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Reflectarray Concept for Interference Mitigation in Radio Astronomy

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***Abstract*—This paper proposes a composite reflectarray system for realizing a reflector antenna for radio astronomy applications. The system is equipped with a tunable reflectarray rim that enables nulls to be formed within the field of view and reduce the impact of interferers on the observations. Full-wave simulation results of a physical reflectarray system are presented to validate the concept.**

I. Introduction

Terrestrial radio telescopes are subject to significant amounts of radio frequency interference (RFI) from a variety of sources. A considerable amount of this interference can originate from satellites within the field of view of the instrument, particularly from low Earth orbit (LEO) satellites. Interference from medium Earth orbit and geostationary satellites (such as those for GNSS) can also have an impact [1]. A variety of strategies exist for mitigating RFI, including signal blanking, adaptive cancellation techniques, and spatial filtering [2]. Of these techniques, the latter is of significant interest, since it prevents RFI from entering the signal chain at the antenna level.

In this paper, we present the idea of using a composite reflectarray to realize a reflector antenna with adaptive interference mitigation capability. This capability is realized by augmenting a standard fixed reflectarray with peripheral electronically reconfigurable reflectarray rim. This allows the instrument's main antenna to be realized in a completely flat form factor, while also providing a practical way to implementing beam-forming that can be used to null out interferer(s) in the field of view.

II. Reflectarray Concept

The fundamental interference mitigation concept has been described previously [3]. The rim added is only a small fraction of the overall reflector size has the ability to produce sufficient scattering fields to produce nulls in the vicinity of the main beam using suitable algorithms [4], while incurring only a minor gain reduction in the overall reflector. These nulls can be adaptively reconfigured as the RFI source moves. To this point, the concept has been demonstrated using physical optics approximations of the reflector and associated rim, where the phase of induced surface currents on the rim are adjusted to simulate the actual reflectarray. Here we take the concept further by: 1) replacing the main (fixed) reflector with a reflectarray, in order to yield a more compact instrument; and 2) analyzing a full-wave model of the entire reflectarray system, in order to yield a more realistic picture of the performance of the proposed system.

The model used in this paper is illustrated in Figure 1. The reflector operates at a frequency of 1.5 GHz, adjacent to nearby protected bands for radio astronomy bands. The model is based on an 18 m reflector configuration proposed previously [3], which employs a prime focus-fed paraboloidal reflector for the main reflector. The main difference is that the main reflector is replaced by a reflectarray, and the f/D ratio is 1 instead of 0.4. The rim, which also comprises reflectarray elements, has a width w such that the diameter of the entire reflector system is $D = D_r + 2w = 18$ m, where D_r is the diameter of the fixed portion of the reflector. The reflector system is fed by a Gaussian feed establishing an edge taper of -11 dB at the outer edge of the rim.

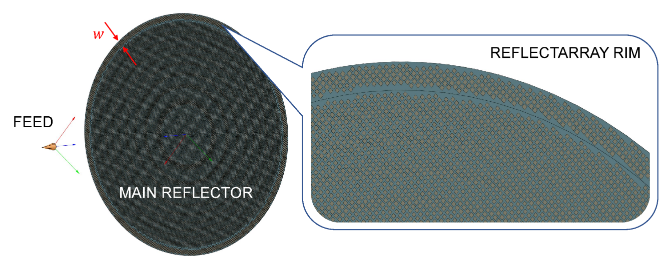

Fig. 1. Reflectarray model

The reflectarray elements on the main reflector are simple square patch elements for concept demonstration. They are realized on a Rogers 5880 substrate ($\epsilon_r = 2.2$) with a thickness of $h = 3.0$ mm. Dielectric and conductor losses are assumed to be negligible in this study. The cell period is 10 cm and the patches are varied in length from 4.0 cm to 9.5 cm, yielding a phase curve that has a phase range of approximately 340°. The main reflector's reflectarray elements are phased using standard techniques to produce the main beam in the boresight or $(\theta, \phi) = (0°, 0°)$ direction with respect to the reflectarray's coordinate system.

The reflectarray elements on the rim are intended to be reconfigurable elements. For the purposes of this study, we employ surrogates for reconfigurable elements based on the same square patch elements used on the main reflector. Various reflectarray elements with continuously tunable phase control have been experimentally demonstrated previously [5], and the phasing of the rim's reflectarray elements can also be carried out with only binary or quarternary phase states [4], suggesting that even switch-based elements could potentially be employed.

III. Simulation Results

For the analysis, TICRA Tools is employed using both GRASP and QUPES (the quasi-periodic surface) modules. For initial results, a rim width of $w = 1$ m is used [3] is used ($\approx 11\%$ of the total reflector area). The rim in this case comprises $2,044$ reflectarray elements, while the main reflectarray comprises $22,364$ elements. For reference, a standard paraboloidal reflector with the same feeding configuration is used. It produces 48.09 dBi of boresight gain with 80.55% aperture efficiency, as determined using GRASP.

To synthesize a null, the optimization goal is a single-point gain minimization at a specified angle (θ_n, ϕ_n), with a target gain of -10 dBi or lower. In the first experiment, the null is to be synthesized at $(\theta_n, \phi_n) = (1.75°, 0°)$, which is the location of the peak of the second sidelobe of the reference 18 m reflector, and hence a challenging case. An optimizer employing the minimax algorithm in TICRA is employed, where the optimization variables comprise the length (width) of the reflectarray elements in the rim portion of the reflector.

The results of the optimization process are shown in Figure 2. The optimized solution is able to produce a null in the vicinity of the requested null location, where the gain at $1.75°$ is -6.51 dBi, close to the targeted value. This is over 50 dB of suppression relative to the main beam. The angular width of the null, taken at a threshold 20 dB down from the second sidelobe peak of 21.8 dBi (i.e., threshold of 1.8 dBi) is approximately $0.12°$.

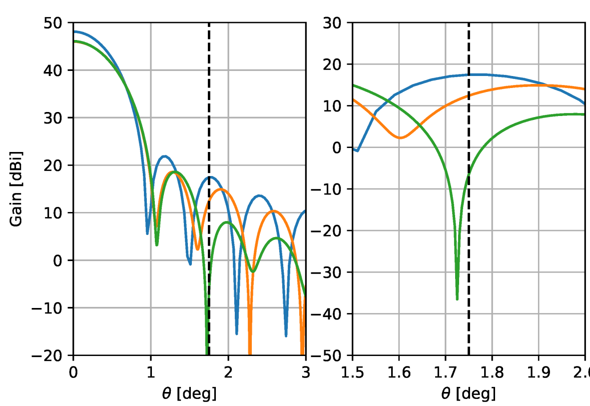

Fig. 2. Simulated gain of the reflector system (left) with a zoomed-in region (right). Legend: 18 m reference reflector (blue), 17 m reflectarray without rim (orange), composite optimized reflectarray (green)

The gain of the composite system is $G = 46.08$ dBi, 2.00 dB lower than the reference reflector. In fact, the 17 m reflectarray acting without the rim (also plotted in Figure 2) has a gain of 46.00 dBi. A 17 m paraboloidal reflector using an identical feeding arrangement has a simulated gain of 47.59 dBi, so the 17 m reflectarray implementation of the main reflector suffers 1.59 dB of additional gain loss. Meanwhile, the composite reflector achieves approximately the same gain (in fact, 0.08 dB higher due to the slightly larger area). This illustrates that while the efficiency of the main reflector could be improved, the rim itself is not responsible for significantly affecting the gain of the main reflectarray.

An additional experiment is attempted whereby the null is specified at $(\theta_n, \phi_n) = (2.4°, 0°)$, which is the location of the peak of the third sidelobe in the 18 m reflector. Using the same optimization process, the resulting gain of the final reflectarray system is plotted in Figure 3. The peak gain of the composite reflector is $G = 46.08$ dBi, which is virtually the same as the earlier nulling case (to numerical precision).

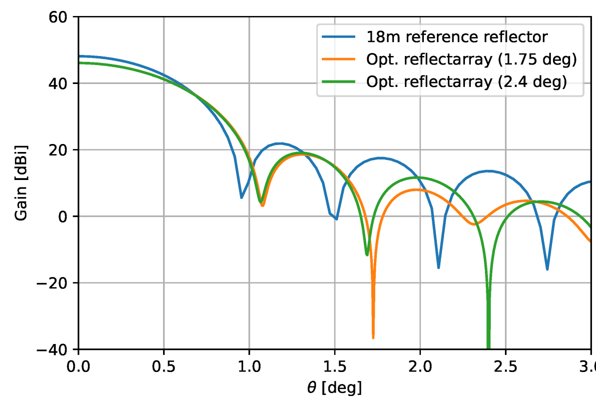

Fig. 3. Simulated gain of the reflector system for two null angles

IV. Conclusion

This paper has presented the first steps toward realizing a reflector with interference mitigation capabilities for radio astronomy. Using an entirely reflectarray-based implementation, simulation results demonstrate the null-forming capability of a fixed reflectarray augmented with a tunable rim. Future work will focus on improving the performance of the main reflectarray, as well as investigate experimental implementations.

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