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2x2 Array Microstrip Patch Antenna Designing and Validation with Artificial Neural Networks

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ABSTRACT
A novel and successful method for RF, microwave modelling, and antenna design has gained attention: computational modules based on neural networks. The behavior of active or passive components or circuits can be taught to neural networks. The design of a microstrip patch antenna utilizing an artificial neural network (ANN) is discussed in this research. Computer Simulation Technology (CST) is used to establish the antenna's size and characteristics in order to create a successful ANN model. The feed-forward back-propagation neural network and Levenberg Marquardt optimization algorithm are used to model the antenna design. High-Frequency Structure Simulator (HFSS) software, operating at 2.4 GHz, is used to build the initial microstrip patch (ISM band).A 2.4GHz operating frequency is used to create a 2*2 microstrip planar array. A variety of neural networks are evaluated and trained to produce the most ideal results after generating and modelling discoveries using HFSS simulation software and the Finite Difference Time Domain (FTDT) approach. In this research, neural networks are utilized. In order to identify the most ideal solution, optimization is performed using a radial basis function neural network (RBF NN) and a feed-forward backpropagation approach.

Keywords: Computer Simulation Technology, MicrostripPatch Antenna, Artificial Neural Network (ANN), High-Frequency Structure Simulator (HFSS) modeling,

I. INTRODUCTION

Early in the 1950s, microstrip antennas were created, and it wasn't until the 1970s that they were widely used. Other names for them include patch antennas and planar antennas. The substrate, patch, and ground plane are its three component pieces. The ground plane supports the whole structure and is put on top of the dielectric substance. In the early 1950s, microstrip antenna gave rise to planar antenna [1]. Because of its many attractive properties, such as simplicity of manufacture, conformity, lightweight, low profile, compact design, cheap cost, small volume, etc., microstrip antennas are in great demand in many wireless communication areas.Modern wireless communication systems, such as the Global Positioning System (GPS), the Worldwide Interoperability for Microwave Access (WiMAX), satellite communication, radar communication, mobile communication, etc., require microstrip antennas to work better. Additional thought is required on the performance traits of microstrip antennas, such as antenna gain [2]. To increase their radiation performance, microstrip antennas with a flawed ground structure and/or a slotted radiating patch are typically used [3].

In its simplest form, a microstrip patch is a narrowband antenna. Radio transmission, medicinal applications, as well as various commercial and governmental uses all make use of microstrip patch antennas (MPA). Mobile radio, wireless communication, and each have standards that partially meet their demands. High-frequency communications,

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mainly in the microwave region, utilise microstrip-based antennas [1].

Constraints such as poor bandwidth and power handling capability can be overcome by selecting the proper feeding strategy, substrate thickness, and dielectric constant [4]. One of the most often occurring problems with this antenna is surface wave excitation. A vital part of next-generation wireless networks are microstrip antennas. These come in a variety of dimensions and forms, including elliptical, round, square, and rectangular. The disadvantages of these antennas include the production of spurious feed radiation, low radiating efficiency, restricted frequency bandwidth, scan performance, and poor polarization immaculateness. Proper design considerations can help with a lot of constraints. Therefore, in order to construct a patch antenna, it is crucial to accurately measure the resonance frequency [5].

The bandwidth of microstrip antennas may be increased using a variety of techniques, such as adding parasitic components to the stack or coplanar arrangement, modifying the radiator patch's geometry by creating slots, or creating an H-, E-, or U-shaped patch antenna using foam or a thick substrate. This study examines the microstrip antenna's bandwidth using an ANN technique. [7].

The term "ANN" refers to data processing techniques that are inspired by the structure and function of biological neurons. The computational power of an ANN is determined by the training process, connection weights, and design [8]. The creation of microstrip patch antennas is only one of the technological and scientific fields where ANNs have been used [9]. ANNs have been used to determine the patch antenna's resonance frequency at the suggested dielectric constant, height, length, and width [10].Using ANN based on multilayer perceptron's (MLPs) and the radial basis function neural network, the resonance frequency of the microstrip circular antenna with the thick and thin substrate is calculated (RBFNs). Applying the right learning approach, the ANN may be taught to achieve a small error between the target and the network output. The basic construction of the microstrip patch is shown in Figure 1 [1].

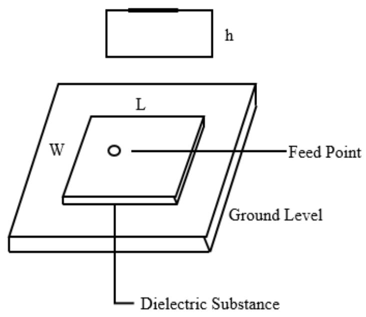

Figure 1: Microstrip patch fundamental diagram

II. RELATED WORK

In this study, Sagik et al. [11] used a structure composed of metamaterial to boost the antenna's gain and directivity (MTM). The MTM design structures and the antenna communicate. The antenna's frequency, directivity, and gain are then trained to predict the best settings using an artificial neural network technique. The gain and directivity of the antenna are boosted as a result of the connection between the microstrip patch antenna and MTM structures.

Chabaa et al. [12] suggested to predict the notch frequency of an ultra-wideband (UWB) antenna operating in the frequency range of 3.85 to 12.38 GHz, and the estimated coefficient of regression suggests a value of R equal to one changing a good regularity between the predicted notch frequency and the simulated frequency. The proposed UWB antenna design in CST simulations and HFSS uses a notched band from 5.1 to 6.0 GHz with an emphasis on 5.51 GHz; these characteristics avoid interference between the use of HIPERLAN/2 WLAN and (WLAN) IEEE802.11a and UWB-based technologies.

A reduced microstrip patch antenna that considerably enhances cross-polarization purity was presented by Poornima et al. [13]. The method is used to decrease cross-polarization in any operating conventional Patch without changing the ground plane or patch itself. Without changing the radiating patch or the ground plane, a superior antenna design was produced. The recommended suppression of the XP value, antenna size, gain, and impedance matching have all been considered. This technique could be useful for telecom and satellite antennas.

In order to get the best impedance matching and high gain, Badra et al. [14] devised a technique for effective antenna design. They also used ANN to construct microstrip-based antenna. The elliptical patch antenna is appropriate for 2.4 GHz wireless use tasks. The ANN receives data from the CST EM simulator in order to train and test the NN model. A feed-forward back-propagation ANN and the

Levenberg-Marquart method are used to simulate the antenna. Numerous studies have been conducted utilizing statistical factors including mean error, standard deviation error, and mean square error to create an efficient ANN model (MSE).

According to Bhoot et al. [15], the performance of four different shaped antennas is contrasted using the F, H, T, and E forms. The operating frequency of the antenna is 2.4 GHz. The characteristics of these variously shaped antennas change when the design criteria are varied. The RL, power radiation gain, and direction are all greatly affected by changes in design factors. In terms of practical applications, the assessed companies' E-shaped Microstrip Patch Antenna (MPA) is the best option. Any application requiring a lot of bandwidth makes use of the E-shaped antenna.

A concept for creating a Microstrip Patch Antenna in Neural Network mode for an Ultrawideband frequency range was proposed by Khanna et al. [16]. The computational instrument for the aforementioned process is the neural network. The length and breadth of the patch, which are geometrical dimensions, were determined by the author with more accuracy and correctness at the output of the constructed network for height and dielectric constant. In the last stage, the factors of the enhanced antenna are determined using the information gained by shifting backward the input and output data of the synthesis process. The desired resonant frequency and the synthesized resonant frequency are contrasted in the ANN analysis.

A wideband MPA with a hybrid fractal slot and a partial ground plane was presented by Sharma et al. [17]. The partial plane's size is changed to maximize the antenna's gain and bandwidth. The most effective ground plane in terms of gain and bandwidth has been found to be 8 mm long. The intended antennas have been built, and their measured bandwidths for the Koch-Koch slot and Koch-Minkowski slot, respectively, are 3237 MHz and 3326 MHz Comparison of the recommended antenna's simulated and measured results reveals a respectable degree of agreement.

A four-port stacked patch antenna for multiple-input multiple-output (MIMO) applications with bandwidth enhancement was described by Wen et al. in [19]. The created stacked patch antenna is made up of two collocated MPA imprinted on the lower and top substrates. By examining Characteristic Modes, it determined eight desired modes that are driven to resonate at the operating band (CM). The bottom patch's resonant modes may be stimulated to produce four different radiation patterns. One series resonance and two parallel resonances that have been combined to produce a wider operational band are the three resonance frequencies that make up the interesting frequency range for each radiation pattern. For four-port MIMO applications, the developed stacked patch antenna can boost the bandwidth of a multi-mode microstrip antenna.

In order to determine the ideal geometry of a fractal antenna with a circular form for a certain resonant frequency, Pattnaik et al. [20] suggested an ANN ensemble model as a function of the aim of a PSO algorithm. The superiority of the ANN ensemble over the component ANN mode has been established. The size reduction capabilities of the projected fractal antenna are used to design an antenna for the 5.8 GHz WLAN band that is 41.64 % smaller than a conventional circular microstrip antenna. The antenna's reduction will enable the creation of compact wireless communication technology.

Neurocomputational methods to predict the characteristics of a circular-shaped microstrip patch antenna were proposed by Shivia et al. [21]. To assess the various performance characteristics of a circular-shaped Microstrip Patch antenna, a trained Levenberg-Marquardt algorithm and Feed-Forward Back-Propagation Artificial Neural Network (FFBPANN) are used. With respect to measurements, simulations, and theoretical calculations, the results of the neurocomputational assessment are highly consistent.

ANNs are a particular class of learning model that are used to estimate unknown functions with plenty of inputs [23]. ANNs are modelled as a system of interconnected, talkative "neurons." This does the same tasks as a human brain. An ANN, a smart algorithm, is used to model a microwave issue. A neural network is a mysterious device that simulates antenna construction using its learning skills. The ANN multilayer perceptron (MLP) design is depicted in Figure 2 [10].

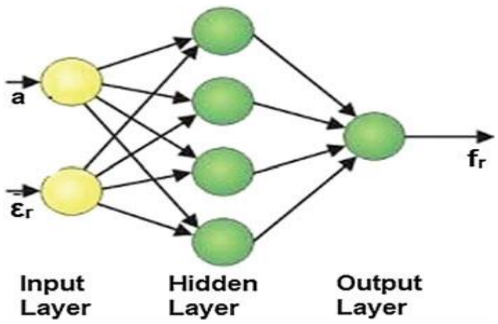

Figure 2: Structure of ANN [10]

A proposed microstrip patch antenna is simulated using ANN. It is made up of three layers: an input layer, an output layer, and a hidden layer. Nodes in each layer are connected to nodes in a hidden layer

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through nodes in the input layer. Similar to this, hidden layer nodes and output layer nodes are connected [24–28].

To create a successful ANN model, the antenna's size and characteristics are established with the use of computer simulation technology (CST). The ANN models the nonlinear relationship between the inputs and outputs. The network input factors are the three main axes (R1, R2, and R3) of the three linked ellipses. The ANN input characteristic is constrained by the resonance frequency. The output parameters are gain and return loss. A feed-forward back-propagation neural network and the Levenberg Marquardt optimization algorithm are used to model the antenna design. Because of its high convergence features and ease of learning, this method is recommended [29].

A dataset that correlates to the frequency response is input into the ANN. For further processing, the data is divided into 100 training sets and 60 testing sets. The neural network training process is facilitated by the use of MATLAB, a toolkit for neural networks. Its objective is to lower the mean square error (MSE), which reveals how well ANN performs as per Equation (1) [30].

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}[y_i - F_{ANN}(x_i)]^2 \qquad (1)$$

Where n signifies observations quantity, y_i indicates the CST targeted output, and F_{ANN} (x_i) calculates ANN's expected output.

2.1 Feed Forward Back Propagation

The Multilayer Feed-forward Neural Network (MLFNN), which uses the back-propagation learning technique, is the most well-known type of ANN. These kinds of ANN designs, which process data forward, have hidden layer(s) made up of computation-related nodes known as hidden neurons [32]. The architecture of FFBP NN is made up of the input, hidden, and output layers. FFBP takes the lead in both forward and backward directions. It computes output in the forward procession and computes error in the reverse procession.

Through the input layer, training data are fed forward to the NN. The hidden layer, which is entirely responsible for the data's continued processing, receives the data after that. The data is then used to calculate the output in the output Layer, which also contains the activation function. When stride is the function at the output layer, the classification issue is resolved. When the function at an output layer is linear, the regression problem is resolved.

The computed values for the forward pass are contrasted with the desired output. The difference between the actual and desired output is referred to as the error. Calculated and sent back to the Hidden Layer is this mistake. The gradient of the mistake is computed and applied to node k as follows:

$$e_k = d_k - y_k \qquad (2)$$

Where y_k is neuron k's estimated output, d_k is the output desired and e_k is the error on the output of a single neuron k.

Therefore, the gradient (δ_k) is calculated as shown in equation (3).

$$\delta_k = \left(\frac{\delta y_k}{\delta x_k}\right) \times e_k \qquad (3)$$

Where x_k is the weighted sum of node k's input values.

2.2 Radial Basis Function Neural Network (RBFNN)

A feedforward NN is an RBFNN [33] that has a more integrated structure and a quicker learning rate than other networks. RBFNN is composed of three layers: the input layer, the output layer, and the hidden layer. According to [34], the Gaussian activation function is preferred because it may be used to create a non-linear link between the input from neurons in an input layer and the output from neurons in an output layer. The Gaussian activation function φ_I (x) is represented by the following equation:

$$\varphi_i(x) = e^{\frac{||\sum_{j=1}^{N} w'_{ji}x_j - c_i||^2}{2\sigma_i^2}}$$

Here, the status of $w'_{ji} = 1$ as alternative values of w'_{ji} result in the biased selection that precedes weighted 2-satisfiability. As stated in the equations below, σ_i is the width and c_i is the center:

$$c_i = \frac{1}{m}\sum_{i=1}^{N} x_i \qquad (5)$$

$$\sigma_i^2 = \frac{1}{m}\sum_{i=1}^{N} ||x_i - c_i||^2 \quad (6)$$

Where x_i is the input binary value for N neurons input, m is several neurons per clause and the Euclidean norm ||space|| is given in equation (7):

$$||\sum_{i=1}^{N} x_i - c_i|| = \sqrt{\sum_{i=1}^{N}(x_i - c_i)^2} \quad (7)$$

RBFNN $f(w_i)$ produces the following final output by using equation (8):

$$f(w_i) = \sum_{i=1}^{j} w_i\varphi_i(x) \qquad (8)$$

Where $f(w_i) = (f(w_1), f(w_2), f(w_3),.., f(wk))$ is the RBFNN output value and $w_i = (w_1, w_2, w_3,.., w_N)$ is the output weight.

III. METHODOLOGY

The suggested learning technique, procedure, and outcomes of the validation process employing feed-forward ANN and RBF are described in this section. These are depicted in Figure 3. At work, the emphasis is on using the HSFF tool to generate the dimensions of a microstrip route and then using ANN to verify directivity with a MATLAB tool. Additionally, this paper demonstrates how to employ RBF NN to optimize the size of a microstrip patch.

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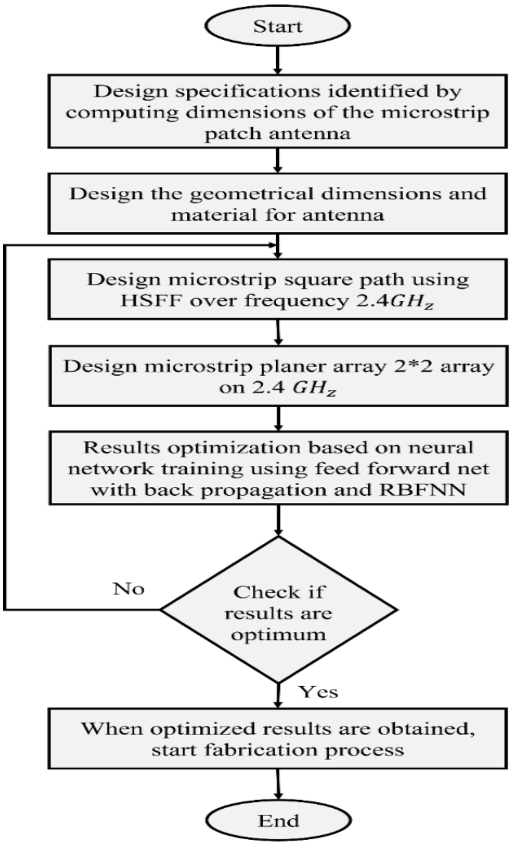

Figure 3: Proposed Methodology

The Feed Forward Net with Back Propagation Algorithm and RBF Neural Network are used to optimize the process, and the results are compared to find the best results. Figure 4 shows a flowchart of the procedure for learning and outcome validation.The input and target data must first be provided before selecting an ANN structure. There are three logic layers in the ANN framework. The first layer is referred to as the input layer, while the final layer is referred to as the output layer. Then, three groups of data samples—training, testing, and validation—are created.

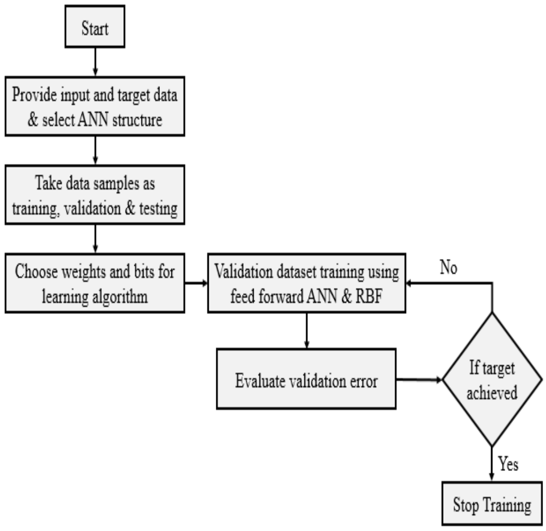

Figure 4: Learning and Result Validation Process

Then, the weights and bits, or the number of neurons and hidden layers in each learning method, are selected. The validation dataset is trained using the feed-forward ANN and the RBF to produce the model. Assess the validation mistake once again, then determine whether the goal has been attained. If a goal is met, the training process should be stopped; otherwise, feed-forward ANN and RBF should be used once again to confirm the dataset training.

IV. DESIGNING OF 2×2 MICROSTRIP ARRAY PATCH ANTENNA

This section provides a detailed description of the design of the 2x2 microstrip patch array antenna depicted in figure 5(b).A microstrip patch antenna is created using 2.4 GHz 3D High-Frequency Structure Simulator (HFSS) software.

The frequency of the patch antenna is fed to pass the wavelengths to the ground plane during the design of the microstrip patch antenna using a metal layer known as the feed wire or transmission line. The feed wire creates a connection between the patch antenna and ground plane.

The patch has the following dimensions: L=70mm W=70mm and it is positioned on top of the substrate, which is a dielectric circuit board, and has the following thickness, H=0.5mm.

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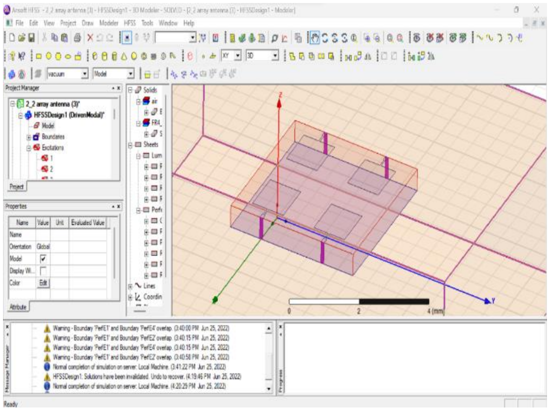
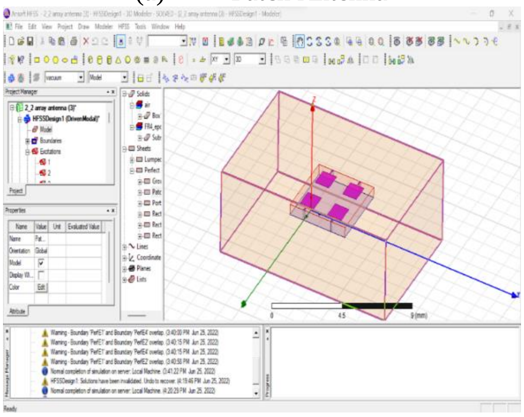


(a) Patch Antenna



(a) 2×2 microstrip patch array antenna

Figure 5: (a) Patch Antenna (b) 2×2 microstrip patch array antenna

V. RESULT AND DISCUSSION

This section uses computer simulation technologies and an artificial neural network to demonstrate various outcomes of the proposed microstrip patch antenna design. Utilizing the MATLAB tool, the study paper presents the construction of an ANN-based design model. Each stage of the implementation process is shown in the results below.

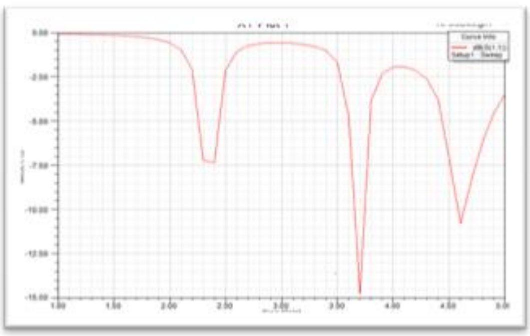


Figure 7: Gain dB (S (1,1) Vs frequency graph

Figure 7 shows a return loss graph for a microstrip antenna. A frequency between 1 GHz and 5 GHz is utilized to get the findings that are shown. The return loss plot establishes the resonance frequency. The frequency range in which the return loss (S1,1) is greater than -10.0 dB is known as the antenna bandwidth (BW). The return loss at 2.4 GHz is -7.75 dB.

An antenna's directivity and electrical efficiency must be taken into account when calculating the gain of the antenna. Operational frequency ranges for the antennas in Figure 8 are 3.7 MHz to 3.8 MHz and 2.3 MHz to 2.4 MHz, with corresponding gains of -35.2 dB and -34.8 dB, respectively.

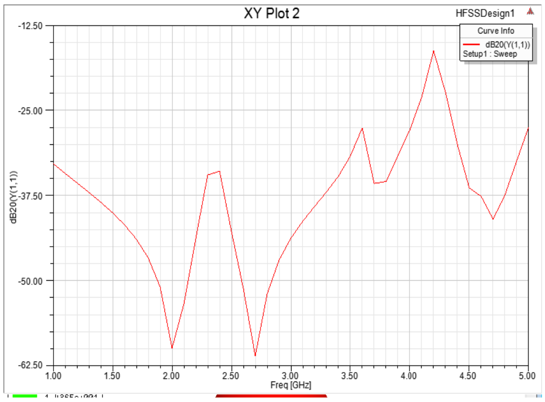


Figure 8: frequency vs gain graph

Based on figure 9, With a VSWR of 2.0, the antenna offers a fantastic impedance match at 2.4 GHz. Less than 1.5:1 is the optimal VSWR. In low power circumstances when power loss is more pronounced, a VSWR of 2:1 is only moderately acceptable. With the right tools, however, a VSWR of up to 6:1 may be employed.

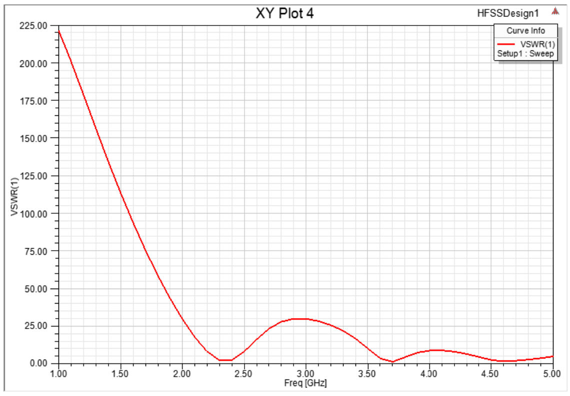


Figure 9: VSWR plot for the substrate

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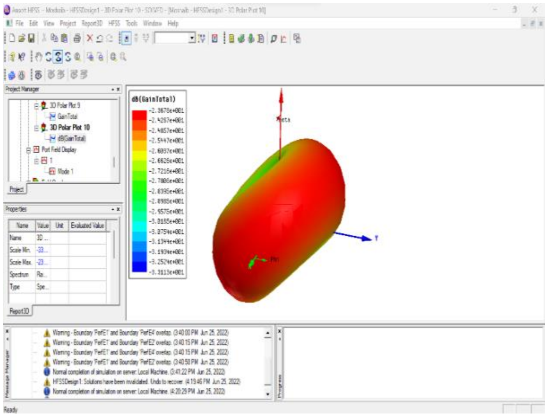

Figure 10: 3D radiation pattern of the proposed antenna

The suggested microstrip patch antenna, which has a directivity gain value of 3.3988e+000 dB, is depicted in Figure 10 as a 3D radiation pattern. An antenna's radiation pattern is related to its directivity. The 3D radiation pattern's red portion depicts the antenna's maximum gain region, while the yellow portion explains its average gain pattern. Null radiation follows, which is represented by the green portion of the pattern.

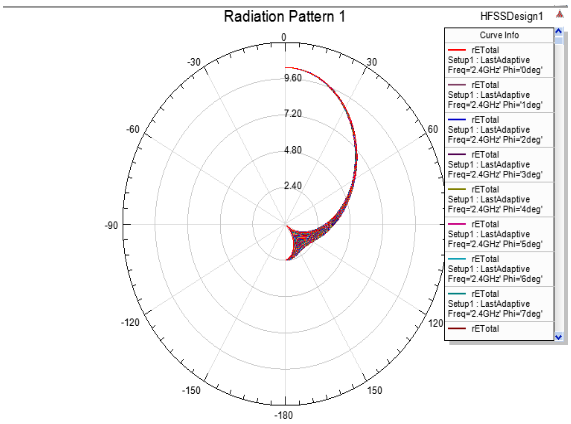

Figure 11: Radiation pattern of an antenna

The radiation pattern, which depicts the energy released by an antenna, is a term used to describe the distribution of radiated energy into space as a function of direction. The radiation pattern of the constructed microstrip patch antenna is seen in Figure 11.

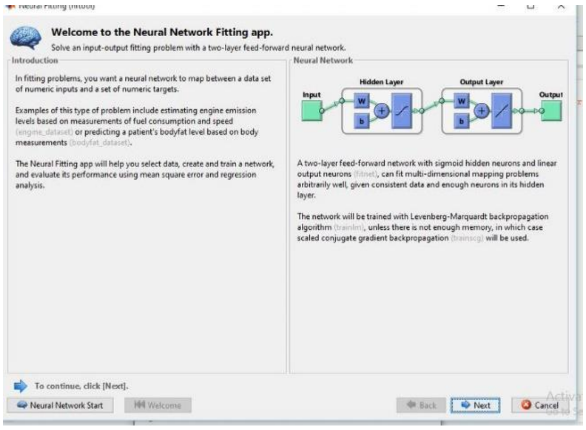

Figure 12: Multilayer Artificial Neural Networks

Artificial neural networks are computer models that were recently developed as a modelling and design tool that might be used in place of numerical models and analytical models. These models were inspired by the structure and function of biological neurons. The most popular artificial neural network model employed today is the Multilayer Perceptron (MLP) model, as shown in Figure 12.

Figure 13 shows a method for feeding input to an artificial neural network in a certain order, where x and y stand for a matrix containing static data. The target data is utilized to describe the desired network output as a y variable, whereas the input data represents the input as x variables.

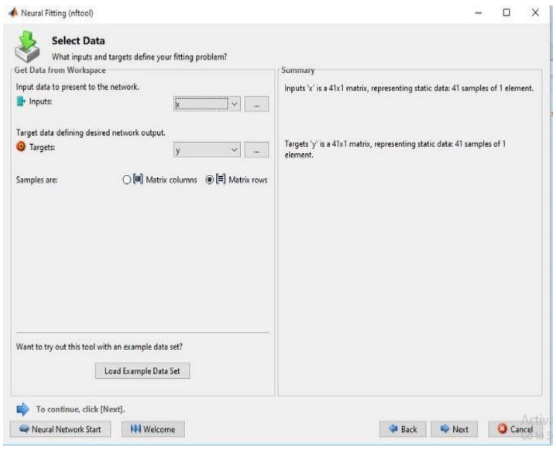

Figure 13: show input step is given to present a neural network

One hidden layer and 50 neurons in artificial neural networks are utilized to examine a microstrip patch antenna. As shown in figure 14, there are 41 samples collected, of which 70% are utilized to train the model, 15% to verify the model, and 15% to test the model.

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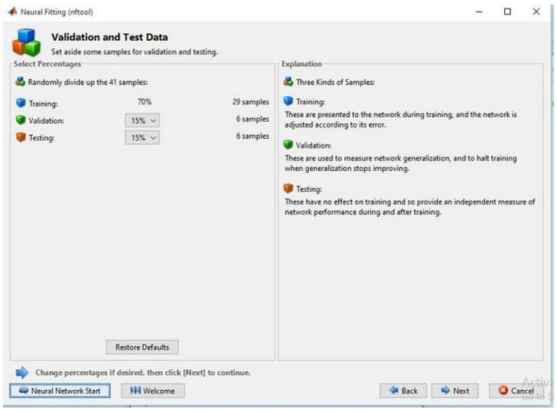

Figure 14: Represent the percentage of validation, testing, training data in samples

With the only objective of minimizing error in achieving the resonant frequency at the given dimensions of the planned antenna, the samples are trained using neural network training techniques. 29 samples were picked from the dataset of 41 samples for training, 6 samples for validation, and 6 samples for testing, with respective mean square errors of 5.00272e-1, 8.02812e-0, and 14.96138e-0. Figure 15 illustrates the training of a network with quick convergence using the Levenberg-Marquardt method.

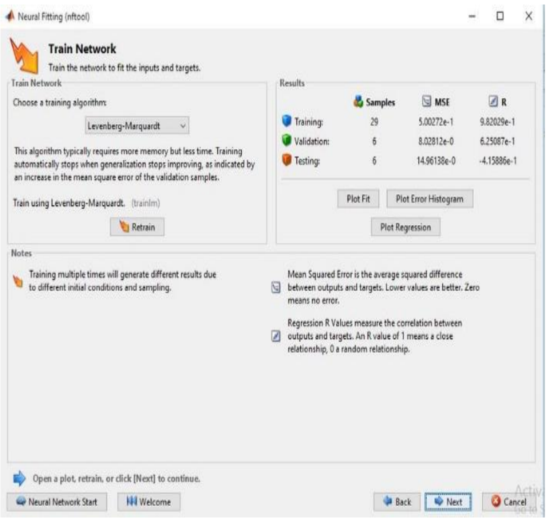

Figure 15: Network training

The artificial neural network architecture used for creating and testing microstrip patch antennas is shown in Figure 16. The neural network is built using the hidden and output layers. Based on physical to electrical parameters for the training, 50 neurons are selected for the neural network.

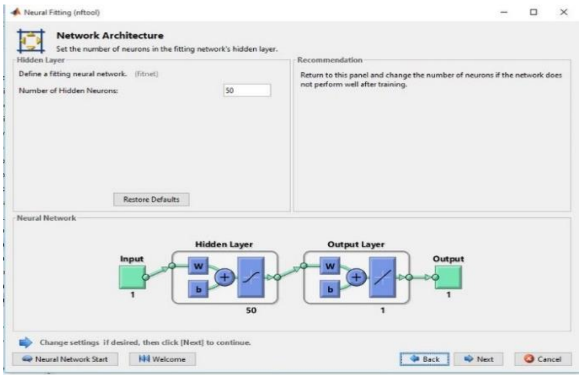

Figure 16: Architecture of artificial neural network

Figure 17 depicts general simulation concerns with 5 iterations in the epoch count and a 2 msec execution duration. 3.93e-28 is the result of Performance, 3.68e-13 is the gradient, and 4 is the value of the validation tests. 1.00e-08 is the mu finding.

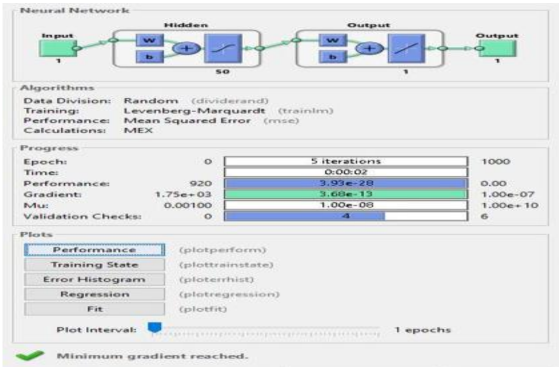

Figure 17: Performance parameters

The network is implemented using the MATLAB tool, and because there are only 41 samples, the input as the x variable in figure 12 is split into 70% for learning, 15% for validation, and 15% for testing. The ANN model was used to produce the output, which is shown in figure 12 as y variables. Figure 18 shows the input as x variables and the outcome as y variables. At 3.5 epochs, or iterations, the maximum error occurs.

Using a probability value between 0 and 1 as its output, cross entropy is a measurement of the results. The "Cross-Entropy" is therefore computed as a performance parameter, as shown in figure 19. Performance data for the training, testing, and validation datasets are shown, with epoch 1's validation performance peaking at 8.0281 as the best.

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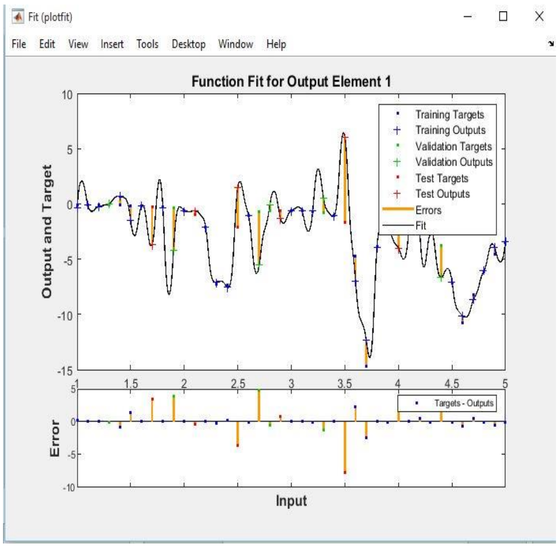
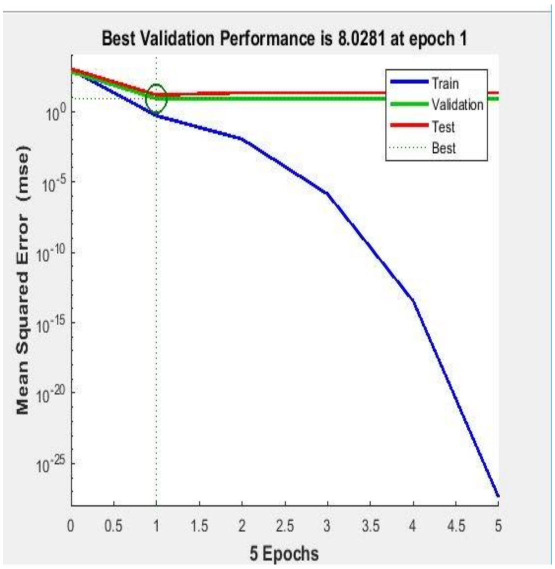


Figure 18: Function fit for output vs input and error vs input



. Figure 19: Graph between Mean Square Error and Epoch

Gradient evaluates how each weight has changed as a result of the change in error. The outcomes of the gradient and validation check are shown in Figure 20. The best gradient value was found in the fifth epoch and is 3.6846e-13. While the fifth epoch yields the number 4 that serves as the ideal validation check.

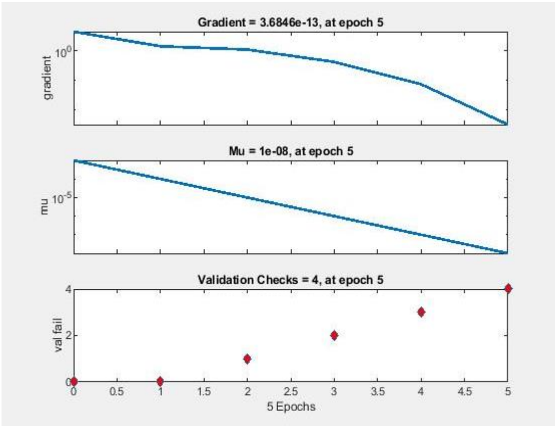


Figure 20: Show Gradient, mu and Validation Fail results at epochs 5

The findings of the 20-bin error values at 0.08929 are displayed in Figure 21. Error is a discrepancy between the desired objective and the result. The incorrect values appear in the training dataset at around 21 instances and in the validation dataset at about 22 instances.

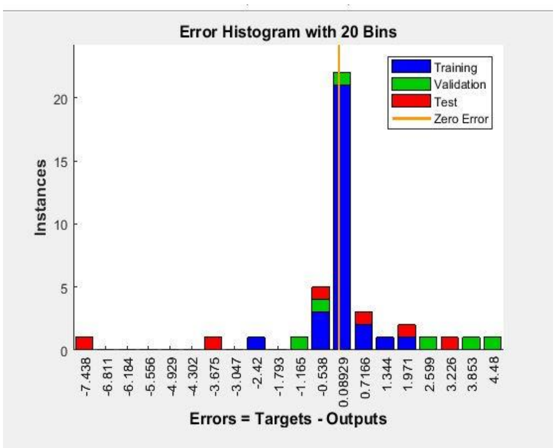


Figure 21: Error value histogram

The regression graph for the whole process, including training, validation, and testing, is shown in Figure 22. Regression's R-value measures how closely the target and the output are related, with R values closer to one indicating an even stronger association. The target and the outputs are identical in an idealistic setting. The data demonstrates that the R-value of the regression for the suggested model's training is 98.203 percent accurate. it comes a little bit closer to one. It is almost an ideal regression model. The R-values for the test and validation are around 62.509% and 41.589%, respectively. In terms of output and target, it indicates that test and validation data have significant differences.

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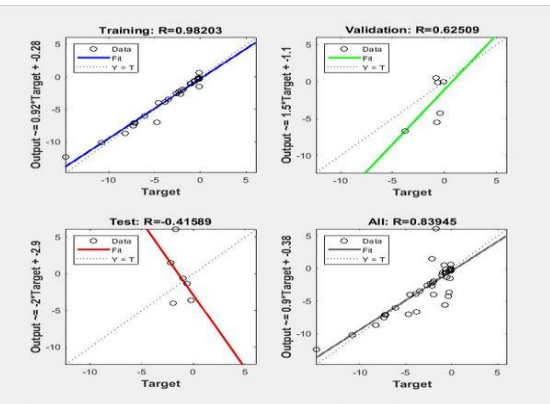

Figure 22: Physical to electrical parameter's regression graph

Comparative study

The performance of the developed patch antenna, 3.93e^{-28} in 5 epochs, outperforms the current performance, 0.000165626 in 21 epochs. As can be seen from Table 1's comparison of the data, the suggested model beats the most recent model.

Table 1: Result comparison

[Reference no.]	Heaton, [27]	Proposed work
Patch antenna performance	0.000165626	$3.93e^{-28}$
Epoch's count	21	5

VI. CONCLUSION

This study's main objective is to develop and validate a microstrip patch antenna using artificial neural networks. The investigation shows that this neural network model is highly accurate. It is feasible to achieve a minimum mean square error by altering the buried layer's number of neurons. With the aid of CST, the size and characteristics of the antenna are established in this study in order to create a successful ANN model. The feed-forward back-propagation neural network and Levenberg Marquardt optimization algorithm are used to model the antenna design. A microstrip patch with an ISM band frequency of 2.4 GHz is constructed using the HSFF simulation programme. 3.3988e+000 dB is the directivity gain value for the proposed antenna.The operating frequency range for the proposed antenna design is 3.7 MHz to 3.8 MHz and 2.3 MHz to 2.4 MHz, respectively, with corresponding gains of -35.2 dB and -34.8 dB. The process of designing an antenna often requires a lot of time. But it is quicker and more precise using a neural network model.

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