Design of Dual-Polarized Contoured Beam Reflectarrays with Cross-Polar and Sidelobe Suppression

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***Abstract*—An efficient power pattern synthesis of contoured beam reflectarrays is presented. Using the presented synthesis technique, an offset dual-polarized contoured beam reflectarray to cover an European region with cross-polar and sidelobe suppression has been designed. Simulations show that the presented technique allows the cross-polar and the sidelobe level to be effectively suppressed in given regions.**

I. Introduction

Printed reflectarrays provide a way for realizing low-cost, high-gain antennas for space applications and are the subject of increasing research interest [1]. For satellite broadcast and telecommunication applications, where highly shaped contoured beams are required to illuminate specific geographical areas, the design requirements are extremely stringent and an accurate yet efficient synthesis procedure is essential to meet the necessary requirements. To cover the required geographical areas, the electric size of contoured beam reflectarrays is usually very large, and an accurate and efficient synthesis is therefore a challenging task. A direct power pattern synthesis where all array element parameters are simultaneously optimized in an iterative procedure can be computationally unaffordable, since it requires the analysis of all array elements at each iteration. Thus, contoured beam reflectarray synthesis is often done in two steps: first, a phase-only pattern synthesis is performed to determine the phase distribution on the reflectarray surface; and second, the array elements are optimized to match the phase distribution by using an analysis routine based on the Spectral Domain Method of Moments (SDMoM) assuming Local Periodicity (LP) [2]. In this approach, the analysis of all array elements at each iteration can be avoided and the computation time is reduced. Although this approach is efficient, a power pattern synthesis, where all the elements are simultaneously optimized, can potentially produce more optimal designs. Such an approach was presented in [3], where a contoured beam reflectarray was designed, fabricated, and measured. However, discrepancies between simulations and measurements were observed, and the authors of [3] mention that further work is needed to improve the accuracy of the reflectarray analysis.

A thorough investigation on accurate analysis of printed reflectarrays was presented in [4], where the accuracy of the analysis methods were established by comparison with measurements. The results of this investigation have been implemented in a new power pattern synthesis procedure, which is presented in this paper. To demonstrate its capabilities, an offset dual-polarized contoured beam reflectarray with cross-polar and sidelobe suppression has been designed.

II. Antenna Design

A. Reflectarray Analysis and Optimization Methods

The analysis method used in the optimization is based on the SDMoM and is briefly described in this section.

In the SDMoM computations, each array element is assumed to be illuminated by a locally plane wave. For an accurate representation of the incident field, a measured feed pattern is used.

To account for singularities of the electric currents at the edges on the array elements, higher order hierarchical Legendre basis functions as described in [5] are applied. These basis functions provide good convergence properties and yield results that are identical to those obtained with singular basis function, but using less computation time. With the accurate representation of the incident field and the suitable set of basis functions, it was shown in [4], [6], that the LP approach produces accurate results, also for the cross-polar radiation. The approach is a good trade off between accuracy and efficiency, and is therefore used in the optimization.

For the radiation calculations, technique II from [6] is used. This technique employs the field equivalence principle in conjunction with the scattering coefficients which are calculated using the fundamental Floquet mode from the LP formulation. It yields good results in the forward hemisphere provided that the finite substrate and ground plane size are correctly accounted for. In addition, the scattering coefficients can be pre-calculated and stored in a look-up table which can be accessed and interpolated during the optimization process. Consequently, the analysis of all array elements at each iteration is avoided, and the computation time is greatly reduced.

The optimization method is based on the minimax algorithm [7], where the maximum discrepancy between realized and specified gain at each iteration is minimized. The optimization routine is capable of optimizing both co- and cross-polar radiation, and for several feeds simultaneously. Thus, it is suitable for optimization of dual-polarized contour/multiple beam reflectarrays including cross-polar and sidelobe suppression.

B. Optimized Reflectarray

To demonstrate the capabilities of the synthesis, we consider an offset dual-polarized reflectarray that radiate a high-gain beam on an European coverage with cross-polar suppression within the same coverage and sidelobe suppression within a southern African contour. The coverages are shown in Fig. 1 as red polygons. The reflectarray consists of 2500 array elements and is designed for two orthogonal linear polarizations. The dimension of the reflectarray is selected to be $60 \times 60\,\mathrm{cm}^2$ corresponding to approximately 20×20 square wavelengths at $10\,\mathrm{GHz}$. The array is illuminated by a corrugated horn, whose measured radiation pattern is used in the analysis during the optimization.

First, the reflectarray is only optimized for the two orthogonal polarizations to cover the European region without any constraints on the cross-polar and sidelobe level (design 1). Identical patches are used as the initial guess for the array elements. In this design, the min. cross polarization discrimination (XPD) for both polarizations is around $21.5\,\mathrm{dB}$. The radiation on the southern African coverage is above $0\,\mathrm{dBi}$ with a min. high/low (Europe/Africa) gain isolation below $18\,\mathrm{dB}$.

Cross-polar suppression within the European coverage and sidelobe suppression within the southern African coverage are subsequently added in the optimization goals, and a new antenna (design 2) is designed. The co-polar radiation for the vertical polarization is shown in Fig. 1. The min. directivity within the European coverage is $26.1\,\mathrm{dBi}$, whereas the radiation on most of the southern African coverage is below $0\,\mathrm{dBi}$, yielding a min. isolation above $25\,\mathrm{dB}$. The cross-polar radiation has been reduced to a min. XPD of $25.8\,\mathrm{dB}$ compared to the $21.5\,\mathrm{dB}$ of the first design. For the horizontal polarization, the design has a very similar performance. A summary of the performance is listed in Table I. For this antenna, square patches were used. It is believed that even better results can be obtained by adding more degrees of freedom in the optimization, e.g. using rectangular patches or other types of array elements.

The optimized reflectarray is being manufactured and comparison of numerical simulations and measurement results will be presented at the conference.

III. Conclusion

An efficient power pattern synthesis of printed reflectarrays for contoured beam applications has been presented. Both co- and cross-polar radiation can be optimized for several feeds simultaneously, thus enabling the possibility of designing advanced contoured beam reflectarrays for dual-polarization with cross-polar and sidelobe suppression. An offset dual-polarized reflectarray that radiate a high-gain beam on an European coverage with cross-polar suppression within the same coverage and sidelobe suppression within a southern African contour has been designed. Simulations show improvements in the min. XPD as well as coverage isolations levels as compared to a similar reflectarray optimized only for the co-polar radiation without any constraints on the cross-polar and sidelobe level. The optimized reflectarray is currently being manufactured and measurement results will be presented at the conference.

TABLE I
Performance of Design 1 & 2

	Min. directivity	Min. XPD	Min. isolation
Design 1 (V-pol.)	27.0 dBi	21.5 dB	17.8 dB
Design 1 (H-pol.)	27.0 dBi	21.2 dB	17.1 dB
Design 2 (V-pol.)	26.1 dBi	25.8 dB	25.1 dB
Design 2 (H-pol.)	26.0 dBi	25.5 dB	26.0 dB

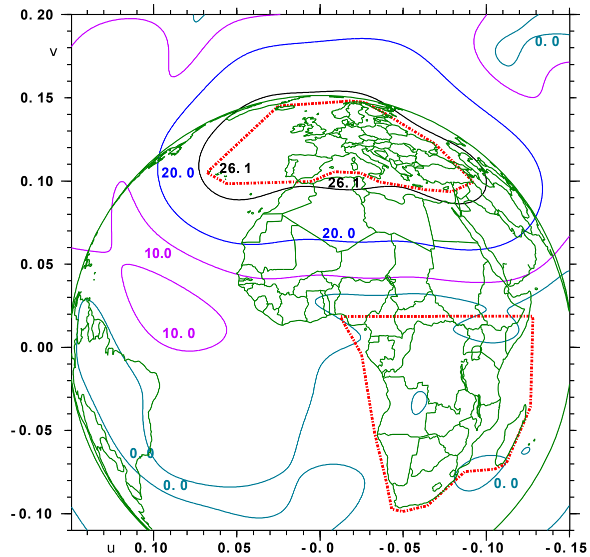

Fig. 1. Co-polar radiation of the optimized reflectarray at $10\,\mathrm{GHz}$ for vertical polarization. The coverages are defined by the red polygons. The reflectarray is optimized for high-gain radiation with cross-polar suppression within the European coverage and sidelobe suppression within the southern African coverage.

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