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A Novel Method to Compute Resonant Frequency of Metamaterial Based Patch Antennas Using Neural Networks

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Abstract: This paper presents a novel metamaterial based miniaturised patch antenna for wireless application, whose resonant frequency is computed using an artificial neural network approach. The conventional patch resonates at 2.5 GHz; but when loaded with Complementary Split Ring Resonator (CSRR) structures; it achieves miniaturisation and is then found to resonate at 1.77 GHz. The extent, to which metamaterial creates miniaturisation, is so far not addressed analytically and is conventionally computed by a trial and error method in some commercial antenna simulators. In this paper, an attempt is made to predict the resonant frequency of the patch after it is loaded with meta-structures using neural networks for which the neural tool box in MATLAB 10 is utilized. Of all neural algorithms, the feed forward Levenberg's back propagation algorithm based is found to provide accurate results with minimum error when trained with sufficient number of inputs. The inputs and outputs for training the network are generated from rigorous parametric analysis carried out in ANSYS HFSS® an FEM based commercial software. The analysis results are presented along with the measured performance of an experimental prototype that is found in close agreement.

Keywords: Metamaterial, Feed Forward Back Propagation Algorithm, CSRR, Artificial Neural Networks (ANN), Resonant Frequency Computation.

I. INTRODUCTION

Microstrip patch antennas (MPA) find application in the wireless domain due to many of its remarkable features. The basic drawback of such antennas is narrow bandwidth [1]. The continuous demand in the wireless market of antennas with features like compact, cheap, multi resonant operation are met with new techniques such as PBG, EBG, DGS, Fractal antennas and Metamaterials (MTM's).

Metamaterials were first proposed by Vessalago in the year 1968 through Maxwell's equations [2]. MTM's have been an emerging area for wireless application in the recent past; its equivalents and expressions are found in articles [3-4]. The peculiar and remarkable features of MTM are negative permeability, permittivity and backward waves. Parametric extraction details of such materials are available in F. Ballesta *et al*. [5]. The transmission line based MTM was actually proposed by Caloz et *al*. [6]. Application of MTM for antenna research was carried out with CSRR structures by Yuandan *et al*. and Raghavan *et al*. [7-8]. MTM's were found to be very promising in antenna research particularly for creating multi resonances and miniaturisation [9-16].

The MPA was found to resonate at lower frequencies when loaded with CSRR structures but the mathematics of miniaturisation is not yet established fully. In this paper, a novel method of finding the resonant frequency of the patch after it is loaded with CSRR structures by means of Artificial Neural Networks (ANN) using feed forward back propagation algorithm is proposed, by which both resonant frequency and miniaturisation percentage can be visualized for any proposed model. The paper is organized and presented in seven sections; Section I: Introduction, Section II: Design of MPA, Section III: Design of a Compact Antenna with Meta Load on the Patch, Section IV: Computation of Resonant Frequency of Proposed Structure with ANN, Section V: Validation of Proposed Method With Measured Results, Section VI: Discussion, Section VII: Conclusion.

II. DESIGN OF MPA

An MPA is designed to resonate at 2.5 GHz. The patch dimensions are determined as 34 mm X 47 mm [1]. The antenna is fed with a 50-ohm microstrip line at a distance of 7.4 mm from the radiating edge. The proposed antenna is of single layer configuration. From the analyzed input characteristics (Fig. 1), it is seen, that the antenna resonates at the intended frequency of 2.5 GHz, with a return loss of - 22.18 dB.

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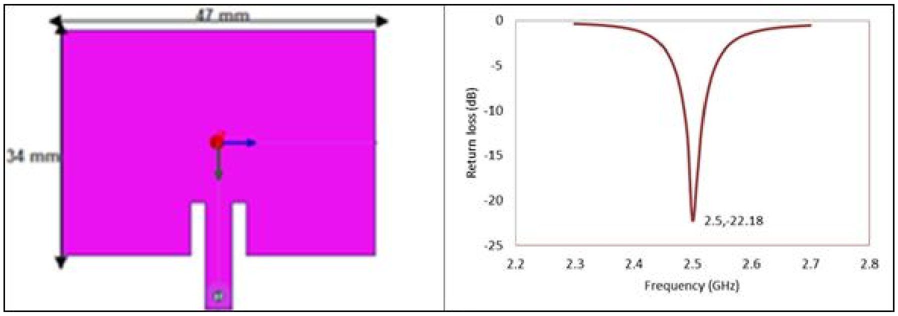

Fig. 1 MPA & its Return Loss Characteristic

III. DESIGN OF A COMPACT ANTENNA WITH META LOAD ON THE PATCH

A popular metamaterial structure, the complementary split resonator is obtained when split ring resonators are etched on metallic structures. CSRR are planar structures exhibiting negative permittivity; hence are MTM structures. The CSRR with four rings are shown in Fig.2. The original designed patch is modified by adding a CSRR design.

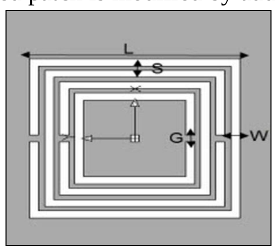

Fig. 2 CSRR

To behave as a MTM, the unit cell size of CSRR structures may be less than or equal to quarter of wavelength (Homogeneous condition). In our case, the CSRR is designed to have its unit cell size less than one tenth of its wavelength (for which the wavelength is computed first). Now, the length of unit cell cannot exceed 30 mm, so as to satisfy homogeneous condition. The resonant frequency of CSRR is calculated from the set of equations [5]. Care is taken to design the CSRR with frequency lesser than that of original patch resonance (2.5 GHz). Three pairs of CSRR loads are synthesized and etched onto patch as shown in Fig. 3. The length of CSRR is varied between 6 to 11 mm without deviating homogeneity condition. The modified antenna is targetted for DCS application whose spectra are (1710–1880) MHz [17].

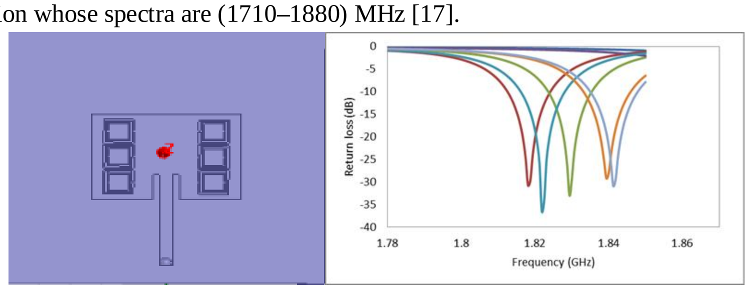

Fig. 3 Simulated Model of the Proposed Antenna & Parametric Return loss plot

IV. COMPUTATION OF RESONANT FREQUENCY OF PROPOSED STRUCTURE WITH ANN

So far only the trial-and-error method is employed by most researchers for determining the resonant frequency of meta-loaded patch. An attempt is made herein to obtain these using ANN that are successfully trained to predict the resonances created by a CSRR if it is loaded onto a patch. To our best knowledge, this is the first attempt of this type; which is the novelty of the current work. By using the parametric analysis feature available in HFSS®, three pairs of CSRR with same dimesnions are etched on the original patch (CSRR outer ring length varied in steps of 0.05 from 6.00 to 11.00 mm) and their individual return loss characteristics are generated. Out of these, 90% of the data are now given as I/p's for training and remaining 10% retained for testing of the neural network using feed forward Levenberg-Marquard back propagation algorithm [18]. The Input to the networks are the resonant frequency of CSRR while the corresponding resonances obtained from return loss characteristics (HFSS® simulation) are specified as actual frequency output. The input to hidden layer has tangent sigmoid function while the hidden to output layer has linear activation function. There are 12 hidden neurons. The details of the artificial neural network

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)

along with its progress details are shown below in Fig. 4. Few of the data results (actual and predicted frequency), as well as optimized dimensions of CSRR on the patch from ANN are shown in Tables 1 & 2. The **MSE** is found to be **0.000438**. The Validation plot and training states are shown in Fig.5, which clearly depicts the gradual reduction of MSE epoch after epoch while **Mu** from the plot indicates that the network converges quickly. It is found that three pairs of CSRR structures with lengths as 9.5 mm cause resonance at the required spectra. The CSRR dimension sets may be manually tweaked, if required.

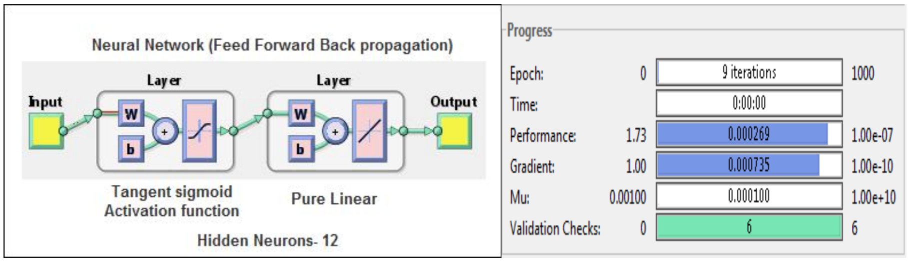

Fig. 4 NEURAL MODEL(for computation of resonant frequency) & Progress Details

Table 1 ACTUAL AND PREDICTED FREQUENCY FROM ANN (MSE: 0.000438)

No.	Actual Frequency (GHz)	Predicted Frequency (GHz)
1	2.290000	2.279868
2	2.280000	2.276722
3	2.310000	2.275336
4	2.300000	2.274780
5	2.290000	2.274566
6	**1.820000**	**1.813453**

Table 2 THE OPTIMISED DIMENSIONS OF CSRR

Parameter	Value (mm)
CSRR Width	0.5
CSRR Gap	0.6
CSRR Space	0.5
CSRR Length	9.5

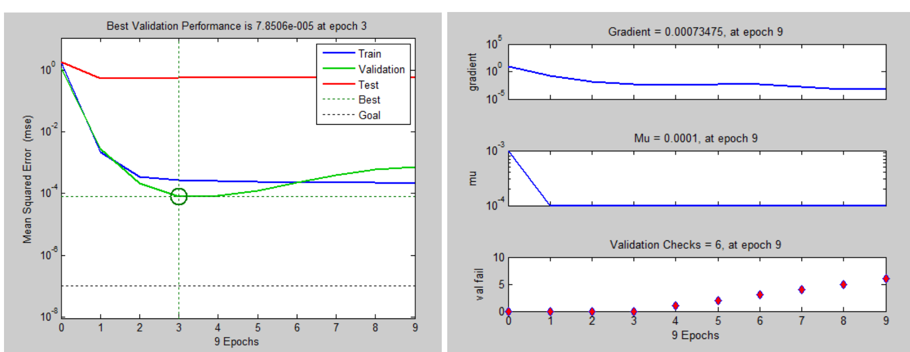

Fig. 5 Validation plot (for computation of resonant frequency) & Training State

V. VALIDATION OF PROPOSED METHOD WITH MEASURED RESULTS

To validate the frequency predicted by the developed neural network, the proposed antenna is fabricated using Photolithographic technique. An Rogers substrate with a thickness of 60 mils is used to realize the radiator. The antenna is fed through a 50 Ω coaxial cable after proper soldering. The return loss measurement on the final antenna is carried out using Rohde & Schwarz Vector Network Analyzer. The simulated frequency is 1.82 GHz; while the prototype is found to resonate at 1.77 GHz. This agrees well with the predicted ANN value that is 1.81GHz, which is highlightened with red colour in Table 1.

Volume 4 Issue I, January 2016
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International Journal for Research in Applied Science & Engineering Technology (IJRASET)

The fabricated antenna is shown in Fig. 6; while its simulated, measured return loss are shown in Fig. 7.

VI. DISCUSSION

The antenna is found to achieve a good miniaturisation of 43% when compared with the conventional patch antenna. A square shaped CSRR was chosen as they can be easily realised. Since Photolithographic techniques are used it is an inexpensive antenna which can be effectively used for the suggested application in DCS. Also the suggested antenna is of single layer configuration; thus there is no problem of stacking / aligning multiple layers. The resonant frequency(ies) for the meta-loaded structures can also be predicted through neural networks thereby avoiding costly design iterations / cycles typically necessary in trial-and-error approach employed till now. The slight drift in predicted and measured frequency is due to fabrication irregularities which is well within tolerance level. The future course of research along this line may be for broadbanding through any known technique and to specify a band spread for the ANN to obtain the design dimensions for the same.

Fig. 6 Proposed Variant (Photograph)

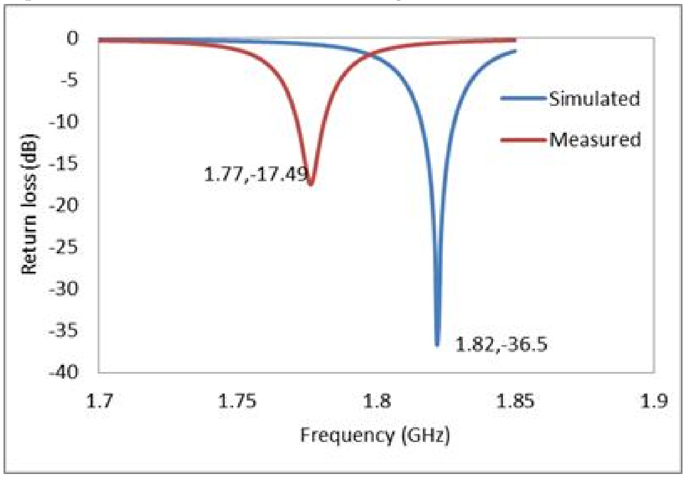

Fig. 7 Simulated & Measured Return Loss Characteristic

VII. CONCLUSION

A compact, antenna is proposed and successfully demonstrated with a target for DCS, application. A novel method to estimate the resonant frequency of a metaloaded antenna is proposed in this paper that employs an artificial neural network. The ANN is trained using inputs from a commercial simulator and then executed to obtain the resonances. The validation of the method is demonstrated by the measured results of an experimental prototype which agrees well with the ANN predicted frequency.

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