

# Designing a Compact Microstrip Antenna Using the Machine Learning Approach

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**Abstract**—This paper presents how machine learning techniques may be applied in the process of designing a compact dual-band H-shaped rectangular microstrip antenna (RMSA) operating in 0.75–2.20 GHz and 3.0–3.44 GHz frequency ranges. In the design process, the same dimensions of upper and lower notches are incorporated, with the centered position right in the middle. Notch length and width are verified for investigating the antenna. An artificial neural network (ANN) model is developed from the simulated dataset, and is used for shape prediction. The same dataset is used to create a mathematical model as well. The predicted outcome is compared and it is determined that the model relying on ANN offers better results.

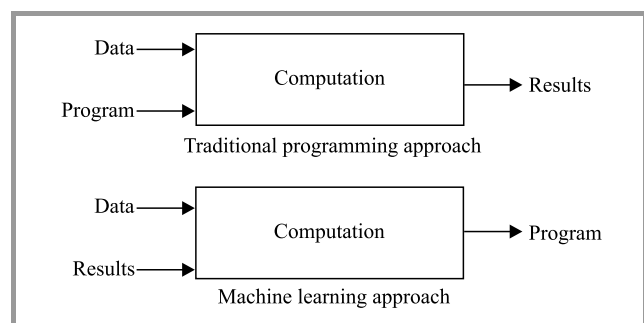
**Keywords**—artificial neural network, dual band, microstrip antenna, notch.

## 1. Introduction

New developments in the field of wireless communications call for compact, wide-band, high efficiency, multiband, and low cost antennas that are suitable for modern day applications. Microstrip antennas offer numerous advantages, such as small size, low weight and ease of fabrication due to their planar configuration. An antenna of this type is easy to mount on a rigid surface, supports dual-polarization and, unlike solutions of other types, multiband operation. The different techniques relied upon to make the antenna compact [1] without affecting its basic parameters include reactive loading [2], using a monopole antenna with defected ground structure (DGS), and modified patch [3]–[7]. Those methods are capable of reducing the antenna size by up to 70%. Meta-material [8]–[14] and engineered ground structure [15]–[18] may reduce the size of the antenna by up to 74% as well. Other miniaturization methods, like deployment of fractal structures in antenna design [19]–[21] may reduce the size of the antenna by up to 75% and engineered substrates [22]–[24] allow to reduce the size of antenna by 80% and by introducing close-ended or open-ended slots [25]–[30] of various shapes H, L, U, E, V, W, D, S double E, double U may reduce the size of the antenna by up to 86.5%. In some cases, more than one technique is used to make the antenna as compact as possible.

Machine learning (ML) is a subset of artificial intelligence (AI), effectively used in all areas of engineering, espe-

cially in communication network automation. ML is a specific type of data analytic techniques enabling machines to learn from experience (training) and to predict new data. A comparison between the traditional and the ML approach is given in Fig. 1. ML is preferred to solve complex mathematical problems with lots of variables and massive amounts of data. Today's methods relied upon while designing antennas require such a high level of expertise, as in most cases the design process requires a trade-off between such antenna parameters as small size and good bandwidth. AI approaches have been used in antenna design and optimization since the 1990s [31]. The most significant advantages that the use of the AI approach in antenna design has over the traditional methods lies in the ability to simultaneously handle multi-objective problems in order to achieve the specified goal and to provide the best automated solution [32]–[35].



**Fig. 1.** Computational approaches.

The drawback of analytical-based methods consists in big-computation overheads experienced in the design process. To cope with this, the trial-and-error approach may be used to achieve the specified goals. Slot-loading turns out to be the technique that is most widely used among all aforementioned methods allowing to make antennas compact [28] in size.

## 2. Synthesis and Analysis Problem for Microstrip Patch Antenna Using ANN

ANN is one of the approaches used in ML to map nonlinear data efficiently [36], [37] based on experience (training),

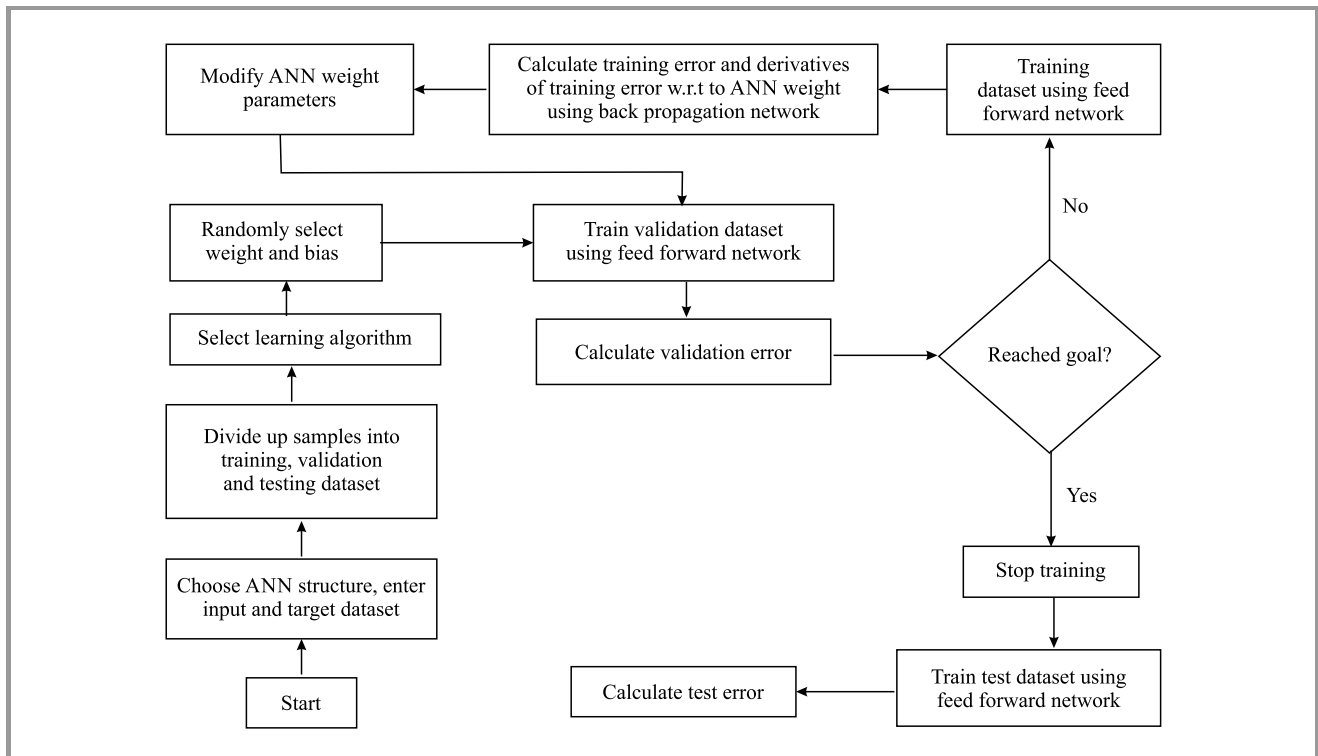


Fig. 2. Flowchart of ANN back-propagation algorithm.

while dealing with new data. Basically, three logic layers are distinguished in ANN architectures. The first is known as the input layer, while the last is referred to as the output layer. Between the input and the output layer, there is a number of hidden layers. Each hidden layer has one or more neurons. The number of the hidden layers, neurons, the activation function and the learning algorithm are all specific to the application. There are no rules to determine the number of hidden layers and neurons, but in most problems two to three hidden layers are used at the most in order to approximate all types of mathematical functions. The performance of ANN model depends upon the data collection, learning algorithm, weight initialization, change in an activation function, etc. In the case of antenna design, data should be collected either through simulations or measurements. The range of data always extends, marginally, beyond the model's utilization range [38]. Initially, data samples are divided into three sets, known as training (with the usage ratio of 70%), testing (15%), and validation (15%). According to the needs of a specific application, the percentages may be different. Next, the network size is chosen, i.e. the number of hidden layers and neurons in each of them is determined. Finally, the algorithm is selected based on feed-forward, back propagation, and feed-forward back propagation, to train the ANN and obtain the model. A flowchart of ANN feed-forward back-propagation algorithms is presented in Fig. 2.

To achieve the minimum mean squared error (MSE) It is necessary to train the model with accurate data. In this case, a total of 80 samples has been collected by simulating H-shaped RMSA using IE3D software. To minimize

MSE, different ANN algorithms have been tested by varying the number of hidden layers and neurons in each hidden layer. Finally, the best combination for the proposed model was selected. To train the ANN model, highly accu-

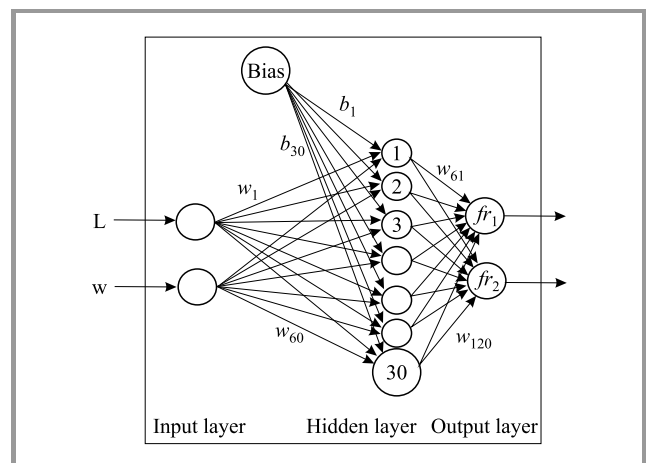


Fig. 3. Proposed ANN model for the analysis of compact H-shaped RMSA.

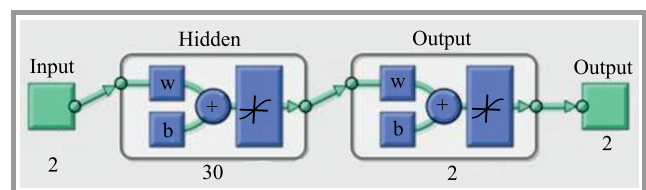


Fig. 4. ANN network architecture to train physical-to-electrical parameter.

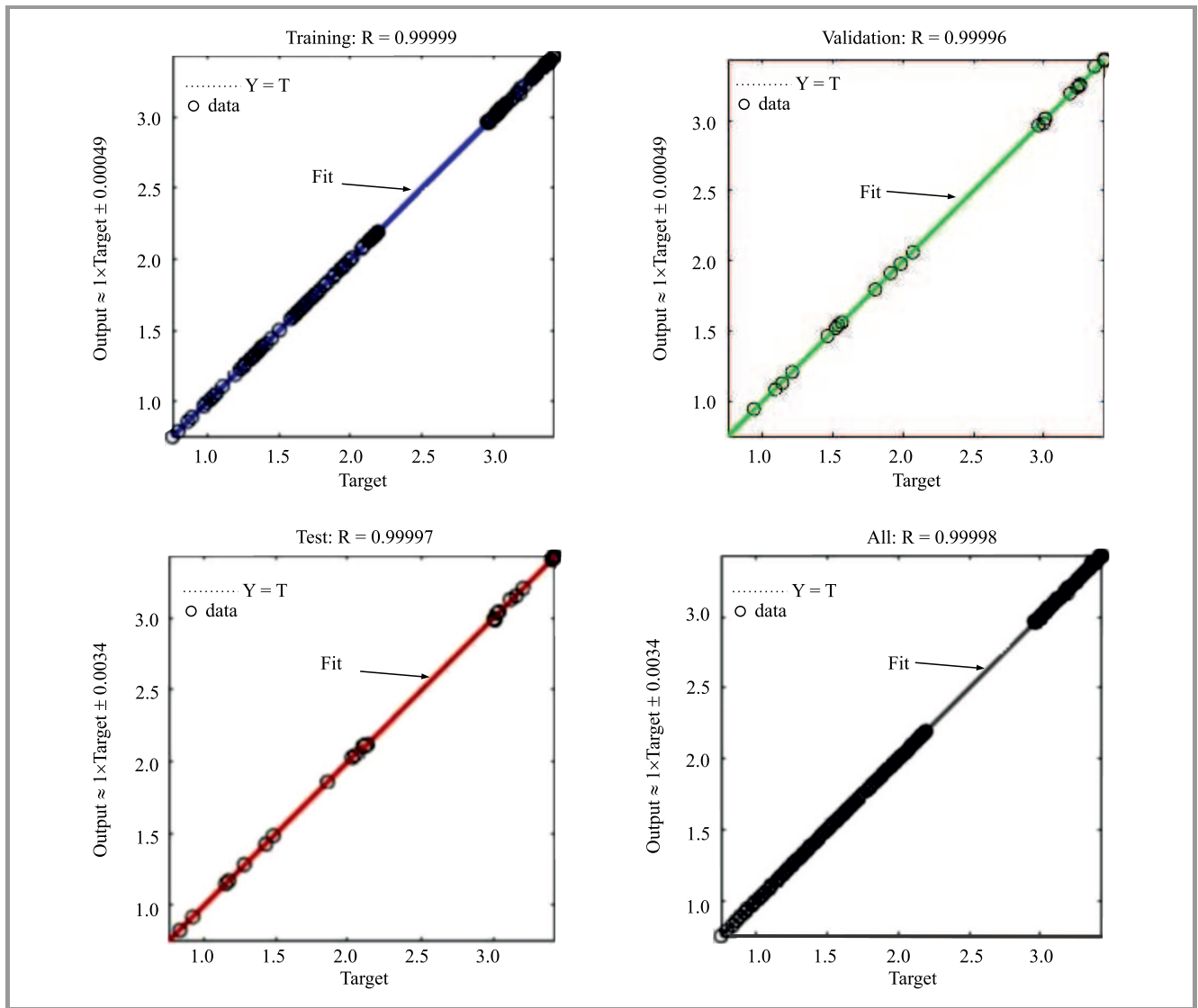


Fig. 5. Regression plot for physical to electrical parameters.

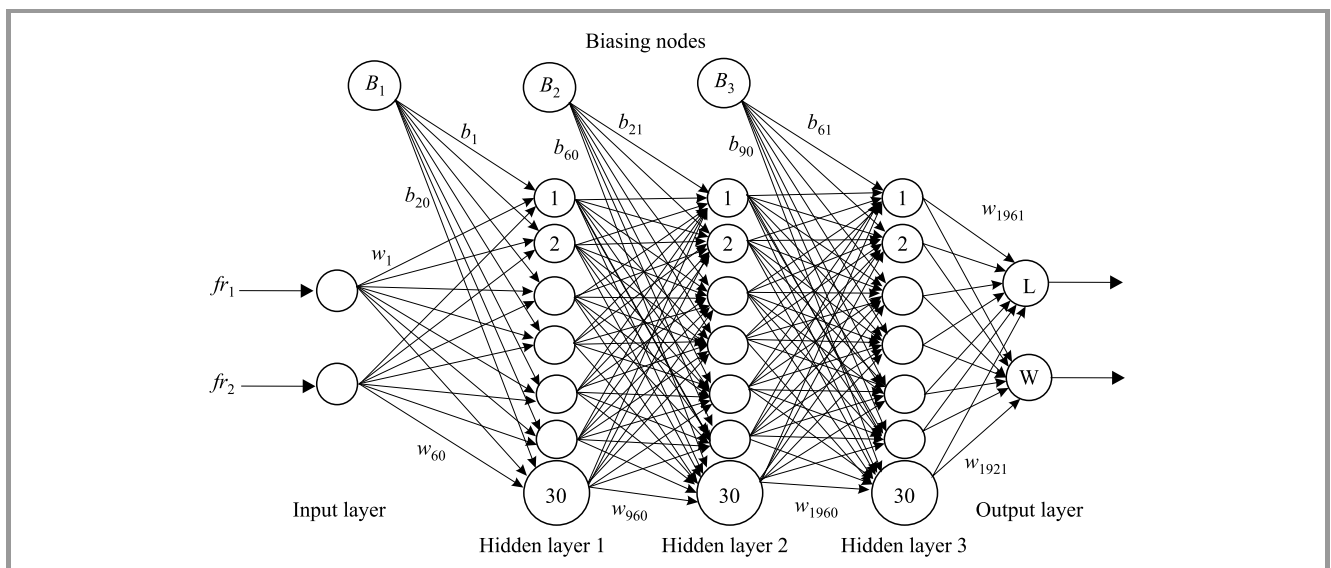
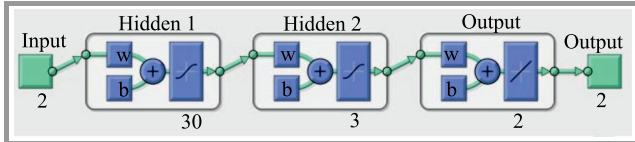


Fig. 6. Proposed ANN model for synthesis of H-shaped compact RMSA.

rate back propagation algorithms with minimum MSE were used [39].

Figure 3 shows a detailed architecture of the hidden layer of the proposed ANN model which uses the train set and predicts the dual resonant frequencies ( $f_{r1}, f_{r2}$ ), as well as the physical aerial parameters, i.e. slot length ( $L$ ) and width ( $W$ ) as input values. The Levenberg-Marquardt (LM) back propagation algorithm is used as ANN. ANN network architecture is shown in Fig. 4 with two input and output parameters, one hidden layer and 30 neurons. The regression plot of training, testing, validation, and overall process is shown in Fig. 5.



**Fig. 7.** ANN network architecture to train electrical-to-physical parameters.

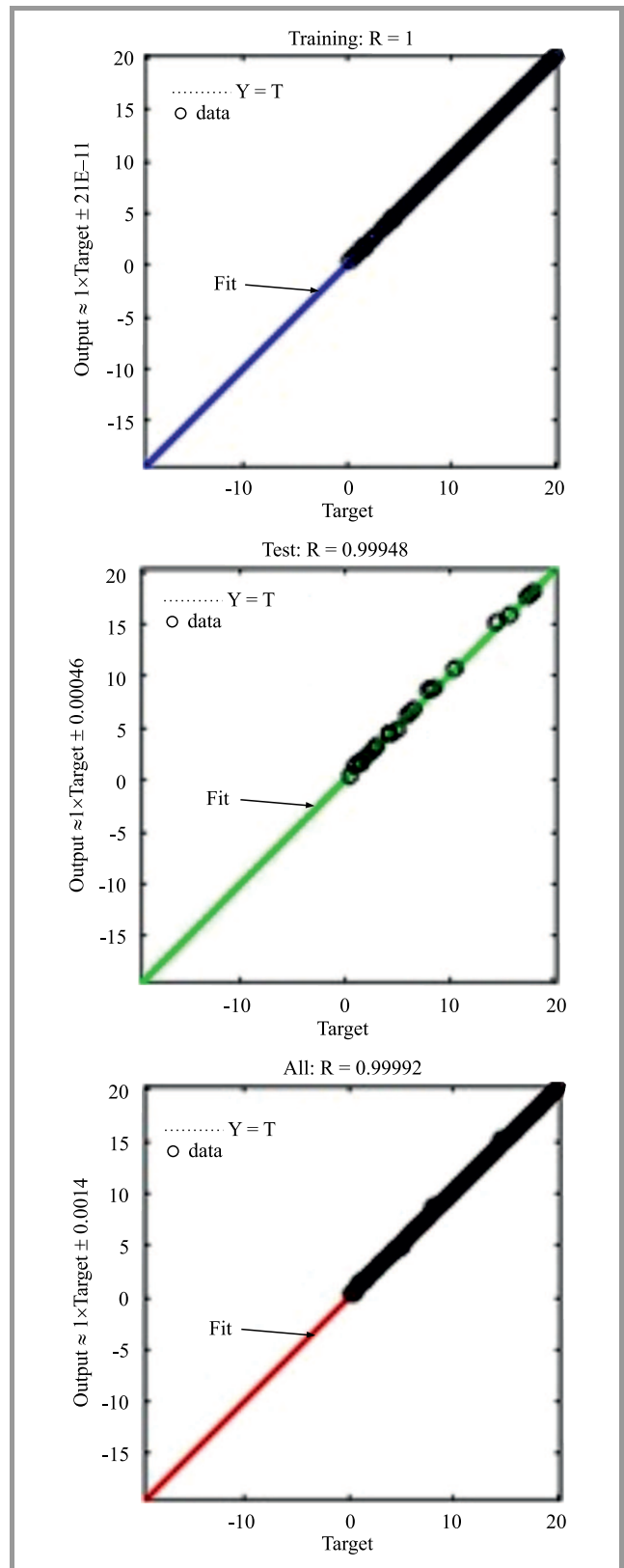
To train the ANN model for predicting physical dimensions of antenna, Bayesian Regularization (BR) back propagation algorithm have been used. ANN network architecture is shown in Figs. 6–7, where input and output parameters equals to two, the number of hidden layer is three, each hidden layer consists of thirty neurons. the regression plot of training, testing, and overall process is shown in Fig. 8. In the next step, using the same dataset, a mathematical model was developed to map the dominant resonance mode ( $TM_{10}$ ) and the higher mode ( $TM_{02}$ ) of a dual band compact H-shaped patch antenna using the curve fitting tool in Matlab software. Equation 1 represents the dominant mode ( $TM_{10}$ ) and Eq. 2 represents the higher mode ( $TM_{02}$ ):

$$fr_1 = 2.279 - 0.145l + .07311w, \quad (1)$$

$$fr_2 = 3.37 + 0.1202l - 0.081w - 0.05906l^2 + 0.04877lw + 0.002621l^3 - 0.002256l^2w. \quad (2)$$

### 3. Result and Discussion

Analysis of the H-shaped compact RMSA using the proposed ANN model is performed by taking one hidden layer and 30 neurons, as shown in Fig. 4. 80 samples were taken to train the model, with 70% used for training, 15% for validation and 15% for testing. Figure 5 shows the regression plots for training, validation, testing, and the overall process. The regression R value indicating the correlation between output and target, R value closer to one means that the close relationship. In the ideal case, both outputs and target are equal. It is clear from the evidence shown that the R value for training, validation, and testing of the proposed model is 99.998% accurate, meaning that it is perfect regression model. The synthesis of H-shaped compact RMSA using the proposed ANN model is performed by taking three hidden layers and 30 neurons per hidden layer, as shown in ANN network architecture in Figs. 6–7.



**Fig. 8.** Regression plot for electrical to a physical parameters.

In this case, 80 samples are used to train the model (85% for training, 15% for testing). Figure 8 shows regression plots for training, testing, and the overall process. It is clear from the evidence shown that the regression R value





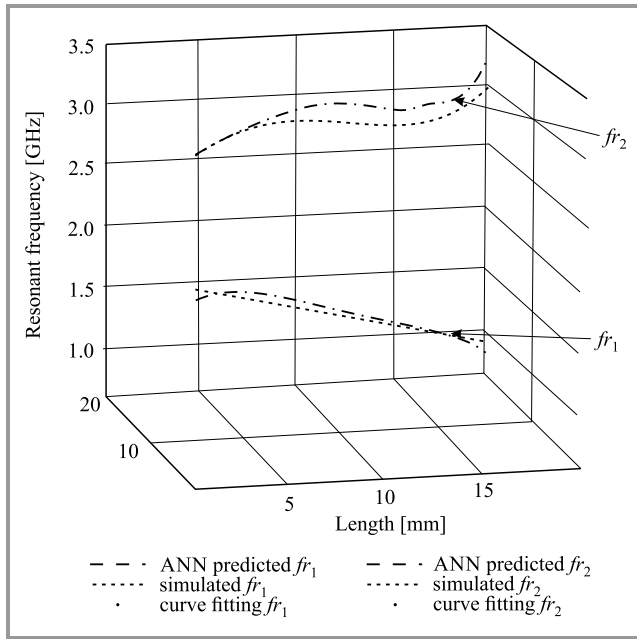


Fig. 10. Notch dimension vs. resonant frequency for  $TM_{10}$ , and  $TM_{02}$  modes of operation.

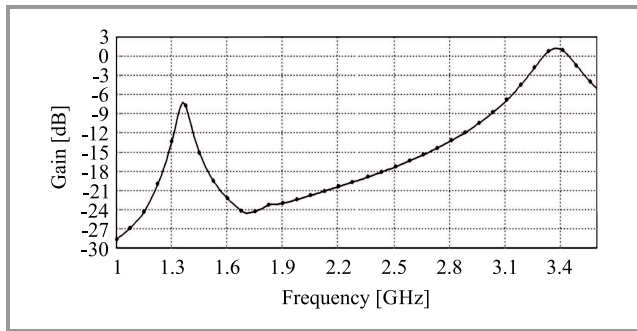


Fig. 11. Maximum gain vs. frequency plot for sample H-shaped RMSA.

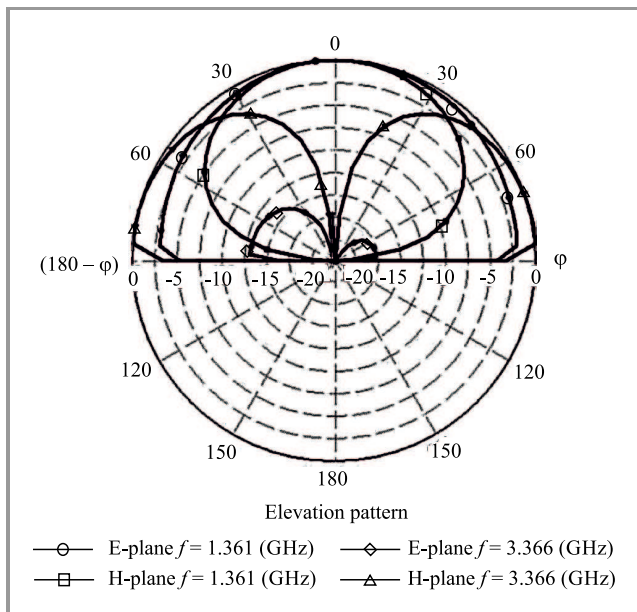


Fig. 12. Radiation pattern for sample H-shaped RMSA.

number of samples, in comparison to examples existing literature [40].

## 4. Design Specification and Dataset

Design specifications of the proposed dual-band H-shaped compact RMSA with an infinite ground plane are shown in Fig. 13, and the list of parameters used in the design

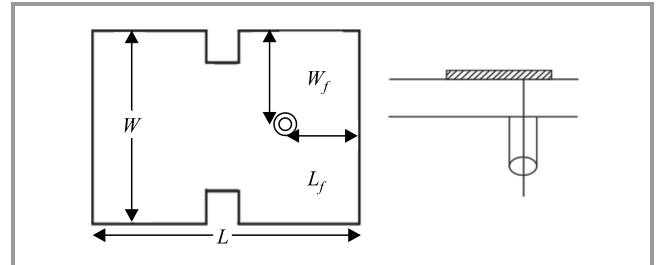


Fig. 13. Top and side view of H-shaped RMSA used for modeling.

is presented in Table 4. Along the radiating edge, two rectangular notches that are equal in dimensions are cut (upper, lower and centered in the middle), starting with the notch dimensions of  $0.2 \times 0.5$  mm, increased to  $20 \times 20.25$  mm in fixed steps of 0.25 mm in  $L$  and  $W$ . 80 samples were collected using IE3D simulation software.

Table 4  
Specification of H-shaped RMSA

Parameter	Value
Operating frequency	2.33 GHz
Patch length	$L = 32$ mm
Patch width	$W = 42$ mm
Substrate	FR-4
Substrate thickness	1.6 mm
Dielectric constant	4.4
Loss tangent	0.025
Feed type	Coaxial
Notch length	0.25 to 20 mm
Notch width	0.5 to 20.25 mm
Feed location ( $L_f, W_f$ )	6.575 mm, 21 mm

## 5. Conclusion

Machine learning is one of the methods used to design antennas quickly. The proposed model is simple, time-efficient and does not require any complex mathematical calculations. It may easily predict, with high accuracy, the physical or electrical parameters within the range of data provided for training, for a dual-band (0.75 to 2.20 GHz and 3.0 to 3.44 GHz), compact microstrip antenna that may be used in a variety of wireless applications.

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