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A novel GO-based optimization technique for the design of shaped double reflectors

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Abstract

In this paper we present a novel technique based on a geometrical transformation and the Geometrical Optics, for the design of dual reflector antenna systems. The method is applied to the design of an antenna with a sectoral radiation pattern for radar surveillance.

1. Introduction

Dual reflector antenna systems represent a very flexible arrangement which can cover requirements no easy to fulfill with the simpler single reflector, especially when size constrains are imposed. Beyond the standard dual reflector configurations based on canonical shapes (conical surfaces) such as Gregorian, Cassegrain, etc., the possibility of using arbitrarily shaped surfaces allows an extreme flexibility on the pattern shaping because of the huge number of degrees of freedom. Specifically, by moving the two surfaces, the aperture distribution can be controlled both in amplitude and phase [1]. However, the design and the optimization of such shaped dual reflectors is not straightforward [2]. In the literature various methods have been proposed for the synthesis of dual reflectors antennas [3]-[5] based either on Physical Optics, or Geometrical Optics [6]-[11]. In this paper we propose a novel method based on a Geometrical Transformation Optics which combines the Geometrical Optics analysis with a geometrical mapping from the feed radiation pattern domain (which parametrize the subreflector surface) into the aperture distribution (which drives the description of the main reflector). The method is very fast and simultaneously reshape the two mirrors. It is successfully applied to the design of a compact sectoral antenna with high roll-off.

2. Formulation

With the goal of obtaining a high roll-off sectoral pattern for a surveillance radar application at 77GHz, we consider a double reflector configuration where a feeding horn illuminates a subreflector, which in turn illuminates a main reflector. To obtain a sharp almost rectangular pattern, we adopt the following approach. We aim to create a sinc-type aperture distribution, whose Fourier transform (radiation pattern) is rectangular. In practice only a limited number of lobes can be arranged in a limited size aperture. Such a limited sinc distribution can be obtained as the radiation pattern of a simple horn where the field distribution is assumed to be shaped as the fundamental rectangular waveguide mode TE_{10}. The sinc distribution is therefore projected onto a subreflector which is mapped in spherical coordinates with center at the horn phase center and an arbitrary shape $r = r(\theta, \phi)$,which has to be optimized and it is initially assumed as spherical. A number of control points are chosen in the *u*-*v* angular domain of the feed (Figure 1). Next, the rays impinging on the control points are forced to reflect toward a set of corresponding control points distributed on the main reflector surface mapped as $z = z(x, y)$, which also has to be optimized and it is initially assumed flat. This mapping from the subreflector to the main reflector is imposed *a priori* to squeeze the angular sinc distribution radiated by the feed onto a spatial sinc distribution on the aperture. Finally, the rays impinging at the control points on the main reflector are forced to reflect toward the boresight.

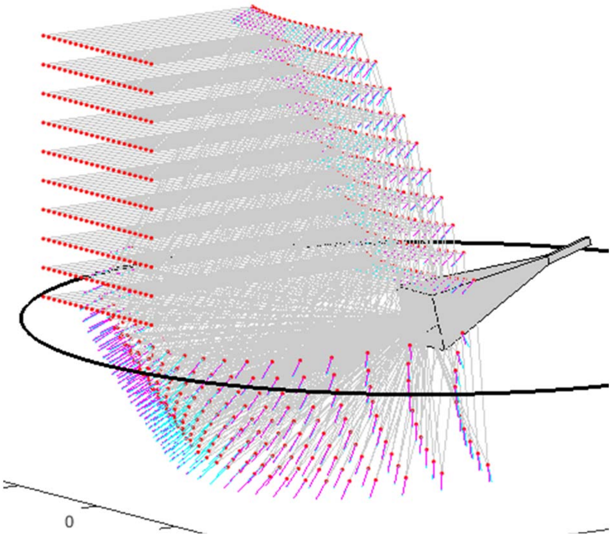

Figure 1. Dual reflector antenna system. Control points (red) define the mapping from the subreflector, to the main reflector, and finally to the aperture. Rays launched from the horn phase centre reflect at the control point where the bisecting unit vector (magenta) and the surface normal (cyano) are forced to be equal in the optimization loop.

The operation of "forcing" the GO rays to follow the requested path corresponds to imposing that the normal to the surfaces (both the subreflector and the main reflector) lies at the bisecting unit vector between the impinging and the reflected ray. Therefore, at any control point the desired normal to the surface is easily defined. Since the normal to the surface is expressed as the gradient of the unknown surface functions, i.e., $\hat{\mathbf{n}}_{sub} \sim \nabla r$, $\hat{\mathbf{n}}_{main} \sim \nabla z$, the complete surface is reconstructed, by integrating the samples of the normal unit vectors

$$r(u,v) = r(0,0) + \int_{(0,0)}^{(u,v)} \nabla_{uv} r \cdot d\ell \, ,$$

$$z(\ell) = z(\ell_0) + \int_{\ell_0}^{\ell} \nabla_{xy} z(\ell') \cdot d\ell' \, .$$

This operation allows to explicitly update the two reflector surfaces, which rapidly (4-5 steps) converge to the optimum shape, requiring only few seconds on a laptop. The analytical details of the algorithm are here omitted for the sake of brevity but will be shown in the conference presentation. Then, the antenna performance is evaluated by using the Physical Optics (Figure 2).

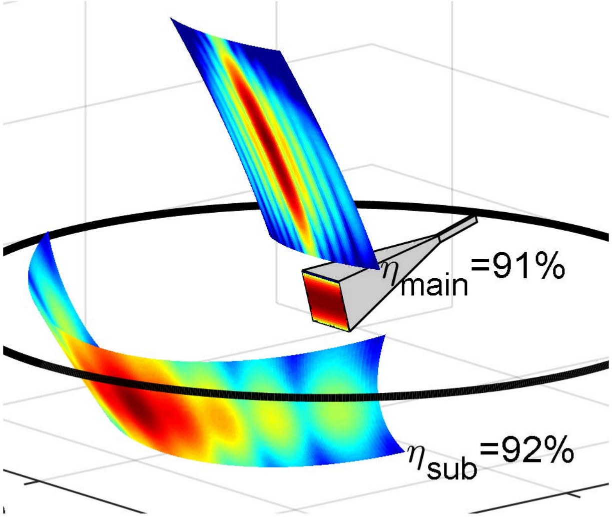

Figure 2. Dual reflector antenna system. The horn aperture and reflector surfaces are coulered with the PO electric current denity relative strenght. The spherical sinc distribution radiated by the feed horn is remapped by the reflection onto the subreflector into a spatial sinc distribution onto the main reflector. Its radiation provides a very sharp sectoral pattern.

3. Design example

As an example, we present the design of a radar antenna operating in the band 76-77GHz, which is required to exhibit an azimuthal sector of surveillance of 30° and an as small as possible elevation beamwidth. The targeted aperture distribution is uniform in the elevation plane and sinc in the azimuthal plane. In Figure 2 the final structure obtained by the optimization method is shown. The reflector surface is colored proportionally to the (relative) induced PO current strength (0dB=maximum, red; –40dB=blue). It is rather apparent as the sinc pattern radiated by the feed horn is intercepted by the subreflector and remapped by a proper reflection onto the main reflector, which finally redirect the wavefront toward the boresight.

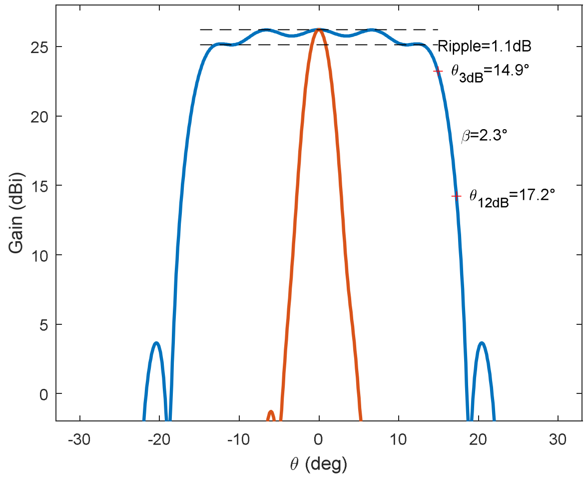

Figure 3. Radiation pattern in the azimuth (blue) and elevation planes of the optimized double reflector antenna system predicted by PO..

The radiation pattern in the elevation (red) and azimuth (blue) plane as predicted by PO is reported in Figure 3. The azimuth pattern appears quite flat (1.1dB of ripple) in the coverage beamwidth of HPBW=30°. The pattern falls down to -12dB in only 2.3° with a Rolloff = 3.9 dB/°. During the conference, several example of application will be presented with various antenna design.

4. References

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