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ANN Models for Microstrip Line Synthesis and Analysis

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Abstract**—**Microstrip lines, widely used for good reason, are broadband in frequency and provide circuits that are compact and light in weight. They are generally economical to produce since they are readily adaptable to hybrid and monolithic integrated circuit (IC) fabrication technologies at RF and microwave frequencies. Although, the existing EM simulation models used for the synthesis and analysis of microstrip lines are reasonably accurate, they are computationally intensive and time consuming. Neural networks recently gained attention as fast and flexible vehicles to microwave modeling, simulation and optimization. After learning and abstracting from microwave data, through a process called training, neural network models are used during microwave design to provide instant answers to the task learned.This paper presents simple and accurate ANN models for the synthesis and analysis of Microstrip lines to more accurately compute the characteristic parameters and the physical dimensions respectively for the required design specifications.

Keywords**—**Neural Models, Algorithms, Microstrip Lines, Analysis, Synthesis

I. INTRODUCTION

EARLIER to year 1965 nearly all microwave equipment utilized coaxial or wave guide lines.With the introduction of Monolithic Microwave Integrated Circuits (MMICs), microstrip lines have become more suitable and are used extensively because they provide a free and accessible surface on which solid state devices can be attached. A planar geometry implies that the characteristics of the element can be determined from the dimensions in a single plane. Several configurations for microstrip lines have been realized and some of these lines support TEM modes, other hybrid or higher order modes. The circuits realized by any of these lines or combination of them have distinct advantages such as light weight, small size, improved performance, better reliability and reproducibility and low cost [1].

The general structure of a microstrip is illustrated in Fig.1. A conducting strip (Microstrip line) with a width W and a thickness t is on the top of a dielectric substrate that has a relative dielectric constant ε_r and a thickness h, and the bottom of the substrate is a ground (conducting) plane. The fields in the microstrip extend within two media-air above and dielectric below-so that the structure is inhomogeneous. Due to this inhomogeneous nature, the microstrip does not support a pure TEM wave. This is because a pure TEM wave has only transverse components, and its propagation velocity depends only on the material properties, namely the permittivity (ε) and the permeability (μ). However, with the presence of the two guided-wave media (the dielectric substrate and the air), the waves in a microstrip line will have no vanished longitudinal components of electric and magnetic fields, and their propagation velocities will depend not only on the material properties, but also on the physical dimensions of the microstrip.When the longitudinal components of the fields for the dominant mode of a microstrip line remain very much smaller than the transverse components, they may be neglected. In this case, the dominant mode then behaves like a TEM mode, and the TEM transmission line theory is applicable for the microstrip line as well. This is called the quasi-TEM approximation and it is valid over most of the operating frequency ranges of microstrip. In the quasi-TEM approximation, a homogeneous dielectric material with an effective dielectric permittivity replaces the inhomogeneous dielectric–air media of microstrip. Transmission characteristics of microstrips are described by two parameters, namely, the effective dielectric constant ε_{re} and characteristic impedance Z_c, which may then be obtained by quasistatic analysis [2]. In quasi-static analysis, the fundamental mode of wave propagation in a microstrip is assumed to be pure TEM.

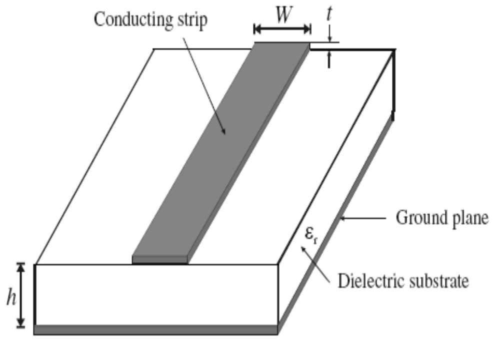

Fig. 1 General Microstrip structure

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Referring to Fig.1, it should be apparent that a basic (unshielded) microstrip line is not really a practical structure. It is open to the air and, in reality, it is desirable to have circuits that are covered to protect them from the environment as well as to prevent radiation and EM interference (EMI). Also, the microstrip configurations that have been so far discussed are transversally infinite in extent, which deviate from reality. Covering the basic microstrip configuration with metal top plates on the top and on the sides leads to a more realistic circuit configuration, a shielded microstrip line with a housing (Fig. 1).The main purposes of the housing or package are to provide mechanical strength, EM shielding, germetization, and heat sinking in the case of high-power applications. Packaging must protect the circuitry from moisture, humidity, dust, salt spray, and other environmental contaminants. In order to protect the circuit, certain methods of sealing can be used: conductive epoxy, solder, gasket materials, and metallization tape [3]. Most of the conventional models for various Microstrip lines are the analysis models [4,5] that have been used to determine the characteristic parameters of Microstrip structures. The synthesis models presented in the literature [4,6] are directly used to obtain the physical dimensions of Microstrip structures for the required design specifications. These models are accurate but computationally intensive and time consuming. Hence a better model for the synthesis and analysis of the microstrip line is required to be introduced to address the above issues.

Artificial Neural Network (ANN) represents a promising modeling technique, especially for data sets having non-linear relationships that are frequently encountered in engineering [7-16]. In the course of developing an ANN model, the architecture of ANN and the learning algorithm are the two most important factors. ANNs have many structures and architectures [17,18]. The class of ANN and/or architecture selected for a particular model implementation depends on the problem to be solved [19-21]. After several experiments using different architectures coupled with different training algorithms, in this paper, the Multi Layered Perceptron (MLP) neural network architecture is used in calculating the physical dimensions of Microstrips. MLPs have a simple layer structure in which successive layers of neurons are fully interconnected, with connection weights controlling the strength of the connections. The MLP comprises an input layer, an output layer, and a number of hidden layers. MLPs can be trained using many different learning algorithms. Once the ANN model is fully developed, the computation time is usually negligible and much faster than any EM simulator. Though a considerable effort is required in developing an ANN model, it is worthy doing so if repeated design and analysis is required.

In this paper, simple and accurate neural models with a very wide range of usage for Microsrip synthesis and analysis are presented within the following design-parameter ranges: $2.2 \le \varepsilon_r \le 19$,$20 \le Z_c \le 100\ \Omega$, $0.25 \le h \le 1.2$ mm and$1 \le f \le 10$ GHz. These neural models are trained with, Sparse Training (ST),Conjugate Gradient(CG), Adaptive Back Propagation(ABP), Quasi-Newton (QN-MLP), Quasi-Newton(QN), Huber-Quasi-Newton (HQN), and Simplex Method (SM) algorithms.For the validation of the neural models proposed in this paper, the neural results have been compared with the results proposed by Wheeler [6] and Hammerstad [4] for the Synthesis; and the results proposed by Hammerstad and Jensen [5] for the Analysis.

II. SYNTHESIS FORMULAS FOR MICROSTRIP LINE

The general structure of a microstrip is illustrated in Fig .1. A conducting strip (microstrip line) with a width W and a thickness t is on the top of a dielectric substrate that has a relative dielectric constant ε_r and a thickness h, and the bottom of the substrate is a ground (conducting) plane. Approximate expressions for W/h in terms of Z_c and ε_r, derived by Wheeler [6] and Hammerstad [4], are given by

$$For\, W/h \le 2$$

$$\frac{W}{h} = \frac{8 * \exp(A)}{\exp(2A) - 2}$$

$$Where\ A = \frac{Z_c}{60}\left\{\frac{\varepsilon_r + 1}{2}\right\}^{0.5} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left\{0.23 + \frac{0.11}{\varepsilon_r}\right\} \tag{1}$$

$$And\ \ for\, W/h \ge 2$$

$$\frac{W}{h} = \frac{2}{\pi}\left\{(B-1) - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\}$$

$$Where\ B = \frac{60\pi^2}{Z_c\sqrt{\varepsilon_r}} \tag{2}$$

These expressions also provide accuracy better than one percent. If more accurate values are needed, an iterative or optimization process based on the more accurate analysis models described previously can be employed.

III. ANALYSIS FORMULAS FOR MICROSRIP LINE

Hammerstad and Jensen [5] report more accurate expressions for the effective dielectric constant and characteristic impedance:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10}{u}\right)^{-ab}$$

$$Where \quad u = W/h\, , and$$

$$a = 1 + \frac{1}{49}\ln\left(\frac{u^4 + \left(\frac{u}{52}\right)^2}{u^4 + 0.432}\right) + \frac{1}{18.7}\ln\left[1 + \left(\frac{u}{18.1}\right)^3\right] \tag{3}$$

$$b = 0.564\left(\frac{\varepsilon_r - 0.9}{\varepsilon_r + 3}\right)^{0.053} \qquad (4)$$

The accuracy of this model is better than 0.2% for $\varepsilon_r \le 128$ and $0.01 \le u \le 100$.

The more accurate expression for the characteristic impedance is

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ln\left[\frac{F}{u} + \sqrt{1 + \left(\frac{2}{u}\right)^2}\right]$$

$$Where\, u = W/h, \eta = 120\pi\; ohms, and$$

$$F = 6 + (2\pi - 6) * \exp\left[-\left(\frac{30.666}{u}\right)^{0.7528}\right] \qquad (5)$$

The accuracy for $Z_c\sqrt{\varepsilon_{re}}$ is better than 0.01 % for $u \le 1$ and 0.03% for $u \le 100$.

IV. SYNTHESIS AND ANALYSIS MODELS BASED ON ANN'S FOR MICROSTRIP LINES

Of the two models proposed, the first neural model computes the strip width *W* and Length *L* for a given substrate (,ε_r,h) and required characteristic impedance Z_c by choosing an appropriate frequency (f). The second neural model calculates the effective dielectric Constant ε_{re} and Characteristic Impedance Z_c for a given substrate (W/h, ε_r). Fig. 2 and 3 shows the first and second neural model used for neural computation of the strip width, length and effective dielectric Constant, Characteristic Impedance of Microstrip Lines, for the synthesis and analysis respectively.

ANN models are a kind of black box models, whose accuracy depends on the data presented to it during training. A good collection of the training data, i.e., data which is well-distributed, sufficient, and accurately simulated, is the basic requirement to obtain an accurate model. For microwave applications, there are two types of data generators, namely measurement and simulation. The selection of a data generator depends on the application and the availability of the data generator. The training data sets used in this paper were obtained from the respective quasi-static analysis and contain 7500 samples. The design parameter ranges of the Microstrip Lines in these samples are $2.2 \le \varepsilon r \le 19$,$20 \le Z_c \le 100\ \Omega$, $0.25 \le h \le 1.2$ mm and $1 \le f \le 10$ GHz.2400 data sets, which are completely different from training data sets, were used to test the ANNs. The aim of the training process is to minimize the training error between the target output and the actual output of the ANN. ANN output is then compared to the known output of the training data sets and errors are computed. Error derivatives are then calculated and summed up for each weight until all the training examples have been presented to the network. These error derivatives are then used to update the weights for neurons in the model. Training proceeds until errors are lower than prescribed values.Selection of training parameters and the entire training process mostly depend on experience besides the type of problem at hand. After several trials, it was found in this paper that three hidden layered network was achieved the task in high accuracy. The most suitable network configuration found was 4 × 8 × 5 × 3 ×2. It means that the numbers of neurons were 4, 8, 5, 3, and 2 for the input layer, the first, second, and third hidden layers and the output layer, respectively.

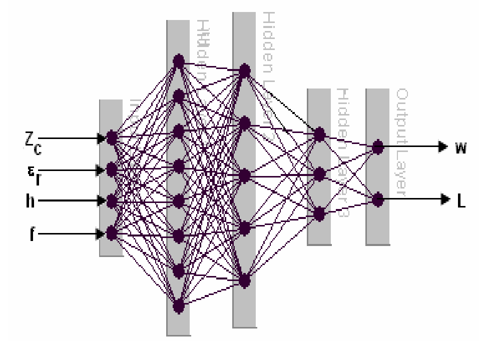

Fig. 2 Neural model for Microstrip Synthesis

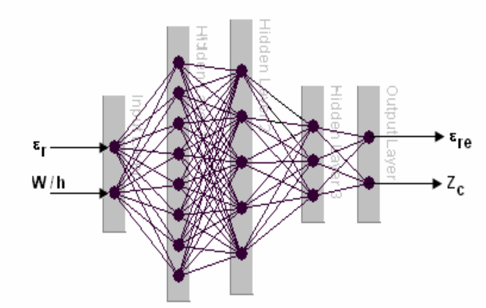

Fig. 3 Neural model for Microstrip Analysis

V. NUMERICAL RESULTS AND DISCUSSION

ANNs have been successfully used to compute the Strip width, Length, and Characteristic parameters, of a Microstrip line of a given substrate material. In order to obtain better performance, faster convergence, and a simpler structure, ANN models were trained with the Sparse Training , Conjugate Gradient, Adaptive Back Propagation, Quasi-Newton (MLP), Quasi-Newton, Huber-Quasi-Newton and Simplex Method learning algorithms. The training and test errors obtained from the first and second neural models are given in Table 1 and 2. It is clear from the results that the neural models trained by the Quasi Newton, Huber Quasi Newton and Simplex Method algorithms are better for Sysnthesis and the Analysis of the Microstrip lines respectively .

TABLE I
TRAINING AND TEST ERRORS OF NEURAL MODELS FOR THE SYNTHESIS OF MICROSTRIP LINES

Algorithm	**Training Error**	**Testing Error**	
		Avg. Error	**Worst case Error**
S T	0.010063	0.939859	24.165545
CG	0.00312158	0.30974	4.4140954
ABP	0.00312267	0.30974	4.4140954
QN (MLP)	$2.95*10^{-04}$	0.029497	0.3313487
QN	$2.95*10^{-04}$	0.029474	0.33218488
HQN	$2.95*10^{-04}$	0.029474	0.33218488
SM	$2.95*10^{-04}$	0.029474	0.33218488

TABLE II
TRAINING AND TEST ERRORS OF NEURAL MODELS FOR THE ANALYSIS OF MICROSTRIP LINES

Algorithm	**Training Error**	**Testing Error**	
		Avg. Error	**Worst case Error**
ST	0.010062	1.0018047	18.297659
CG	0.0099272	1.0033152	17.437292
ABP	0.0099249	1.0033152	17.437292
QN (MLP)	1.46E-04	0.01484634	0.10400163
QN	1.46E-04	0.01484634	0.10400163
HQN	1.46E-04	0.01484634	0.10400163
SM	1.46E-04	0.01484634	0.10400163

In order to validate the neural models for Microstrip line synthesis and analysis, comprehensive comparisons have been made. In these comparisons, the results obtained from the first neural model trained by Quasi Newton algorithm are compared with the results proposed by Wheeler [6] and Hammerstad [4] for Synthesis as shown in Table 3**.** The results obtained from second neural models trained by Huber Quasi Newton algorithm are compared with the results proposed by Hammerstad and Jensen [5] for Analysis as shown in Table 4.

TABLE III
COMPARISON OF SYNTHESIS RESULTS WITH THAT OF ANN RESULTS
(h=0.725mm,f=5.5GHz)

z_0	ε_r	W_ANN	W_Synth
95.78947	2.2	0.713	0.713
41.05263	3.4	2.258	2.257
57.89474	4.6	1.041	1.040
57.89474	5.8	0.856	0.855
62.10526	7	0.623	0.622
70.52631	8.2	0.390	0.389
74.73684	8.2	0.334	0.334
49.47368	10.6	0.671	0.669
45.26316	11.8	0.724	0.724
36.84211	13	0.982	0.982
87.36842	14.2	0.086	0.085
32.63158	15.4	1.055	1.054
78.94737	16.6	0.095	0.095
74.73684	17.8	0.104	0.103
74.73684	19	0.092	0.091

z_0	ε_r	L_ANN	L_Synth
95.78947	2.2	10.235	10.230
41.05263	3.4	8.193	8.155
57.89474	4.6	7.376	7.360
57.89474	5.8	6.687	6.676
62.10526	7	6.208	6.202
70.52631	8.2	5.861	5.849
74.73684	8.2	5.888	5.876
49.47368	10.6	5.077	5.076
45.26316	11.8	4.799	4.799
36.84211	13	4.502	4.499
87.36842	14.2	4.665	4.663
32.63158	15.4	4.121	4.118
78.94737	16.6	4.326	4.317
74.73684	17.8	4.183	4.167
74.73684	19	4.069	4.045

TABLE Iv
COMPARISON OF ANALYSIS RESULTS WITH THAT OF ANN RESULTS

W/h	ε_r	Zcal_Ann	Zcal
8.199	16.600	9.164	9.165
8.199	1.000	34.034	34.035
2.072	3.400	53.469	53.469
5.136	10.600	16.684	16.684
5.136	11.800	15.838	15.837
7.689	1.000	35.793	35.792
8.710	10.600	10.857	10.855
0.541	14.200	54.243	54.240
8.199	17.800	8.858	8.855
7.689	5.800	16.141	16.138
5.136	9.400	17.687	17.684
2.583	8.200	31.030	31.027
8.199	10.600	11.426	11.422

W/h	ε_r	ε_{re} _ANN	ere
8.199	16.600	13.790	13.791
8.199	1.000	0.997	1.000
2.072	3.400	2.665	2.666
5.136	10.600	8.439	8.436
5.136	11.800	9.365	9.362
7.689	1.000	0.995	1.000
8.710	10.600	8.936	8.935
0.541	14.200	8.940	8.943
8.199	17.800	14.773	14.773

VI. CONCLUSION

Accurate and simple neural models are presented to compute the physical dimensions of Microstrip for the required design specifications. These models have been developed by training the neural network with the numerical results of quasi-static analysis in the required ranges of model input variables. It was shown that the results of the neural models trained by the Quasi Newton algorithm and Huber Quasi Newton algorithms are better for synthesis and analysis of Microstrip line.

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