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Bandwidth enhancement of electrically large shaped-beam reflectarray by modifying the shape and phase distribution of reflective surface

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ABSTRACT

In this paper the bandwidth performance of a reflectarray antenna to obtain fixed shaped-beam radiation pattern is studied. In order to achieve this purpose two parameters including the curvature of reflective surface and the phase distribution of reflective surface in the whole frequency band are simultaneously manipulated. Phase synthesis procedure is used to analyze the reflectarray. The particle swarm optimization is also used for obtaining the shaped-beam radiation pattern in the whole frequency band. It is shown that the bandwidth of a large reflectarray is considerably enhanced by decreasing the path length difference between phase center of the feed antenna and each point of the reflective surface. To verify this purpose, a shaped-beam reflectarray with concave reflective surface has been designed and simulated in the X-band with the commercial full-wave electromagnetic software, CST Microwave Studio and results to about 17% bandwidth for the stable cosecant square radiation pattern and pencil beam radiation pattern in E and H planes respectively.

1. Introduction

Reflectarray antennas are combination of reflector antennas and array antennas. These antennas are composed of some radiation elements etched on a surface and a feed antenna to illuminate radiation elements as shown in Fig. 1. Conformal reflectarray antennas are the most important types of reflectarrays that are used in radars and communication systems [1]. However, there are some limitations for installation of these antennas on communication equipment. Shaped-beam radiation pattern is an important topic in the synthesis of the reflectarray antenna. Antennas with the shaped-beam radiation patterns are required in many communication systems such as satellite communications, radar and wireless communications [2,3]. Moreover, shaped beam configurations can provide desirable area coverage [3–7]. In Ref. [7] the authors use the reflectarray for Direct Broadcast Satellite (DBS) applications. All efforts, which are reported till now to generate shaped-bema patterns, are implemented on single, multilayer and folded structures [2–9].

Several advantages of reflectarray antennas have low profile structure, simple feed network due to spatial feeding of array elements, possibilities to generate reconfigurable features and electronically scan radiation pattern compared to reflector antennas. The main disadvantage of these antennas is their low bandwidths [8]. The bandwidth drawback usually depends on two factors: radiation elements and the difference of spatial phase delay between elements and the feed antenna. Narrowband behavior of radiation elements is the main reason for having low bandwidth of small and moderate size reflectarrays.

In general, there are two approaches for enhancement of the bandwidths of reflectarray antennas. One approach is the use of the broadband radiation elements and another one is the decrease of the special phase delay between the feed antenna and all of the radiation elements. In small and mediocre reflectarrays, the first factor is more important than the second one. However in large reflectarray antennas, special phase delay is a very important factor because the difference of distance between each element and feed antenna is considerable and should not to be neglected. Therefore, in addition to the use of the broadband elements, shaping the reflective surface should be considered to enhance the bandwidth performance significantly in large reflectarrays.

Several literatures are reported till now to improve the bandwidth of the reflectarray antennas. Most of them focused on improving the first factor that is improving the bandwidths by

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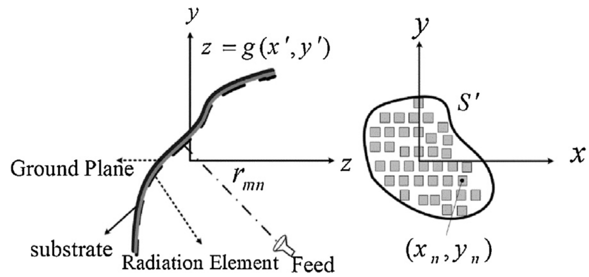

Fig. 1. Geometry of a general reflectarray antenna with arbitrary shape of reflective surface and its cross section.

designing the broadband radiation elements. Many broadband structures such as multilayer patch with different dimensions, artificial impedance surfaces, multi cross loop elements and rectangular patch-ring combination elements, have been proposed in Refs. [10–13]. In Ref. [14] the authors enhance the bandwidth about to 10.9% by decreasing the period of the radiation elements. However a cycle of 360° of phase shift is not achieved. Multi-resonant single layer elements are other favorable structures that are very useful to increase the bandwidth of small and moderate size reflectarrays because of low cost manufacturing process and high performance [15]. In recent years, few researches are done in order to increase the bandwidth of large shaped-beam reflectarray configurations. The use of the parabolic surface for reflectarray [16], dual-offset flat reflectarray [17], Dual-reflector antennas comprised of a reflectarray sub-reflector and parabolic reflector [18] are some examples. In Ref. [16] combination of two reflectarrays in a special arrangement has been designed and enhanced the bandwidth about to 20%. High cost and difficult manufacturing process are two important drawbacks of this antenna.

In Ref. [18] the authors combine the high gain and broadband advantages of a parabolic main reflector with the simplicity of manufacturing a small sub-reflectarray.

In this paper, we examine the effect of the shape of the reflective surface on the bandwidth of a large reflectarray antenna, neglecting the type of the radiation element. In order to verify the proposed method, an X-Band reflectarray antenna has been designed and simulated with CST Microwave Studio and a comparison was done between the simulated and the numerical results. In general, there are several bandwidth definitions for antenna configurations: (1) voltage standing wave ratio (VSWR) or impedance bandwidth, (2) axial ratio (AR) bandwidth, that are usually used for circularly polarized microstrip antennas [20], (3) 1-dB drop gain bandwidth which is almost used for reflectarrays with pencil beam patterns and finally [21] (4) stable shaped pattern bandwidth which is used for shaped-beam antennas. In this research the operating bandwidth is defined such that the antenna has relatively stable shaped-beam pattern for both elevation and azimuth planes in the whole band. Radiation pattern has been assumed a pencil beam and cosecant squared shape in azimuth and elevation planes, respectively. Several applications such as local multipoint distribution system central station [3], Ground-Mapping airborne radars and ground-based search radars use cosecant squared pattern. By using this type of patterns, antenna can get the required elevation coverage where the received power is independent of the radar range for a constant height target. In addition to shaping the elevation plane, realizing the pencil beam in azimuth plane can add the capability of scanning the pattern in large volume with high resolution in these configurations [22].

In order to enhance the frequency bandwidth of large reflectarray with stable shaped-beam radiation pattern, two works must be done. The large reflective surface can be modified so that the differential special phase delay becomes minimum, and optimize the necessary phase distribution of elements with respect to the frequency variations. Similar efforts have been done in Refs. [16,23]. The authors in Ref. [23] apply a novel wideband phase synthesis approach to optimize the reference phase at two sample frequency.

This paper is organized in two parts: in the first part, desired conditions to achieve a broadband large shaped-beam reflectarray such as the shape of the reflective surface and the optimum phase distribution on the reflective surface are argued. In the second part, a broadband reflectarray is implemented with the help of simple elements to realize the optimum phase distribution obtained in the first part. The first part is composed of two sections. In the first one, accurate analysis method based on phase only synthesis (POS), described in Ref. [9], is used to obtain the radiation pattern for different types of reflective surfaces with different curvatures. In this method, regardless of the element type, the phase distribution of the reflective surface has been calculated based on shaped-beam radiation pattern. For this end an optimization procedure is used to calculate the optimum phase distribution.

Afterwards, optimized phase distribution is adjusted such that the antenna obtains a shaped-beam pattern with a wide frequency bandwidth performance. For this purpose an intelligent algorithm called Particle Swarm Optimization (PSO) is adopted and parameters associated with reflected phase and frequency parameter are considered as the inputs of the optimization algorithm. Putting the frequency parameter in the optimization process leads to consider the effect of variation of the frequency on the radiation pattern in the whole band; therefore, other optimization parameters are tuned in their best state such that the effect of varying the amount of the frequency is alleviated and the goal function would be satisfied. Thus it can be said that the obtained parameters related to the reflected phase of the elements, have minimum influences from changing the frequency parameter. Moreover, it will be shown that the shape of the reflective surface influences on not only the shape of the radiation pattern, but also the enhancement of the bandwidth of the reflectarray antenna. This is realized by diminishing the differential special phase delay. Note that beside these considerations, a broadband radiation element should be designed to realize these optimum requirements.

2. Part 1: Principle of designing the reflectarray antenna

In this section, the overall process to design a large shaped-beam reflectarray antenna has been described. The shape of the reflective surface, suitable radiation element and finally adoption of an effective synthesis method are the factors needed to design a large shaped-beam reflectarray antenna. First, theoretical aspects of design of a shaped-beam reflectarray antenna are proposed. In this step, a reflective surface with three types of curvature including concave, convex and flat has been considered and the effect of reflective surface shape is examined on the shaped-beam radiation pattern and the best configuration is selected with respect to desired pattern. Afterward the suitable curve surface is used in the next step where a broadband shaped-beam reflectarray antenna will be designed and shown that this configuration helps to enhance the bandwidth of large reflectarrays.

2.1. Design equations

Several approaches have been utilized to design a reflectarray antenna such as array concept and physical optic [19], [24–26]. The authors have been used physical-optic approach in this study.