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# Ascertaining Resonant Frequency of Rectangular Patch Antenna using Neural Network

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## ABSTRACT
In this paper, with the help of Artificial Neural Network (ANN), we are determining the resonant frequency of a rectangular patch antenna at a given length, width, height and dielectric constant. After training phase of ANN(Artificial Neural Network), the obtained results are compared with the theoretical obtained value of resonant frequency at the same length, width, height and dielectric constant. The resonant frequency is maintained at Ku (12 GHz-18 GHz) band which is used for satellite communication and radar applications.

## General Terms
Antenna, nftool, error histogram, regression curve.

## Keywords
ANN, downlink, fringing effect, resonant frequency, uplink.

## 1. INTRODUCTION
There exist application based different types of antennas for example, patch, aperture, half wave dipole etc. but the main advantages associated with micro strip patch antenna are its portability and cost effectiveness as a result of which it is gaining popularity day by day in this scenario of advanced technology. In this era of wireless communication antenna is of primary importance and is used in every field of communication. Artificial Neural Network (ANN) is the manmade network that mimic the human brain and hence its called the “Artificial”. Human brain is the most complex structure in human body that works $24 \times 7$. Human brain learns either from its environment or by means of teaching. The same concept is used in ANN where we train the neural network and after that training it is capable of providing an output to the same kind of input [1]. This is in analogy to the student who is firstly taught some questions in the class and later on asked the moulded version of the same question in an examination but in a different manner. In such cases student as well as ANN has to predict the answer based on his classes or training respectively. The basic structural analogy between the human brain and ANN are listed in the table I. below [2].

**Table 1. The Structural Analogybetweenthe Human Brainand ANN**

| Human Brain | In-between |
|---|---|
| Neurons in human brain | Processing element of ANN |
| Dendrites | Input |
| Cell body | Transfer (or Threshold) function |
| Axons | Output |
| Synapses | Weights, that controls the amount of input to the network |

This paper aims to provide the resonant frequency ($f_r$) at a given dimensions of a rectangular patch- length ($l$), width ($w$), height ($h$) and the dielectric constant ($\varepsilon_r$) as shown in figure 1.

The transmission line model is used to design rectangular patch where the equations (1)-(4) are used.

$$\varepsilon_{r_{eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2} \quad (1)$$

$$\frac{\Delta l}{h} = \frac{0.412\left[\varepsilon_{r_{eff}}+0.3\right]\left[\frac{w}{h}+0.264\right]}{\left[\varepsilon_{r_{eff}}-0.258\right]\left[\frac{w}{h}+0.8\right]} \quad (2)$$

$$w = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (3)$$

$$h = \frac{1}{2f_r\sqrt{\varepsilon_{r_{eff}}\sqrt{\mu_0\varepsilon_0}}} \quad (4)$$

Where, $\Delta l$ is called the fringing length [3]. Due to the fringing effect the length and the width of the patch increases as a result of which the length and width of the antenna becomes bigger than its actual dimensions.

In this paper the resonant frequency, i.e. the optimised frequency where inductive as well as the capacitive reactance cancels each other and hence the antenna appears to be purely resistive is calculated.

The resonant frequency is made to vary within the Ku band (12 GHz-18 GHz). The significance of this frequency band is it implies wide range of applications mainly in satellites and radars.

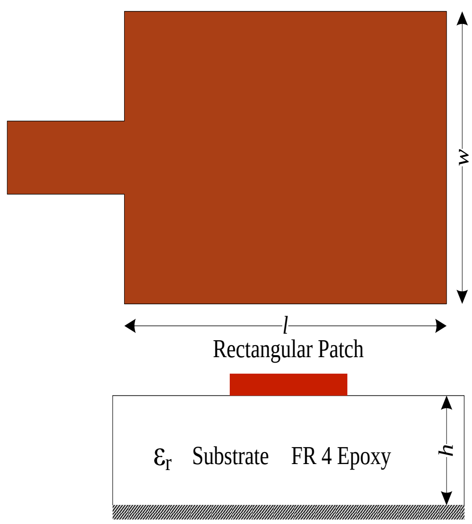


**Fig 1: Structure of Micro Strip Patch Antenna**

Satellite communication widely uses 14/16 frequency band where 14 GHz is used for downlink (from satellite to earth station) and 16 GHz is used for uplink (from earth station to satellite). The uplink and downlink are taken different in order

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to avoid interference so that uplink frequency will not interfere with the downlink because they are different [4]. Then the question arises: which frequency to be taken as uplink and which as downlink? In answer to this question, higher frequency means more attenuation because of propagation loss and to compensate such loss, more power need to be provided to the transmitting signal. But the satellite in space has limited amount of power whereas earth station is capable of providing high power to the transmitting signal in order to compensate the loss therefore the higher frequency i.e. 16 GHz is taken as uplink and the lower frequency 14 GHz is taken as downlink.

In this paper we have generated a datasheet of 168 samples for training the ANN as described in the next section. The care is taken to maintain the resonant frequency under the range of 12-18 GHz only.

## 2. DATA GENERATION AND THE ANN COMPUTATIONS

All Neural network is trained by providing length (*l*), width (*w*), height (*h*) and the dielectric constant ($\varepsilon_r$) as an input and the target matrix containing the resonant frequency hence there are five matrix, four for the input and one is the output matrix. The height of the substrate is varied between 0.3 and 1.58 (0.3<*h*<1.58). The value of dielectric constant is 4.7, taken constant. Dielectric substrate FR4 has a value of 4.7. FR4 is widely used dielectric substrate material for micro strip patch antenna due to its two main advantages i.e. firstly, it is easily available and secondly, it is cheap and cost efficient. The specification of FR4 material is listed in table II[5]. The ANN consists of three layers namely input layer, hidden layer and the output layer. There are ten hidden layers used. The structure of neural network is shown in figure 2. The back propagation model is used to train the ANN.

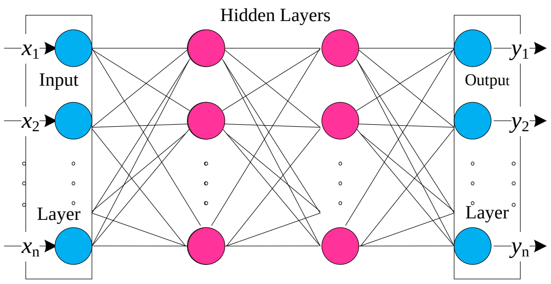


**Fig 2: The general structure of ANN**

**Table 2. The Specifications of FR4 Dielectric Material**

| | |
|---|---|
| Young's Modulus | X,Y = 16850, Z = 7375 |
| Poisson's ratio | XY = 0.110, XZ = 0.390, YZ = 0.390 |
| Thermal Coefficient of expansion(ppm/k) | X,Y = 14.5 Z = 67.2 |
| Surface Resistivity(MΩ) | 106 |
| Permittivity $\varepsilon_r$ | 4,6 |
| Electrical Strength(Kv/mm) | 45 |

**Table 3. The Data Sample Distribution in Training ANN using nftool**

| Mode | Number of Samples | Sample Percentage |
|---|---|---|
| Training | 168 | 70% |
| Testing | 36 | 15% |
| Validation | 36 | 15% |

The datasheet thus generated contains 240 samples of data out of which 168 samples are used for training and 36 samples are used for testing and validation. The validation and test data are depicted in table III.

**Table 4 Comparative analysis of different training algorithms**

| TrainingMethods | No. of hidden neurons | Best validationPerformance |
|---|---|---|
| **Bayesian Regularization (BR)** | 5 | Epoch 867 |
| | 6 | Epoch 391 |
| | 7 | Epoch 1000 |
| | 8 | Epoch 1000 |
| | 9 | Epoch 694 |
| | 10 | Epoch 1000 |
| **Levenberg Marquart (LM)** | 5 | Epoch 85 |
| | 6 | Epoch 21 |
| | 7 | Epoch 582 |
| | 8 | Epoch 8 |
| | 9 | Epoch 160 |
| | 10 | Epoch 109 |
| **Scaled ConjugateGradient (SCG)** | 5 | Epoch 18 |
| | 6 | Epoch 24 |
| | 7 | Epoch 69 |
| | 8 | Epoch 27 |
| | 9 | Epoch 22 |
| | 10 | Epoch 52 |

Training is done using different algorithms to find the best suitable method. The different algorithms used are *Bayesian Regularization* (*BR*), *Levenberg-Marquart* (*LM*) and *Scaled Conjugate Gradient (SCG)*. Table 4 represents the comparison of above written three different algorithms on the basis of number of neurons and the best validation performance. The Fig. 3, 4and 5 Show the training, testing and validation curves for the different algorithms used. Epoch is the iteration or the number of repetition carried out to train the neural network. The curves also show the best performance epoch after which the *ANN* is considered to be trained perfectly.

## 3. RESULTS

The ANN to determine the resonant frequency of a rectangular patch antenna is trained with the help of nftool using MATLAB. After training the network, its testing is performed by taking 15 distinct input data samples which were not included in the datasheet. The network resonant frequency output is then, compared with the theoretical calculated resonant frequency at the same given antenna dimensions as given in table 4. It represents the above analysis of the different back propagation algorithms in a tabular form. The training method is said to be efficient if it has minimum mean square error (MSE) along with the best performance reached in less epoch. As seen from the graph, the MSE is maximum initially but with the increase in training iteration the MSE decreases exponentially.

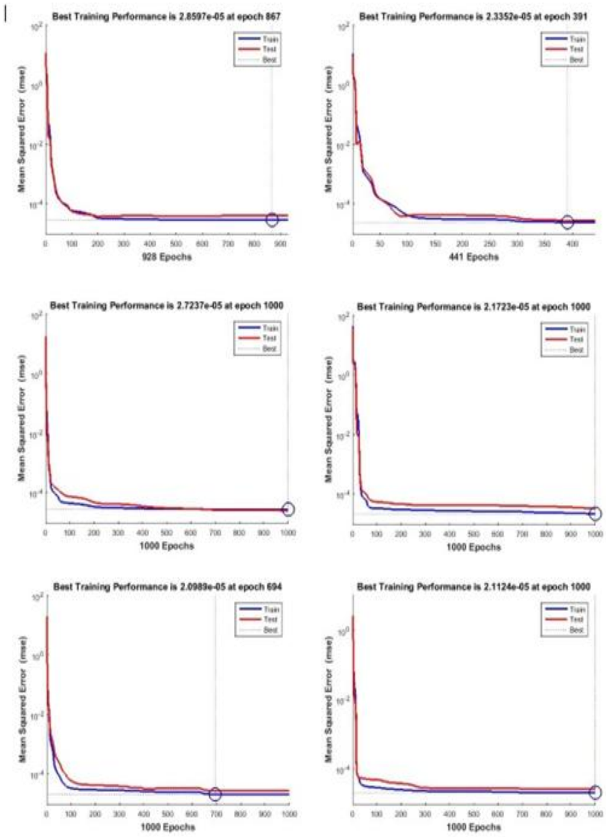


**Fig 3: Performance analysis of *BR* back propagation algorithm at different number of hidden neurons**

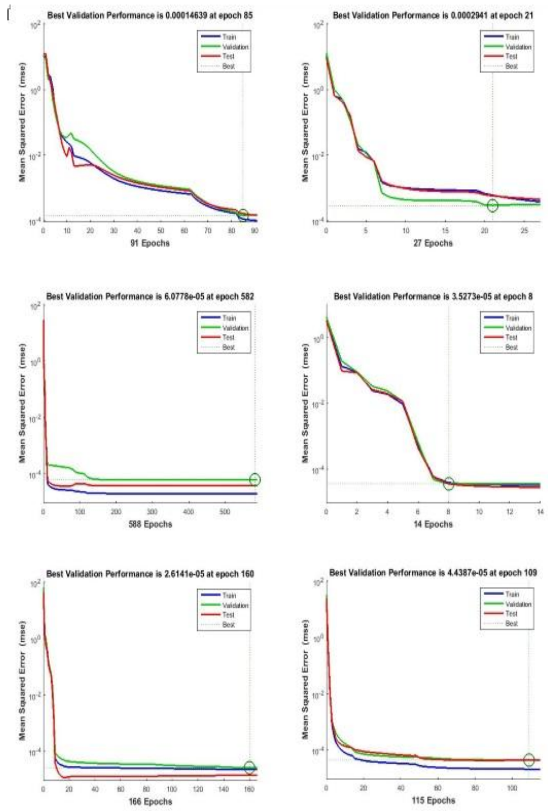


**Fig 4: Performance analysis of *LM* back propagation algorithm at different number of hidden neurons**

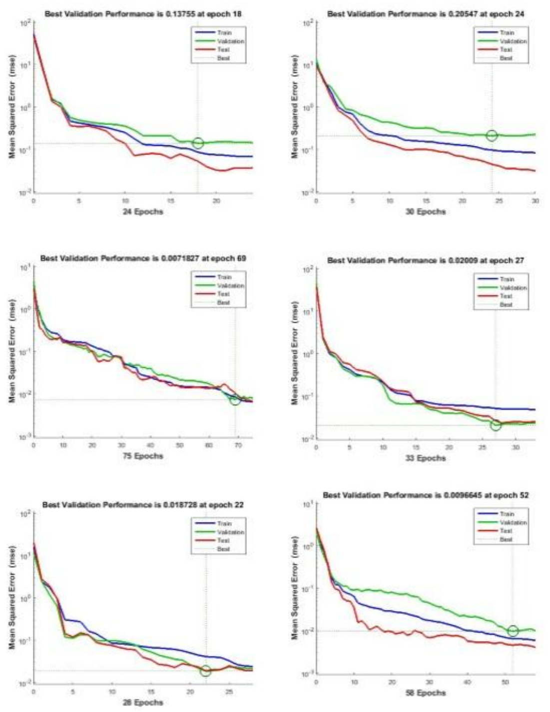


**Fig 5: Performance analysis of SCG back propagation algorithm at different number of hidden neurons**

The values of resonant frequency thus obtained from the ANN and the theoretical formula are approximately the same. Hence this verifies the proper training of ANN. Figure 6 shows the performance curve of the network during training, validation and the testing mode of the new data. Along with the point of best obtained result. The closer the value of mean square error to zero on y-axis, the better is the result. The error histogram of ANN training, validation and the testing mode is shown in Figure 7 and the regression curves are shown in Figure 8.

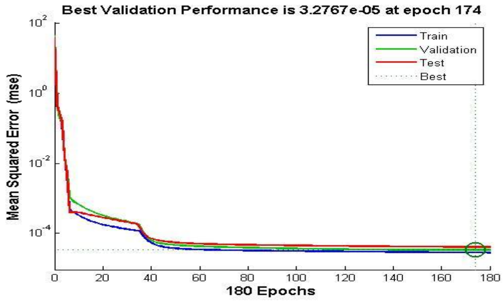


**Fig 6: The performance curve for computed ANN**

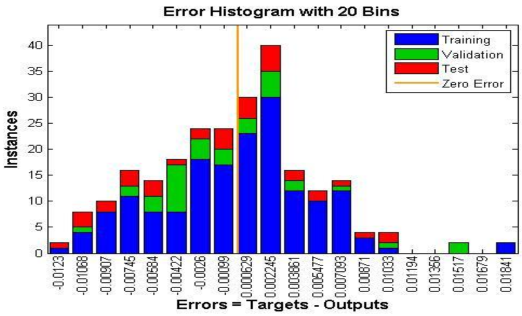


**Fig 7: The error histogram of ANN**

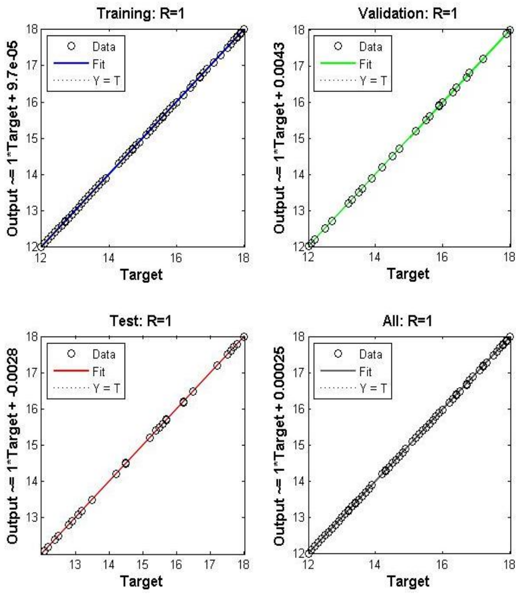


**Fig 8: The regression curves of trained ANN**

## 4. CONCLUSION

This paper aims in determining the resonant frequency of the rectangular patch antenna with the help of ANN. One can obtain the resonant frequency by putting the rectangular patch antenna's dimensions with high accuracy. The ANN removes the problem of iteration and thus its importance is that it is capable of predicting the value of resonant frequency even when the corresponding dimensions of an antenna are not present in the training datasheet.

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