Reflectarrays in Future Satellite Antenna Systems: Application and Design

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Abstract—There has been significant interest in reflectarray antennas in recent years. The latest research have shown that reflectarrays can be used to provide solutions which are not possible using conventional technologies. In this paper, we present a general design framework for the design of advanced reflectarrays and show how it can be used to design antenna systems for future space-borne applications.

I. Introduction

In the last decade, research and development of transmit- and reflectarrays have gained momentum and many advanced reflectarrays have been designed [1]. Despite this, reflectarrays have not yet gained widespread use for space applications where conventional reflectors still are preferred. A major reason for this is believed to be the lack of dedicated design tools for reflectarrays. Recent developments at TICRA have shown that the performance of reflectarrays can be greatly improved, compared to previously reported results, if appropriate design methods are considered [2]. For this reason, TICRA have been working on developing a general design framework for the design and analysis of reflectarrays and other quasi-periodic surfaces.

In this paper, the general design framework developed by TICRA is presented along with application examples.

II. General Design Framework

For the design of reflectarrays, the process most commonly used today is based on tools with dedicated features for periodic surfaces. First, the type of array elements is designed based on its response in a periodic environment. Subsequently, a phase-only approach is adopted where the array elements are adjusted, element-by-element, to provide the phase distribution that is required over the reflectarray surface to achieve a given performance.

The main drawback of using such a two-step phase-only approach is that it optimizes each element individually by considering the local phase response, which is an intermediate quantity. The actual antenna requirements are formulated in terms of the radiation pattern performance. As a consequence, the direct relation between the optimisation variables and the optimisation goals is not maintained, leading to suboptimal designs.

To circumvent this issue, a direct optimisation approach where all elements of the reflectarray are optimized simultaneously to fulfill the far-field pattern specifications is used. The fact that all elements are optimized simultaneously while the resulting far field of the complete reflectarray is observed, implies that the mismatch between the desired and actual element performance, which is the major source of sub-optimal solutions in phase-only optimisations, does not play a direct role in the optimisation. Hence, instead of the optimized solution being limited by both assumptions made in the optimisation about the performance of the individual elements in the reflectarray as well as the actual performance of the reflectarray, only the latter part plays a role when using the direct optimisation approach.

The design procedure adopted in the general design framework is illustrated in Fig. 1. The initial two steps are identical to the existing design methods. The third step involves a large-scale direct optimisation of all array elements simultaneously. Typically, the number of optimisation variables ranges between 10,000 and 100,000. As a final step, the reflectarray elements can be optimized together with the remaining part of the antenna system, e.g., the feed and the platform. This gives the possibility to optimize the reflectarray in its final operational environment and thus compensate for the influence of this in the design of the reflectarray.

For the analysis, it is essential that the analysis methods used during the optimisation are both accurate and efficient. To this end, several analysis methods are included in the framework which can be used depending the application at hand. The methods are based on the local periodicity assumption and have been specifically tailored to handle realistic configurations involving multiple panels, holes, as well as both planar and curved surfaces. The analysis accuracy has been verified against full-wave simulations and various measurements campaigns.

For the optimisation, we have developed an efficient algorithm that is well-suited for large-scale optimisation problems. The algorithm is a gradient-based minimax algorithm that is also used in TICRA's commercial software packages [3].

III. Applications

The developed design tool described above has been essential for several of the research activities that TICRA has been involved in. In the following, a few application

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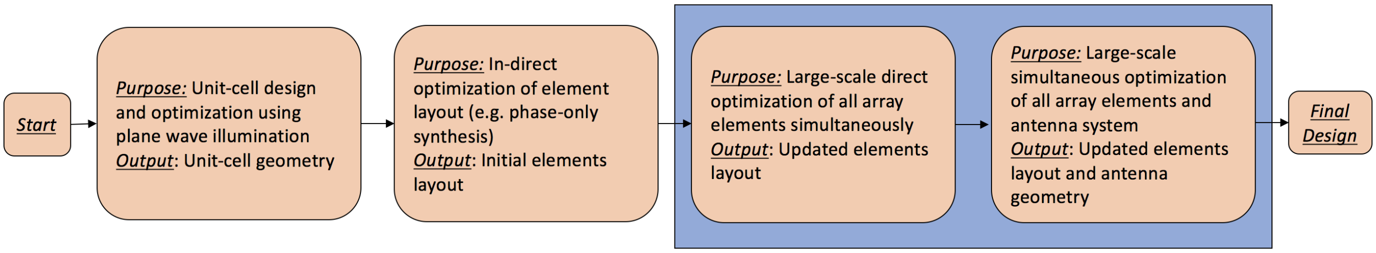

Fig. 1. Design procedure for the design of reflectarrays. The steps in the blue box are unique capabilities introduced in the design framework presented in this paper. The initial steps in the design process are identical to the existing design methods.

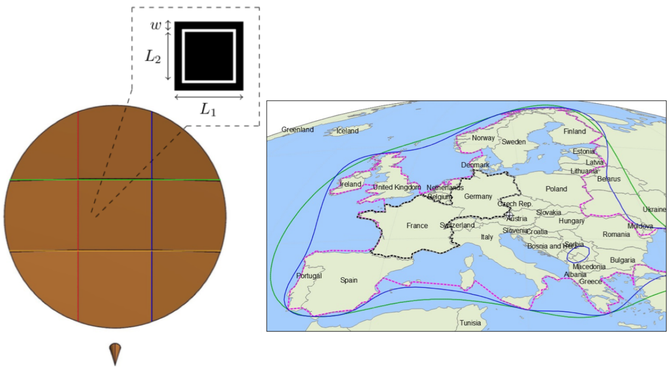

Fig. 2. C-band 6 m faceted reflectarray consisting of nine tilted panels and its radiation pattern compared to a 3 m shaped reflector.

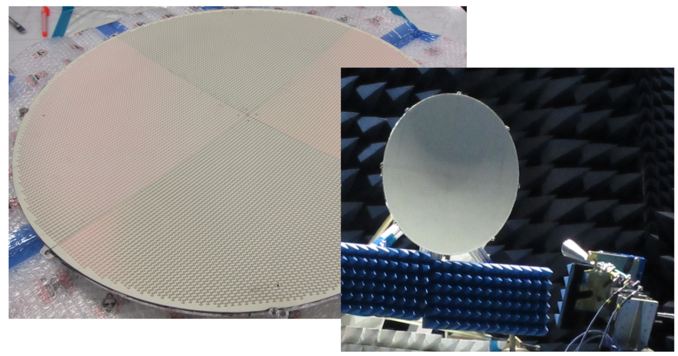

Fig. 3. Ka-band Tx/Rx curved multiple spot beam reflectarray.

examples are presented to highlight the capabilities of the developed tool.

A. Contoured Beam Applications

Reflectarrays provide a cheaper alternative solution for shaped reflectors which are currently the preferred technology for contoured beam applications. However, in order to match the performance of traditional shaped reflectors, curved reflectarrays are needed to enhance the bandwidth. The design of such reflectarrays is not trivial, in particular due to the fact that the curvature of the reflectarray surface. We have shown that using a standard parabolic surface, the requirements of multiple missions in Ku-band can be covered by simply changing the reflectarray element pattern while maintaining performances comparable to shaped reflectors [4].

For lower frequencies, e.g., C-band, where the size of the reflectors needs to be >3 m, reflectarrays can be a viable solution. To this end, a reflectarray can be made up by combining several planar panels which can be tilted with respect to each other to emulate the surface of a shaped reflector. In [5], we designed a faceted reflectarray with a diameter of 6 m operating in C-band. It consists of nine planar panels which are tilted with respect to each each other, see Fig. 2. It was found that a panelised 6 m reflectarray could achieve gain values within 0.4 dB of a solid shaped 6 m reflector while only needing a 2 m by 2 m envelope during launch (XPD values were still better than 30 dB over the entire coverage area).

B. Multiple Spot-Beam Applications

Multiple-beam reflector-antennas are the backbone of High-Throughput Satellites (HTS). The increased popularity of HTS and even VHTS platforms for telecommunication applications is due to their ability to reuse the allocated spectrum and thereby achieve increased bandwidth for the users of their services.

Currently, the state-of-the-art uses four single-feed-per-beam reflectors to cover a contiguous spot beam coverage following the 4-color reuse scheme. Using a parabolic reflectarray, it is possible to reduce the number of antennas from four to two. This is achieved by illuminating the two antennas with a set of dual-linearly polarized feeds and let the reflectarray create two circularly polarised beams, each slightly tilted in opposite directions. The concept was presented in [2] and in an on-going ESA activity, TICRA has, together with MDA, Canada, designed and manufactured the doubly curved multiple spot beam reflectarray shown in Fig. 3, which is the first of its kind.

An excellent correlation between simulations and measurements, illustrated in the plots in Fig 4, was obtained, demonstrating the high accuracy of the design tool and the manufacturability of a curved reflectarray.

C. CubeSat and SmallSat Applications

The number of commercial mission using small satellites and CubeSats has grown significantly over the past decade. For many of these small applications, high-gain antennas

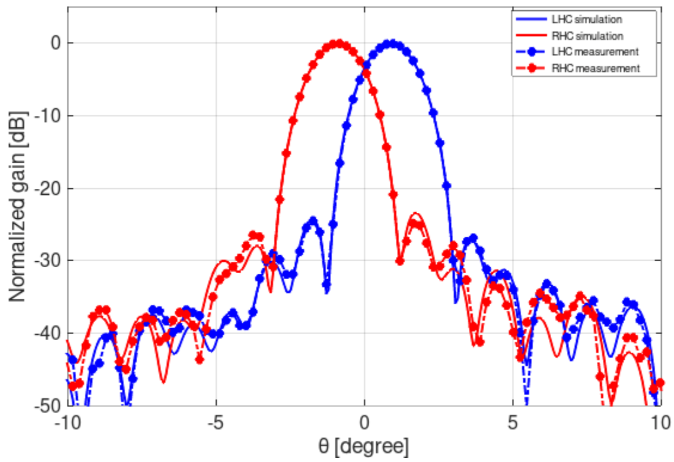

Fig. 4. Comparison of predictions and measurements of beams in the Tx band (18.8 GHz) of the doubly-curved linear-to-circular polarization reflectarray.

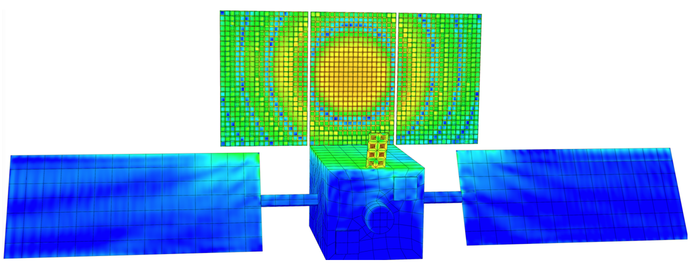

Fig. 5. Reflectarray model on ESA's M-ARGO CubeSat.

are needed, but due to the limited size and power of the satellite platforms it can be challenging to use classic paraboloidal reflectors or array antennas. Deployable reflectarrays, on the other hand, are ideal candidates on such satellites due to their ability to be stowed in very flat accommodation envelopes during launch. Consequently, several space agencies, e.g., NASA and ESA, are working on reflectarrays for CubeSats and TICRA's design tool is being used in these work, see Fig. 5.

D. Earth Observation

For earth observation missions that require high resolution SAR instruments the trend is moving towards more advanced beam stearing and multibeam-systems to achieve better resolution. An example of this is the Tandem-L mission currently being developed by the German Aerospace Center DLR [6] which uses digital beamforming to create multiple receive beam in each of the two SAR systems to be flown. Such a system architecture introduces extra risks in the mission due to the large number of active antenna elements and also has a high power consumption. As an alternative to this, each beam may be generated by its own feed and aperture, something which is possible with the use of reflectarray which can be stowed efficiently during launch and deployed on-orbit. The reflectarray technology is a promising candidate to meet these requirements and both NASA and ESA have identified this. Currently, TICRA is working together with Airbus Defence and Space on an ESA funded activity on this topic.

IV. Conclusion

In this paper, an overview of the running and recently completed reflectarray-related projects at TICRA and our collaboration partners were presented. Further details will be presented at the conference with emphasis on the benefits achievable when using direct optimisation instead of the commonly-used phase-only approach and the many different satellite applications in which reflectarrays have proven to be superior to regular reflectors.

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