M-Port Rotationally Symmetric Antennas for Advanced MIMO Applications

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***Abstract*- Multiple-input multiple-output (MIMO) technology has emerged as a highly promising solution for wireless communication, offering an opportunity to overcome the limitations of traffic capacity in high-speed broadband wireless network access. By utilizing multiple antennas at both the transmitting and receiving Sub-6GHz ends, the MIMO system enhances the efficiency and performance of wireless communication systems [1]. This work presents a comparison of the performance of two families of M-Rotationally Symmetrical MIMO antenna design approaches one based on the Magneto Electric (ME) dipole antenna and a second one based on the Circular Cavity principle intended for their use into advanced MIMO applications like Orthogonal Angular Momentum (OAM) and high capacity channels. A comparison of the relevant performance parameters in terms of frequency bandwidth (both input impedance S_{ii} and inter-port isolation S_{ij}) and radiation pattern are presented for the two Sub-6GHz prototypes.**

I. INTRODUCTION

The 5th generation (5G) first and now the 6G wireless system is being developed to satisfy the new requirements in terms of data rate, latency, efficiency, and reliability [2], [3] due to the enormous growth data traffic in the current all-connected era. The 5G NR frequency bands are composed of the frequency range one (FR1) working at the so-called sub-6 GHz bands and the frequency range two (FR2), which cover the millimeter wave bands. The early deployment of the 5G is currently supported by the sub-6 GHz bands (FR1) due to the compatibility with the 2G/3G/4G infrastructure. The frequency bands which have received the most attention worldwide are the n77 (3.3-4.2 GHz), the n78 (3.3-3.8 GHz), and the n79 (4.4-5 GHz) bands. This new scenario has raised the interest in multiple antennas solutions for 5G sub-6 GHz applications.

In this context, one of the most relevant features for providing high data rates is the multiple-input multiple-output (MIMO) technology. When studying advanced MIMO channels, we may consider different multiplexing option like the conventional MIMO communication channel or the more recent circular travelling-wave Orbital Angular Momentum (OAM) Antennas that with a larger element spacing may further increase channel capacity for long enough communication distances [4]. For the frequency management two different approaches may be considered. On the one side multiple-band solutions such as a triple band design [5] with a dual-polarized antenna working both at 2G/3G/4G bands and at 5G band are adaptable but limited, especially when looking ahead on the new coding strategies. Instead wide-band solutions while more demandant in terms of design they are increasingly used for their flexibility and world-wide compatibility.

In this paper we present two wide-band MIMO compact antenna design one based on the Magneto Electric (ME) dipole principle and the other one into the Circular Cavity (CC) principle both able to support both conventional and OAM modes.

II. 4-PORT ROTATIONALLY SYMMETRIC ANTENNA DESIGN

In this section we are presenting the 4-Port ME and CC geometry designs, with their main circuital and radiation parameters for the frequency band approximately covering from 2 to 5 GHz.

A. The 4-Port Magnetoelectric (ME) Antenna Geometry

The Magnetoelectric dipole design comprises an electric dipole and a magnetic dipole positioned orthogonally [6]. These dipoles can either be co-located or separated by a small distance. In the scenario where the electric dipole and the magnetic dipole are co-located and excited with equal power and phase, the resulting radiation pattern manifests a cardioid shape with identical patterns in both the E-plane and the H-plane. In this way, the magnetoelectric dipole antenna exhibits broadband operational frequency and significantly suppresses back radiation, making it highly desirable for communications [7]. Also, the combination of the two (magnetic and electric) dipoles results in a more stable unidirectional radiation due to equal E and H planes. Moreover, unidirectional antennas with radiating elements on the same plane often experience lower mutual coupling, providing a significant advantage in the context of miniaturized MIMO array antenna systems. Fig 1, represents its basic geometry in which an horizontal planar electrical dipole limits an open-ended waveguide behaving as a magnetic dipole, both fed by a Γ-shape probe.

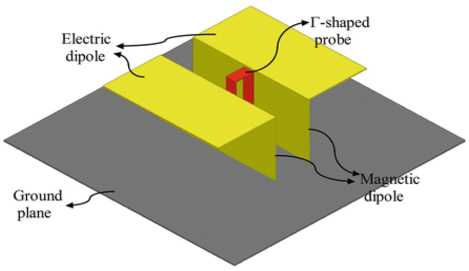
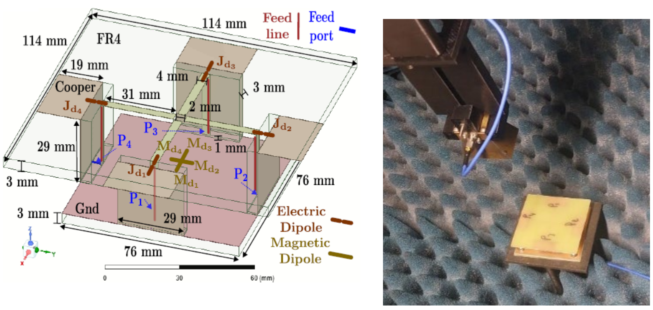


Fig. 1. Basic scheme of a ME dipole

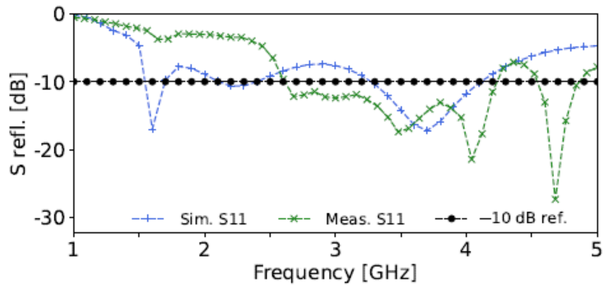
Based on this principle a 4-element antenna was designed as represented in Fig. 2 [8]. This antenna configuration comprises angularly equally spaced electric λ/2-dipoles positioned on the xy-plane and with λ/4 feeding lines along z-axis (Fig. 2.a) Consequently, together with the ground plane, the combination generates xy-plane magnetic dipoles. Then, all these electric and magnetic dipoles constructively interfere in the +z direction, while destructively interfere in the −z direction, and results in achieving an effective emission mostly on the positive z hemisphere. In Fig. 2.b the fabricated antenna located into a Mini Anechoic Chamber is shown for the measurement of its broadside radiated field distribution



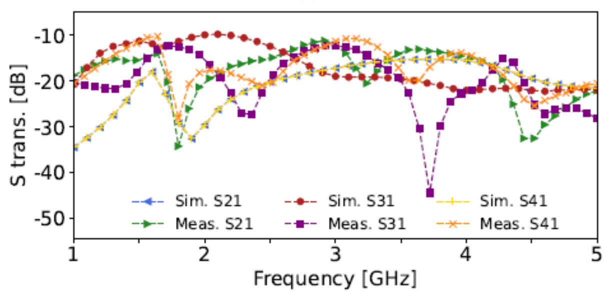
(a) (b)

Fig. 2. Scheme of the 4-port ME antenna (a) and picture of the fabricated prototype, (b)

The S-parameters of the antenna were numerically simulated with Ansys HFSS and experimentally measured from 1 GHz to 6 GHz using a Network Analyzer. The results obtained from the antenna testing exhibit adequate performance, particularly in terms of its S parameters. The antenna resonates at a frequency of 3.5 GHz, showcasing a bandwidth close to 2GHz, shown in Fig. 3a. This bandwidth, coupled with matching and minimal cross-coupling between ports, Fig. 3.b, underscores the antenna's efficiency in transmitting and receiving signals. Additionally, the radiation pattern of the antenna, Fig. 3.c, was analyzed within the controlled environment of an anechoic chamber for the conventional and OAM MIMO solutions and results show a good behavior.



(a)



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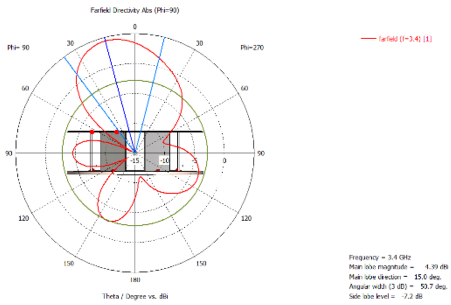


Fig. 3. Comparison of simulated and measured results for the 4-port ME antenna: a) S_{11}, b) S_{IJ}, c) E-plane radiation pattern

B. The 4-Port Coaxial Cavity Antenna Geometry

In this section, the analysis of a coaxial cavity is addressed. It may be an open or closed geometry, the last having a top cover enclosing the structure. Closed cavities are described in the electromagnetic literature using cavity modes, and the electric and magnetic fields are derived for canonical geometries of the coaxial cavity, which is analytically described in [9]. Instead, open cavities are not analytically described, so we propose the use of characteristic mode analysis to analyze open cavities and sectors.

In order to reduce the mutual coupling between the close radiating elements, a solution based on a coaxial cavity structure is proposed, with the objective of increasing the decoupling. Open coaxial cavity modes have been studied which have a very similar behavior to closed cylindrical cavities, especially in the resonances that depend on the radius and the ϕ variable

In order to achieve good performance, higher order modes with azimuthal symmetry have been studied. Resonances of semi-cylindrical or sectorial structures have also been studied [10] These modes can be fed with resonant structures such as planar monopoles or quarter-wavelength wire resonators.

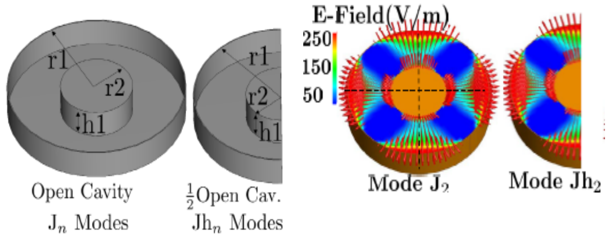


Fig. 4. Basic scheme for the coaxial cavity: a) Geometry, b) Modal currents distribution

A structure, Fig. 4, with a rotational symmetry of order 4 has been developed, which allows a large bandwidth, with filtering capabilities in the 3 to 5 GHz band, and which also has an isolation between 13 and 15 dB in the band of interest.

Figure 5 shows the basic schematic of the antenna, previously presented in [11] and a photograph of the developed prototype of which new measurement results are presented. Figure 6 shows the measured values of the S-parameters and radiation pattern.

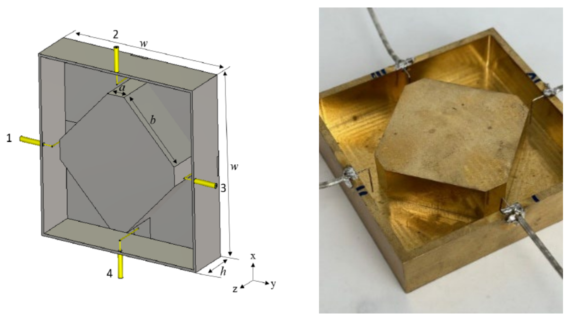


Fig. 5. 4-port Coaxial Cavity geometry. a) basic scheme, b) fabricated antenna

Regarding the radiation patterns, they have linear polarization for each of the ports and are decoupled between them, with very low values of the envelope correlation coefficient (ECC). With this type of structure, four orthogonal modes can be achieved with four degrees of freedom.
The best known is to achieve 2 orthogonal linear polarizations (vertical, horizontal) or two circular polarizations CW and CCW. With this type of antenna, it is also possible to obtain vertical or horizontal monopulse modes with linear polarization, or equivalently the 2 higher order OAM modes with nulls in the broadside direction.

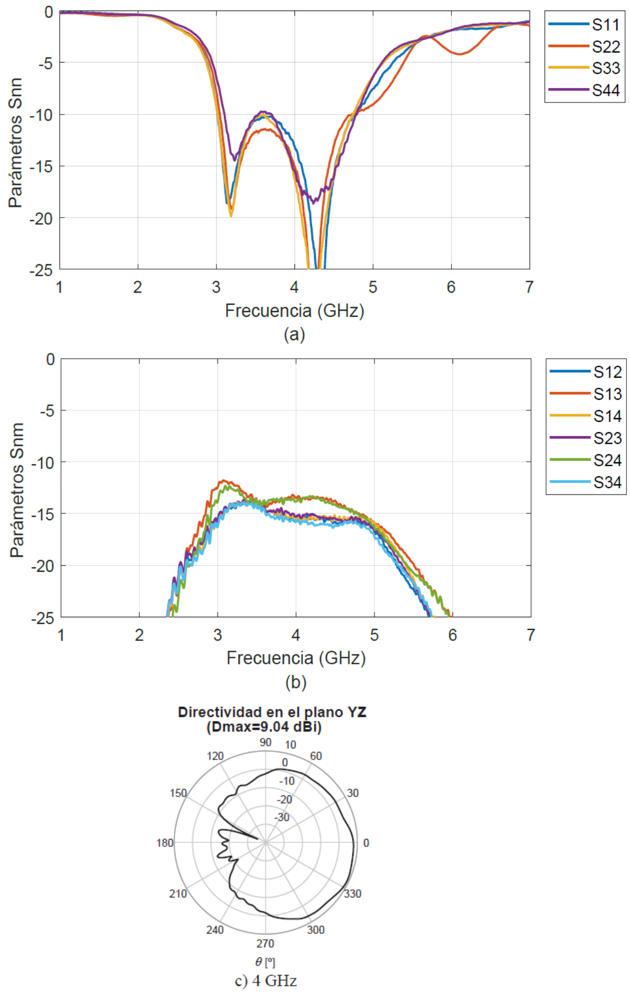


Fig. 6. Measured results for the 4-port coaxial antenna. a) S_{11}, b) S_{ij}, c) radiation pattern

C. Comparison of the parameters for the ME and CC 4-Port Antenna Geometries

The two proposed antennas have similar bandwidth and matching characteristics, with 4 independent and decoupled ports. Both can achieve up to 4 independent radiation modes, which can be expressed as OAM modes, or more conventionally as sum and difference modes for two polarizations.

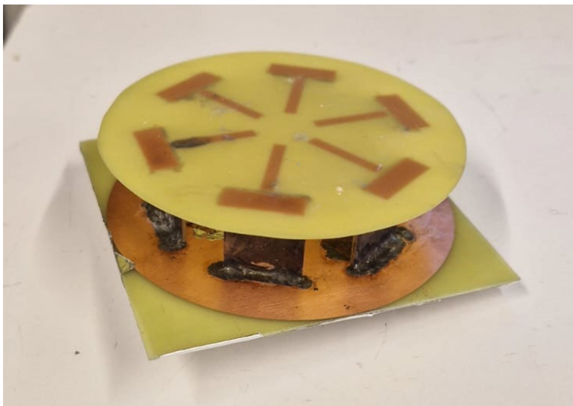
Table I shows the most relevant frequency, matching and isolation parameters.

Antenna	f min	f max	S_{11}	S_{ij}
Mag-Elec	2.5 GHz	4.2 GHz	-10 dB	-10 dB
Coaxial Cavity	3.0 GHz	4.8 GHz	-10 dB	-13 dB

TABLE I

III. Towards the M-Port Rotationally Symmetric Antenna Design. The 6-port initial geometry

When looking into the mentioned applications for both conventional MIMO and OAM-MIMO, the main objective may be to increase the capacity based on increasing the number of modes. In order to extend the number of modes a higher order rotationally symmetric structures with a large number of ports have been studied. Two examples of order 6 are shown in Fig. 7. Results of circular clusters of up to 10 ports have also been previously presented [12].



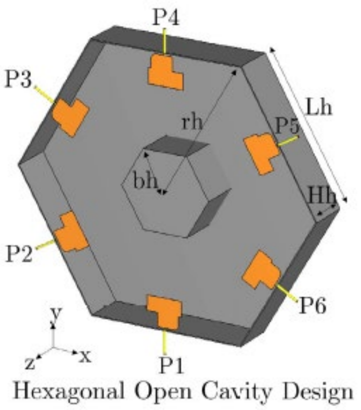


Fig. 7. 6-port ME and CC prototypes

IV. Conclusions

Two 4-port Rotationally Symmetric planar antennas have been presented and their parameter compared in terms of frequency bandwidth, inter-port isolation and radiation patterns. While their principle of design the magnetoelectric for the first case and the coaxial cavity for the second are different, final results are quite close.

The magnetoelectric principle proposes a clear physical principle to understand the radiation parameters while the modal technique gives a clear way to optimize the parameters of the antenna.

The combination of the two techniques results on a good methodology to afford the design of the kind of m-port antennas.

Acknowledgements

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