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MIMO Antenna Design Through Genetic Algorithm

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Abstract. Massive multiple-input multi-output (MIMO) is a technology established more than a decade ago; since then it has been employed as an integral part of the fifth generation (5G) mobile technologies. Recently, MIMO antenna designs have taken the attention of researchers due to their benefits such as reduced bit errors, high throughput, low latency and others. MIMO antennas consist of multiple radiating elements leading to have complex designs. Hence, frequently, optimization-based methods are required during their design; this paper provides one possible optimization-based methodology for designing them. The design procedure starts with configuring the MIMO antenna and then employing the genetic algorithm (GA) for optimizing the design parameters describing the MIMO antenna geometry. Using the GA method, leads to have a valid electromagnetic (EM)-verified post-layout generation and reduces the efforts of any designer in providing ready-to-fabricate layout. For validating our proposed method, we design and optimize MIMO antenna with a bandwidth of 400 MHz in the frequency band 4.1 GHz - 4.5 GHz.

Keywords: optimization, genetic algorithm, multiple-input and multi-output (MIMO) antenna

1 Introduction

In the wireless communication systems, especially fifth generation (5G) and sixth generation (6G), the multiple-input multiple-output (MIMO) antennas are becoming commonly used due to the their capability in supporting large amount of data. Hence, MIMO antennas can be used widely for increasing the accuracy of wireless systems [1] and they are suitable for increasing the spectral and energy efficiencies of these advanced communications systems. In MIMO antenna structure, the number of antenna array elements is additionally increasing by an order of magnitude leading to have complex structure [2]. These structures lead to build directive beams and simultaneously serve multiple users using the same resources of time and frequency [3]. Figure 1 presents a general view about MIMO antenna used in such communication systems.

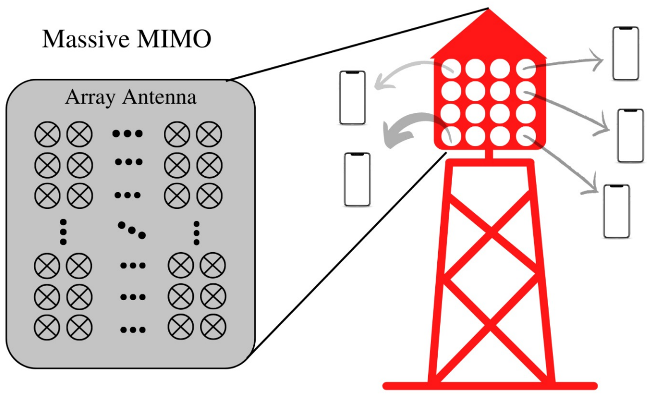

Fig. 1. General view of MIMO antenna in 5G communication systems.

In the 5G and 6G technologies, high data transmission speed, lower latency and greater energy efficiency are the important specifications any designer has pay attention to [4]. In the wireless systems, other important factors can be channel estimation and signal detection [5] for investigating the transmitted and received signals. These MIMO antennas can be used in THz range as well, which can bring various benefits for the 6G standard. In [1], various challenges are presented and one of the important provocation is how to implement and develop the massive radio frequency (RF) chains using the MIMO antennas. For this case, peak-to-average power ratio (PAPR) specification per array element should be considered by the designers [6, 7].

As it is expected, MIMO antennas have complex structures and achieving optimal design parameters is not straightforward. Optimization-based methods are required for enhancing the performance of these complex designs [8]. Recently, various methods have been presented for optimizing MIMOs [9–14]. However, determining the most critical design parameters inside the structure needs additional efforts and time.

This paper devotes to design and optimize MIMO antenna based on the genetic algorithm (GA) leading to exhibit wide-band features. For this case, we firstly construct the MIMO antenna in the CST tool [15] and then employ the incorporated GA optimization algorithm for optimizing the design parameters. Beside the algorithm, the Electromagnetic (EM) rules are also employed for producing the ready-to-fabricate layout. The remaining part of the manuscript is structured as follows: Section 2 presents the employed optimization method for designing the antenna. Section 3 discuses the achieved simulation results and finally Sec. 3 concludes this manuscript.

2 Optimization method for designing MIMO antenna

This section provides the general design steps of MIMO antenna leading to additionally provide ready-to-fabricate layout. Optimization is an effective necessity in any complex designs. For this case, in this paper we prefer to employ GA algorithm due to its capability in dealing with a larger set of solution space and parallelism capability [16–18]. Figure 2 presents the general overview of the GA method [19]. In a nutshell, this method starts with a random population namely $w_1, w_2, .., w_n$ and then a fitness equation $w_1 \cdot x_1, w_2 \cdot x_2, .., w_n \cdot x_n$ is constructed. The initial parameters provided for starting the optimization process that are indicated by w and then constant multiplications as x are provided in each iteration. Afterwards by employing the objective functions (here, S-parameters) and the stopping criteria (here, the bandwidth), the GA is applied for achieving the targeted solutions with the *apriori* set accuracy.

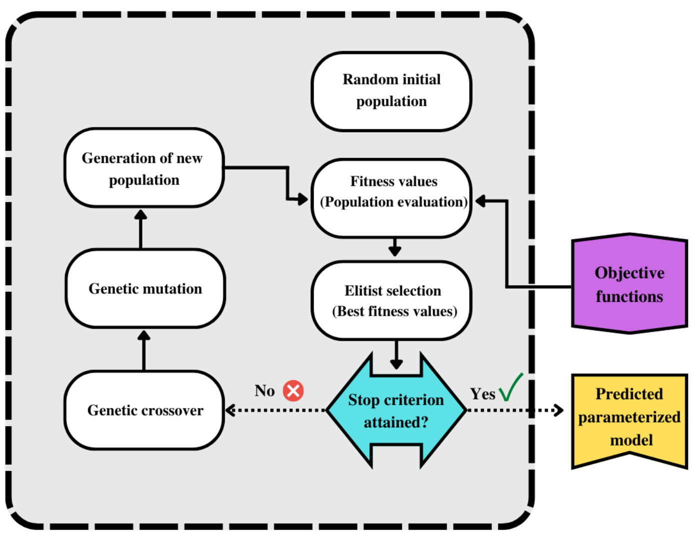

Fig. 2. Comprehensive description of the GA algorithm.

For this case, we start designing the initial structure of MIMO antenna in the CST tool and then we employ the GA algorithm for achieving the optimal

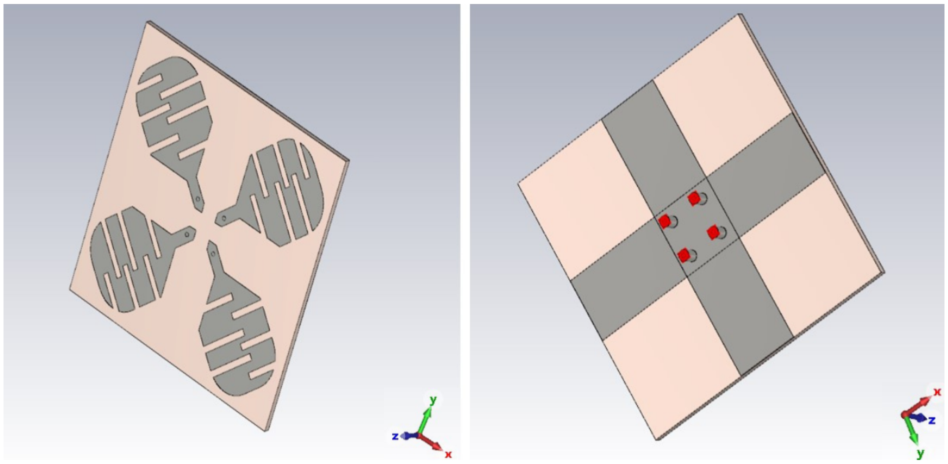

Fig. 3. MIMO antenna geometry: top view of the four arms (left) and ground configuration (right).

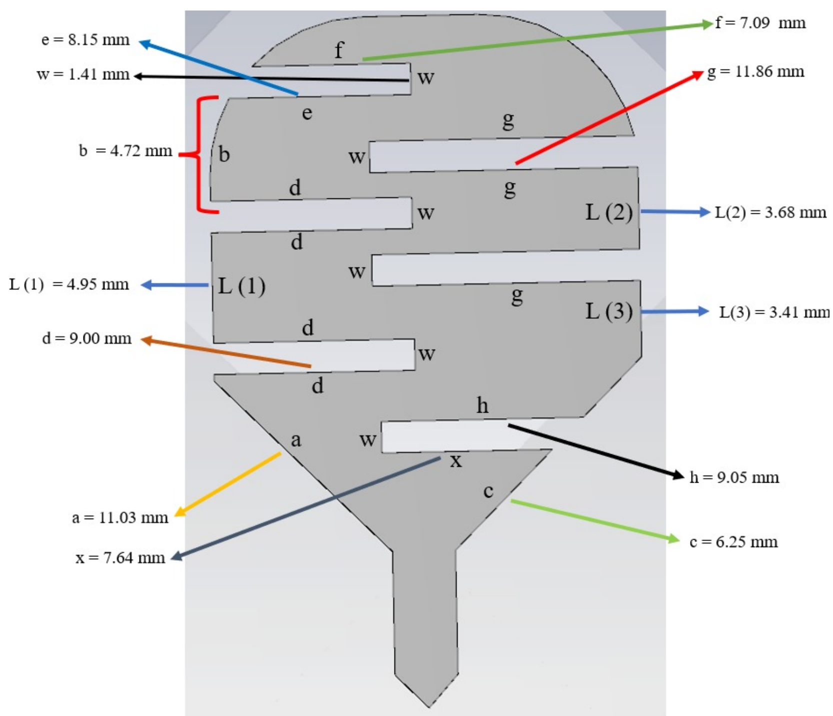

Fig. 4. Size details of each single antenna.

design parameters. For generating the ready-to-fabricate layout, the design rules for passing EM-simulation are also employed inside the optimization process. In particular a four-arm structure is considered, where each arm is singularly fed by an SMA connector. The four arms are identical, and are rotated by 90° one with respect to the other. The geometry is based on a meander-line configuration assuring a reduced spatial extension. The dimension of the ground is reduced as much as possible to prevent radiation in a single direction, extending in this way the operational performances. Figure 3 presents the final structure of the MIMO antenna; the FR4 substrate (standard, low-cost material for PCB fabrication) with dimension of 60×60 mm^2 has a thickness of 1.60 mm. The detailed values of various parameters are presented in Fig. 4.

3 Simulation results

This section provides the simulation outcomes of optimized MIMO antenna with GA. The MIMO antenna is fed through four coaxial cables (SMA connectors). The configured antenna covers the frequency band of 4.10 GHz to 4.50 GHz and Fig. 5 presents the S_{11} specification. The other reflection coefficients (not reported) exhibit identical behaviour. Sequentially, Fig. 6 presents the radiation patterns for the three frequencies of 4.10 GHz, 4.30 GHz, and 4.50 GHz, i.e., at band limits and at the central frequency. The plots refers to the case when all ports are fed with unitary amplitude; the phases of the collinear radiators are fed with a phase difference of 180°.

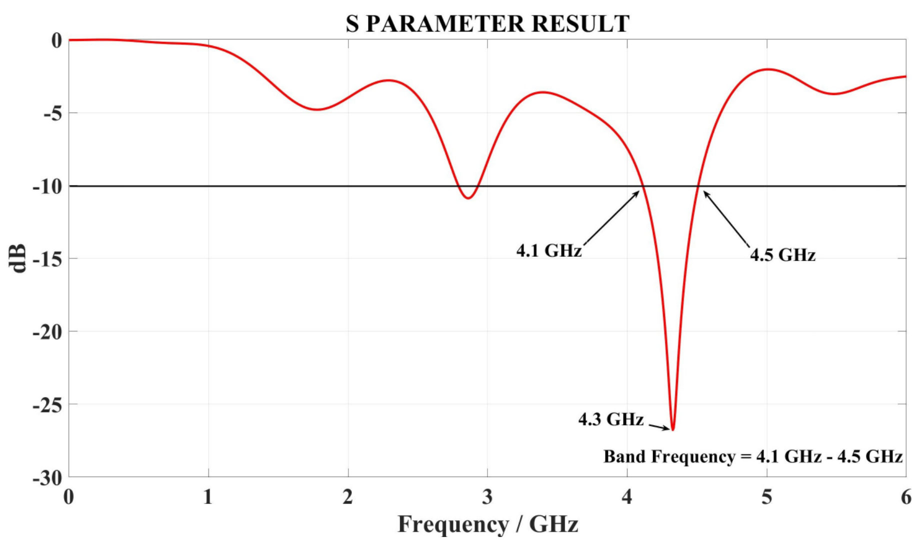

Fig. 5. Input scattering parameter at one of the ports of the designed antenna.

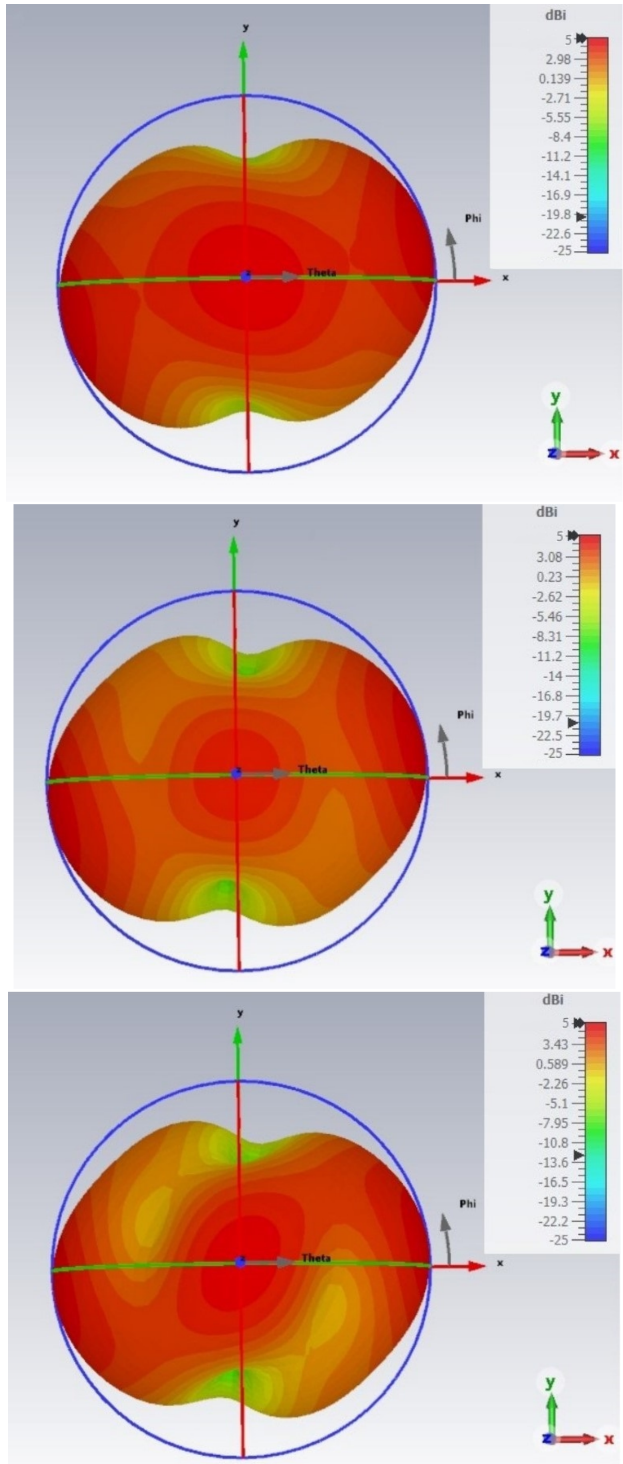

Fig. 6. 3-D radiation pattern of the considered antenna at 4.1 GHz (bottom), 4.3 GHz (middle) and 4.5 GHz (top).

4 Conclusion

Generating a ready-to-fabricate layout for RF designs especially antennas is not straightforward and requires additional time and effort. This paper provides a methodology for optimizing the MIMO antennas leading to have a ready post-layout. The employed method is based on the GA algorithm where it considers the EM rules and leads to conclude on the optimal design parameters. All the optimization process is performed using the CST tool. The validity of the performance is presented by designing and optimizing the MIMO antenna in the 4.10 - 4.50 GHz frequency band.

References

1. F. A. Pereira de Figueiredo, "An overview of massive mimo for 5g and 6g," *IEEE Latin America Transactions*, vol. 20, no. 6, pp. 931–940, 2022.
2. H. Tataria, M. Shafi, A. F. Molisch, M. Dohler, H. Sjöland, and F. Tufvesson, "6g wireless systems: Vision, requirements, challenges, insights, and opportunities," *Proceedings of the IEEE*, vol. 109, no. 7, pp. 1166–1199, 2021.
3. D. Kuswidiastuti, L. P. Ligthart, and G. Hendrantoro, "A transmitter design for the multi-beam cc-ofdm azimuth scanning mimo radar," *IEEE Access*, vol. 10, pp. 53 682–53 702, 2022.
4. N. P. Le, F. Safaei, and L. C. Tran, "Antenna selection strategies for mimo-ofdm wireless systems: An energy efficiency perspective," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 4, pp. 2048–2062, 2016.
5. M.-S. Baek, S. Kwak, J.-Y. Jung, H. M. Kim, and D.-J. Choi, "A supplementary explanation for experimental environment of "implementation methodologies of deep learning-based signal detection for conventional mimo transmitters"," *IEEE Transactions on Broadcasting*, vol. 67, no. 1, pp. 356–357, 2021.
6. M. Yao, M. Carrick, M. M. Sohul, V. Marojevic, C. D. Patterson, and J. H. Reed, "Semidefinite relaxation-based papr-aware precoding for massive mimo-ofdm systems," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 3, pp. 2229–2243, 2019.
7. R. Zayani, H. Shaiek, and D. Roviras, "Papr-aware massive mimo-ofdm downlink," *IEEE Access*, vol. 7, pp. 25 474–25 484, 2019.
8. L. Kouhalvandi, L. Matekovits, and I. Peter, "Deep learning assisted automatic methodology for implanted mimo antenna designs on large ground plane," *Electronics*, vol. 11, no. 1, 2022. [Online]. Available: https://www.mdpi.com/2079-9292/11/1/47
9. Z. Chu, K. Cumanan, Z. Ding, M. Johnston, and S. Le Goff, "Robust outage secrecy rate optimizations for a mimo secrecy channel," *IEEE Wireless Communications Letters*, vol. 4, no. 1, pp. 86–89, 2015.
10. Z. Liu, J. Li, and D. Sun, "Circuit power consumption-unaware energy efficiency optimization for massive mimo systems," *IEEE Wireless Communications Letters*, vol. 6, no. 3, pp. 370–373, 2017.
11. N. Gupta and A. K. Jagannatham, "Transceiver optimization for unicast/multicast mimo cognitive overlay/underlay networks," *IEEE Signal Processing Letters*, vol. 22, no. 10, pp. 1556–1560, 2015.

12. M. Shao and W.-K. Ma, “Binary mimo detection via homotopy optimization and its deep adaptation,” *IEEE Transactions on Signal Processing*, vol. 69, pp. 781–796, 2021.
13. S. Gong, C. Xing, Y. Jing, S. Wang, J. Wang, S. Chen, and L. Hanzo, “A unified mimo optimization framework relying on the kkt conditions,” *IEEE Transactions on Communications*, vol. 69, no. 11, pp. 7251–7268, 2021.
14. F. Jiang, Z. Zhang, Q. S. Cheng, S. Shen, C.-Y. Chiu, and R. Murch, “An efficient optimization scheme for mimo antenna decoupling networks using space mapping techniques,” *IEEE Journal on Multiscale and Multiphysics Computational Techniques*, vol. 6, pp. 56–61, 2021.
15. “CST Studio, Suite, Dassault Systemes,” v. 2022.
16. Y. Tominaga, Y. Okamoto, S. Wakao, and S. Sato, “Binary-based topology optimization of magnetostatic shielding by a hybrid evolutionary algorithm combining genetic algorithm and extended compact genetic algorithm,” *IEEE Transactions on Magnetics*, vol. 49, no. 5, pp. 2093–2096, 2013.
17. K. Choi, D.-H. Jang, S.-I. Kang, J.-H. Lee, T.-K. Chung, and H.-S. Kim, “Hybrid algorithm combing genetic algorithm with evolution strategy for antenna design,” *IEEE Transactions on Magnetics*, vol. 52, no. 3, pp. 1–4, 2016.
18. Y.-F. Cheng, W. Shao, S.-J. Zhang, and Y.-P. Li, “An improved multi-objective genetic algorithm for large planar array thinning,” *IEEE Transactions on Magnetics*, vol. 52, no. 3, pp. 1–4, 2016.
19. D. A. Elvira-Ortiz, A. Y. Jaen-Cuellar, D. Morinigo-Sotelo, L. Morales-Velazquez, R. A. Osornio-Rios, and R. d. J. Romero-Troncoso, “Genetic algorithm methodology for the estimation of generated power and harmonic content in photovoltaic generation,” *Applied Sciences*, vol. 10, no. 2, 2020. [Online]. Available: https://www.mdpi.com/2076-3417/10/2/542