Application of Two-Dimensional AWE Algorithm in Training Multi-Dimensional Neural Network Model

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ABSTRACT

Artificial neural network (ANN) plays very important role in microwave engineering. Training a neural network model is the key of neural network technique. The conventional methods for training, such as method of moment (MoM), are time-consuming when the training parameters are a bit more. In order to aid the training process by reducing the amount of costly and time-consuming sampling cycles, a lot of algorithms have been developed, such as asymptotic waveform evaluation (AWE). In this paper, MoM in conjunction with the two-dimensional AWE is applied to accelerate the process of training the neural network model based on the input impedance response on frequency and that on other parameters of a microstrip antenna. In AWE method, the derivatives of Green's function are required. A closed form of microstrip Green's function is used for this requirement. Then, the derivative matrices respect to both frequency and permittivity can be obtained from the original matrix. With these matrices in hand, coefficients of the two-dimensional Pade polynomial can be obtained. So the sampling data for training neural network model can be obtained and the process of training neural net model can be completed quickly and accurately. Numerical results demonstrate the efficiency of this technique.

KEY TERMS

AWE, neural network, microstrip antennas

1 INTRODUCTION

Artificial neural networks (ANNs) have emerged as a powerful technique for modeling general input/output relationships. ANNs provide electromagnetically trained ANN (EM-ANN) models for use in CAD of RR/microwave circuits, antennas, and systems [1]. The training is the most important step in the development of ANNs. The actual training process involves algorithms for finding values of weights associated with various neurons. This process can be viewed as an optimization one. Various well-known optimization techniques, such as genetic algorithms and so on, can be used for this purpose. This process is quite time-consuming. For example, to train an ANN which is available in a wide frequency band, the computation should be carried out repeatedly at different frequencies. To overcome this difficulty, the space-mapping (SM) technique has been introduced [2]. This technique establishes a mathematical link between the coarse and the fine models and directs the bulk of the CPU-intensive computation to the coarse model, while preserving the accuracy offered by the fine model. Alternatively, the asymptotic waveform evaluation (AWE) has also been applied in finite difference solution [3-6]. This technique extrapolates the data from one point to a certain range based on the value and the high order derivatives at this point. From this concept, it is seen that this technique is computationally efficient due to involving the analytical relationships and is available to the cases where the derivatives may be obtained. AWE requires the derivatives of Green's functions, so it is often used for free-space problems [7-8]. In this paper, the 2-D AWE has been developed to extrapolate the responses over frequency and permittivity simultaneously to characterize microstrip antennas, so the response over certain frequency and permittivity ranges can be extrapolated from single point accurately and quickly. To check the validity of this method, the analysis of microstrip patch antenna is chosen as an example by using method of moments (MoM). The variables in the model are frequency, relative permittivity, position of feed line and the dimension of the patch. In the training process, two-dimensional AWE is responsible for providing the response of both frequency and relative permittivity simultaneously within certain range.

2 FORMULAS

2.1 Two dimensional AWE method [9]

MoM with the substrate Green's function usually results in a matrix equation in the following form:

$$Z(k,\varepsilon_r)I(k,\varepsilon_r)=V(k,\varepsilon_r) \tag{2.1}$$

Where Z is a square matrix and only can be determined by the object analyzed, I is an unknown vector of the induced currents on the patch, V is a known vector associated with the source or excitation, and k is the wave number and ε_r is permittivity. In accordance with the AWE method, $I(k,\varepsilon_r)$ is expanded into a two-dimensional Taylor series to obtain the solutions of (2.1) over certain frequency and permittivity ranges.

$$I(k,\varepsilon_{r0})=\sum_{n=0}^{Q}\sum_{m=0}^{P}a_{nm}(k-k_0)^n(\varepsilon_r-\varepsilon_{r0})^m \tag{2.2}$$

$$a_{nm}=Z^{-1}\left[\frac{1}{(n+m)!}C_{n+m}^{n}\frac{\partial^{m+n}V}{\partial^n k\partial^m\varepsilon_r}-\sum_{i=0}^{n-1}\sum_{j=0}^{m-1}a_{ij}\frac{1}{(n+m-i-j)!}\times C_{n+m-i-j}^{n-i}\frac{\partial^{n+m-i-j}Z}{\partial^{n-i}k\partial^{m-j}\varepsilon_r}\frac{1}{(n+m-i-j)!}\right] \tag{2.3}$$

Where k_0 is the wave number on the expansion point, a_{nm} denote the unknown coefficients, and $P\times Q$ denotes the total number of such coefficients.

In order to get the coefficients a_{nm}, the derivatives of matrix I have to be generated. A closed form Green's function $G_e^{(1)}(\rho)$ that is easy to get derivatives is used [10].

$$G_e^{(1)}(\rho)=a\frac{\pi}{2}[L_0(\frac{\varepsilon_r\rho}{h})-L_0(\frac{\rho}{\mu_r h})] -a^2(\frac{e^{-jk_0\rho}-1}{k_0\rho}) \tag{2.4}$$

$$L_0(z)=H_0(z)-Y_0(z) \tag{2.5}$$

Where a is defined as $a=((\varepsilon_r\mu_r-1)/\varepsilon_r)k_0h$, H_0 and Y_0 are the Struve and Neumann functions of zero order and $\rho=\sqrt{(x-x')^2+(y-y')^2}$. The Green's function $G_e^{(1)}(\rho)$ in (2.4) is valid subject to the conditions $k_0\rho(k_0h/\varepsilon_r)^2<<1$ and $k_0\rho(\mu_rk_0h)^2<<1$.

The Taylor expansion has a limited bandwidth. To obtain a wider bandwidth, we represent $I(k,\varepsilon_r)$ with a better rational Padé function:

$$I(k,\varepsilon_r)=\frac{\sum_{i=0}^{X}\sum_{j=0}^{Y}b_{ij}(k-k_0)^i(\varepsilon_r-\varepsilon_{r0})^j}{\sum_{l=0}^{F}\sum_{m=0}^{G}c_{lm}(k-k_0)^l(\varepsilon_r-\varepsilon_{r0})^m} \tag{2.6}$$

Where $c_{00}=1$ and XF+YG+X+F+Y+G+1 =PQ+P+Q. If we make Y=G, the unknown coefficients $b_{i,j}$ and $c_{i,j}$ can be calculated by substituting (2.2) into (2.6), multiplying (2.6) by the denominator of the Padé expansion, and matching the coefficients of the equal powers of k-k_0 and $\varepsilon_r-\varepsilon_{r0}$. This leads to the matrix equation (2.7). Where n is from 1 to X. If we solve equation (2.7) in turn, $b_{i,j}$ and $c_{i,j}$ can be obtained, and the current vector $I(k,\varepsilon_r)$ can be obtained by the calculated Padé model.

2.2 Neural networks [11]

Multilayer perceptrons (MLP) are the most popular type of neural networks in use today. Typically, an MLP neural network consists of an input layer, one or more hidden layer, and an output layer, as shown in Fig. 2.1. The top layer is the output layer and the input impedance and other scattering parameters can be outputted. The bottom layer is the input layer, and four parameters, frequency, relative permittivity, position of feed line and the dimension of patch, are inputted. The other two layers are hidden layers, and it can be automatic treated in the software [12].

can be simultaneously obtained by the two-dimensional AWE method. In AWE, the differentiation operates on the Green's function which does not involve the dimensions of the object to be analyzed. Therefore it is not available to obtain the response with respect to the dimensions through AWE. In this case, the sampling data for training variables respect to the dimension of the microstrip and position of feed line can only be calculated point by point. Even in this case, the speed of training is about one or two orders faster than that of direct training. With the two-dimensional AWE method and neural network technique in hand, we can accurately and efficiently construct the neural network model. The flowchart is shown in Fig. 2.2.

$$
\begin{bmatrix}
1 & 0 & \cdots & 0 & 0 & \cdots & 0 & -a_{0,0} \\
0 & 1 & \cdots & 0 & 0 & \cdots & -a_{0,0} & -a_{1,0} \\
\vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots \\
0 & 0 & \cdots & 1 & -a_{X-F,0} & \cdots & -a_{X-1,0} & -a_{X,0} \\
0 & 0 & \cdots & 0 & -a_{X-F+1,0} & \cdots & -a_{X,0} & -a_{X+1,0} \\
\vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots \\
0 & 0 & \cdots & 0 & -a_{X+1,0} & \cdots & -a_{X+F,0} & -a_{X+F+1,0}
\end{bmatrix}
\begin{bmatrix}
b_{0,n} \\ b_{1,n} \\ \vdots \\ b_{X,n} \\ c_{F,n} \\ \vdots \\ c_{0,n}
\end{bmatrix}
=
\begin{bmatrix}
\sum_{i=0}^{n-1} c_{0,i} a_{0,n-i} \\
\sum_{i=0}^{n-1} c_{0,i} a_{1,n-i} + \sum_{i=0}^{n-1} c_{1,i} a_{0,n-i} \\
\vdots \\
\sum_{i=0}^{n-1} \sum_{j=0}^{X} c_{j,i} a_{X-j,n-i} \\
\sum_{i=0}^{n-1} \sum_{j=0}^{X+1} c_{j,i} a_{X+1-j,n-i} \\
\vdots \\
\sum_{i=0}^{n-1} \sum_{j=0}^{X+F+1} c_{j,i} a_{X+F+1-j,n-i}
\end{bmatrix}
$$

2.3 Hybrid of AWE and ANN

AWE method is an accurate and efficient technique that is based on the electromagnetic mechanism. In the practical application, the response varied with frequency and permittivity

As the neural network model is constructed, the response of object varied with each parameter can be immediately obtained. This trained model may be used in the optimization of microstrip structures other than microstrip antennas.

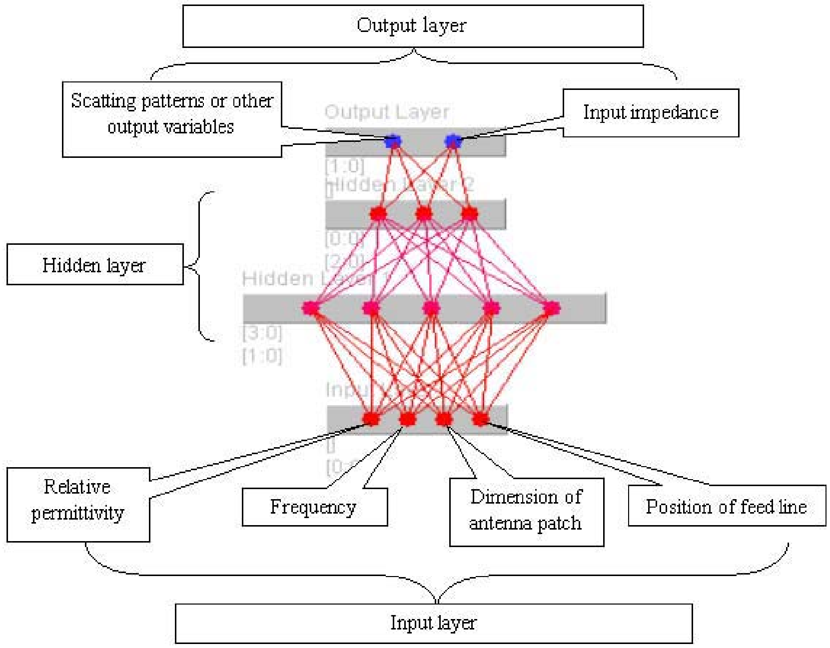

Figure 2.1 Multilayer perceptrons (MLP) structure.

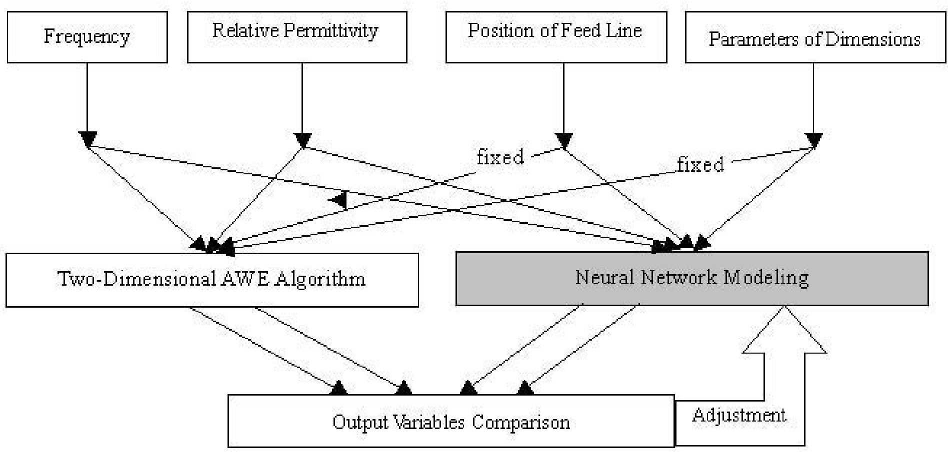

Figure 2.2 The process of the hybrid technique.

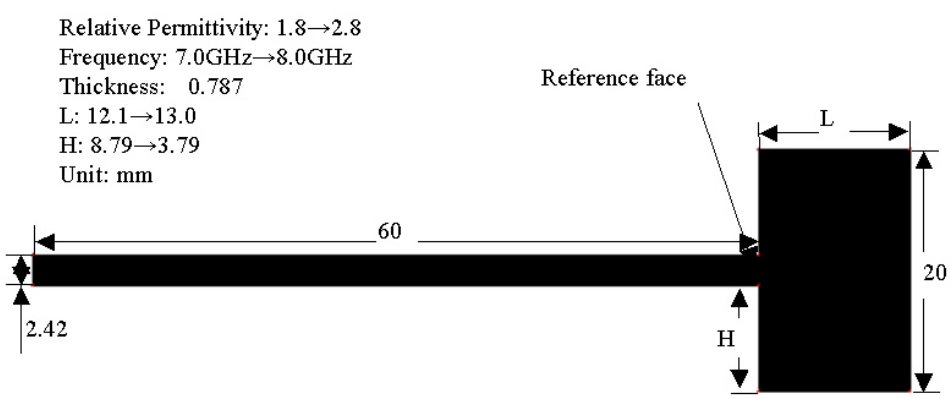

Fig.3.1 The antenna geometry

3 NUMERICAL RESULTS AND DISCUSSION

The example is a microstrip antenna consisting of a conducting patch residing on a dielectric substrate having thickness h=0.787mm (Fig. 3.1). The increments of frequency, relative permittivity, position of feed line H and dimension of patch L are 0.01GHz, 0.01, 0.1mm and 0.01mm respectively. In order to get the response under the following specification: the frequency varies from 7.5GHz to 8.4GHz; the permittivity varies from 1.8 to 2.8; the dimension L varies from 12.0mm to 13.0mm; the feed line position H varies from 8.79 to 0.79, the direct method requires 7.5×10^9 seconds to obtain the solution on a Personal Computer (1.2GHz AMD K7 processor). With general neural network algorithm, including the training time, to obtain the same accuracy, 1.4×10^6 seconds are need. But with hybrid method, only 1.2×10^5 seconds are needed, which is 6.3×10^4 times faster than the direct method and 1.2×10^1 times faster than the general neural network method (Table 3.1). The training process of the software- "Neuralmodeler" is shown in Fig. 3.2 and the final error is less than 0.01. Figure 3.3 and Figure 3.4 show the real and imaginary parts of the input impedance as a function of frequency, relative permittivity, dimension L and position H by using the hybrid method of the two dimensional AWE method and neural network algorithm, respectively (Due to difficulty in presenting four dimensional figure, the variables, dimension L and position H, are fixed). When this four variables neural network model for this antenna patch is obtained, consequently the optimizing and designing will be an easy job. This neural network model gives the complete characterization of the microstrip patch antenna. Because of its computational efficiency, it is realizable in the optimization and the observation of the sensitivity of the parameters, such as the relative permittivity (Fig. 3.5). In this example, only four variables are involved. It is observed that the more the variables to be optimized, the more the reduction of the computer time.

4 CONCLUSION

The AWE algorithm has been extended from one dimensional to two dimensional cases. This extension results in the extrapolation for two variables simultaneously. Compared to the one-dimensional AWE, the computer time is further reduced significantly. The hybrid of AWE and ANN makes full use of the advantages of both algorithms. Numerical results demonstrate the efficiency of this hybrid scheme.

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Table 3.1 The compare of neural network methods and direct method

Time		Neural network method		Direct method
		Hybrid method	General method	
Training	Sampling	$1.2\text{x}10^5$ s	$1.4\text{x}10^6$ s	No training
	Modeling	$7.0\text{x}10^1$ s	$7.0\text{x}10^1$ s	
Generating response		Almost zero	Almost zero	$7.5\text{x}10^9$ s
Total time		$1.2\text{x}10^5$ s	$1.4\text{x}10^6$ s	$7.5\text{x}10^9$ s

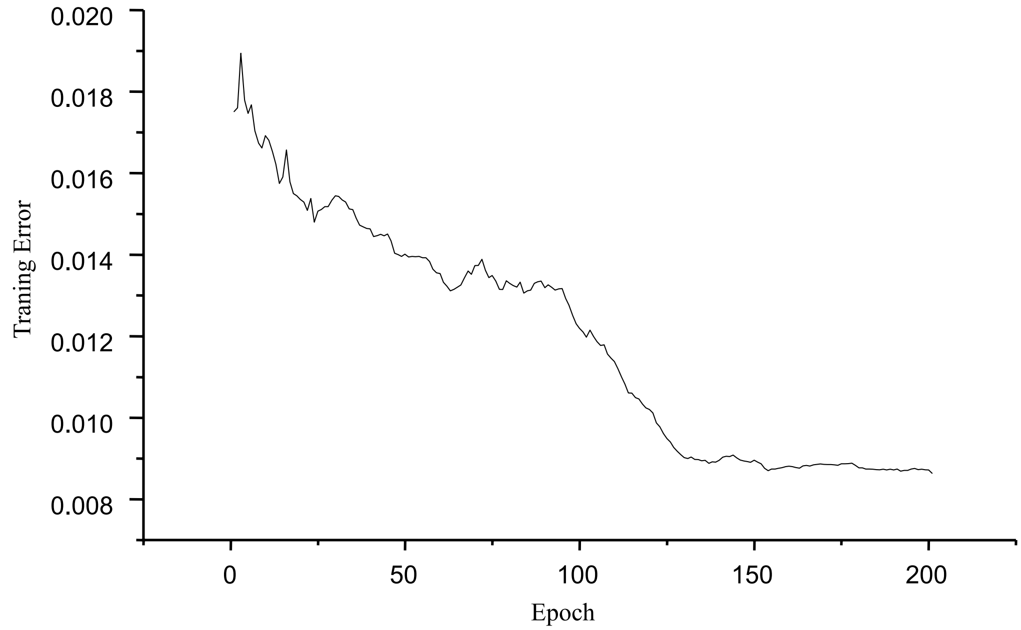

Figure 3.2 Effect of hybrid method on the training errors.

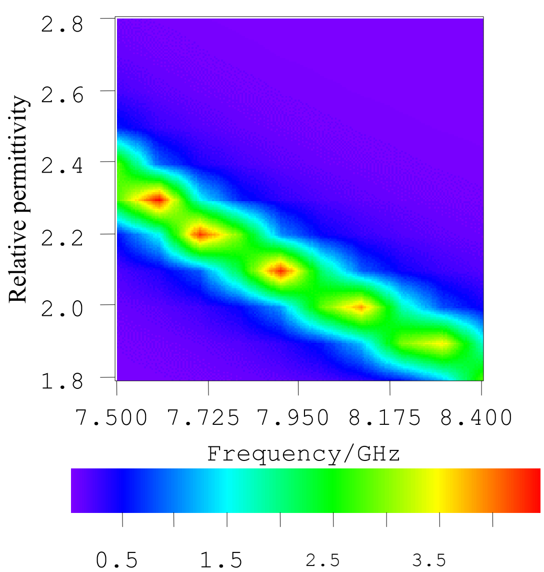

Figure 3.3 The real part of the input impedance
(L =12.5 mm, H=8.79mm).

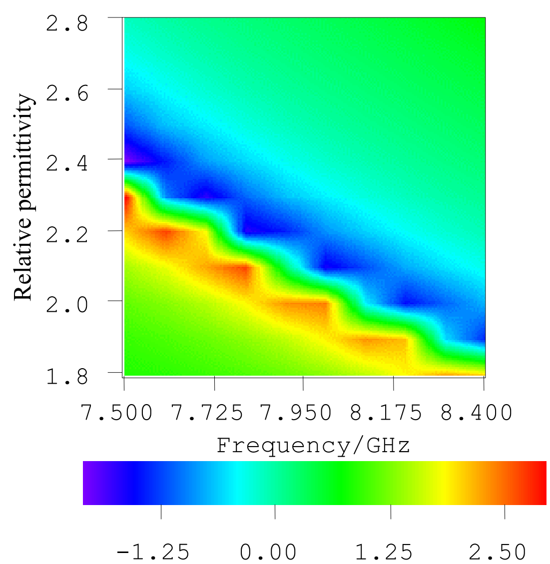

Figure 3.4 The imaginary part of the input impedance
(L =12.5 mm, H =8.79mm).

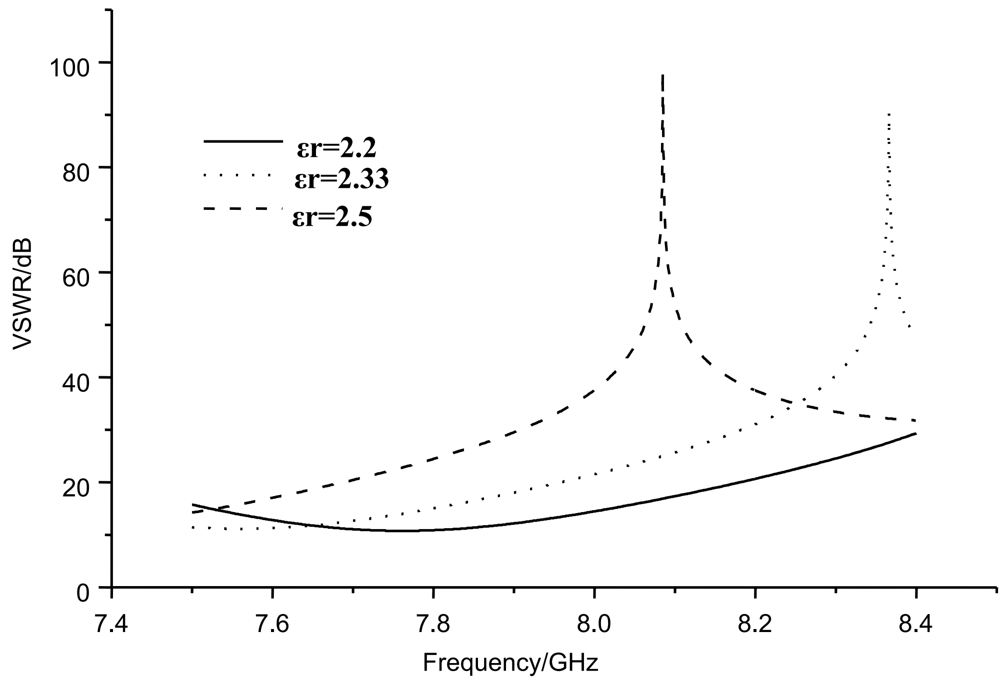

Figure 3.5 Sensitivity of the permittivity (L=12.5mm, H=8.79mm).

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