ANN Models for Coplanar Strip Line Analysis and Synthesis

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Summary

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 analysis and synthesis of CPS structures to very accurately compute the characteristic parameters and the physical dimensions respectively for the required design specifications.

Key words:
Neural Models, Algorithms, Coplanar strip lines ,Analysis, Synthesis

1 . Introduction

The coplanar strip line (CPS) consists of a dielectric substrate with two parallel strip conductors separated by a narrow gap. Microwave integrated circuits (MICs) using coplanar lines have been developed as an attractive alternative to microstrip based circuits owing to the advantages of coplanar waveguides (CPWs) and coplanar strips (CPSs), such as easy incorporation of series and shunt elements and uniplanar features. However, the application of coplanar lines (CPW, CPS) to microwave circuit designs is not yet widespread due to the lack of adequate tools for coplanar circuit design and optirnisation. It is noted that so far, all the conventional CAD models for coplanar lines are analysis models where the electrical parameters are obtained by the geometrical parameters of coplanar lines [l]. No closed-form synthesis formulas to directly obtain the physical dimensions of coplanar structures for the required design specifications are available in the literature. In contrast, both analysis and synthesis closed-form formulas for microstrip lines have existed for a long time [2]. Its applications include balanced mixers and feed network work for printed dipole antennas.

Most of the conventional models for various CPSs are the analysis models [1,3] that have been used to determine the characteristic parameters of CPS structures. The synthesis models were also presented in the literature[4–6]. These synthesis models are directly used to obtain the physical dimensions of CPS structures for the required design specifications. The model proposed by Deng et al. [4] is mathematically complex. The models presented by Yildiz [5] and Yildiz et al. [6] are simple but do not have very good accuracy. Hence, they are not very attractive for the CPS synthesis.

ANN represents a promising modeling technique, especially for data sets having non-linear relationships that are frequently encountered in engineering [7]. In the course of developing an ANN model, the architecture of ANN and the learning algorithm [8] are the two most important factors. ANNs have many structures and architectures [9]. The class of ANN and/or architecture selected for a particular model implementation depends on the problem to be solved. After several experiments using different architectures coupled with different training algorithms, in this paper, the multilayered perceptron (MLP) neural network architecture is used in calculating the electrical parameters and physical dimensions of CPSs.Neural model for the CPS synthesis was introduced for the first time by Salivahanan et al. [10]. This neural model has some disadvantages. First of all, it can be used only in the narrow range. It is not possible to design CPSs having small characteristic impedances ($Z0 < 70$ Ω) .Thus, this neural model is not suitable for practical ranges. Moreover, the neural model proposed in [10] was trained using only one learning algorithm.

In this paper, simple and accurate neural models with a very wide range of usage for CPS analysis and synthesis are presented within the following design-parameter ranges: $2.2 \le \varepsilon_r \le 50$, $0.01 \le S/H \le 1.86$, and $0.01 \le W/H \le 5.59$. These neural models were trained with, Back Propagation (BP-MLP3), Sparse Training (ST),Conjugate Gradient(CG), Adaptive Back Propagation(ABP), Quasi-Newton (QN-MLP), Quasi-Newton(QN), Huber-Quasi-Newton (HQN),Auto Pilot (AP-MLP3) and simplex method (SM) algorithms.For the validation of the neural models proposed in this paper, the neural analysis and synthesis results have been compared with the results of the quasi-static analysis [1] and the synthesis formulas proposed by Deng et.al [4].

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2. Analysis and Synthesis Formulas for Coplanar Strip lines

A CPS with a finite dielectric thickness configuration is depicted in Fig. 1, where *S,W,H*, and ε_r represent the slot width, strip width, substrate thickness, and relative dielectric constant of the substrate material, respectively. All the conductors are assumed to be infinitely thin and perfectly conducting. Owing to the increasing popularity of coplanar waveguides (CPW) and coplanar strip lines (CPS) for the design of hybrid and monolithic microwave integrated circuits, it is important to have a set of reliable analytical formulas for their quasi-TEM electrical parameters (characteristic impedance Z_0 and effective dielectric constant ε_{eff}).

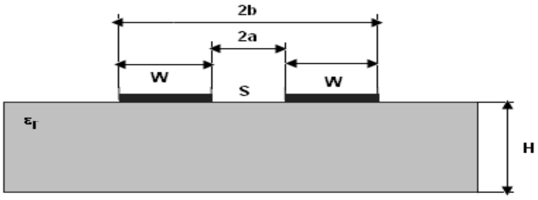

Fig. 1. Configuration of a CPS

The following analysis formulas proposed in [1] calculates the characteristic impedance Z_0 and effective dielectric constant ε_{eff} given by

$$Z_0 = \frac{120.\pi}{\sqrt{\varepsilon_{eff}}} \frac{K(k)}{K(k')} \tag{1}$$

While ε_{eff} is given by

$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2} \frac{K(k')K(k_1)}{K(k)K(k_1')} \tag{2}$$

Where

$$k = a/b;$$

$$k_1 = \frac{\sinh(\pi a/2H)}{\sinh(\pi b/2H)} \tag{3}$$

K is the complete elliptic integral of the first kind and

$$k' = \sqrt{(1-k^2)} \tag{4}$$

The following synthesis formula proposed in [4] calculates the strip width (*W*) and slot width (*S*) for a given substrate (*H*, ε_r) and required characteristic impedance Z_0 by choosing an appropriate slot width (*S*) and strip width (*W*).

$$W = \frac{S}{G(\varepsilon_r, H, Z_0, S)} \tag{5}$$

$$S = W.G(\varepsilon_r, H, Z_0, W) \tag{6}$$

The Synthesis formulas given above are valid for the ranges of, $S/H \le 10/3(1+\ln\varepsilon_r)$, $W/H \le 10/(1+\ln\varepsilon_r)$ and $2.2 \le \varepsilon_r \le 50$

3. Analysis and Synthesis models based on ANNs for CPSs

In this paper, three simple and accurate neural models are proposed for CPS analysis and synthesis. The first neural model computes the electrical parameters (Z_0,ε_{eff}) for a given Substrate (S,W, *H*, ε_r).The Second neural model computes the strip width *W* for a given substrate (*H*, ε_r) and required characteristic impedance Z_0 by choosing an appropriate slot width *S*. The third neural model calculates the slot width *S* for a given substrate (*H*, ε_r) and required characteristic impedance Z_0 by choosing an appropriate strip width *W*. Fig. 2,Fig.3 and Fig.4 shows the first , second and third neural models used for neural computation of the electric parameters, strip width and slot width of CPSs, 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 and testing data sets used in this paper were obtained from the respective quasi-static analysis and synthesis formulas proposed by Deng et.al [1,4] are used for ANN analysis and synthesis .The design parameter ranges of the CPSs in these samples are $2.2 \le \varepsilon_r \le 50$, $0.01 \le S/H \le 1.86$, $0.01 \le W/H \le 5.59$, $200\ \mu\text{m} \le H \le 1250\ \mu\text{m}$, and respective characteristic impedance $30\Omega \le Z_0 \le 150\Omega$. The train and test data sets were generated under the following constraints: normalized strip width $W/H \le 10/(1 + \ln \varepsilon_r)$, normalized slot width $S/H \le 10/[3(1 + \ln \varepsilon_r)]$,and relative dielectric constant $2.2 \le \varepsilon_r \le 50$. The aim of the training process is to minimize the training error between the target output and the actual output of the ANN. 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 one hidden layered and three hidden layered networks were achieved the task in high accuracy for analysis and synthesis. The most suitable network configuration found was 5 x 20 x 2 for analysis and 4 × 4 × 12 × 12 × 1 for synthesis. It means that the numbers of neurons were 5,20, and 2 for the input layer, the hidden layer and the output layer, respectively.

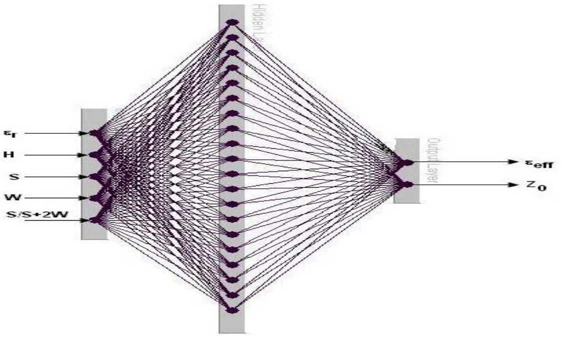

Fig 2. Neural models for CPS Analysis

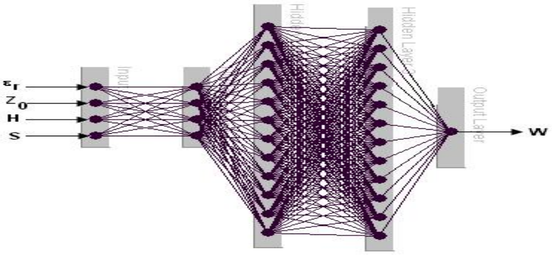

Fig 3. Neural model used to calculate the strip width of a CPS

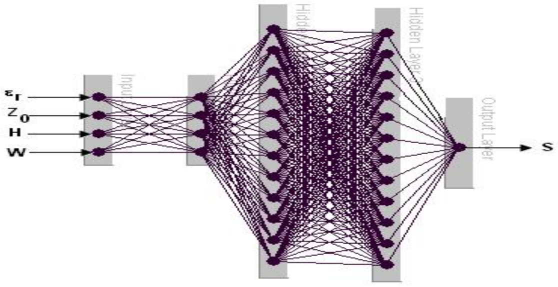

Fig.4. Neural model used to calculate the slot width of a CPS

4.Numerical Results and Discussion

ANNs have been successfully used to compute the electrical parameters, strip width or slot width of a CPS for a given substrate material by choosing an appropriate slot or strip width. In order to obtain better performance, faster convergence, and a simpler structure, ANN models were trained with the Back propagation (MLP3), Sparse Training , Conjugate Gradient, Adaptive Back Propagation, Quasi-Newton (MLP), Quasi-Newton, Huber-Quasi-Newton ,Auto Pilot (MLP3) and Simplex method learning algorithms. The training and test errors obtained from the first, second and third neural models are given in Table 1,2 and 3. It is clear from **Table 1,2 and 3** that the results of the neural models trained by the Huber Quasi Newton algorithm is better for the Analysis and Quasi Newton algorithm is better for Synthesis of the neural models.

Table 1.Training and Test errors of Neural models for the Analysis of CPSs

Algorithm	Training Error	Testing (Correlation Coefficient)
BP-MLP3	0.016106	0.99960
ST	0.015719	0.99960
CG	0.015469	0.99968
ABP	0.015282	0.99970
QN-MLP	0.009259	0.99988
QN	0.009259	0.99988
HQN	0.009077	0.99988
AP-MLP3	0.009077	0.99988
SM	0.009077	0.99980

Table 2.Training and Test errors of Neural models for the Synthesis of Strip width of CPSs

Algorithm	Training Error	Testing (Correlation Coefficient)
HQN	0.00805	0.99568
SM	0.00805	0.99570
CG	0.00803	0.99571
ABP	0.07373	0.99571
QN	0.00805	0.99573
QN-MLP	0.00805	0.99573
ST	0.05170	0.99573

Table 3.Training and Test errors of Neural models for the Synthesis of slot width of CPSs

Algorithm	Training Error	Testing (Correlation Coefficient)
HQN	0.00845	0.99957
SM	0.00845	0.99957
CG	0.15612	0.92564
ABP	0.08898	0.98313
QN	0.00845	0.99957
QN-MLP	0.00845	0.99957
ST	0.25109	0.84738

In order to validate the neural models for CPS analysis and synthesis, comprehensive comparisons have been made. In these comparisons, the results obtained from the first neural model trained by Huber Quasi Newton algorithm are compared with the results of respective quasi-static analysis [1] as shown in **Table 4.** The results obtained from second and third neural models trained by Quasi Newton algorithm are compared with the synthesis results proposed by deng et.al [4] as shown in **Table 5**

Table 4. Comparison of Analysis Results with that of ANN Results (ε_r=26.0975, S=14348.5)

H (μm)	**S/S+2W**	**Z_0(Ω)**	
		Analysis Result	**ANN Result**
200	0.362253	239.2087	243.1355
1133.36	0.672755	214.0315	212.9292
900.02	0.672755	227.6684	225.4993
666.8	0.672755	245.493	245.7611

Table 5. Comparison of Synthesis Results with that of ANN Results (ε_r =25.2,H=725)

Z_0(Ω)	**S (μm)**	**W(μm)**	
		Synthesis Result	**ANN Result**
70	980.8	1450.275	1448.033
90	368.78	136.97	131.27
110	613.3	113.626	113.1882

[7]

Z_0 (Ω)	**W (μm)**	**S (μm)**	
		Synthesis Result	**ANN Result**
30	633.263	19.2142	18.699
52.5	422.842	160.8903	161.9004
75	2	3.0097	3.119733

5. Conclusion

Accurate and simple neural models are presented to compute the physical dimensions of CPSs 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 Huber Quasi Newton algorithm and Quasi Newton algorithms are better for analysis and synthesis of CPSs. The neural results have also been compared with the results of the respective quasi-static analysis and the synthesis formulas available in the literature.

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