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Wolosinski, G., Fusco, V., & Rulikowski, P. (2018). Mode-Based MIMO Antenna with Polarization and Pattern Diversity for Base Station Applications. In 2018 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting IEEE .

Published in:
2018 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting

Document Version:
Peer reviewed version

Mode-Based MIMO Antenna with Polarization and Pattern Diversity for Base Station Applications

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Abstract—**This paper introduces a new design approach for multi-element MIMO antennas that exploit the mode-based technique. Such a technique applied to a multi-element antenna with circular symmetry allows to obtain orthogonal radiation patterns and full port decoupling by means of a mode decomposition network (MDN). Typically, the MDN input ports require matching networks to achieve proper antenna operation. The objective of the proposed design approach is to overcome the need of such matching networks therefore enabling wider operating bandwidths. This approach is then used to design a four-element MIMO antenna capable to achieve polarization and pattern diversity by means of four radiation patterns directed along a hemisphere. Simulation results of the antenna show that very low envelope correlation coefficients (ECC) and good mean effective gains (MEG) can be achieved. These features along with full port decoupling make the proposed antenna design very attractive for base station applications of next generation.**

Keywords— MIMO, multimode antenna, mode decomposition network, pattern diversity, polarization diversity, port decoupling.

I. INTRODUCTION

In the last two decades, Multiple-Input-Multiple-Output (MIMO) technology has received massive interest in wireless communications due to the potential of improving spectral efficiency by exploiting multiple transmit and receive antennas [1]. In order to achieve the promised MIMO performance multipath propagation with low spatial correlation is required [1]. In practice, the lack of scattering within the physical channel and insufficient antenna separation increase spatial correlation reducing thus the achievable system performance. Moreover, a close distance between the antennas can further degrade the performance due to mutual coupling effect [2]. The most effective schemes aimed to reduce both mutual coupling and spatial correlation in physically constrained antenna systems are polarization and pattern diversity. Recently, these diversity schemes have been separately implemented by means of the mode-based technique [3]-[4]. This technique allows to diagonalize the scattering matrix of a multi-element antenna with circular symmetry by cascading a mode decomposition network (MDN) to the antenna ports. As a result, the input ports of the MDN correspond to orthogonal modes or eigenmodes that feature full port decoupling and orthogonal radiation patterns. In general, these beneficial features come at the expenses of mismatching at the MDN input ports requiring thus matching networks that can limit the bandwidth of the antenna system. In this paper we propose a design approach for mode-based multi-element MIMO antennas that overcomes the need of matching networks at the MDN input ports. The proposed approach is then used to design a four-element MIMO antenna that features polarization and pattern diversity.

II. MODE-BASED MIMO ANTENNA DESIGN

In the following we refer to the mode-based technique applied to a four-element antenna with circular symmetry [3]. The scattering matrix $\mathbf{S}_a$ of such antenna features circulant structure thus it is completely characterized by S_{11}, S_{12}, and S_{13}. The typical approach to implement the mode-based technique is the following. First, the multi-element antenna is designed at the operating frequency determined by S_{11}. Next, to diagonalize $\mathbf{S}_a$, the antenna ports are cascaded with a MDN whose S-parameters must correspond to the eigenvectors of $\mathbf{S}_a$, i.e. (1,1,1,1), (1,1,−1,−1), (1,−1,1,−1), and (1,−1,−1,1). As a result, four eigenmodes are obtained at the input ports of the MDN whose reflection coefficients correspond to the eigenvalues of $\mathbf{S}_a$, that are $S_{11}+2S_{12}+S_{13}$, $S_{11}-S_{13}$, $S_{11}-2S_{12}+S_{13}$, and $S_{11}-S_{13}$. Finally, these new reflection coefficients generally require matching networks at the MDN input ports to restore the operating frequency. In the following we propose and adopt a more efficient approach to implement the mode-based technique. The basic idea consists to design the multi-element antenna in such a way to optimize the eigenvalues of $\mathbf{S}_a$ instead of $\mathbf{S}_a$ itself. Since the eigenvalues depend on S_{11}, S_{12}, and S_{13}, this approach requires a more accurate antenna design. However, such an antenna cascaded to the MDN ports provides the a priori optimized input reflection coefficients overcoming thus the need of matching networks.

III. ANTENNA STRUCTURE

Fig. 1 shows the proposed MIMO antenna which consists of four petal-shaped radiators etched on the top of a FR-4 substrate with thickness of 1.6 mm, a cross-shaped parasitic element etched on the bottom of the substrate, a planar reflector, and four coaxial cables arranged in a novel fashion. The inset in Fig. 1 shows the details of one of the four feeding sections. Each feed cable connects two consecutive petals similarly to a dipole configuration, however, the circular symmetry implies that each petal is driven by two feed cables.

This work was supported by Marie Curie European Industrial Doctorate (EID) programme ARTISAN, grant no. 316426, and Nokia Bell Labs, Ireland.

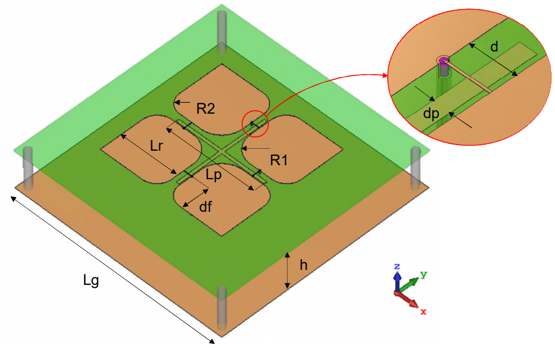
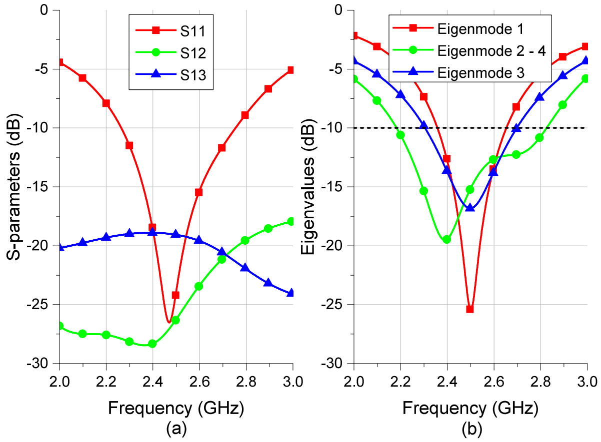


Fig. 1. Isometric view of the proposed MIMO antenna. The inset shows details of one feeding section. Lg=150, h=27.5, R1=10.7, R2=15, Lr=41, Lp=63.7, d=5.7, dp=2.1, df=19.4. Units are in mm.

This feeding arrangement allows an accurate optimization of the antenna electrical performance as the position of the feeds is adjustable. The role of the parasitic element is to provide additional degrees of freedom in the optimization process, while the goal of the reflector is to provide directional radiation patterns as typically required in base station applications.

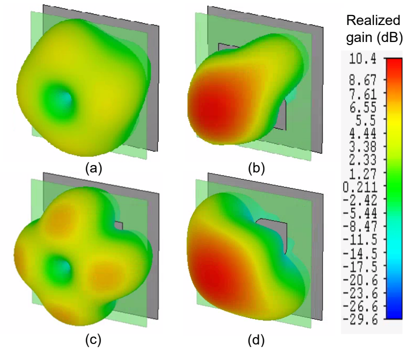
IV. SIMULATION RESULTS AND DISCUSSION

The proposed MIMO antenna has been optimized to operate in a bandwidth as wide as possible around 2.5 GHz. The simulated S-parameters and relative eigenvalues of the antenna are reported in Fig. 2 (a)-(b). The eigenmode 1 and 3 resonate at 2.5 GHz showing a fractional bandwidth respectively of 12% and 16%, by considering 10 dB of return loss. The resonance of eigenmode 2 and 4 occurs at 2.4 GHz, however the behavior of their eigenvalue provides a bandwidth of 26% which overlaps the bandwidth of eigenmode 1 and 3. As a result, the four eigenmodes can simultaneously operate in 12% of bandwidth centered at 2.5 GHz. The radiation pattern of each eigenmode, hereinafter eigenpattern, is reported in Fig. 3. The eigenpattern 2 and 4 feature a maximum at antenna boresight and a linear polarization state similarly to the basic modes of a dual linear-polarized antenna. These eigenpatterns correspond to radiation from an electric dipole. Instead, the eigenpattern 1 and 3 correspond to radiation from a magnetic dipole and an electric quadrupole, respectively. Indeed, these eigenpatterns feature a null along antenna boresight and a variable linear polarization state with spatial direction.



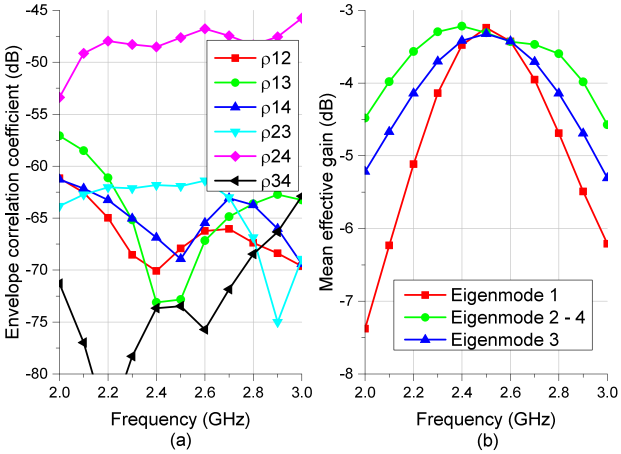
(a)
(b)

Fig. 2. (a) S-parameters and (b) relative eigenvalues of the proposed antenna.



(a)
(b)
(c)
(d)

Fig. 3. Eigenpatterns at 2.5 GHz of eigenmode (a) 1, (b) 2, (c) 3, and (d) 4.



(a)
(b)

Fig. 4. (a) Envelope correlation coefficients between the eigenpatterns and (b) mean effective gain of the eigenpatterns.

The polarization states and shape of the eigenpatterns allow to achieve simultaneously polarization and pattern diversity. The envelope correlation coefficient (ECC) between each pair of eigenpatterns and their mean effective gain (MEG) are computed assuming a rich isotropic multipath environment [5]. The ECCs as a function of frequency are reported in Fig. 4 (a) whose very low values, i.e. <−45 dB, confirm the orthogonality between the four eigenpatterns. The MEG of each eigenpattern as a function of frequency is reported in Fig. 4 (b). The MEGs show values within the operating bandwidths close to the theoretical −3 dB confirming thus the efficient antenna operation achieved without the use of matching networks.

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