# Innovative MIMO Antennas for 5G Communication Systems

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***Abstract*—A key element in next generation 5G communication systems is the adopted antenna configuration. Among several possible solutions, particularly interesting for this application are the Multiple-Input Multiple-Output (MIMO) antennas, that allow to improve the channel capability exploiting the spatial properties of the channel itself. In this paper, after some general considerations on MIMO antennas, some preliminary results on an innovative configuration for their realization are presented.**

***Index Terms*—MIMO antenna, Multibeam antenna, MIMO beamforming**

## I. Introduction

The next 5th Generation (5G) of communication systems is expected to guarantee performances much higher than those provided by the previous standards: they will be able to serve a total amount of data that will increase by roughly 1000 times, with a worst data rate of 1 Gb/s, latency below 1 ms and reduced costs and energy consumption [1]. In order to satisfy all these requirements [2], a notable effort in the research and exploration of novel and revolutionary technologies is needed. In particular, the need of high data rates can be satisfied increasing the available frequency bands and the spectral efficiency. The first goal can be achieved moving towards higher frequencies (i.e. mm-waves) but also properly using the unlicensed bands in the $\mu$-wave spectrum (e.g. those below 6 GHz). The higher spectral efficiency can be obtained with the use of massive Multiple-Input Multiple-Output (MIMO) architectures [3]–[5]. Massive MIMO antennas are characterized by a number of radiating elements larger than the served user terminals: in this way, it is possible to enhance the throughput capacity, keeping high the energy efficiency, reducing the latency and increasing the communication systems robustness against possible interferences. These features can be obtained exploiting the spatial properties of the channel, especially taking advantages of the presence, in many environments as the urban one, of several mutipaths in addition to the line-of-sight one. The design of an efficient MIMO system involves two main aspects, i.e. the design of the actual antenna and of the beamforming algorithm.

The enabling technology for the realization of the radiating structures of a MIMO system is represented by multibeam antennas able to radiate several independent, high gain beams covering different angular regions. A wide overview of the existing multibeam antenna technologies that could be adopted for the design of MIMO antennas is provided in [6]: both passive and active solutions are considered, ranging from phased arrays to configurations based on the use of reflector and proper feed-arrays. Among the others, 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 (see [7] and references therein). They can be seen as a discrete version of a lens, where the curvature is simulated by a planar surface, divided in unit-cells with size equal or lower than half wavelength at the working frequency. In order to obtain the desired radiation pattern, the phase of the incident field is properly adjusted acting on one or more geometrical parameters of each unit-cell; moreover, the distance between the feed and the TA surface is generally optimized to reduce the spillover and to enhance the gain. For these reasons, TA are potential candidate for the design of multibeam antennas to be used in MIMO systems. While some results have already been presented in [8], the research in this field is still at the beginning and further studies are needed.

In this paper, after some general considerations on the working principles of a MIMO antenna and its beamforming, some results on the possibility to realize multibeam TAs are discussed.

## II. MIMO Antenna and Beamforming

A Tx/Rx MIMO system consists in a number $N_T$ of transmitting radiating elements and a number $N_R$ of receiving ones, as sketched in Fig. 1.

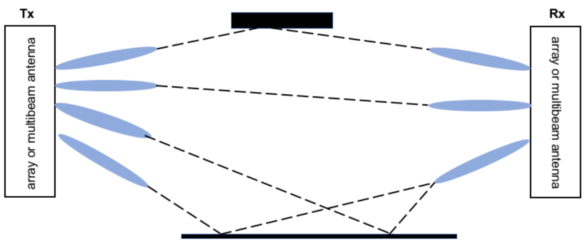


Fig. 1. Fig. 1. Sketch of a MIMO antenna systems, using multipath to connect Tx with Rx block.

The higher efficiency of a MIMO antenna over other configurations is related to the fact that it uses multipath, considered an interference source in conventional communication systems, to increase the channel throughput. To understand why this occurs, let firstly consider the case of an array, made up of $N$ elements, that has to send data to $N$ separate users. Its beamforming is designed in such a way that the antenna radiates several patterns (i.e. it shows a multibeam behavior), each one transmitting data just to a single user. If each radiation pattern encodes a different data stream, the entire system can transmit simultaneously to all the users with a spectral occupancy equal to that of a single transmission and therefore the total channel capacitance increases. In MIMO antennas something similar happens: if between the Tx and the Rx there are several possible paths (see Fig. 1), each of them can transmit a different data stream, increasing the channel throughput.

The system performances depend on different aspects: the characteristics of the antennas, i.e. its radiation pattern, polarization, bandwidth, etc. and the capability of modeling the communication channel. This last feature affect the definition of the beamforming algorithm: as better as it is able to predict the behavior of the channel as higher are the performances of the entire system. However, the structure of the propagation environment could only be communicated to the transmitter by the receiver, after its estimation, and this operation drastically increases the complexity of the algorithm; therefore, in many cases less performing but easier solutions are adopted.

## III. Multibeam Transmitarray for MIMO Systems

From the point of view of the antenna structure, the most popular solution for realizing MIMO multibeam systems are the phased-arrays, even if their complexity drastically increases with the number of radiating elements. For this reason, recently other possible solutions are investigated. Here, the feasibility of a multibeam transmitarray is analyzed.

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. 2.

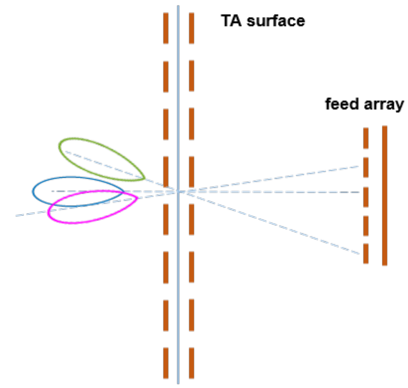


Fig. 2. Sketch of a multibeam transmitarray antenna.

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 the focus is on the first of these two elements and therefore the feed is simply modeled with a horn, whose position is changed along a circular focal arc. The preliminary results here presented are aimed to verify what is the effect of the rotation of the feed on the radiation pattern; in order to its minimization, an efficient unit-cell has been considered. It consists in a three layer dielectric structure: the central layer presents a square hole, whose size W is varied to control the phase of $S_{21}$; the two identical external ones have a truncated pyramid hole, with smaller basis equal to W and they act as matching circuits between the equivalent characteristic impedance of the central layer and that of the free-space. Several interesting features characterize this unit-cell, as a wide bandwidth behavior a reduced sensitivity to the direction of arrival of the incident wave: for this reason, it seems to be particularly suitable for the realization of a multibeam TA [9].

A square, reduced size ($10\lambda_0 \times 10\lambda_0$ at the working frequency $f_0$) transmitarray has been designed, considering the feed centered and located at a distance F = $10\lambda_0$ from the TA surface; the full-wave numerical analysis of that configuration, carried on with CST-Microwave Studio, returns the radiation pattern corresponding to red solid curve in Fig. 3. It is characterized by a maximum gain of 28 dB, HPBW of 6.3° and side lobe level (SLL) of almost -22 dB.

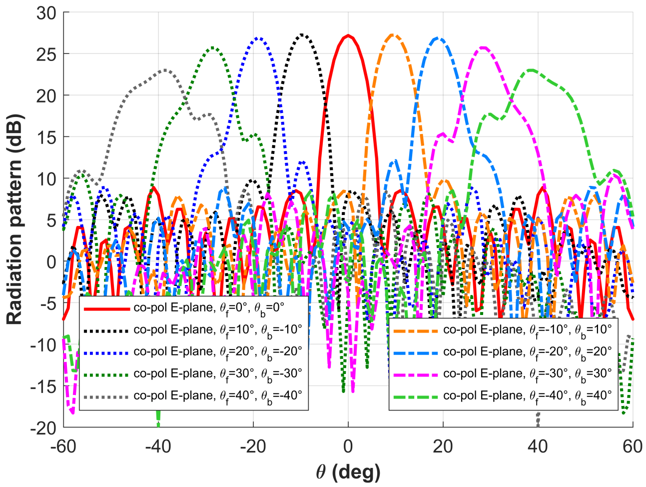


Fig. 3. E-plane radiation patterns of the designed TA for different values of the scanning angles ($\theta_b$), corresponding to different feed positions, identified by different values of $\theta_f$.

When the feed is rotated, a defocusing effect occurs, and the radiation pattern of the entire antenna worsens, as it emerges looking at the other curves plotted in Fig. 3, each one corresponding to a different position of the feed, identified by a different value of the angle f between the direction of maximum radiation of the feed itself and the z-axis, orthogonal to the TA surface: the main lobe becomes wider, the side-lobes increase and the gain decreases. Nevertheless, thanks to the good properties of the unit-cell, this deterioration becomes considerable for scanning angles $\theta_b$, locating the pointing of the antenna main beam, at least equal to 30°, in correspondence of which the gain is lowered of 2.5 dB approximately, the HPBW is enlarged of around 2° and the SSL increases of about 9.5 dB For smaller scanning angles, the radiation performances are just slightly worse than in the broadside direction ($\theta_b = 0°$).

Despite of these promising results, a proper design technique has to be used for the design of a multibeam TA, in order to improve its performances also for larger scanning angles: its development will be the object of further investigations, whose results will be presented during the Conference.

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