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ANN model of waveguide bandspass filter formed by circular posts of magnetized ferrite cylinder inside rectangular waveguide

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ABSTRACT

The goal of this research is to discover the most appropriate approach for finding the reflection and transmission coefficients of the dominant mode scattering by a circular dielectric/ferrite cylindrical post in a rectangular waveguide and to generalize this approach so that it can be applied to the case of the layered posts as well. Microwave waveguide post filters are practically useful and the procedure of filter synthesis using dielectric/ferrite posts requires a solution to the inverse scattering problem. Typically, an algorithm for solving the inverse scattering problem requires a lot of computation time, because in each iteration it has to solve a number of forward problems. To speed up a process of a solution of the inverse problem it is required to find an approach that provides the small computation time. The problem can be solved by using some flexible methods, such as finite element method, finite difference method and finite difference method in the time domain [1] or software based on these methods such as HFSS or Ansys. Despite great flexibility of these methods, they, require a great amount of computation time. Using some geometrical properties that reduce computational effort by solving a part of problem by analytical means or at least by converting a problem to its simpler equivalent it is possible to reduce numerical effort considerably.

Introduction

Scattering of a plane wave from a dielectric cylinder has been discussed in a number of papers[1-5].The complete solution for arbitrary incidence has been given by Wait[1] He also discussed approximate solutions in the case of a cylinder whose diameter is small compared with the wavelength. In this work the scattering of a plane wave from a homogeneous dielectric and ferrite cylinder is investigated. The discussion is restricted to the case of normal incidence, for which an exact solution in form of a series of Bessel functions can be found. The ferrite rod is magnetized along its axis. Because of the nonreciprocal properties of the ferrite material, a nonsymmetrical distribution of the scattered field with respect to the direction of incidence is expected. The scattered field is a function of the permeability tensor of the ferrite, which in turn depends on the applied magnetic dc field. It is, therefore, possible to control the scattering pattern of the ferrite cylinder by the magnetic field.

The Mathematical Solution

When a static magnetic field is applied to a ferrite material, this material shows anisotropic and dispersive characteristics. If a high frequency magnetic field is applied perpendicularly to the direction of the static magnetic field Hin, the magnetic dipoles of the ferrite are rotating around the axis of the static magnetic field. The material is therefore called gyrotropic material and can be tuned by the static magnetic field. This behaviour is strongly non-reciprocal and very often used in microwave passive components like filters.

An infinitely long ferrite cylinder with its axis along the z direction is considered. A dc magnetic field is applied along its axis. A plane wave is incident in the positive x direction. With these assumptions the problem is reduced to two dimensions in the x-y plane. The polarization of the wave is arbitrary. The field then be decomposed in two waves, one which is polarized normal to the cylinder axis (E= En) and one which is polarized parallel to it (E= Ep.) In the first case the magnetic field of the wave is parallel to the axis and to the applied magnetic dc field and, therefore, nonmagnetization of the ferrite takes place. Hence the tensor permeability reduces to a scalar. In other words the problem is the same as that one for a dielectric cylinder. For the wave polarized parallel to the z axis, however, the magnetic dc and ac fields are normal to each other, so that the ac field interacts with the processing magnetic dipoles of the ferrite. In this case one has to use the tensor permeabilities in Maxwell's equations, because there is no variation in the z. direction, Nonreciprocal interaction between the field and the magnetization of the ferrite takes place. Losses are neglected so the conductivity is zero everywhere. The magnetic permeability is of key importance in this model as it is the anisotropy of this parameter that is responsible for the nonreciprocal behavior of the ferrite device. The model assumes that the static H_0 magnetic bias field is much stronger than the alternating magnetic field of the microwaves and linearization for a small signal analysis around this operating point. Further it is assumed that the applied magnetic bias field is strong enough for the ferrite to be in magnetic saturation.

Considering the electromagnetic wave scattering from two-dimensional arbitrary obstacles one can observe a two areas of active research. The first approach concerns open problems – obstacles in free space, where the far scattered field patterns can be investigated [1, 2], while the second is a closed problems – presents the frequency responses of described structure in a rectangular waveguide [3, 4].

In the last decade, a recursive algorithm has been developed

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for the scattering by arbitrarily shaped obstacles [5]. Elsher-beni et al. [6] proposed an iterative solution for the scattering by M different parallel circular cylinders. Recently, Valero and Ferrando [7] presented the method, which segments the problem into regions that are characterized by their generalized admittance matrices.

A modified iterative scattering procedure, which has been used for open problems [8] and the orthogonal expansion method to describe an equivalent scattered field by lossy dielectric, ferrite cylinders on the surface of a separated interaction region, which then can be used both for open and closed structures. The main advantage of this method is that we can obtain a total scattered field from all cylinders and match it with other incident fields to define scattering matrix of investigating structure. This technique can be applied to analyze a waveguide structures where incident fields are the TE_{m0} mode and open structures to define the far scattered field patterns for Ez-wave excitation.

Method of moments solution to the two-dimensional problem of transverse magnetic (TM) or transverse electric (TE) scattering by a dielectric and/or ferrite cylinder near a perfectly conducting waveguide boundary has already been investigated by earlier researcher[2]. This solution is an extension of [3] where the material cylinder was dielectric only and the polarization was TM. The equivalent electric and magnetic polarization currents are found as a solution to a set of coupled simultaneous integral equations. The integral equations are solved by a pulse basis and point matching MM technique. For the TM case the MM impedance matrix requires the evaluation of the half-plane fields of longitudinally polarized (with respect to the half-plane edge) electric line currents and transversely polarized magnetic line currents. For the TE case the MM impedance matrix requires the evaluation of the half plane fields of longitudinally polarized magnetic line currents and transversely polarized electric line currents. However,using a theorem by Mayes [5], the fields of the transversely polarized magnetic or electric currents are found as the fields of equivalent longitudinally polarized electric or magnetic currents, respectively.

Theory of scattering by conducting, lossy dielectric, ferrite cylinders is investigated using a combination of a modified iterative scattering procedure and the orthogonal expansion method. The scattered field patterns for open structures and frequency responses of the transmission coefficients in a rectangular waveguide describing the resonances of the posts on the dominant waveguide mode can be [8-9] derived. The validity and accuracy of the method is verified by comparing the numerical results with those given in literature.

Considering the phenomenon of electromagnetic wave scattering from two-dimensional arbitrary obstacles two different areas can be identified. The first area concerns open problems — obstacles in free space, where the far scattered field patterns can be investigated [1–6], while the second is a closed problem which presents the frequency responses of described structure in a rectangular waveguide [7–13].For open structures, different techniques like integral equation formulation, partial differential equation, hybrid techniques combining the partial differential equation method with the eigenfunction expansion method have been developed for plane wave and line source excitations [1–4] In the last decade, a recursive algorithm has been developed for the scattering by arbitrarily shaped obstacles [5].

Elsherbeni

Gesche and L¨ochel applied the orthogonal expansion method for one [11] and two from each obstacle has been cross section of a rectangular waveguide. Recently, Valero and Ferrando [13] presented the method, which segments the problem into regions that are characterized by their generalized admittance matrices. expansion method. Sahalos and Vafiadis [8] presented multifilament current model and for the first time applied circular interaction region instead of rectangular used by Nielsen. The boundary- and finite element methods have also been utilized in [9, 10]. Gesche and L¨ochel applied the orthogonal expansion method for one [11] and two from each obstacle which has been transferred to infinity by far field approximations. A lot of methods have been applied to cross section of a rectangular waveguide. Recently,

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A number of approaches have appeared proposed by various authors for solving problems of scattering by a cylindrical post in a rectangular waveguide. The approach followed is a modified version of one of those approaches that provides sufficiently rapid convergence and results with a reasonable degree of accuracy. This modification allows a solution to the problem of scattering by a layered post. The approach divides the waveguide into separate regions by introducing imaginary cylindrical surface. In the outer regions the electromagnetic field is represented in terms of infinite series of rectangular waveguide modes. In the central region as well as in the layers of post, the field is represented in terms of cylindrical waves. By applying the point-matching method at the imaginary cylindrical surface and truncation of infinite series, a system of linear algebraic equations is obtained.

Theory

The dominant mode TE10 propagating in a rectangular waveguide in direction of z axis. The width of the broad wall of the waveguide a is chosen so that only the dominant mode of the waveguide can propagate. Since higher order modes decay exponentially with distance from the post, the reflected and transmitted waves consist only of dominant modes. Nerveless, solving the boundary problem on the surface of the post, all existing higher order modes have to be taken into account, since they essentially affect the field distribution in immediate vicinity of the post. Since the geometry of the problem as well as the distribution of fields are uniform along the y axis, the problem can be reduced to an equivalent two-dimensional

thus considerably simplifying the solution. This approach has been generalized to the case of scattering by a layered post. Such an approach is of interest because it provides a faster solution to the problem than other approaches and software employing flexible methods, like finite element method and finite difference method.

ANN Model

From this model the interval activity of the neuron can be shown to be:

$$v_k = \sum_{j=1}^{p} w_{kj} x_j$$

The output of the neuron, yk, would therefore be the outcome of some activation function on the value of vk.

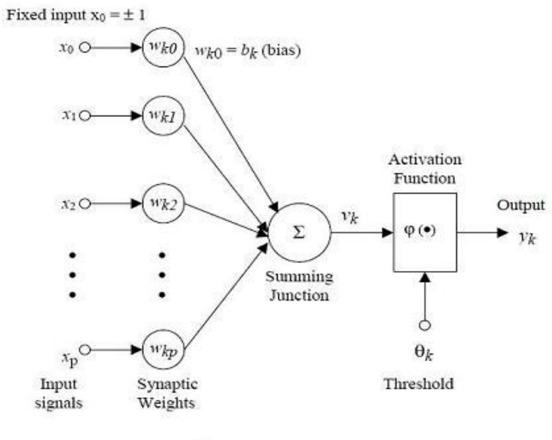

Fig 1: A General Neural Network Configuration

the activation function acts as a squashing function, such that the output of a neuron in a neural network is between certain values (usually 0 and 1, or -1 and 1). Here the sigmoid function(hyperbolic tangent function) is used . in the range between 0 and 1.

$$\varphi(v) = \tanh\left(\frac{v}{2}\right) = \frac{1-\exp(-v)}{1+\exp(-v)}$$

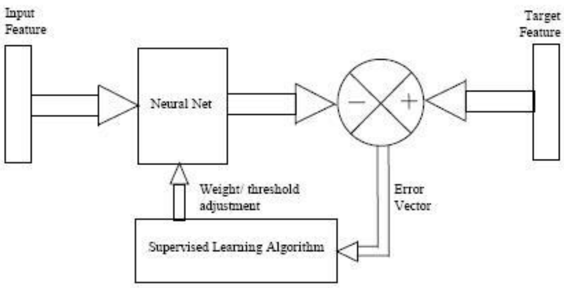

Fig 2. Training of artifcial neural networks

Both learning paradigms supervised learning and unsupervised learning result in an adjustment of the weights of the connections between units, according to some modification rule. Virtually all learning rules for models of this type can be considered as a variant of the Hebbian learning rule suggested by Hebb.

The basic idea is that if two units j and k are active simultaneously, their interconnection must be strengthened. If j receives input from k, the simplest version of Hebbian learning prescribes to modify the weight wjk with

$$\Delta w_{jk} = \gamma y_j y_k,$$

where Y is a positive constant of proportionality representing the learning rate. Another common rule uses not the actual activation of unit k but the difference between the actual and desired activation for adjusting the weight $\Delta w_{jk} = \gamma y_j (d_k - y_k),$ in which dk is the desired activation.

This is often called the Widrow-Hoff rule or the delta rule. The speed of convergence of a network can be improved by increasing the learning rate epsilon. Unfortunately, increasing e will usually result in increasing network instability, with weight values oscillating erratically as they converge on a solution. Instead of changing e, most standard backpropagation algorithms employ a momentum term in order to speed convergence while avoiding instability.

Problem Formulation

To develop a neural network model we need to identify input and output parameters of the structure under consideration to generate and preprocess data for carrying out ANN training. Generally Multi Layer Perceptron (MLP) model is being chosen where weights are initialized by assigning with small random values. The purpose of the neural network training is to adjust the weights such that the error function is minimized. As the error function is a nonlinear function of the adjustable weight parameters, iterative algorithms are used to update it with an appropriate learning rate. The back propagation training algorithm updates weights along the negative direction of the gradient of the training vector. Finally the quality of the neural network model is evaluated with an independent set of data and a quality measure is performed based on average test error and standard deviation.

Neural Network Configuration

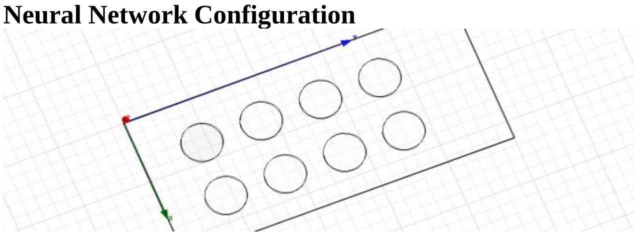

Fig 3. 3D view of the Four Circular ferrite Post in Rectangular waveguide

A five layer MLP is used to model the scattering from full height ferrite post in rectangular waveguides. The post positions are chosen to be symmetric with respect to x axis for a suitable application of the structure as filter. The input layer has four independent neuron which represents four input parameters normalized with their maximum value. For this purpose of input layer modeling two post positions (the other two are symmetrically placed) relative to y axis of the waveguide ,their internal separation and the diameter are taken as inputs. The three hidden layers are chosen having 72, 36 and 24 number of neurons respectively. The output layer has four neuron representing Reflectance(S11), Transmittance (S11) and Reflectance(S21), Transmittance(S21). The waveguide used here is WR-90 (22.86 mm x 10.16 mm.) for the X band frequencies As the training data generated from the electromagnetic analysis has a normalized range from –1 to +1, the bipolar sigmoid function has been chosen as activation function. The ANN model is trained using 950 data sets involving various combinations of normalized input parameters. The average error over the entire training data has been checked repeatedly till the training phase continues. The resulting mean-squared error between the network's output and the target value over all the training pairs are minimized. Here the gradient decent back propagation model is used for minimizing the error function. After proper training the average relative error is found to be 0.15 for Re (S11), 0.12 for Im (S11) and 0.1 for Re(S21) and 0.14 for Im(S21) over a set of test data spanning the entire X band of frequencies and different values for the position of the ferrite posts, which have not been used in the training process,.The trained neural network model is found to be working within the error boundary limited by the practical measurement error of Re (S11),, Im(S11), Re(S21) ,Im(S21) for a array of four ferrite post in rectangular waveguide.

From this model the interval activity of the neuron can be shown to be:

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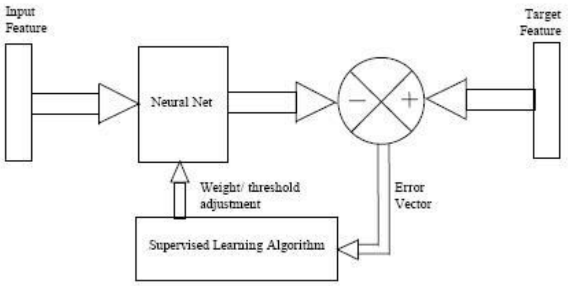

Fig 4. Training of artifcial neural networks

Both learning paradigms supervised learning and unsupervised learning result in an adjustment of the weights of the connections between units, according to some modification rule. Virtually all learning rules for models of this type can be considered as a variant of the Hebbian learning rule suggested by Hebb.

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Neural Network Configuration

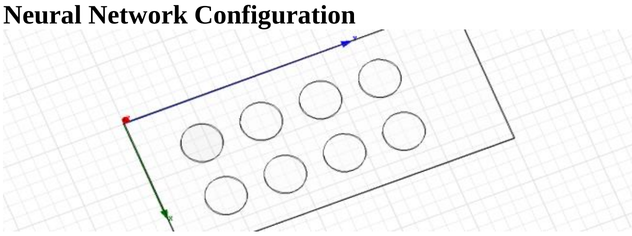

Fig 5. 3D view of the Four Circular ferrite Post in Rectangular waveguide

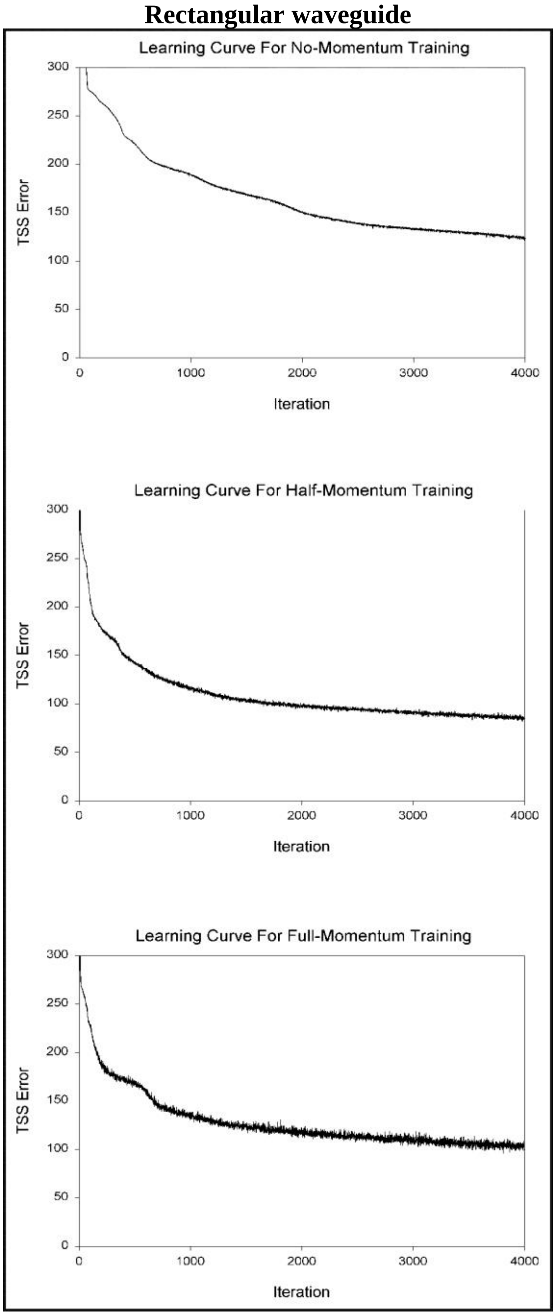

Fig 5. NN convergence result

A five layer MLP is used to model the scattering from full height ferrite post in rectangular waveguides. The post positions are chosen to be symmetric with respect to x axis for a suitable application of the structure as filter. The input layer has four independent neuron which represents four input parameters normalized with their maximum value. For this purpose of input layer modeling two post positions (the other two are symmetrically placed) relative to y axis of the waveguide ,their internal separation and the diameter are taken as inputs. The three hidden layers are chosen having 72, 36 and 24 number of neurons respectively. The output layer has four neuron representing Reflectance (S11), Transmittance (S11) and Reflectance(S21), Transmittance(S21). The waveguide used here is WR-90 (22.86 mm x 10.16 mm.) for the X band frequencies As the training data generated from the electromagnetic analysis has a normalized range from –1 to +1, the bipolar sigmoid function has been chosen as activation function. The ANN model is trained using 950 data sets involving various combinations of normalized input parameters. The average error over the entire training data has been checked repeatedly till the training phase continues.

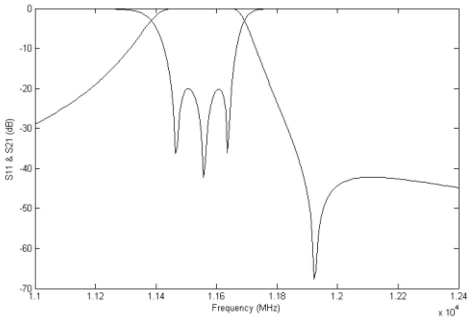

Fig 6. Comparison of Neural Network response with the computed values for Reflectance and Transmittance of S11 and S21 of four ferrite post embedded in rectangular waveguide

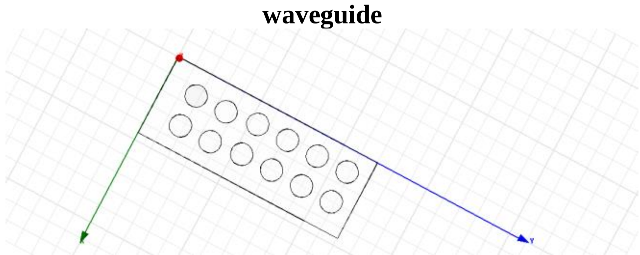

Fig 7. 3D view of the four circular ferrite Post (three layer) embedded inside rectangular waveguide

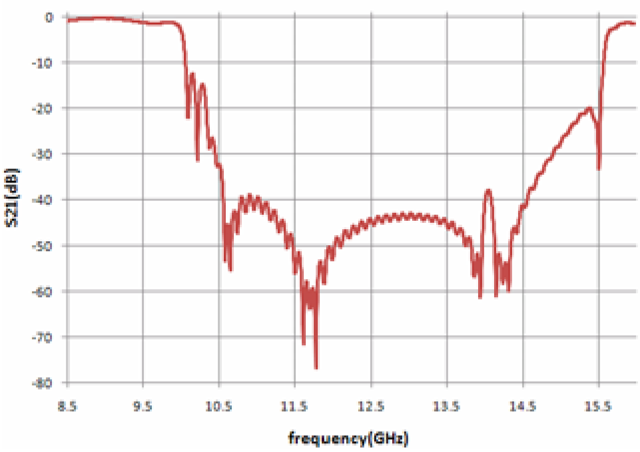

Fig 8.Synthesis of bandpass filter response from ANN model using two ferrite post in three layer embedded in a rectangular waveguide

The resulting mean-squared error between the network's output and the target value over all the training pairs are minimized. Here the gradient decent back propagation model is used for minimizing the error function. After proper training the average relative error is found to be 0.15 for Re (S11), 0.12 for Im (S11) and 0.1 for Re(S21) and 0.14 for Im(S21) over a set of test data spanning the entire X band of frequencies and different values for the position of the ferrite posts, which have not been used in the training process,.The trained neural network model is found to be working within the error boundary limited by the practical measurement error of Re (S11),, Im(S11), Re(S21) ,Im(S21) for a array of four ferrite post in rectangular waveguide.

Conclusion

In this work neural network technique has been used for non-linear modeling of the frequency response of the electromagnetic behaviour of array of long circular ferrite post in a three dimensional rectangular waveguide in X band. Analysis data has been used to generate S11 and S21 data for the structure and 70% of them are used for proper training of the neural network. Rest of the data generated is used for testing the model for the required accuracy. This type of model is very useful in optimization problems [4] where a fast and accurate response is required which cannot be obtained from rigorous electromagnetic simulation.

Future scope of work

The theoretical analysis and ANN modeling tool can be utilized to optimize a bandpass filter using multiple ferrite rod inserted within a waveguide. A single cylindrical post, centrally placed across the waveguide parallel to the electric field of the dominant mode seems to be the most simple configuration to analyze. However, the post size must be changed according to the value of the obstacle susceptances. Normally, the center cavity post is largest and the other posts' sizes are reduced toward both ends of the filter. So, thinnest posts would be located in the two ends When the number of cavities and the filter band-width increase, these two end posts' diameters become extremely thin and this leads to two major problems; first, higher order modes are generated and, second, it becomes difficult to produce the filter in mass production. Variations in posts' diameters do not allow simple automation, too. An alternative to eliminate higher order modes is the use of symmetrical multiple posts, but manufacturing becomes complex.

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