Il Colle di Galileo

Report on workshop "Super resolving systems: Toraldo pupils"

Villa Il Gioiello, Arcetri, Florence, October 12, 2017

P. Bolli (INAF-OAA), D. Mugnai (CNR-IFAC), L. Olmi (INAF-OAA)

Abstract. A one-day workshop entitled "Super resolving systems: Toraldo pupils" was held at Villa Il Gioiello (also known as Villa Galileo) in Arcetri on October 12, 2017. The workshop was an opportunity for all the researchers involved in the "PUTO" project to meet together. "PUTO" is aimed at investigating the use of super-resolving Toraldo pupils in radio astronomy, and during the workshop several topics related to the Toraldo pupils were discussed: from basic principles to advanced computational electromagnetic simulations, and from laboratory measurements to the test planned with the Medicina 32-m radio telescope. Finally, alternative designs for Toraldo pupils based on metamaterials were also discussed and a possible application of these optical systems to non-invasive microwave probing techniques was reported.

Keywords. Radio astronomy, super-resolution, electromagnetic simulations, anechoic chambers, near field – far field transformations, metamaterials.

1. Introduction

In 1952, Giuliano Toraldo di Francia suggested that the resolving power of an optical instrument could be improved using a filter consisting of finite-width concentric coronae of different amplitude and phase transmittance, now known as Toraldo pupils (TPs) [1]. The concept of "super-resolution" was born, and in the current literature it is generally associated with various methods for improving the angular resolution of an optical imaging system beyond the classical diffraction limit. In the microwave range, the first successful laboratory test of TPs was performed in 2003 [2], but it was only in 2014 that the use of TPs to achieve super-resolution in Radio Astronomy was proposed. This interest led to the PUTO ("Pupille Toraldo") project, a scientific collaboration among several research institutes (INAF and CNR) and universities (Università di Salerno and Cardiff University), co-funded by the Fondazione Cassa di Risparmio di Firenze. The workshop held in Arcetri on October 12, 2017, was an opportunity for all the researchers involved in the "PUTO" project to meet together, to receive updates on the scientific activity performed by each partner and to discuss the future directions of the project.

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2. Scientific report

The basic concepts of TPs were introduced by Daniela Mugnai, who discussed the analytical model of a TP. The super-resolution effect, i.e., an angular resolution beyond the classical diffraction limit, can be achieved by interposing a filter consisting of either infinitely narrow concentric rings or finite-width concentric annuli of different amplitude and phase transmittance in the entrance pupil of an optical system. The super-resolution is, however, accompanied by a decrease in the efficiency and an increase in the side-lobes amplitude. The laboratory measurements performed in 2003 and 2004 showed for the first time that a 3-coronae TP was able to reduce the width of the main beam at 10 GHz. The second talk by Pietro Bolli described the electromagnetic (EM) simulations of the TPs by using the FEKO, a commercial software computational code. This numerical analysis was used to compare the EM and analytical models and also to simulate the laboratory measurements performed in the anechoic chambers of the Arcetri Astrophysical Observatory and of the Institute of Applied Physics "Nello Carrara". These experimental measurements were performed by sampling the complex radiation field scattered by two different TPs in a near-field planar region [3]. The current simulation activity is focused on predicting the results for the collimator system, operating at 20 GHz, to be installed on the Medicina 32-m radio telescope.

The design of this optical module, whose purpose is to interface the TP with the telescope, was discussed in more detail by Luca Olmi during his presentation. He presented the goals of the planned tests at Medicina and described how the collimator will be mounted in front of the K-band receiver. Because of mechanical constraints, the nominal Cassegrain focus must be axially shifted away from the receiver by displacing the subreflector in the same direction, to make room for the collimator. The tests at the Medicina radio telescope will consist of two different phases: *i)* preliminary pointing and tracking of the satellite and planets, which will be used as point sources, and *ii)* after mounting and tuning the collimator, cross-scans with and without the TPs will be performed toward the point sources.

Francesco D'Agostino and Massimo Migliozzi, from the University of Salerno, contributed to the project with their experience in antenna pattern measurements. Francesco D'Agostino discussed the theory and techniques of both near-field measurements in anechoic chambers and open site test range for far-field measurements. He also discussed the near-field to far-field transformation. A new approach to designing and fabricating TPs was presented and discussed by Giampaolo Pisano from Cardiff University. In the current TP system, the required 180-degree phase shift is obtained by using conventional dielectric material with the appropriate thickness. However, Giampaolo Pisano showed that more effective and wider frequency band phase shifts can be obtained by using so-called metamaterials. This technology is widely used in different areas to cre-

ate dielectrically embedded multi-layer filters, flat mesh lens or even artificial materials like magnetic conductors.

The second part of the workshop was devoted to an overview of the current status and future perspectives of the 32-m Medicina Radio Telescope and the 64-m Sardinia Radio Telescope (SRT) and also to discuss other possible applications of TPs. Alessandro Orfei (INAF-IRA) gave a review of the current status of the Medicina Radio Telescope, specifically focusing on the continuous effort to maintain the antenna fully operational. A proposal is also underway to extend the maximum usable frequency of the radio telescope from 26 GHz up to 100 GHz. This would require replacing and re-aligning the main reflector panels and also a new sub-reflector, thus resulting in the possibility to observe at 100 GHz with reasonable efficiency. As a further step, the installation of an active surface with electromechanical actuators would provide at 100 GHz an almost flat aperture efficiency at every elevation. Then, Alessandro Navarrini (INAF-OAC) gave an overview of the SRT, focusing in particular on the most challenging aspects, like the recently refurbished active surface, and the shaped optical configuration. The Italian Space Agency observed the grand finale of the Cassini mission with an X-band receiver, and a six-month Early Science Program consisting of 12 large projects was completed by Aug. 2016. As a result of this program, several scientific papers are being published. Currently, a new cycle of technical and scientific recommissioning has started with the goal of offering a new Early Science Program in autumn 2018 and then to open SRT to the international community in early 2019.

Finally, presenters discussed the possibility of using a Phased Array Feed of Vivaldi antennas with digital beam-former to obtain the phase and amplitude distribution as requested by the TP, in order to achieve a super-resolution effect. The final talk of the workshop, given by Cristiano Riminesi (CNR-ICVBC), presented a different use of the TP. The idea is to exploit the super-resolving characteristics to improve non-invasive microwave techniques for diagnosis, monitoring and support for the purpose of restoring works of cultural heritage. These diagnosis methods are required to be non-destructive, portable, with an analysis depth up to 20-30 cm, a resolution accuracy on the order of 1 cm and real-time response. Different methods have been developed based on frequency modulated continuous wave radar or measurements of the reflection coefficient. Cristiano Riminesi concluded his talk by suggesting that TPs could give real benefits to this research field.

All presentations and the workshop program can be found on the PUTO webpage: http://www.ifac.cnr.it/PUTO/index.htm

3. Acknowledgments

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4. References

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Meeting Photo