Wideband Design and Optimization of Reflectarray Antennas

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Abstract

This paper describes a technique for the design and optimization of wideband reflectarrays based on the generalized intersection approach and a direct layout optimization using a method of moments based on local periodicity. Results for two very large dual-linear reflectarrays for direct-to-home applications are provided and discussed. The first is a reflectarray working in a 15% bandwidth with European coverage. The second antenna provides coverage to South America in two frequency bands with very tight requirements.

1. Introduction

Reflectarray antennas suffer from an inherent narrow bandwidth due the differential space delay with regard to a parabolic surface and the resonant nature of the reflecting elements [1, 2]. There are several solutions to overcome these limitations, including the use of broadband reflectarray elements with several resonances, sub-wavelength periodicity, faceted or curved reflectarrays, etc.

In this work we propose a wideband design technique based on the use of a multi-resonant unit cell with up to eight Degrees of Freedom (DoF) [3] and a optimization algorithm based on the generalized intersection approach [4] to compensate for the differential space delay at several frequencies. In addition, the process is divided in several stages to facilitate convergence towards a wideband performance. Both copolar and crosspolar requirements are taken into account. This technique has been applied to two large reflectarray antennas for space applications, improving the results of others works in the literature.

2. Wideband Design Procedure

Figure 1 shows a flowchart of the proposed design methodology. First, a Phase-Only Synthesis (POS) is carried out at central frequency to obtain an initial narrowband layout. Next, a wideband optimization is carried out. In order to facilitate convergence, the initial stages only deal with a copolar synthesis, starting with a limited number of degrees of freedom with are progressively increased. Later on, cross-polarization requirement may be included in the process as well.

The main idea behind this process is to solve increasingly difficult problems by first dealing with a single frequency design, then only with copolar requirements in a wideband and finally including both copolar and crosspolar specifications. At the same time, by considering only a limited number of DoF per reflectarray element, the number of local minima is reduced, improving convergence [4]. However, to fully exploit the capabilities of the multi-resonant unit cell, the number of DoF is increased in successive stages to improve the performance of the optimized antenna.

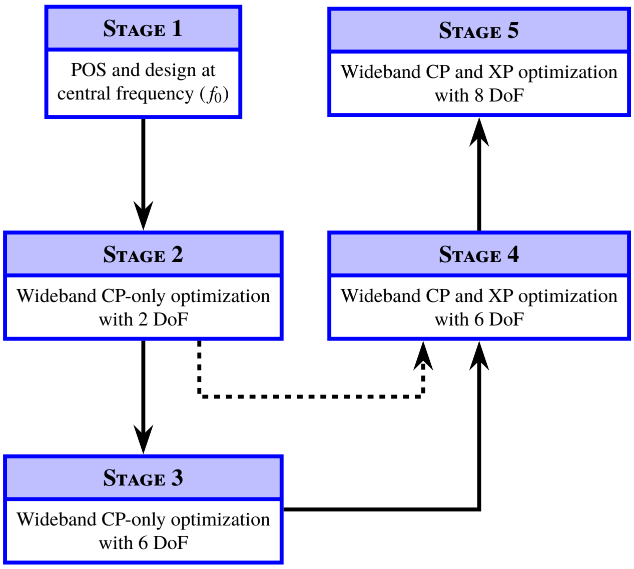

Figure 1: Flowchart of the wideband design procedure based on the generalized intersection approach. Stages three and five may be optional.

This procedure has been applied to two large reflectarray for space applications, in particular for direct-to-home broadcast from satellites in geostationary orbit.

3. Reflectarray with European Coverage

For the first example, the same antenna as in [5] is considered here. It is a 1 meter reflectarray comprised of 5180 elements working in a 15% frequency band (10.95 GHz – 12.75 GHz). The goal is to achieve a minimum copolar gain of 28 dBi in the coverage zone and a minimum crosspolar discrimination ($\mathrm{XPD}_{\mathrm{min}}$) of 30 dB, both in dual-linear polarization in the 15% frequency band.

Table 1 shows the results of this wideband design. It can be seen how both the minimum copolar gain and $\mathrm{XPD}_{\mathrm{min}}$ significantly improve after following the wideband design procedure described in Section II. In fact, compared to [5],

Table 1: Wideband performance of the reflectarray with European coverage for both linear polarizations in a 15% relative bandwidth, showing the minimum copolar gain ($\mathrm{CP_{min}}$) and minimum crosspolar discrimination ($\mathrm{XPD_{min}}$).

		10.95 GHz		**11.40 GHz**		**11.85 GHz**		**12.30 GHz**		**12.75 GHz**	
		X	Y	X	Y	X	Y	X	Y	X	Y
$\mathrm{CP_{min}}$ (in dBi)	**Initial layout**	25.99	25.94	28.79	28.59	30.11	30.06	26.03	28.21	15.15	23.69
	Optimized layout	28.23	28.32	28.77	28.83	28.48	28.83	28.56	29.09	28.04	29.27
$\mathrm{XPD_{min}}$ (in dB)	**Initial layout**	28.32	26.96	31.08	30.16	30.74	32.02	29.68	28.29	22.76	22.14
	Optimized layout	33.86	32.13	37.16	36.69	39.65	39.58	41.18	40.23	38.98	39.43

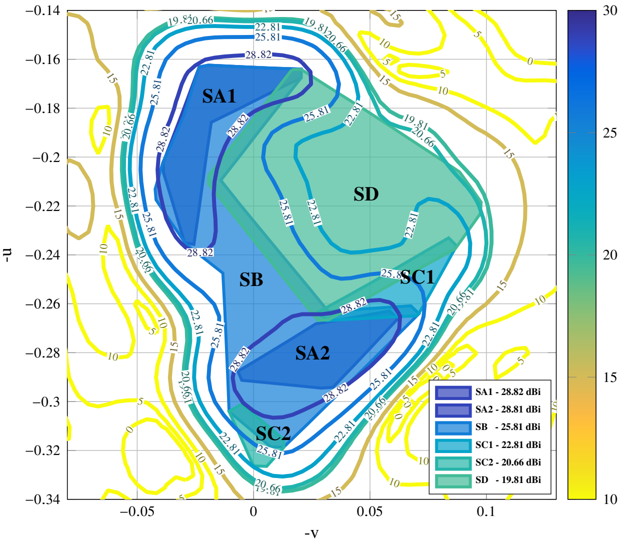

Figure 2: Copolar pattern for Y polarization at 11.70 GHz for the large reflectarray with South American coverage.

now a better cross-polarization is achieved in a wider band (11.3% vs. 15%), while using a simpler unit cell (three layers vs. two layers).

4. Dual-Band Reflectarray with South American Coverage

For the second example, the same reflectarray and requirements as in [6] is considered here. The coverage corresponds to the PAN_S mission of the Amazonas satellite, providing coverage to South America. The lower band (11.70 GHz – 12.20 GHz) is used for transmission while the upper band (13.75 GHz – 14.25 GHz) is used for reception.

Figure 2 shows the copolar pattern for Y polarization at 11.70 GHz with the South American coverage. All the requirements are met in both bands for dual-linear polarization with a loss budget of at least 0.59 dB. More results will be shown in the final paper and presentation.

5. Conclusions

A methodology to design wideband reflectarrays with improved copolar and crosspolar requirements has been presented. It is based on the generalized intersection approach and the use of a multi-resonant unit cell with several degrees of freedom. It is divided in several stages to facilitate convergence towards a wideband performance. It has been applied to the design of two large reflectarray antennas for space applications, obtaining excellent results.

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References

[1] J. Huang and J. A. Encinar, *Reflectarray Antennas*. Hoboken, NJ, USA: John Wiley & Sons, 2008.

[2] D. M. Pozar, “Wideband reflectarrays using artificial impedance surfaces,” *Electron. Lett.*, vol. 43, no. 3, pp. 148–149, Feb. 2007.

[3] R. Florencio, J. A. Encinar, R. R. Boix, V. Losada, and G. Toso, “Reflectarray antennas for dual polarization and broadband telecom satellite applications,” *IEEE Trans. Antennas Propag.*, vol. 63, no. 4, pp. 1234–1246, Apr. 2015.

[4] O. M. Bucci, G. D’Elia, G. Mazzarella, and G. Panariello, “Antenna pattern synthesis: a new general approach,” *Proc. IEEE*, vol. 82, no. 3, pp. 358–371, Mar. 1994.

[5] J. A. Encinar, M. Arrebola, M. Dejus, and C. Jouve, “Design of a 1-metre reflectarray for DBS application with 15% bandwidth,” in *First European Conference on Antennas and Propagation (EuCAP)*, Nice, France, Nov. 6–10, 2006, pp. 1–5.

[6] J. A. Encinar, R. Florencio, M. Arrebola, M. A. Salas-Natera, M. Barba, J. E. Page, R. R. Boix, and G. Toso, “Dual-polarization reflectarray in Ku-band based on two layers of dipole arrays for a transmit-receive satellite antenna with South American coverage,” *Int. J. Microw. Wirel. Technol.*, vol. 10, no. 2, pp. 149–159, 2018.