Post-print of: D. Szypulski, G. Fotyga and M. Mrozowski, "An Efficient Simulation Method of Massive MIMO Antenna Arrays used in 5G Mobile Phones," 2020 23rd International Microwave and Radar Conference (MIKON), Warsaw, Poland, 2020, pp. 282-284, doi: 10.23919/MIKON48703.2020.9253785.

# An Efficient Simulation Method of Massive MIMO Antenna Arrays used in 5G Mobile Phones

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***Abstract*—This paper deals with a model-order reduction method, applied to speed-up the simulations of MIMO antenna arrays, performed by means of finite element method. The obtained results of the numerical tests show that the described technique is reliable and considerably increases the efficiency of the standard finite element method.**

***Index Terms*—finite element method, model order reduction, MIMO antenna array, 5G**

## I. Introduction

In the near future the fifth generation (5G) cellular network will become a worldwide standard for wireless communication. One of the key development areas of 5G is a design process of MIMO antenna arrays for mobile phones. Examples of such structures have been reported in [1], [2], [3]. However, a simulation and optimization process of such devices using standard numerical techniques (f.e. finite element method—FEM [4] or finite difference method - FDM [5]) may be extremely time-consuming, because of the complex geometries and the wide operating frequency bands.

In this paper, we applied the fast frequency sweep (FFS) method described in [6] for efficient simulation of MIMO antenna arrays. The numerical tests are performed on a 12-port antenna array operating in the long-term evolution (LTE) band 42/43/46 used for 5G massive multiple-input multiple-output (MIMO) applications in mobile handsets. The obtained results prove the accuracy and efficiency of the proposed method.

## II. Background

We start the analysis of the massive MIMO antenna array with the definition of a source-free computational domain $\Omega$. We assume that it is bounded by the perfect electric conductor walls (PEC), denoted by $\Gamma_{PEC}$ and absorbing boundary conditions (ABC) of the first kind, denoted by $\Gamma_{ABC}$. In order to simulate the behaviour of the antenna, one has to solve the following frequency-domain boundary problem (BVP):

$$\begin{aligned} \nabla \times ({\mu_r}^{-1} \nabla \times \vec{E}) - k_0^2 \epsilon_r \vec{E} = 0 \qquad & \text{in } \Omega, \\ \vec{E} \times \hat{n} = 0 \qquad & \text{on } \Gamma_{PEC}, \\ \hat{n} \times (\nabla \times \vec{E}) + jk_0 \hat{n} \times (\hat{n} \times \vec{E}) = 0 \qquad & \text{on } \Gamma_{ABC}. \end{aligned} \tag{1}$$

In the above equations $j$ is the imaginary unit, $\hat{n}$ is the outward unit vector, $k_0$ is the wavenumber, $\epsilon_r$ and $\mu_r$ are relative permittivity and permeability, respectively, $\mu_0$ is the permeability and finally, the distribution of the electric filed is denoted by $\vec{E}$. We assume that the excitation of the antenna array is applied through the lumped ports, which are defined inside the computational domain. More precisely, the surface of each of the port is placed on the surface which covers the two conductors, and on each of the conductors a voltage (0V or 1V) is assigned. More details can be found in [7].

Following the subsequent steps of the FEM procedure [7], one gets the $n$-dimensional linear system of equations of the form:

$$\begin{aligned} (\mathbf{\Gamma} + s\mathbf{G} + s^2\mathbf{C})\mathbf{E} = s\mathbf{BI}, \\ \mathbf{U} = \mathbf{B}^T\mathbf{E}. \end{aligned} \tag{2}$$

In (2) $\mathbf{\Gamma}, \mathbf{G}$ and $\mathbf{C}$ are $n \times n$ FEM system matrices, $\mathbf{B}$ is the matrix, associated with the excitation applied to the ports (with the number of columns equal to the number of ports), $\mathbf{E}$ is a matrix of unknowns with the same size as $\mathbf{B}$, $\mathbf{U}$, $\mathbf{I}$ are the vectors of amplitudes of the voltage and current waves, respectively, and finally, $s = j\omega/c$ is the complex frequency, and $c$ is the speed of light in vacuum.

Once, the system of equations is solved for $\mathbf{E}$, one can compute the scattering parameters of the structure (reflection coefficients and isolations between the adjacent ports), as well as the radiation patterns of the antennas. However, since the antenna array operates in the wide-frequency band (LTE bands: 42/43 and 46), this process can be extremely time-consuming. In order to speed-up the computations, more precisely, to perform a fast frequency sweep, one can use the reliable greedy multipoint model order reduction (RGM-MOR), proposed in [6]. As the result of the fully-automated reduction process, system (2) is transformed to the reduced form:

$$\begin{aligned} (\mathbf{\Gamma}_R + s\mathbf{G}_R + s^2\mathbf{C}_R)\mathbf{E}_R = s\mathbf{B}_R\mathbf{I}, \\ \mathbf{U} = \mathbf{B}_R^T\mathbf{E}_R. \end{aligned} \tag{3}$$

where:

$$\mathbf{\Gamma}_R = \mathbf{Q}^T\mathbf{\Gamma}\mathbf{Q} \tag{4}$$

$$\mathbf{G}_R = \mathbf{Q}^T\mathbf{G}\mathbf{Q} \tag{5}$$

$$\mathbf{C}_R = \mathbf{Q}^T\mathbf{C}\mathbf{Q} \tag{6}$$

$$\mathbf{B}_R = \mathbf{Q}^T\mathbf{B} \tag{7}$$

In above equations, $\mathbf{Q}$ is an $n \times q$ projection basis and $q$ is the size of the reduced model. Since $q \ll n$, the computations

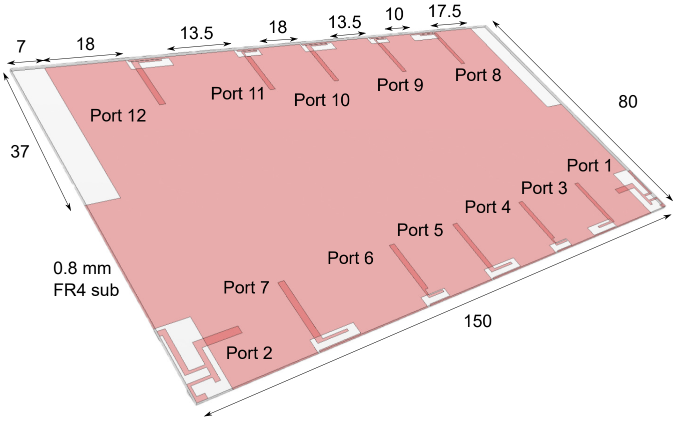


Fig. 1. 12-port 5G massive MIMO antenna array [8].

using a reduced-order model are performed much faster, without devoting the computational accuracy.

## III. Numerical results

In this section, the MOR method proposed in [6] is used to compute the scattering parameters of the MIMO antenna array. Tests were performed in InventSim environment [9] using an Intel i5-7400 processor and 32GB RAM. The large sparse FEM systems of equations have been solved using Intel MKL PARDISO library [10].

The geometry of the analyzed MIMO antenna array with the detailed dimensions is provided in Fig. 1 and Fig. 2. The size of the FR4 substrate is: 80mm by 150mm by 0.8mm, the values of dielectric permittivity and loss tangent are equal to 4.4 and 0.02, respectively. The antenna is designet to be used in the mobile handset, operating in the LTE bands: 42, 43 and 46, thus the simulations has been performed in the 2.5-6.5 GHz band, at 101 points, where the size of the FEM model: $n = 1.2e6$.

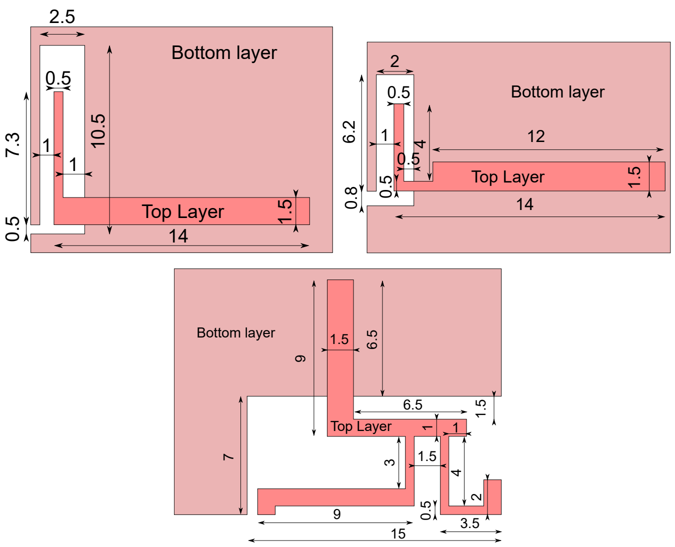


Fig. 2. Detailed dimensions of the three antennas used in structure shown in Fig.1 [8]

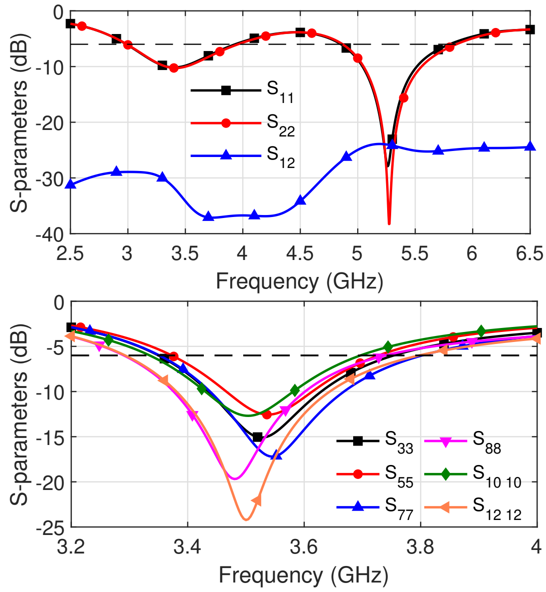


Fig. 3. Scattering parameters of the analyzed MIMO antenna. Dashed black line corresponds to -6dB level.

TABLE I
Simulation results, 12-port 5G MIMO antenna array.

| Method | DIRECT | RGMMOR |
|---|---|---|
| Total time | 1900 | 322 |
| Basis size | - | 228 |
| Approx speedup | - | 5.9 |

The results are summarized in Tab. I. The total time needed to obtain reference characteristics (computed using the standard FEM scheme) is equal to 1900 s. The proposed

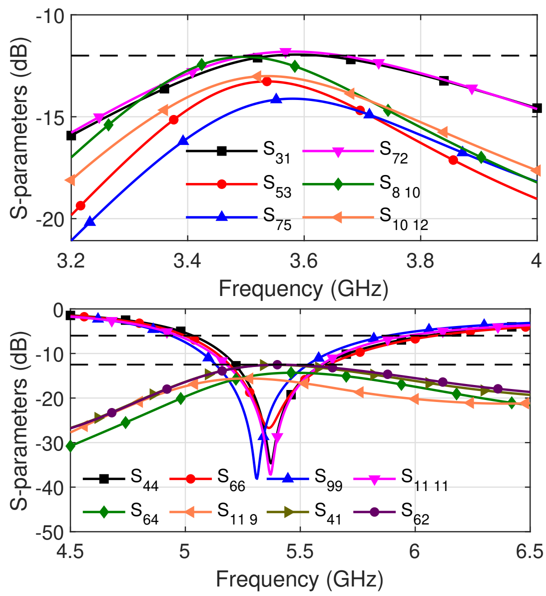


Fig. 4. Scattering parameters of the analyzed MIMO antenna. Dashed line in the first Fig. corresponds to -12dB level, the dashed lines in the second Fig. corresponds to -6dB and -12.5dB levels.

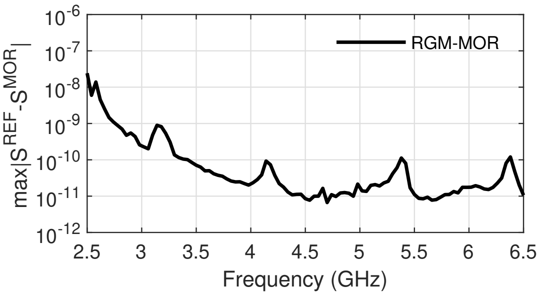


Fig. 5. Maximum actual error of scattering parameters.

RGM-MOR method generated the projection basis composed of 228 vectors. The total reduction time is equal to 322 s giving an approximate speedup equal to 5.9. The scattering parameters computed using RGM-MOR can be found in Figs. 3-4, whereas the plot of the actual error is shown in Fig. 5. It can be seen that its maximum value is below 1e-7.

## IV. Conclusions

A simulation of 5G MIMO antenna array was performed using a fast frequency sweep method called RGM-MOR. It allowed to obtain high speedup of computations, without comprising the computational accuracy, with regards to the standard FEM simulations.

## Acknowledgment

This work was supported by the Foundation for Polish Science within the TEAM-TECH program, cofinanced by the European Regional Development Fund, Smart Growth Operational Program 2014-–2020 (project EDISOn: Electromagnetic Design of flexIble SensOrs). The authors would like to thank Dr. A. Lamecki for providing the FEM code.

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