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Optimization Process for Bending a Periodic Structure: Start Ahead with Neural Networks

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Abstract—Optimizing high-dimensional designs requires essential efforts; bending of a radiating device is one of such examples. Such appearance appears in various applications like medical, space, radar, etc. Consequently, strong numerical methods are becoming necessary. In the present work, an optimized bent periodic structure, multiple-input and multiple-output (MIMO) antenna designed through a neural network (NN) is presented. The main goal of this optimization is to focus on the curvature of the antenna to find the suitable results for S-parameters both in terms of reflection S_{11} , and transmission S_{21} coefficients, and also total active reflection coefficient (TARC). Through the proposed method, the antenna configuration loaded by meandered slot and surrounded by printed meander line of different periodicities is designed and optimized in three frequency bands within the 12.94 GHz to 25 GHz range, namely, 12.94 - 14.79 GHz, 16.09 - 17.25 GHz, and 19.17 - 25 GHz.

Index Terms—Bended antenna, multiple-input and multiple-output (MIMO), neural network (NN), periodic structure, total active reflection coefficient (TARC).

I. INTRODUCTION

High-performance antennas are crucial components in the operation of next-generation communication systems [1], including 6G technology [2]. Periodic structures with MIMO antennas, in particular, have gained popularity in industrial applications due to their increased ability to transfer large amounts of data [3]. In order to design antennas required in various applications, multiple specifications such as bandwidth, gain, and total active reflection coefficient (TARC) must be very carefully and simultaneously considered. Handling of such a high-dimension problem requires a significative efforts by the engineers [4].

To handle the above mentioned challenge, various optimization methods have been proposed. In the field of antenna design, chicken swarm optimization [5], artificial bee colony algorithm [6], and genetic algorithm [7] are just some examples. These methods may not be sufficient enough when dealing with large number of design parameters [8]. Advanced intelligent-based methods [9], such as machine learning and artificial neural networks [10], [11] have demonstrated their potential in designing and optimizing these complex devices. By using machine learning and artificial neural networks, engineers can leverage the power of data-driven techniques

to optimize the performance of antennas. These intelligent-based methods can help to identify the optimal design parameters for the antennas, hence leading to improved global performance in terms of various specifications. Overall, the development of high-performance antennas is critical for the advancement of next-generation communication systems, and the use of intelligent-based methods can further enhance their performance and capabilities.

Designing bended radio frequency (RF) circuits that find extensive uses in 6G communication systems is not straightforward. Hence, strong methods are needed for achieving the optimal design parameters also in terms of the angle of bending of the whole or part of the RF device. On this background, this paper introduces an intelligent method for effectively optimize a MIMO antenna structure that involves diverse periodic structure based loads. The whole structure is optimized in terms of descriptive design parameters including the angle used for bending the antenna. In this circumstance, a shallow neural network (SNN) with only one hidden layer is used to optimize the design parameters of a bended MIMO antenna. The SNN predicts the total active reflection coefficient (TARC) specification defined in terms of S-parameters, and the optimal design parameters of the periodic sub-structures. Here the proposed method specifically focuses on addressing the issue of bended MIMO antenna and optimizes the antenna based on its output specifications.

The following is how this work is structured: The proposed methodology for optimizing MIMO antennas is presented in Sec. II. Section III is devoted to explaining the simulation outcomes. Finally, Section IV brings some concluding remarks.

II. METHODOLOGY IN A NUTSHELL FOR DESIGNING AND OPTIMIZING BENDED STRUCTURE WITH PERIODIC LOADS

As introduced above, this work aims to present a methodology for optimizing a periodic-loaded MIMO antenna structure in terms of design parameters incorporating the angle of its bending. In this optimization analysis, SSN is proposed to optimize the antenna specifications in terms of S_{11} , S_{12} , and TARC. TARC depends on scattering parameters as defined in (1); hence, in the output specification all S-parameters with the TARC value are optimized concurrently.

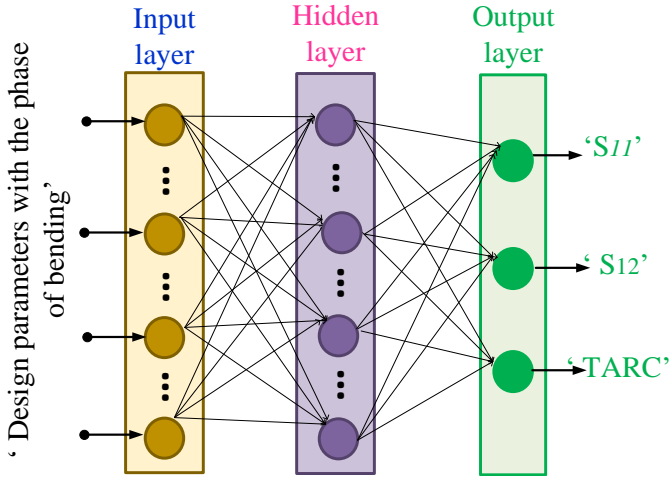


Fig. 1. Proposed SNN for predicting the optimal design parameters with the phase of bending.

$$TARC = \sqrt{((S_{11} + S_{12})^2 + (S_{21} + S_{22})^2)/2} \quad (1)$$

For application of the optimization procedure, a co-simulation environment between an electronic design automation (EDA) tool and a numerical analyser has been created [11]. Here, we use CST Suite and MATLAB simulation tools for creating the automated environment. The general structure of the proposed SNN is illustrated in Fig. 1 where the input layer presents the various design parameters of MIMO antenna; this includes width, length, and phase of bending. Sequentially, the output layer predicts three specification of targeted MIMO antenna in terms of S-parameters (considering symmetry) and TARC.

Training any SNN requires suitable amount of data that can be achieved by iterating randomly the design parameters with the variation of $\pm 10\%$ and $\pm 15\%$. Concurrently, the curvature angle that is used for bending the MIMO antenna is iterated randomly started with $\theta = 0$. Accordingly, the output specifications of the antenna in each of the iteration is achieved and assembled. In total, with the gathered dataset (i.e., input training data (X_{Train}) and output training data (Y_{Train})) the SNN is trained [11].

III. SIMULATION RESULTS

This section is dedicated to present the practical implementation of the SNN and the periodic loaded MIMO antenna, leading to design optimal structure with desired output specifications. For this case, the initial structure of the MIMO antenna (without bending) is designed/implemented in the CST environment (see Fig. 2). Afterwards, random iteration for all presented design parameters with the bending phase (angle) is employed leading to achieve 500 various dataset on the output specifications as S-parameters and TARC, respectively. Number of neurons for the presented SNN in Fig. 1 is achieved through the role of thumb [12] leading to have 200 neuron in the hidden layer. The trained SNN has the accuracy of 0.152

in terms of root-mean-square error. The SNN is trained and constructed by following the method presented in [10].

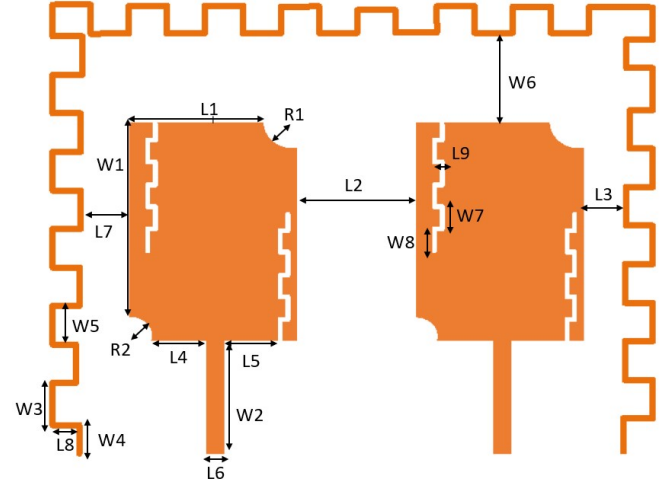


Fig. 2. Initial structure of MIMO antenna.

Figure 3 presents the overall structure of the optimized bended MIMO antenna where it is designed on the FR-4 substrate with the relative permittivity $\epsilon_r=4.3$ and a thickness of 1.6 mm. The optimized design parameters are as follow: $L_1 = 8.77$, $L_2 = 10.25$, $L_3 = 2.55$, $L_4 = 3.45$, $L_5 = 3.08$, $L_6 = 2.2$, $L_7 = 2.55$, $L_8 = 1.3$, $L_9 = 0.22$, $W_1 = 16$, $W_2 = 7.11$, $W_3 = 3.7$, $W_4 = 2.9$, $W_5 = 2.1$, $W_6 = 13.39$, $W_7 = 1.68$, $W_8 = 1.46$, $R_1 = 4$, and $R_2 = 2$ (all parameters units are mm). The angle of wrapping of the antenna antenna is $\theta = 30^\circ$.

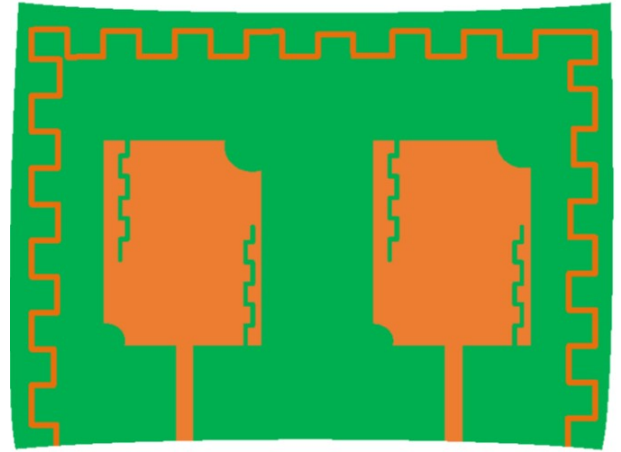


Fig. 3. Optimized structure of bended MIMO antenna.

The results of S_{11} , S_{21} , and TARC achieved for the optimized-bended MIMO antenna depicted in Fig. 3 are reported here below. Figure 4 illustrates the transmission parameter: the structure presents lower than -10 dB value in three different frequency bands. The first band covers 1.85

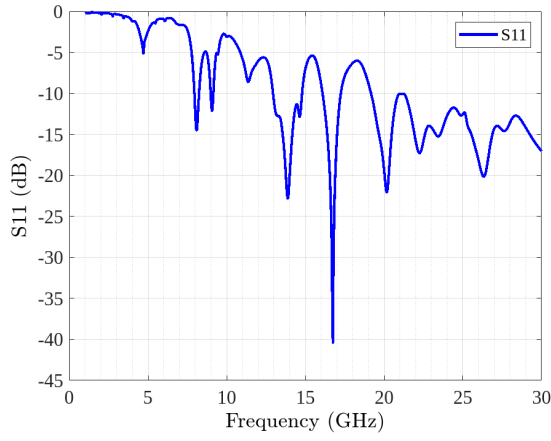


Fig. 4. S_{11} of the optimized MIMO antenna with bending angle 30° .

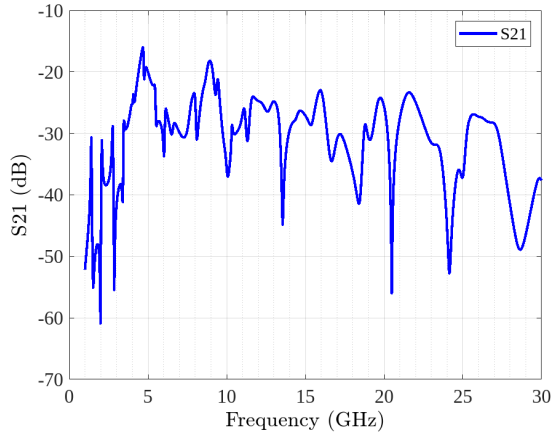


Fig. 5. S_{21} of the optimized MIMO antenna with bending angle 30° .

GHz (12.94 - 14.79 GHz) with -22.61 dB return loss at 13.86 GHz, the second frequency band is from 16.09 to 17.25 GHz with the maximum attenuation loss which takes place at 16.75 GHz (-40.34 dB). Moreover, the third band corresponds to the largest frequency band between 19.17 to 25 GHz (5.83 GHz). In addition, the gain and TARC of the optimized MIMO antenna are presented in Fig. 5 and Fig. 6, respectively.

IV. CONCLUSION

This paper describes an intelligent-based optimization method for designing and optimizing MIMO antennas, loaded by meander slots and lines. Due to the application of the bended MIMO antenna in various wireless communication systems, the design parameters with bending angle are optimized in this work. These sizing specifications are achieved by constructing and training the SNN where it helps in predicting design parameters leading to obtain the targeted output specifications. The bended MIMO antenna is optimized automatically in terms of S-parameters with TARC specifications. The optimization methods in this study are automated through a combination of CST Suite and MATLAB. To validate the proposed approach, a single bended MIMO antenna is designed and tested.

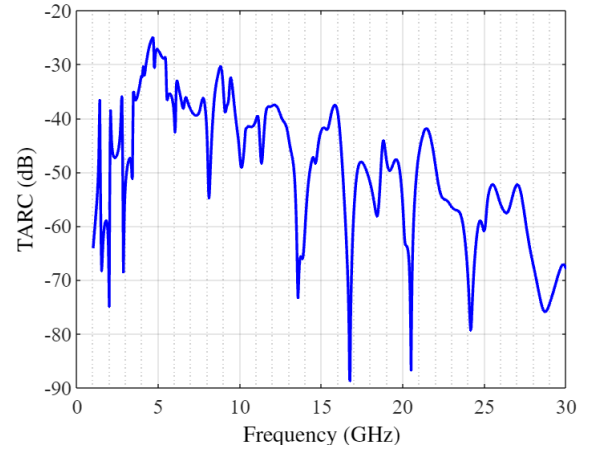


Fig. 6. TARC of the optimized MIMO antenna with bending angle 30° .

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