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Electromagnetic Simulations of a Prototype Super-Resolving Cassegrain Antenna

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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. In optical microscopy several techniques have been successfully developed with the aim of narrowing the central lobe of the illumination Point Spread Function (PSF). In Astronomy, however, no similar techniques can be used. A feasible and practical method to design telescopes with angular resolution better than the diffraction limit consists of using variable transmittance pupils. The simplest pupils are discrete binary phase masks with finite phase-jump positions, also known as Toraldo Pupils (TPs). In 2015 we have started a project devoted to a more exhaustive analysis of TPs, in order to assess their potential usefulness to achieve SR on a radio telescope [1].

The main problem is how to interface the TP with the telescope and receiver optical system. One possible solution is to place the TP at an exit pupil of the telescope, since any modification of the wavefront at this locationis equivalent to modify the wavefront at the entrance pupil of the telescope. Therefore, we have simulated and tested an optical module for K-band, based on standard low refractive index materials, able to narrow the PSF. We have then devised a method to interface this SR module with a test Cassegrain antenna and we have carried out extensive electromagnetic (EM) numerical simulations to study the performance of the complete optical system. The optical module can be designed using either standard dielectric lenses (see Fig.1) or also a fully reflective optical system using ellipsoidal mirrors.

In this work we discuss the results of EM simulations to test both the refractive and reflective optical systems, and we describe some of the problems encountered during the simulations. We show that when the SR module is mounted on the antenna one can effectively achieve a narrower main beam in the far-field (see Fig.1). This system however tends to increase the side lobes of the antenna power pattern and decrease the overall efficiency because of various losses. Some of these undesirable effects can be partially compensated and in a separate work [2] we have also demonstrated that a more efficient *reflective* TP can be designed and fabricated which does not suffer from the limitations of the standard implementation (e.g., absorption and reflection losses, narrow bandwidth, etc.).

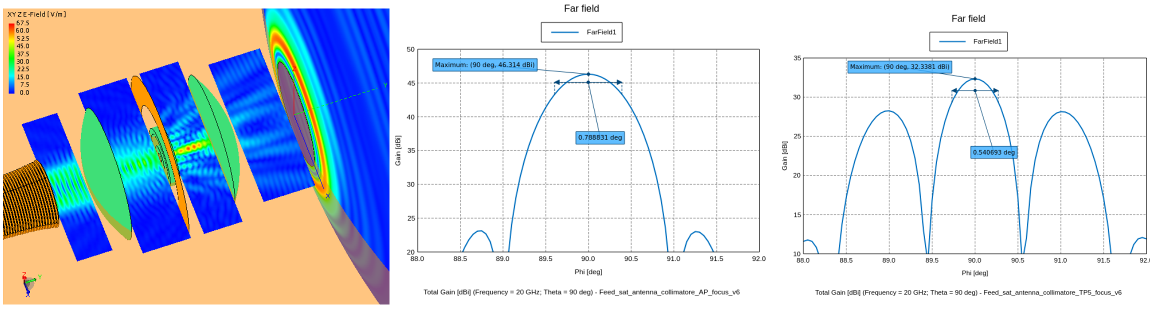

Figure 1. *Left Panel*. CAD model of the feed+lens collimator+antenna K-band system with superimposed the amplitude of the electric field as computed by FEKO. The Toraldo Pupil can be seen in between the two lenses. *Middle panel*. Far field antenna pattern obtained without the Toraldo Pupil. *Right panel*. Antenna pattern obtained when the TP is inserted in the collimator.

References

1. L. Olmi, et al., "Laboratory measurements of super-resolving Toraldo pupils for radio astronomical applications," *Experimental Astronomy,* **43**, 3, pp. 285-309, June 2017, doi:10.1007/s10686-017-9535-4.
2. A. Shitvov, G. Pisano, L. Olmi, P. Bolli, C. Tucker, "Reflective Toraldo pupil for high-resolution millimeter-wave astronomy," *Applied Optics,* **59**, 34, p. 10729, December 2020, doi:10.1364/AO.403490.