Optimization of Cutoff Frequency Limits of Microstrip Circular Patch Antenna Printed on Ferrite Substrate by Artificial Neural Network Analysis

[1]Naveen Kumar Saxena, Raj Kumar Verma[2], Nitendar Kumar[3], P.K.S. Pourush[4]

[1]*Microwave Lab, Department of Physics, Agra College Agra, PIN 282002, Agra (U.P), India.*
[2]*Microwave Lab, Department of Physics, Agra College Agra, PIN 282002, Agra (U.P), India.*
[3]*Solid State Physics Laboratory, Timarpur, Delhi 110007, India.*
[4]*Microwave Lab, Department of Physics, Agra College Agra, PIN 282002, Agra (U.P), India.*

Abstract: *General artificial neural network (ANN) analysis has been applied to optimize the lower and upper frequency limits of cutoff region of switchable microstrip circular patch antenna printed on ferrite (LiTiZn) substrate in the X-band range. The ferrite substrate offered numbers of novel magnetic and electrical characteristics including switchable and polarized radiations from a microstrip antenna with DC magnetic biasing. For particular frequency limits most of the power will be converted into mechanical waves and very little radiates into air. Under such condition the antenna become switch off, in the sense of effectively absence as radiator. In this work Radial Basis Function (RBF) networks has been applied in ANN models. Synthesis has been defined as the forward side and then analysis as the reverse side of the problem. In the RBF network, the spread value has been chosen as 0.01, which gives the best accuracy. RBF has been tested with 100 samples frequencies but trained only for particular cutoff 15 samples frequencies. The obtained optimized of value lower and upper cutoff frequency (w_l & w_u) are very close to the values measured through the material dispersion graph which has been plotted for perpendicular applied 1500 Oe magnetic field.*
Key Words: *Microstrip antennas, tunability, ferrite material, artificial neural networks, reverse modeling.*

I. Introduction

In recent years magnetic materials have received much attention in high frequency applications. Ferrite is one of the important magnetic materials which are very useful in microwave antennas and devices. The ferrite offered number of novel magnetic and electrical characteristics including switchable and polarized radiations from a microstrip antenna with DC magnetic biasing.

Nonreciprocal behavior of ferrite substrate, on applying magnetic biasing tends to ordinary and extraordinary wave propagation. For particular frequency limit, most of the power in the form of extraordinary wave resonance with lattice magnetic vibrations and converted into mechanical waves and little radiates into air. Under such condition the antenna become switch off, in the sense of effectively absent as radiator [1-3]. In the literature, artificial neural network (ANN) models have been built usually for the analysis of microstrip antennas for circular and equilateral triangle patch geometries for computing their resonant frequencies on given dielectric substrate.

There are two popular learning algorithms for neural network implementation. These are the backpropagation algorithm and radial basis function algorithm. The backpropagation network is well known among the current types of neural network system available. It is a multilayer feed forward network with a different transfer function in the neuron and a more powerful learning rule. The learning rule is known as backpropagation, which is a kind of gradient decent technique with backward error propagation. The radial basis function (RBF) network is a two-layer network whose output units form a linear combination of the basis function is computed by the hidden unit. In the aspect of learning, the RBF network is much faster than the back propagation network. The primary reason for this is that the learning process in RBF network has two stages and both stages can be made efficient by using appropriate learning algorithms.

However, in the present work, for the synthesis we include ordinary wave propagation constant (K_d), desired cutoff frequency (w), applied magnetic frequency (w_o) and internal magnetic frequency (w_m) as input parameters to get the extraordinary wave propagation constant (K_e) which is mainly responsible for the switchability of antenna. For analysis we include ordinary wave propagation constant (K_d), extraordinary wave propagation constant (K_e), applied magnetic frequency (w_o), and internal magnetic frequency (w_m) as input parameters to get the desired cutoff frequency limits (w_l & w_u) which is desirable and should be very precise for any communication system [4-9].

II. MICROSTRIP ANTENNA

The circular microstrip antennas with a circular patch of radius '$a_e = 5.3\ mm$' over a ground plane with a LiTiZn ferrite substrate thickness '$h = 2mm$' and dielectric constant '$\varepsilon_r = 16$' as shown in Fig.1 [10].
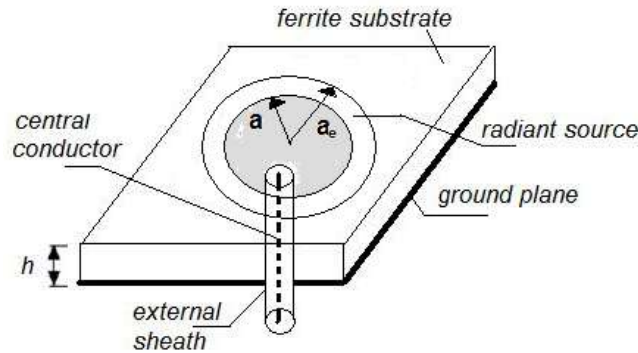

Fig. 1: Schematic Diagram of Microstrip Circular Patch Antenna

It has been established that, for a biased ferrite slab, a normal incident plane wave may excite two types of waves (ordinary and extraordinary wave). In the case of normal incident magnetic field biasing ordinary wave is same as the plane wave in the dielectric slab. On the other hand, the extraordinary wave is a TE mode polarized parallel to the biasing direction with its phase propagation constant K_e [11].

$$K_e = K_d \left[\frac{(w_o + w_m)^2 - w^2}{w_o(w_o + w_m) - w^2} \right]^{1/2}$$

Upper cutoff frequency limit

$$w_u = (w_o + w_m)$$

Lower cutoff frequency limit

$$w_l = [w_o(w_o + w_m)]^{1/2}$$

where

$$K_d = \frac{w}{c}\sqrt{\epsilon_{eff}}$$

$$w = 2\pi f\ , w_o = \gamma H_o\ and\ w_m = \gamma 4\pi M_s$$

where H_o is the bias field, $4\pi M_s$ is the saturation magnetization, γ is the gyromagnetic ratio as $\gamma = 2.8\ MHz./Oe$. Polycrystalline LiTiZn ferrite have been synthesized by the solid state reaction technique (SSRT).

Table 1: The electrical and magnetic properties of LiTiZn ferrite substrate

LiTiZn Ferrite Characteristics	Values
Magnetic Saturation ($4\pi M_s$)	2200 Gauss
Curie Temperature (T_c)	385 K
Density (ρ)	4.21 grams/cm^3
Remanence	0.90
Coercivity	1.50
Dielectric Constant (ε)	16
Resonance Line Width (ΔH)	370 Oersteds
Loss Tangent ($\tan \delta$)	< 0.0005

The ingredients required for the preparation of these ferrites have been calculated on the basis of chemical formula.

$$Li_{0.63}Zn_{0.1}Mn_{0.1}Ti_{0.36}Fe_{1.81}O_4$$
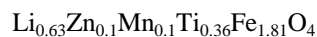
Lithium ferrite is one of the most versatile magnetic materials. It is generally useful for microwave devices, memory-core, power-transformers in electronics, antennas, read/write heads for high speed digital tapes. This material is strategically important due to its high resistivity, low electric losses, high Curie temperature. The electrical and magnetic properties of LiTiZn ferrite substrate has been experimentally calculated in laboratory which is listed in table 1.

III. Neural Network Analysis

A Radial Basis Function (RBF) network has been applied in ANN models and the synthesis / analysis problem to solve the electromagnetic formulae of the microstrip antennas. There are 2 points are especially emphasized: the extraordinary propagation constant (K_e) which is mainly responsible for the switchability of antenna and the corresponding particular desired cutoff frequency (w) which is very desirable to switch off the antenna system [12, 13]. In the Forward Side of the problem the input/output quantities to the ANN synthesis and ANN analysis are shown in fig. 2.
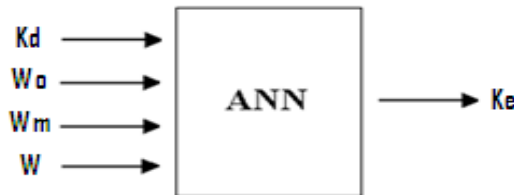

Fig. 2 Forward side ANN model.

In the analysis side of the problem, terminology similar to that in the synthesis mechanism is used, but the cutoff frequency of antenna is obtained from the output for a optimize extraordinary propagation constant, ordinary wave propagation constant (K_d), applied magnetic frequency (w_o), and internal magnetic frequency (w_m). In the Reverse Side of problem the feed forward neural networks with a single hidden layer that use radial basis activation functions for hidden neurons are called radial basis function networks. RBF networks are applied for various microwave modeling purposes. A typical RBF network structure is given in Fig. 3.

Fig. 3 Reverse side ANN model.

The parameters c_{ij} and λ_{ij} are centers and standard deviations of radial basis activation functions. Commonly used radial basis activation functions are Gaussian and multi-quadratic. Given the inputs x, the total input to the ith hidden neuron γ_i is given by

$$\gamma_i = \sqrt{\sum_{j=1}^{n} \left(\frac{x_j - c_{ij}}{\lambda_{ij}}\right)^2} \; , i = 1,2,3 \ldots \ldots N$$

where N is the number of hidden neurons.

In the RBF network, the spread value was chosen as 0.01, which gives the best accuracy. RBF is trained with 100 samples frequencies but tested only for particular cutoff 15 samples frequencies. 4 inputs and 1 output were used for both the analysis ANN the synthesis ANN. The training and test data of the synthesis and analysis ANN were obtained from both experimental results given in previous works and a computer program using formulae given in previous section.

IV. Performance And Result

For synthesis and analysis, RBF network provide the best approximation to the tabulated target values depicted from tables 2 and 3 respectively. The performance, of synthesis ANN is 0.000389852 at 79 epochs while that of analysis ANN is 0.00092708 at 36 epochs & 0.000585216 at 34 epochs. The results of the synthesis and analysis ANN for ferrite material can be compare with dispersion graph (fig. 7) obtained for ferrite

material. Switchability and tunability regions are clearly shown in the dispersion curve plotted at 1500 Oe for LiTiZn-ferrite slab, on which circular microstrip patch antenna has been designed.. It is important to mention that switchability region is of great concern for the present analysis. From the graph and table (w_l & w_u), we can conclude and compare the optimal accuracy for the synthesized and optimized extraordinary propagation constant (K_e). The optimized value of K_e is around 0.3898 and of lower cutoff frequency $w_l = 0.5852$ GHz & of upper cutoff frequency $w_u = 0.9270$ GHz. These optimized value are very close to cutoff values depicted in dispersion graph.
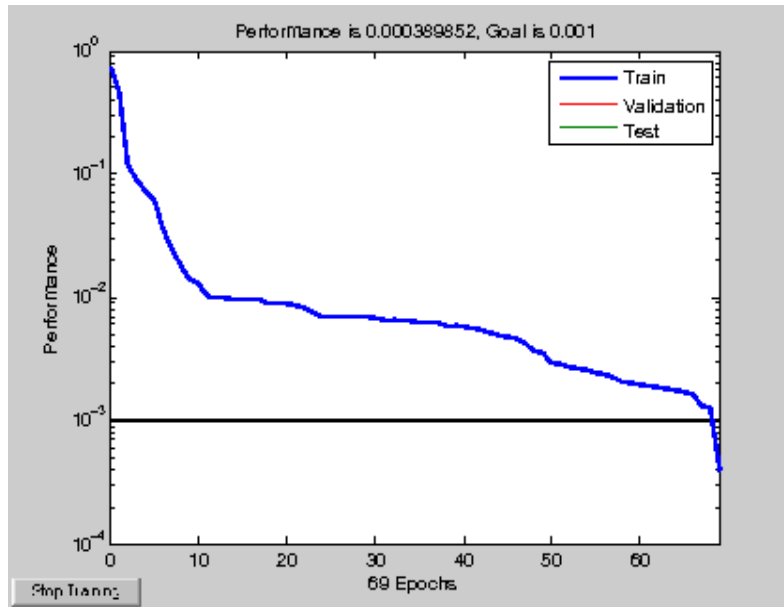

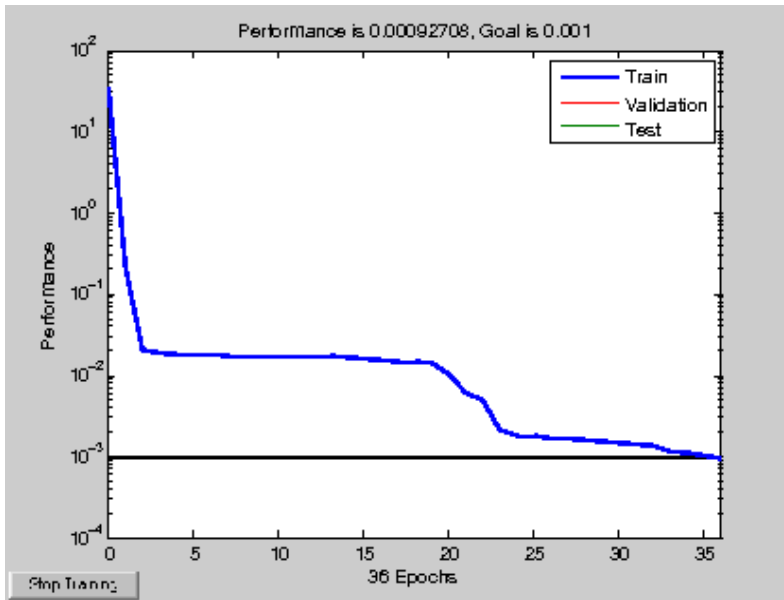
Fig. 4 Training Response for synthesis at 69 Epochs

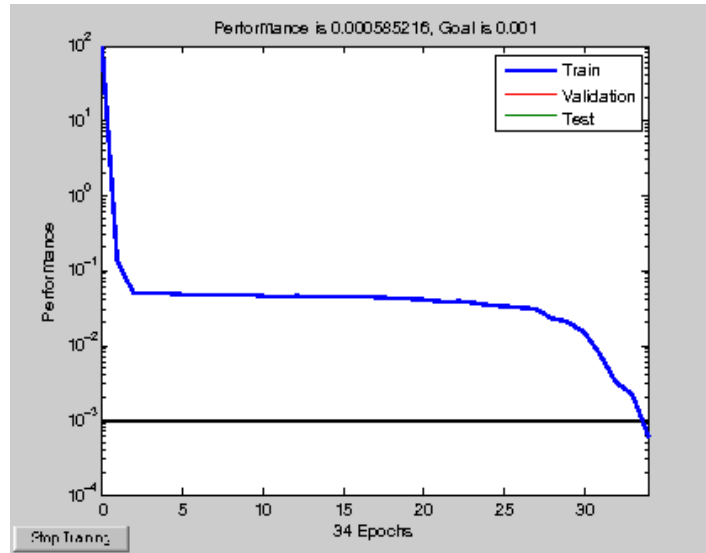**Fig. 5** Training Response for lower frequency limit at 36 Epochs

Fig. 6 Training Response for upper frequency limit at 34 Epochs

Table 2: Results of the synthesis ANN and comparison with target

K_d	w_o(GHz)	w_m(GHz)	w(GHz)	K_e-target	K_e-RBF
8.9630	4.2000	6.1575	6.4277	0.3335	0.32732
8.7002	4.3400	5.9816	6.2392	0.9835	0.95907
8.6125	4.3680	6.0168	6.1764	0.9771	0.94611
9.1996	4.2896	6.0520	6.5973	0.5429	0.53367
7.2720	4.2560	5.8408	5.2150	0.1858	0.22136
8.0868	4.2280	6.2279	5.7994	0.4066	0.38036
8.1745	4.3120	6.3335	5.8622	0.3808	0.3929
8.9630	4.3120	6.2631	6.4277	0.3646	0.35101
9.4011	4.2616	6.2983	6.7419	0.3105	0.30621
8.1307	4.2308	5.8408	5.8308	0.6756	0.67532
7.8643	4.2336	5.9464	5.7994	0.9988	0.99136
9.3979	4.2364	6.1223	6.9304	0.2860	0.30701
9.5428	4.2700	6.0871	7.0372	0.3294	0.30783
6.7566	4.3848	6.3335	4.9826	0.5779	0.58706
6.3875	4.3540	6.1927	4.5742	0.9913	0.95661
8.6354	4.6368	6.3335	6.2832	0.6984	0.69622

Table 3: Results of the analysis ANN and comparison with target

K_d	w_o (GHz)	w_m (GHz)	K_e	w_l - target (GHz)	w_l- RBF (GHz)	w_u - target (GHz)	w_u- RBF (GHz)
8.0000	4.2000	6.1575	0.3273	6.5956	6.6516	10.3575	10.338
8.6000	4.3400	5.9816	0.9590	6.6930	6.7046	10.3216	10.3127
8.4000	4.3680	6.0168	0.9461	6.7350	6.7519	10.3848	10.3752
7.9000	4.2896	6.0520	0.5336	6.6604	6.6802	10.3416	10.3419
7.7000	4.2560	5.8408	0.2213	6.5553	6.5702	10.0968	10.06
8.8000	4.2280	6.2279	0.3803	6.6489	6.6614	10.4559	10.4265
8.2000	4.3120	6.3335	0.3929	6.7752	6.7033	10.6455	10.6377
8.1000	4.3120	6.2631	0.3510	6.7528	6.6965	10.5751	10.5711
8.3000	4.2616	6.2983	0.3062	6.7084	6.7003	10.5599	10.5679
7.8000	4.2308	5.8408	0.6753	6.5277	6.5363	10.0716	10.085
7.7000	4.2336	5.9464	0.9913	6.5649	6.563	10.1800	10.1984

8.5000	4.2364	6.1223	0.3070	6.6245	6.6577	10.3587	10.3537
8.4000	4.2700	6.0871	0.3078	6.6502	6.6607	10.3571	10.3526
8.3000	4.3848	6.3335	0.5870	6.8555	6.8657	10.7183	10.6987
7.8000	4.3540	6.1927	0.9566	6.7765	6.8032	10.5467	10.5338
8.7000	4.6368	6.3335	0.6962	7.1321	7.1331	10.9703	10.8972

V.   Conclusion

The neural network is employed to optimize the cutoff frequency limits (w_l & w_u) of microstrip circular patch antenna printed on ferrite substrate and placed in perpendicular external magnetic field. In this communication for the design procedure, synthesis is defined as the forward side and then analysis as the reverse side of the problem. Here the analysis is considered as a final stage of the design procedure, therefore the parameters of the analysis ANN network are determined by the data obtained reversing the input-output data of the synthesis network. Thus, the extraordinary propagation constant (K_e) resulted from the synthesized antenna geometry is examined against the target in the analysis ANN network.

Acknowledgement

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