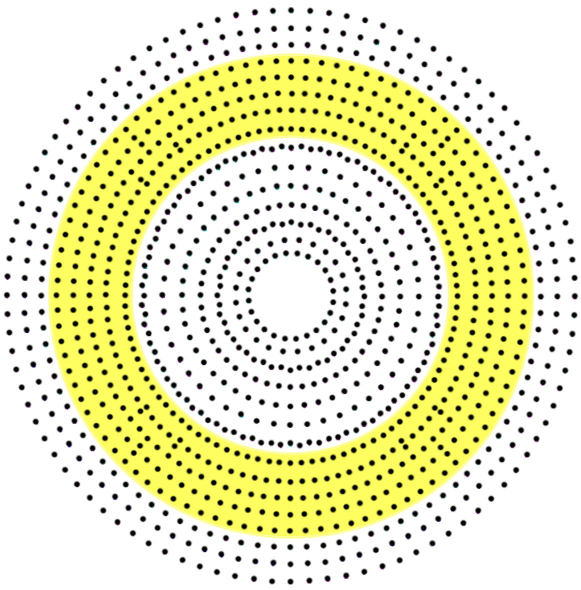

Figure 1. Distribution of the actuators on the active primary surface of the SRT telescope. The yellow-shaded area shows an example of the panels that need to be shifted to mimic the geometry of a three-coronae TP.

surface of the SRT is actually the higher number of panel rings (typically 4 to 6) that can be accommodated within each of the three coronae in which the surface has been divided for the TP3 case study. In the case of the Noto antenna these rings were limited to only 2 for each corona [3].

3. Implementation on the SRT

The primary active reflector of the SRT can be modified to resemble a TP by displacing the appropriate rings of panels. The geometry of the baseline TP that can be implemented with the active surface is limited by the number of panel rings and the size of the individual panels. Therefore, as already done in ref. [3], we discuss the implementation of the simplest TP geometry, i.e., a three-coronae TP (or TP3), which can be approximated using the limited number and geometry of the active rings of panels, as shown in Fig. 1.

The required shift to each panel, and therefore to each actuator, is determined by first calculating the optical path difference between a nominal ray and the ray reflected by the shifted panel. The positions of the actuators are then chosen so that the total path difference is equal to $\lambda/2$ (for all points belonging to the central corona), corresponding to a 180deg phase delay as required by the TP3 model.

4. Results

The numerical radial profile resulting from all the modifications to the original shaped surface is saved and then imported in GRASP. All EM simulations have been carried out at a frequency of 20 GHz, and a summary of our results is shown in Fig. 2. The figure shows that the

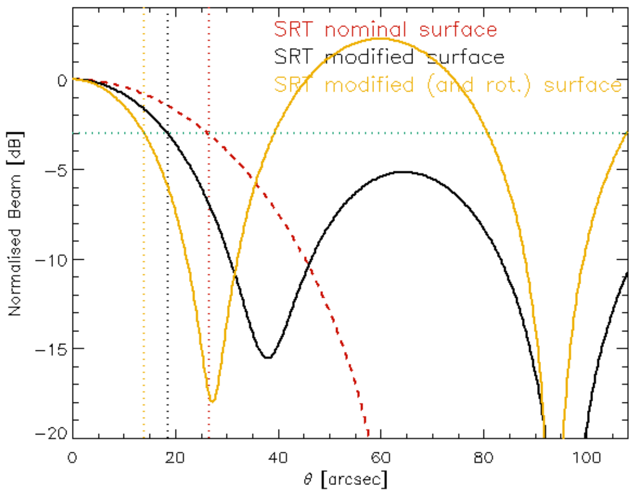

Figure 2. Simulated normalized (with respect to the on-axis value) power pattern of the SRT using GRASP (at 20 GHz). The beam of the nominal, unmodified reflector surface is shown by the dashed red line. The solid black line shows the resulting beam when the active surface is modified according to the TP3 geometry (without taking into account the rotation of the edge panels). The yellow line shows the resulting beam when the partial rotation of the panels is taken into account. The dotted vertical lines indicate the -3dB beam widths.

SR effect is clearly achieved, thus confirming that the active surface of the SRT has better performance compared to that of the Noto antenna.

We have evaluated the far-field beam with and without the inclusion of the partial rotation of the panels at the edge of the TP3 area shown in Fig. 1. The black line in Fig. 3 shows the resulting beam with no rotation of the panels. However, when rotation is included in the simulation we obtain an unexpected narrower beam, accompanied by much higher sidelobes (and an additional gain loss, not shown). These preliminary results show that the active surface of the SRT can actually be used to achieve a significantly narrower beam width, at the cost of a reduced antenna gain and higher sidelobes, as it is always the case with TPs.

Given the intrinsic differences between an idealized TP model placed at the entrance pupil and the actual implementation with the active surface of the primary reflector, an optimization procedure is required in order to determine the best trade-off between SR level, sidelobe level and gain reduction. Field tests will then be required at the SRT to analyze and compare the actual response of the telescope with our EM models.

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