New BOR1 and decoupling efficiencies for characterizing ultra-wideband reflectors and feeds for future radio telescopes

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New BOR1 and Decoupling Efficiencies for Characterizing Ultra-Wideband Reflectors and Feeds for Future Radio Telescopes

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***Abstract*—This paper presents some new topics that will be lectured in the December 2011 course within European School of Antennas course on *Reflector and Lens Antennas*. The new material is mainly related to characterization of wideband feeds for reflector antennas for future radio telescopes, such as for SKA and VLBI 2010. The lectures will contain details of how to design decade bandwidth log-periodic antenna feeds and in particular the so-called eleven feed, as well as focal plane arrays (FPA) for producing multiple beams shaped for optimum system performance. The designs has taken advantages of two newly defined efficiencies that are essential for optimum system performance: i) The socalled BOR1 efficiency characterizing the power loss due to higher order azimuthal variations in the far field function being very important in characterizing decade bandwidth feeds. And, ii) the decoupling efficiency being of importance for characterizing non-uniformly excited arrays such as FPAs, and being related to the classical embedded element efficiencies of normal phased arrays as well as their active (scanned) impedance.**

I. Introduction

This paper will give an overview of the research at Chalmers University of Technology related to developments of reflector and feed antenna technologies for future radio telescopes, such as the Square Kilometer Array (SKA) and the geodetic VLBI2010 (Very Long Baseline Interferometry) projects. The focus of this paper is to explain how two newly defined efficiencies have been of inestimable help in the development; the so-called BOR1 efficiency and the decoupling efficiency. These subefficiencies are together with more common ones like spillover, polarization, illumination and phase efficiencies determining the performance of the feed of reflector antennas. They are all lectured in the October 2011 course on *Reflector and Lens Antennas* within European School of Antennas.

II. BOR1 Efficiency and Single-Pixel Feeds

BOR1 efficiency is a measure of the power lost in higher order azimuth variations of the far field of the antenna (i.e. order 2 and larger). These variations represent losses, because they can never contribute to the directivity. The BOR1 efficiency was introduced already in 1995 [1] and is in that sense not new. However, it's importance has not been seen before, because most traditional feeds for reflectors have a rotationally symmetric geometry (BOR = Bodies of Revolution) in which case the θ and ϕ components of the far field have only first order azimuth variations, so that the BOR1 efficiency is unity. Ultrawideband antennas are normally not rotationally symmetric, so the BOR1 efficiency becomes an important contribution to the overall efficiency.

The BOR1 efficiency has in particular been important during the development of the log-periodic decade bandwidth Eleven feed, as described in [6]. The latest compact model of the Eleven feed working from 1 to 13 GHz is shown in the Figure 1. This successful research has included developments of a new novel antenna geometry [2], special methods and algorithms for designing log-periodic antennas [3][4][5], design of different models [6][7][8], mechanical design for operation when cooled down to 20 K, a cryostat large enough to house the feed (normally only Low Noise Amplifiers (LNAs) are cooled) [8], integration and noise matching to single-ended as well as differential LNAs, testing and more. The lectures will also review other wideband feed alternatives [9][10][11], and how the Eleven feed can be integrated with a waveguide feed to capture an additional higher frequency band [12].

The BOR1 efficiency doe also apply to focal-plane arrays.

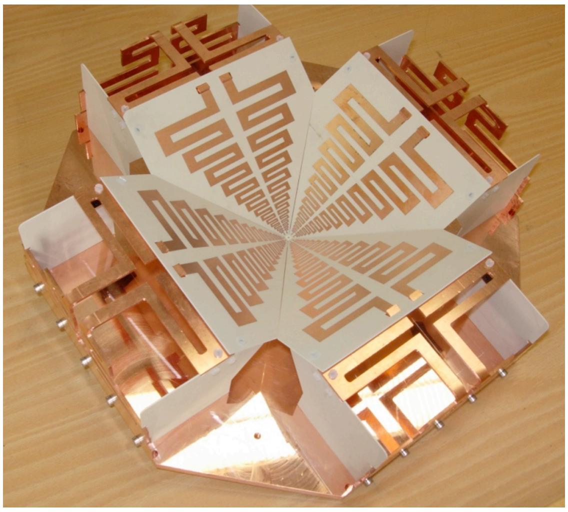

Figure 1: Photo of latest compact 1-13 GHz model of the Eleven feed under development for use in SKA and VLBI2010 radio telescopes. This version has not yet been published. The antenna is not rotationally symmetric, so the BOR1 efficiency characterizes the quality of the antenna in terms of azimuthal variation of the far-field function.

III. Decoupling Efficiency and Focal-Plane Arrays

The single-pixel Eleven feed has extreme bandwidth, but it can only provide a single beam, whereas it is advantageous for SKA radio telescopes to have multiple beams. This is possible with array feeds, such as focal plane arrays (FPA). These have very different and non-uniform excitations of neighboring elements, and each element may simultaneously be used to excite several beams. Therefore, whereas the impedance mismatch of single-pixel feeds are uniquely characterized by the mismatch factor, such mismatch factor cannot be defined on a beam-forming multi-port array antenna. The decoupling efficiency as defined in [13]-[14] comes then into effect and quantifies the total power loss due to both reflections and mutual coupling, at all the ports of non-uniformly excited array elements. This has a classical counterpart in the embedded element efficiency [15]-[16], and the general excitation-dependent formulation of the decoupling efficiency actually covers the whole spectrum of excitations from single-element-excited case (i.e. the embedded element efficiency) to "almost uniform" all-excited case. The latter is a classical array, and the decoupling efficiency becomes then equal to the mismatch factor. The embedded element efficiency has been successfully applied to characterize the focal plane array prototype developed for the Westerbork Synthesis Radio Telescope within the European FP6 program [17].

The decoupling efficiencies can with advantage be measured in a reverberation chamber [8], [19]. Actually, the embedded element efficiency, which as already mentioned is a single-element decoupling efficiency described by the same general formula in [14], is the main characterizing antenna parameter of a MIMO antenna system [20].

Figure 2: Photo of focal plane array developed at Astron, mounted in the focal plane of the reflector of the Westerbork radio telescope (left) and details of the Vivaldi-type elements (right). The antenna is a multi-port antenna with strongly non-uniformly-excited ports, so the decoupling efficiency characterises the mismatch and coupling losses, corresponding to the active (or scanned) mismatch efficiency for classical uniformly-excited phased arrays.

IV. System Optimization

The overall system performance must always be considered. This means for radio telescopes the A/T, i.e. the effective aperture area over the system noise temperature. The feed need to be optimized with the A/T in mind. The system design and noise temperature prediction have been included in [8]. For multi-port FPAs the noise prediction is more complicated, as the equivalent circuit for the noise temperature of the low noise amplifier will depend on the excitation of the elements [18].

V. Conclusion

The presentation will focus on the BOR1 and decoupling efficiencies. The definitions will be exemplified with simulated and measured results on both the eleven feed and the Vivaldi-type focal plane array developed at Astron.

The program of the ESoA course will also be overviewed, including in addition to the above-mentioned work by the authors of the present paper also the following three topics:

1. An introduction to reflector antenna design by Peter Meincke from Ticra. TICRA is recognized as the world-leader of commercial reflector antenna software GRASP9, which will serve to illustrate the presentation by means of examples.

2. Ronan Sauleau will review the lens antenna technologies and applications for millimeter and sub-millimeter wave applications [21][22]. The lectures will cover: 1) the analysis, the synthesis and the optimization of dielectric focusing systems using HF and full-wave techniques 2) the design of homogeneous / multi-shell, axis-symmetric / arbitrarily-shaped lenses (integrated lens antennas, dielectric lenses, dome antennas).

3. Stefano Maci will present high frequency methods used to analyze reflection, diffraction and scattering from reflector antenna surfaces, such as geometrical optics, geometrical theory of diffraction, incremental theory of diffraction [23][24], and shadow boundary integral techniques.

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