RBF Intelligent Model of Microwave Rectangular PDGS-LPF

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Abstract—Periodic defected ground structures (PDGS) with rectangular defected areas has excellent low-pass properties when periodic unit amount and structure sizes meet definite conditions. Microwave low-pass filter (LPF) is a kind of device which can separate different signals within microwave frequency range, widely used in microwave communication system. The precise transmission coefficient $(S21)$ of rectangular PDGS is obtained through FDTD analysis. The results of FDTD simulation and measurement in the references verify the validity of the FDTD method. The influences of lattice dimensions on the characteristic of frequency are studied. According to RBF artificial neural network (ANN) theory, RBF intelligent model of microwave PDGS-LPF with etched rectangles is developed for the first time on the basis of FDTD analysis. The structures sizes of rectangular PDGS-LPF and the frequency are defined as the input samples of the RBF, transmission coefficient are defined as the output samples. After the RBF has been successfully trained with improved Gaussian algorithm, $S21$ at any arbitrary parameters can be obtained quickly from RBF intelligent model within training values range. Finally, RBF intelligent model has been approved by FDTD results. It is also showed that RBF intelligent model is very effective, which will provide powerful approach for the precise analysis and quick design of rectangular PDGS-LPF.

Keywords-FDTD; ANN; RBF; PDGS-LPF; $S21$

I. INTRODUCTION

Defected ground structures (DGS) are recently one of the hottest topics which are researched in microwave domain, which developed from the photonics bandgap (PBG) structures. DGS can achieve high-performance which can not be obtained by conventional technology. Because of the advantage of DGS, such as having small structure size and simple model, it has been widely used in the design of microwave filter, oscillator, coupler, power amplifier and antenna. PDGS with defective rectangles are the structures that are etched periodically using the rectangular holes on their ground plane. Rectangular defected areas and one connecting slot correspond to the equivalently added inductance $(L)$ and capacitance $(C)$, respectively. Accordingly, a resonance occurs at a certain frequency because of the parallel $L$-$C$ circuit. Inversely, it is intuitively known that the equivalent circuit includes a pair of parallel inductor-capacitor from the resonant phenomenon in the $S$-parameter. This means that the microstrip structure having PDGS with defected rectangles does not have all-pass characteristics, but restricted passband properties. PDGS with defected rectangles can be used to prohibit the propagation of electromagnetic waves within a certain band of frequency. Broadband filter can be implemented through the cascading of many PDGS with defected rectangles, which have wide application prospects in microwave circuits and antenna domain.

Finite-difference time-domain (FDTD) method is frequently utilized to analyze rectangular PDGS-LPF, which is a kind of electromagnetic numerical value analysis methods that are precise and strict. FDTD has a strong ability of simulating many complex structures, and can gain time domain waveform of the subject investigated [1-3]. Frequency characteristic can be correspondingly obtained by Fourier transform, furthermore it can avoid sick results likely occurring in the process of calculating equations, and decrease largely memory space and computing time, so FDTD method is applied to research PDGS-LPF. FDTD with the perfectly matched layer (PML) absorbed boundary is used to analyze PDGS-LPF because it has an advantage over traditional Mur absorbed boundary, such as more simple feedback model, smaller calculation space, faster convergence, unconstrained by angle of incidence and frequency. FDTD is precise and strict, but the time-consuming disadvantage of FDTD seriously hinders the precise analysis and quick design of rectangular PDGS-LPF. Effective models of rectangular PDGS-LPF are necessarily built in order to facilitate computer aided design and save time. In this paper, RBF intelligent model of rectangular PDGS-LPF is developed for the first time on the basis of FDTD analysis. The structure sizes of rectangular PDGS-LPF and the frequency are defined as the input samples of the RBF, transmission coefficient $(S21)$ are defined as the output samples. Transmission coefficient of rectangular PDGS-LPF at any arbitrary structure sizes and any arbitrary frequency within training values range can be obtained quickly from RBF intelligent model after the RBF has been successfully trained with improved Gaussian algorithm. Although training RBF will spend much time, trained RBF model can quickly give precise results which have finally been approved by FDTD results [4-7]. It is also showed that RBF intelligent model is very effective, which will provide powerful approach for the precise analysis and quick design of rectangular PDGS-LPF.

II. RECTANGULAR PDGS-LPF

The structures are shown in Fig.1, in which defected rectangles are periodic unit, $l_1$ is the length of the whole structures, $l_2$ is the width of the whole structures, $w$ is the width of microstrip line, $d$ is the space between periodic unit, $a$ and $b$ are the structure sizes. Rectangular PDGS-LPF shown in Fig.1...
have obvious low-pass filter characteristic after being analyzed through FDTD (defected rectangles being supposed equal intervals distribution).

After one dimension distribution PDGS-LPF whose periodic unit being defected rectangles as shown in Fig.1 are analyzed with FDTD, the whole structure size is $l_1=120\text{mm}$, $l_2=30\text{mm}$, the width of microstrip line is $w=3\text{mm}$, the space between periodic unit is $d=20\text{mm}$, the relative dielectric constant is $\varepsilon_r = 2.65$, the thickness of dielectric slab is $1\text{mm}$. Periodic units amounts $n$ are 5 constantly. Defected rectangular holes have the same structure sizes between 6mm and 10mm, that is to say, values range of the structure sizes $a$ and $b$ is from 6mm to 10mm.

The results of the FDTD simulation show good agreements with the results of measurement in the references [2] as shown in Fig.2 and Fig.3 with the same structure parameters. It is said that the results of FDTD simulation and measurement in the references [2] verify the validity of the FDTD method.

III. RBF NEURAL NETWORK

RBF neural networks which have three-layer forward network structures are shown in Fig.4 based on the theory of function approach. In which $\mathbf{X} = [x_1, x_2, \ldots, x_n]^T$ is input vector, $\mathbf{W} = [w_1, w_2, \ldots, w_m]^T$ is weight matrix, $\mathbf{G} = [G_1, G_2, \ldots, G_m]^T$ is transfer function matrix. The networks can afford best approximation and have perfect function. The transfer function in the hidden layer is Gaussian function, and the nerve unit in the output layer is pure line shape transfer function. The primary function in the hidden node has response to input signal in local. The frequent radial primary function has a lot of forms, in which the radial symmetrical Gaussian function is typical. The expression is

$$G_i(x) = \exp \left( -\frac{\|x-c_i\|^2}{2\sigma_i^2} \right) \quad i = 1, 2, \ldots, m. \quad (1)$$

In which $x$ is $n$ dimension input vector, $c_i$ is the $i$ th center of primary function, which has the same dimension as $x$, $\sigma_i$ is the $i$ th variable of perceived, which can be selected freely and decides the distance from the center; $m$ is the perceived unit amounts, $\|x-c_i\|$ shows the distance between $x$ and $c_i$. 

![Figure 1. The structure of one dimension PDGS](image)

![Figure 2. The result of FDTD](image)

![Figure 3. The result of references [2]](image)

![Figure 4. Three-layer RBF neural network](image)
$G_1(x)$ gets the maximum value only in the $c_1$, and decays to zero rapidly as the $\|x - c_1\|$ gets augment. When the preset input $x \in \mathbb{R}^n$, the centers around the $x$ are active. The nonlinear mapping from $x$ to $G_1(x)$ is realized in the input layer, and the linear mapping from $G_1(x)$ to $F(x)$ is realized in the output layer. In the course of trained, the adjusted algorithm to joint weight value is

$$W_i(t+1) = W_i(t) + \eta [d(x) - F(x)]x_i(t) \quad (i = 1, 2, ..., n, j = 1, 2, ..., m.) \quad (2)$$

In which $d(x)$ is the expected output, $0 < \eta \leq 1$ is the learning rate, which is utilized to adjust convergent speed of weight lead to reduce the error between the sample and the practice value. The primary function of RBF neural networks $G_1(x)$ is Gaussian function, so at random $x, G_1(x) > 0$, which losses merit of adjusting weight. When the $x$ is far away $c_1$, the $G_1(x)$ can be treated as zero. Only when $G_1(x)$ is greater than certain value the relevant weight $W_i$ can be modified. So RBF neural networks are provided with some merits: local approach, fast convergence. At the same time, RBF networks have good compactness that Gaussian function doesn’t have. Gaussian function is simple even there is many input variable. The scale of RBF neural networks is generally big, but whose ability of approach is good and the speed is rapid, which can approach a majority of linear or nonlinear functions at arbitrary accuracy.

**IV. RBF INTELLIGENT MODEL OF PDGS-LPF**

RBF intelligent model of rectangular PDGS-LPF is developed for the first time through RBF neural network theory. The precise $S21$ of rectangular PDGS-LPF is obtained on the basis of FDTD analysis. The structure sizes $a, b$ and the frequency $f$ are defined as the input samples of RBF intelligent model, $S21$ are defined as the output samples. The values range of structure sizes $a, b$ is $6\text{mm} \leq a \leq 10\text{mm}$, $6\text{mm} \leq b \leq 10\text{mm}$. Periodic unit amounts $n$ is 5 constantly. Through analyzing transmission characteristic of PDGS with defected rectangles, it is obvious that they have excellent low-pass filter characteristic within the frequency band $0$–$5.5\text{GHz}$. Consequently the values range of frequency $f$ is limited $0\text{GHz} \leq f \leq 5.5\text{GHz}$. In the values range of these parameters which are $a, b$, and $f$, $S21$ is calculated by FDTD. The samples collected will be divided into training samples and test samples. RBF intelligent model is trained arriving at accuracy set in advance. The accuracy set in advance is higher, and the trained neural networks are more precise. Of course training time spent will be much longer. $S21$ of rectangular PDGS-LPF at any arbitrary parameters (including structure sizes $a, b$, frequency $f$) within training values range can be obtained quickly from intelligent model after RBF intelligent model has been successfully trained with improved Gaussian algorithm. As the RBF intelligent model has been trained with improved Gaussian algorithm, $S21$ of rectangular PDGS-LPF at any arbitrary parameters $(a, b)$ being not trained in training values range (for example $a=7\text{mm}$, $b=8\text{mm}$; $a=7\text{mm}$, $b=9\text{mm}$; $a=8\text{mm}$, $b=6\text{mm}$; $a=8\text{mm}$, $b=8\text{mm}$) and the frequencies can be obtained quickly from RBF intelligent model, which greatly overcomes the time-consuming disadvantage of FDTD. Although training RBF intelligent model will spend much time, trained intelligent model can quickly give precise results which have finally been approved by FDTD results. Finally, RBF intelligent model has been approved by FDTD results.

The results of intelligent model and the calculated results of FDTD are compared with in Fig.5–Fig.8. It is shown that these results match very well each other, the average absolute error is less than 1%, which will provide powerful approach for the precise analysis and quick design of rectangular PDGS-LPF.

![Figure 5](image5.png)

**Figure 5.** The calculated results of intelligent model and FDTD

![Figure 6](image6.png)

**Figure 6.** The calculated results of intelligent model and FDTD
V. CONCLUSIONS

RBF intelligent model are developed for rectangular PDGS-LPF for the first time in this paper, and the calculated results of RBF intelligent model are agreement with the results of FDTD. It is shown that intelligent model is very precise and effective. Although training RBF intelligent model has spent much time, the successful intelligent model can quickly provide precise answers to the task in their training values range. It is also showed that successful RBF intelligent model is very effective, which can seriously overcome the time-consuming disadvantage of FDTD to facilitate the precise analysis and quick design of rectangular PDGS-LPF.

ACKNOWLEDGMENT

This paper is supported by National Science Foundation of China (No.60777014).

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