Planar microstrip series-fed array for 5G applications with beamforming capabilities

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***Abstract*— The next generation of mobile networks aim to allow an ubiquitous connection between hundreds different devices, improving the main properties in higher orders of magnitude, such as the capacity, coverage, connectivity, efficiency, among others. New challenges are put to the RF part, namely on the antennas, composed of dozens of radiating elements, whose beamforming abilities is a crucial property, combined with the reduced sizes and higher gains. In this work, a modular planar microstrip array is presented, designed for the 28GHz frequency band, in a 4x4 configuration, with capability to be connected to a RF front-end allowing beamforming. This antenna has small dimensions being a solution for applications of the next 5G networks.**

Keywords—5G, Antenna Array, Beamforming;

I. Introduction

The world is going through the era of communications, emerging every day new features and applications, connecting people and objects. The amount of consumed data grows more and more, together with the expectations of an increasingly technological society, smarter and with better services. In the coming years, an exponential growth of the number of connected devices is expected, as well as the volume of data traffic consumed. The new generation of mobile communications, 5G, aims to respond to this technological advance, providing an increase in capacity, coverage, connectivity, energy efficiency, and reduce the costs, when compared with the current 4G.

The 5G networks, whose a possible scenario is illustrated in the Fig. 1, will allow communication anywhere, static or moving, from the most densely populated to the most remote locations, and its applications can be grouped into three main topics with own requirements and priorities: Massive Internet of Things (IoT), Mission-Critical Services, and Enhanced Mobile Broadband [1-2].

Massive IoT are low power and low-cost communications, typically consists of connecting hundreds of small sensors, and has typical applications in agriculture, automation, smart homes or smart cities. Mission-Critical services require features of high throughput, low latency, with high reliability and security, and have application in autonomous vehicles, drones, and other critical applications. Enhanced Mobile Broadband refers to high throughput, wide coverage and faster internet service applications [1].

Fig. 1. 5G vision scenario.

The spectrum available for the 5G, allocated by the Third Generation Partnership Project (3GPP), is subdivided into bands below 6GHz and above 6GHz (in this case in millimeter waves, at 28GHz and 39GHz). The 5G networks therefore should have RF front-end systems that allow high versatility to adapt to different scenarios, highly efficient, and integrated [1-2].

To meet the new challenges of 5G communications (in different application scenarios), and to allow spatial filtering, beamforming, as well as a greater coverage, the use of adaptive antenna arrays are needed, with the ability to direct its radiation shape (beamforming), either digitally or in a hybrid way, using phase shifters. The use of beamforming allows also to overcome propagation problems that are observed when operating in the mmWave frequencies. These arrays consist of tens of radiating elements, individually controlled, to allow steer its beam.

In this paper, a planar antenna array is presented, designed to operate in the 5G band at 28GHz, to be used as part of a sensor in the 5G networks. This antenna consists of four independent elements that can be individually controlled by a RF front-end, enabling to direct its radiation pattern, and therefore to apply beamforming. Each of the four elements is itself a linear array of microstrip antennas, allowing for higher gains, contributing to a better communication.

This paper is divided into four sections, starting with an introduction to the topic and inserting the objective of this work. Section II describes the design process of the proposed array while the main simulated and measured results are presented and analyzed in the Section III. Finally, Section IV reports the main conclusions taken from this work.

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II. Antenna Structure and Design

To meet the needs of 5G networks in terms of versatility, efficiency, and integration, microstrip antennas are an interesting solution as it combines all these characteristics, allowing for compact and cost-effective solutions that are easily developed and easily integrated in the printed circuit boards of the RF front-end [3]. These antennas consist of a dielectric material covered by conducting material in both sides, one completely filled, working as a ground plane, and the other, with a specific structure designed working as a radiating element.

An antenna array, to present beamforming capabilities and allow steer its beam, each of its elements must be carefully and individually fed. Considering a modular structure, which can be extended according to the application, in this work was assumed a linear array of N=4 elements arranged along the x plane, as shown in the Fig. 2 a). Taking into account the radiation characteristics, especially the sidelobe level and the half power beamwidth (HPBW), and the dimensions of the modular structure, the distance between the elements was set d=0.75λ.

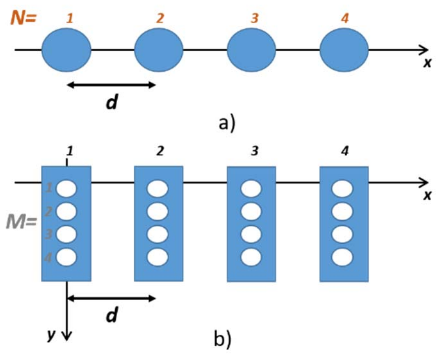

Fig. 2. Antenna array structure : a) Linear array b) Planar array

In order to achieve higher gains, to contribute to a better communication performance, and all the benefits proposed by the 5G networks, each of the N elements rather than a single antenna were considered to be a higher gain radiating structure, an subarray of M=4 elements, as shown in Fig 2 b). This number of elements is a compromise between the overall size and the directivity provided by each subarray antenna (of M elements). However, for other applications M may change.

To connect all the M subarray elements so they are fed in phase, the series feed technique [4] was used since it is a simple and compact solution (with lower losses) for the feeding of antenna arrays as compared with other alternatives. In this feed configuration, the edges of the various microstrip patches are connected by half-guided wavelength microstrip line sections.

Finally, to individually connect each of the N subarrays, considering the physical size of the connectors relative to the overall size of the antennas, extensions of microstrip lines were created, properly designed and separated, ensuring the equal electrical length in the feeding of all subarrays. The array feed network ends with a quarter-wavelength transformer to match the input impedance of the subarray with the 50Ω microstrip line at the input.

The planar array of N×M microstrip patches has been properly designed in CST MWS electromagnetic simulator for the central frequency of 28GHz, using the dielectric substrate Rogers RO4350b whose main characteristics are: relative dielectric constant ε_r=3.48, thickness h=0.762mm and loss tangent tgδ=0.0037. The structure of the final antenna array is presented in the Fig. 3, in which is possible to observer the four subarrays, each with four series-fed microstrip patch antennas.

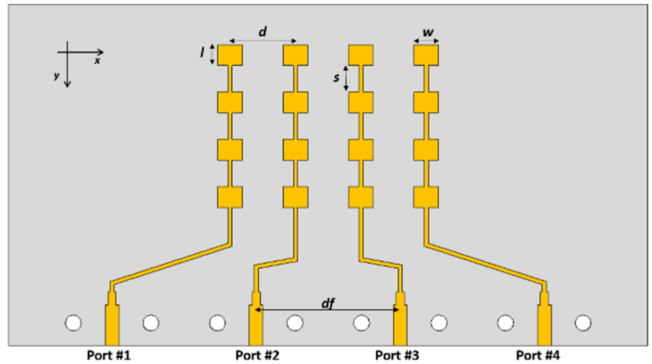

Fig. 3. Designed 4×4 planar antenna array

The main design parameters of the developed antenna are summarized in the Table 1.

TABLE I. Antenna Dimensions

Parameter	w	l	s	d	df
Dimension (mm)	3.03	2.56	3.26	8.03	17.7

This array can provide the control of the radiation pattern in the x-plane, adjusting the feed of each of the four input ports. There are more or less complex algorithms that can be applied to steer and shape the radiation pattern [5], however this work will be exemplified with the application of simplest principle, the phased array, by applying a progressive phase delay between the various ports, given by:

$$\alpha = -\beta d \cos \theta_i \tag{1}$$

where θ_i is the direction in which the maximum of the radiation diagram is to be oriented, d is the distance between elements, and β the phase constant.

III. Results

The designed array was manufactured and its picture is shown in the Fig. 4. The global dimensions are 78.5×42 mm^2.

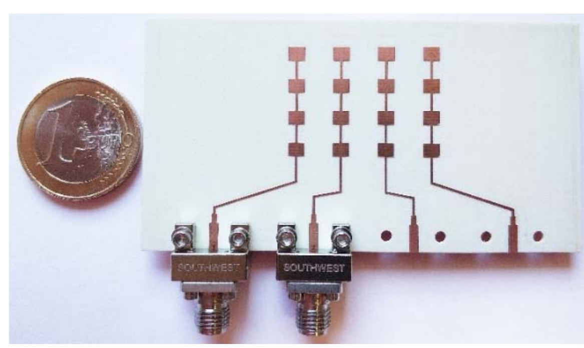

Fig. 4. Photography of the antenna array prototype at 28GHz.

The antenna was measured and its results compared to those obtained by simulation.

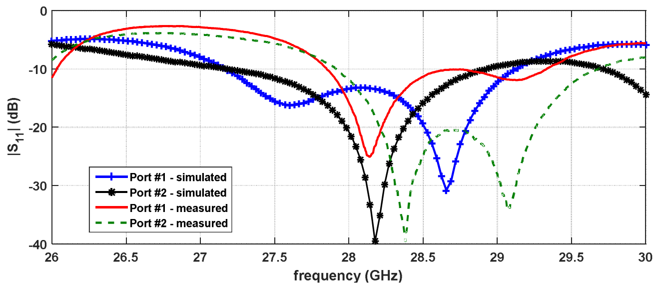

Fig. 5. Simulated and measured reflection coefficient of the antenna array.

Fig. 5 presents the comparison between the simulated and measured S_{11} of the antenna array. Since the array is symmetrical, in the figure it is just shown the results for the ports #1 and #2 (#1 & #4 and #2 & #4 are equal respectively). Both simulated and measured curves present acceptable results with more than 1.5GHz bandwidth (assuming the criteria of S_{11}<-10dB) although there's a small shift in the measured S_{11} of port #2.

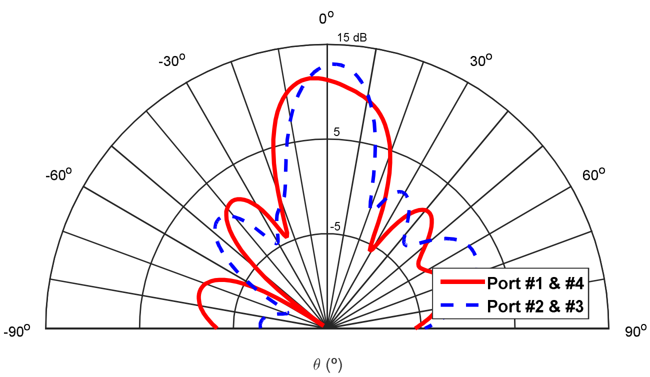

Fig. 6. Simulated radiation pattern (y-plane) of each subarray of M=4 series-fed patch antennas.

Fig. 6 shows the simulated radiation pattern in the plane y of each of the four subarrays. It is possible to observe that there are small differences between the curves, both presenting a very directive shape with gains of 11.5dBi and 12.9dBi respectively.

TABLE II. BEAMFORMING WEIGHTS

	#1	#2	#3	#4
θ=-25º	0	114	228	342
θ=-15º	0	70	140	210
θ=0º	0	0	0	0
θ=15º	0	-70	-140	-210
θ=25º	0	-114	-228	-342

The radiation pattern of the designed antenna array was simulated with the beamforming concept, using different sets of phases applied to its 4 ports, carefully estimated using (1) to steer the beam to different points. The calculated values are summarized in Table 2, and the respective simulated radiation patterns are present in Fig. 7.

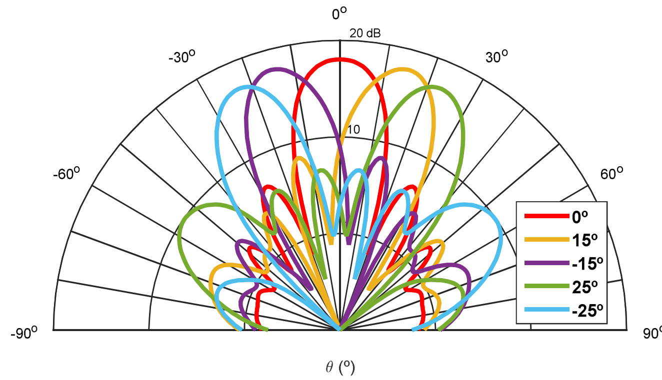

Fig. 7. Simulated radiation pattern (x-plane) of N=4 antenna array with the applied weights.

According to Fig. 7 it is possible to observe that the radiation pattern can be steered in the x-plane by applying a progressive phase in the feed of each of its 4 subarrays. For the boresight direction (θ=0º) the maximum gain is 18dBi, which is naturally reduced slightly as it is directed to different angular positions.

IV. Conclusions

A 4×4 planar microstrip antenna array has been developed to operate in the 5G networks at 28GHz. This antenna has a considerable bandwidth over 1.5GHz and gain about 18dBi, and is presented as a solution for beamforming application scenarios. Moreover, it has small dimensions and a modular structure that can be easily scalable for a greater number of ports and elements.

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