Approximation-free Mutual Coupling Evaluation Approach for MIMO Antennas,

Wolosinski, G., Fusco, V., & Rulikowski, P. (2017). Approximation-free Mutual Coupling Evaluation Approach for MIMO Antennas, In Colloquium, Radio Science and Communications for a Smarter World 2017 (pp. 2)

Published in:
Colloquium, Radio Science and Communications for a Smarter World 2017

Document Version:
Peer reviewed version

Approximation-free Mutual Coupling Evaluation Approach for MIMO Antennas

Grzegorz Wolosinski, Vincent Fusco
ECIT
Queen's University Belfast
Belfast, UK
gwolosinski01@qub.ac.uk

Pawel Rulikowski
RF Access Group
Nokia Bell Labs
Dublin, Ireland

***Abstract*—This paper proposes an approach for the evaluation of mutual coupling effect on MIMO antennas without referring to the canonical minimum scattering (CMS) antenna approximation. The proposed approach is able to separate the effect of mutual coupling on variations of average received power and correlation properties. Full-wave simulations are used to evaluate the mutual coupling effect of two parallel dipoles with variable separation under different propagation channels. Finally, the proposed results are compared with those obtained with the CMS antenna approximation showing the limitations of the latter.**

***Keywords*— MIMO antennas; mutual coupling; multiplexing efficiency**

I. Introduction

In the last two decades, Multiple-Input-Multiple-Output (MIMO) technology has attracted great interest in wireless communications due to the potential of enhancing channel capacity 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 increases spatial correlation therefore reducing the achievable capacity. Moreover, the close distance between the antennas leads to the mutual coupling effect which has been shown to impact either positively or negatively the channel capacity depending mainly on antenna separation [2]. In this regard, the vast majority of the studies have modelled the mutual coupling effect by means of the so called coupling matrix [2−3] which relies on the assumption of canonical minimum scattering (CMS) antennas [4]. This implies that the self-impedance of one antenna is not influenced by the presence of nearby open-circuit antennas. Although this assumption greatly simplifies the study of mutual coupling it can provide misleading results when the considered antennas are not dipoles and for inter-element distances less than half wavelength [5]. For the above reasons, the objective of this paper is to propose a more rigorous and general approach to evaluate the mutual coupling effect in MIMO systems. The proposed theory is then used to evaluate an example MIMO antenna and compare the results with those provided by the CMS antenna approximation.

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

II. Theory

Let us consider a $M \times M$ MIMO wireless communication system under correlated Rayleigh fading channel that is modelled using the Kronecker model [1]. This approach separates the correlation properties between transmit and receive antennas allowing therefore to individually study the performance of a MIMO antenna under test (AUT). In the following we focus on evaluating the mutual coupling effect of an AUT on the system performance by referring to the definition of multiplexing efficiency [6]. As explained in [6], the multiplexing efficiency relates the signal-to-noise ratio (SNR) required by a system equipped with the AUT to achieve a given channel capacity, with the SNR required by the same system equipped with a reference MIMO antenna to achieve the same channel capacity. At high SNR regime the multiplexing efficiency can be expressed as follows

$$\eta_{\text{mux}} = \frac{SNR_0}{SNR} = \underbrace{\frac{\det(\mathbf{\Lambda})^{1/M}}{\det(\mathbf{\Lambda}_0)^{1/M}}}_{\eta_{\text{MEG}}} \cdot \underbrace{\frac{\det(\mathbf{R})^{1/M}}{\det(\mathbf{R}_0)^{1/M}}}_{\eta_{\text{CORR}}} \tag{1}$$

where $\mathbf{\Lambda}$ is a $M \times M$ diagonal matrix containing the mean effective gains (MEGs) of the AUT and $\mathbf{R}$ is the normalized correlation matrix of the AUT [6]. The subscript 0 identifies these quantities for the reference MIMO antenna. The above terms are related to antenna parameters such as radiation pattern and total efficiency and to propagation channel statistics described by the power angular spectrum (PAS) [6]. In order to evaluate the sole effect of mutual coupling in (1) we consider the AUT with its M embedded radiation patterns and the reference MIMO antenna with M isolated radiation patterns taken from the same AUT, i.e. each radiation pattern is obtained by removing the respective $M-1$ radiators from the AUT. 3D radiation patterns and PAS have to be considered in order to obtain approximation-free results.

III. Numerical Results

In this section we consider a 2×2 MIMO system and evaluate the mutual coupling effect of an AUT composed by two parallel dipoles located in free space with variable inter-element distance d between 0.05 – 1.5 λ, where λ is the wavelength at the operating frequency. Each dipole has a total length of 0.44 λ with radius 0.01 λ chosen to resonate at λ in isolation, i.e. when the other dipole is absent. The loads or intrinsic generator impedances attached to the dipoles are set to 50 Ω. CST Full-wave simulations [7] are used to obtain the required antenna parameters which are then post processed in a MATLAB [8] routine to obtain (1). Fig. 1 reports η_{MEG}, η_{CORR}, and η_{MUX} as a function of d/λ for uniform and a Gaussian PAS [6]. The η_{MEG} and η_{CORR} show different trends for different PAS however their combined effect, i.e. η_{MUX}, remains the same regardless of the specific PAS. This fact is a direct consequence of the high SNR approximation [1−2]. The η_{MUX} shows a positive impact of mutual coupling especially for $d/\lambda < 0.28$ and $0.6 < d/\lambda < 0.8$. It is worth noting that for $d/\lambda < 0.28$ the positive impact is always given by a reduction in η_{MEG} and an improvement in η_{CORR}. Fig. 2 compares the η_{MUX} of (1) with the η_{MUX} computed using the coupling matrix approach [2−3], i.e. using the Z-parameters of the AUT.

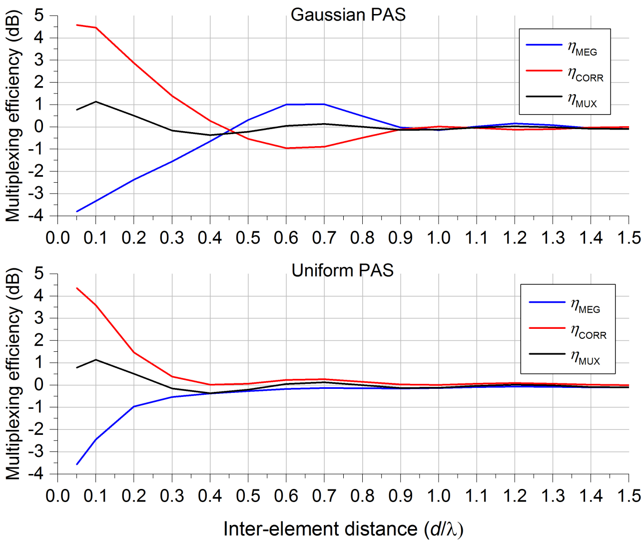

Fig. 1. Multiplexing efficiency and its contributing terms for 3D uniform and Gaussian PAS aligned with antenna broadside direction with $\sigma_\theta = \sigma_\varphi = 20°$ [6].

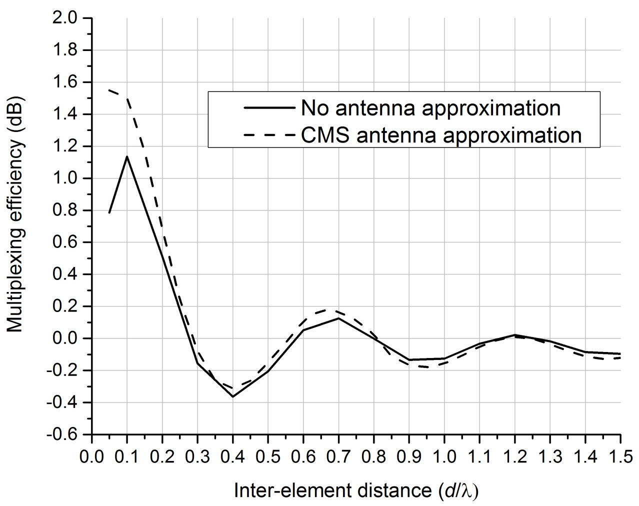

Fig. 2. Multiplexing efficiency of the proposed approach and CMS antenna approximation.

The coupling matrix approach generally shows a good agreement for $d/\lambda \geq 0.25$ while exhibits a high discrepancy respect to the proposed approach as d/λ decreases. This fact is consistent with the minimum inter-element distance between two dipoles that maintains valid the CMS antenna approximation, i.e. $d/\lambda = 0.5$ [5]. Finally, it is worth noting that the coupling matrix approach requires less computational effort respect to the proposed approach, however the latter is valid for any MIMO antenna and it is able to separate the effect of mutual coupling on variations of average received power and correlation properties providing therefore a deeper insight on the effect of mutual coupling on MIMO performance.

IV. Conclusion

In this paper we have proposed a general approach for the evaluation of mutual coupling effect of MIMO antennas without referring to the CMS antenna approximation. As an example, the mutual coupling effect of two parallel dipoles with variable inter-element distance has been investigated. Full-wave simulations have been used for the proposed results which show that at high SNR regime the mutual coupling effect provides a positive impact on the MIMO performance especially for $d/\lambda < 0.28$ and $0.6 < d/\lambda < 0.8$ regardless of the PAS. These results have been compared with those provided by the CMS antenna approximation showing that the coupling matrix approach provides a good approximation for $d/\lambda \geq 0.25$, which however becomes less valid as d/λ decreases. Indeed, a high disagreement between the two approaches has been reported for $d/\lambda < 0.25$ which highlights the limit of the CMS antenna approximation for the study of closely packed antennas.

References

[1] A. Paulraj, R. Nabar, and D. Gore, "Capacity of ST channels," in *Introduction to Space-Time Wireless Communications*, 1st ed., Cambridge, Cambridge University Press, 2003.

[2] B. Clerckx, C. Craeye, D. Vanhoenacker-Janvier, and C. Oestges, "Impact of antenna coupling on 2 × 2 MIMO communications," *IEEE Trans. Veh. Technol.*, vol. 56, no. 3, pp. 1009–1018, May 2007.

[3] R. Janaswamy, "Effect of element mutual coupling on the capacity of fixed length linear arrays," *IEEE Antennas Wireless Propag. Lett.*, vol. 1, no. 1, pp. 157–160, 2002.

[4] P. Rogers, "Application of the minimum scattering antenna theory to mismatched antennas," *IEEE Trans. Antennas Propag.*, vol. 34, no. 10, pp 1223–1228, Oct. 1986.

[5] H. Abdallah and W. Wasylkiwskyj, "A numerical technique for calculating mutual impedance and element patterns of antenna arrays based on the characteristics of an isolated element," *IEEE Trans. Antennas Propag.*, vol. 53, no. 10, pp. 3293–3299, Oct. 2005.

[6] R. Tian, B. K. Lau, and Z. Ying, "Multiplexing efficiency of MIMO antennas in arbitrary propagation scenarios," in *Proc. 6th Eur. Conf. Antennas Propag.*, Prague, Czech Republic, Mar. 26–30, 2012, pp. 373–377.

[7] CST Microwave Studio® 2015, www.cst.com.

[8] MATLAB® 2015, www.mathworks.com.