Optimization Strategies for Multibeam Transmitarray Antennas for 5G Systems

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***Abstract*—Multibeam antennas are the enabling technology for the realization of Multiple-Input Multiple-Output (MIMO) architectures to be used in 5G communication systems. Here, their feasibility with a Transmitarray (TA) is investigated, and three different approaches for their design are presented. The first one is a deterministic method, aimed to design a bifocal surface, the second proposes the use of a concave TA, while the other technique is based on the use of a pseudo-stochastic optimization algorithm.**

I. Introduction

The next 5th Generation (5G) of communication systems is expected to reach a very high data rate (Gb/s), corresponding to a 1000 times faster communication compared to the current technology [1]. In order to satisfy such impressive data traffic requirements [2], a notable effort in the research and exploration of novel and revolutionary technologies is needed. From the antenna point of view, Multiple-Input Multiple-Output (MIMO) antennas seem the most promising configurations to serve multiple users and to overcome the difficulty in covering the communication paths that are not on the line of sight. MIMO architectures require the use of multibeam antennas. Even if their most straightforward realization consists in the use of a phased-array, other alternative solutions can be adopted [3]. Among others, in [3] also Transmitarrays (TAs) are considered as possible candidate for the realization of efficient multibeam antennas.

Transmitarrays are considered one of the most promising solutions for the realization of high gain, low cost and high efficiency antennas [4]. They are also named planar lenses, since their working principle is very closed; nevertheless, TA consists in a planar surface, discretized by a proper number of unit-cells, with size lower or equal to $\lambda_0/2$, being λ_0 the wavelength at the design frequency f_0. Each unit-cell is characterized by one or more degrees of freedom, that are properly adjusted to compensate the incident field radiated by the feed. Transmitarrays can be adopted in a wide range of applications [4], and recently some results have also been presented on their use in massive MIMO systems [5].

II. Multibeam Transmitarray

A multibeam transmitarray consists in a planar surface able to transform the incident field in the desired radiation pattern and in a feed-array, generating beams in different directions: they impinge on the TA surface with different angles of incidence and this affects the direction of maximum radiation of the entire antenna. A sketch of such a configuration is depicted in Fig. 1.

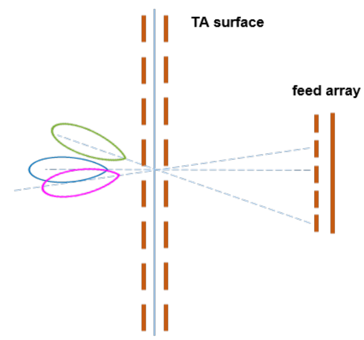

Fig. 1. Sketch of a multibeam transmitarray antenna

When a TA is designed, each unit-cell is adjusted to compensate the phase of the incident field for a given frequency and a fixed position of the feed. Both the unit-cell and the feed are properly chosen to maximize the radiation performances of the antenna, as well as their relative position, i.e., assuming that the feed is centered, their distance. A variation of the feed position clearly implies that the incident field impinges on the TA surface with an angle different from that considered during the antenna design. As a consequence, also the behavior of the unit-cell changes, since the phase and the amplitude of its transmission coefficient S_{21} depend on its selected geometrical parameter(s), but also on the direction of arrival of the incident wave. Therefore, the unit-cell is no longer able to provide the proper value for S_{21} and the radiation pattern is expected to deteriorate.

Even if the design of a multibeam transmitarray involves the definition of both the TA planar surface and the feed-array, here some techniques for the design of the transmitting surface optimization are considered, assuming that the feed is simply a standard horn, able to generate different beams when moved along an arc centered in the center of the TA surface.

III. Optimization Strategies

A. Bifocal TA design

The idea is to design a TA that presents two focal points, each one for a different direction of arrival of the incident field. The procedure for the design of a such TA consists in three steps. In the first one, the required phase distribution on the TA surfaces is computed, assuming the feed located in an off-set position, with the main beam forming an angle θ_1 with the z-axis, orthogonal to the transmittaray itself; then the feed is rotated, so that it keeps the same distance from the TA surface, but the direction of maximum radiation now forms an angle θ_2 with the z-axis, and the new phase distribution is computed. If, as in most of the cases, the unit-cells have just one degree of freedom, they are not able to provide concurrently the two desired phase distributions and therefore the TA is designed so that each element produces the mean value between the phases needed considering θ_1 and θ_2 as angles of incidence. The bifocal TA has better scanning performances that a conventional one, even if at the cost of a reduction of the gain and a deterioration of the main beam in the broadside direction.

B. Design of a concave TA

Another possible solution to optimize the scanning performances of a transmitarray is that of substituting the planar TA with a slightly concave surface. In this way the path difference between the feed and the unit-cells in different points of the TA is reduced and therefore a change in the feed position less affects the resulting radiation pattern.

C. $M_QC_{10} - BBO$ Optimization

The third considered approach consists in using a psudo-stochastic optimization algorithm to improve the performances of a multibeam TA. In particular, one of the schemes introduced in [6] is here adopted. They are enhanced versions of the standard Biogeography-Based Optimization (BBO) [7], with improved model for representing the variation of the quantities that regulate the exchanging of features among solutions, and with the introduction of a further parameter, named cataclysm, aimed to generate a new population when the algorithm stagnates. The application of the different schemes introduced in [6] to several banchmark functions and antenna problems proves that the most efficient is the M_QC_{10}-BBO, i.e. that adopting the quadratic model and taking not less than 5×10 iterations between two following cataclysms [6].

The M_QC_{10}-BBO scheme has been applied to optimize the radiation pattern of a multibeam transmitarray made up of 20×20 unit-cells. The phase of the radiated field of each array element is assumed to be a variable in the optimization process. Considering that the structure is symmetrical in both the x and y directions, the total number of the variables is equal to 100 (10×10). To optimize the radiation patterns, a set of shaped masks have been defined for some angles in the considered range: $\theta = -40°$, $\theta = -30°$, $\theta = -20°$, $\theta = -10°$ and $\theta = 0°$ for the E-plane and $\theta = 0°$ for the H-plane The aim of the optimizer is to find the TA configuration that radiates a pattern satisfying all the masks. The cost function is written as summation of terms that allow to control the beam direction, the side lobe levels and the beam width, and it includes numerical weights and penalty functions. The optimization has been carried out using a population of 200 elements, while the total number of iterations is 200. In Fig. 2, the radiation patterns obtained by the optimizer for scanning angles equal to $\theta = -30°$ and $\theta = 0°$ are plotted, together with the corresponding masks.

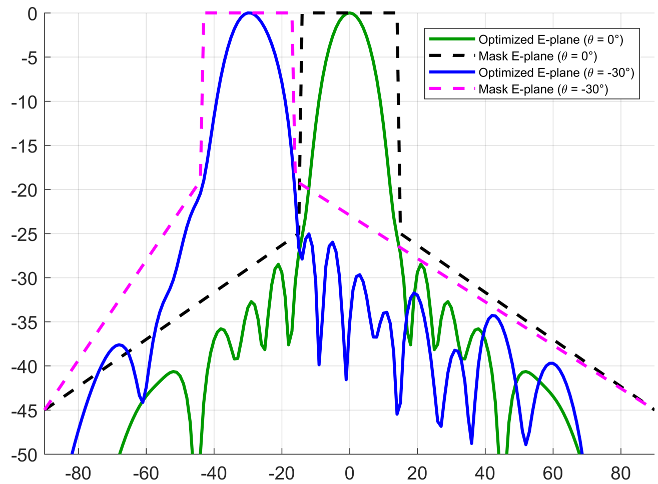

Fig. 2. Optimized radiation patterns (E-plane) for $\theta = 0°$, -30° and related masks

IV. Conclusion

In this paper, some possible techniques for increasing the multibeam capabilities of transmitarrays are discussed. The obtained results show their main potentiality and drawbacks, and in particular they point out that their better or worse behavior is strictly related to the considered type of unit cells. This apsect will be discussed more in detail at the time of the conference.

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