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Analysis of Stepped Impedance Microstrip Low Pass Filter Using Artificial Neural Network

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***Abstract*-In this paper effect of variation of inductive length on the cutoff frequency of stepped impedance microstrip low pass filter has been presented using artificial neural network. The design and simulation of low pass filter are performed using CST software. An ANN model has been developed and tested by simulated values of low pass filter. In this paper three different artificial neural network namely feed forward back propagation, cascaded forward back propagation and non-linear autoregressive exogenous networks are used to trained the proposed model and concluded that cascaded forward back propagation gives quite satisfactory result than other two neural networks.**

***Index Terms*—Artificial Neural Networks (ANN), Feed Forward Back Propagation (FFBP),Cascaded Forward Back Propagation (CFBP), Non-linear Autoregressive Exogenous (NARX), Computer Simulation Technology (CST), Electromagnetic (EM)**

I. INTRODUCTION

A filter is a two-port network used to control the frequency response at a certain point in an RF or microwave system by providing transmission at frequencies within the pass band of the filter and attenuation in the stop band of the filter [1]. General structure of the stepped-impedance lowpass microstrip filters use a cascaded structure of alternating high- and low impedance transmission lines, such filters are usually referred to as stepped-impedance, or hi-*Z*, low-*Z* filters [2]. A low-pass filter has many useful properties like easy fabrication, compact size, and very low insertion loss. Hence, it has increased applications in cellular mobile communication and microwave circuits [2]. In present days neural network models are used extensively for wireless communication engineering, which eliminates the complex and time consuming mathematical procedures [4]. An artificial neural network (ANN) model for a circuit can be established by learning from microwave data which is acquired by measurement and simulation results, through a process called training [4]. ANN model comprises of three layers namely input, hidden and output layer. These layers are connected through weights which adapt themselves according to inputs.Once the ANN is trained, it can be applied for microwave filter design to provide instant answers to tasks it learned, thus eliminates the complex and time consuming mathematical procedures [3].

This paper presents the design of third order stepped impedance microstrip low pass filter at 2.4Ghz using CST software [5]. The paper provides effect of variation of inductive length on cutoff frequency of low pass filter. Here we collected nearly 80 different values from CST software and used them for ANN training. An ANN model based on feed forward Back propagation (FFBP), cascaded forward back propagation (CFBP) and Non-linear autoregressive exogenous (NARX) neural networks are used for training. The mean square error (MSE) of all three networks are compared and concluded that cascaded forward back propagation gives quite satisfactory results than feed forward back propagation and Non-linear autoregressive exogenous algorithm.

II. DESIGN OF FILTER

The prototype low pass filter has pass band ripple L_{AR}=3.01dB and the cutoff frequency Ω_c=1.0 having normalized element values $g_o = g_4 = 1$, $g_1 = g_3 = 1$ and $g_2 = 2$. The normalized element values are then transformed to L-C elements for the desired cut off frequency f_c and normally 50Ω for micro strip filter used source impedance [1]. In this paper cutoff frequency of 2.4Ghz , the FR4 substrate having dielectric constant 4.2 with thickness of 1.6mm has been used.

The inductance and capacitance of different components can be obtained g_k (where k = 1, 2, 3) given in the equations (1) & (2) respectively from the normalized values.

$$L_{k+1} = (Zo\ g_{k+1}) / 2\pi f_c \quad (1)$$

$$C_k = g_k / (Zo 2\pi f_c) \quad (2)$$

The low pass microwave filter, calculate the capacitor and inductor's width and using the following formula

For W/h < 2

$$W/h = 8 \exp (A) / (\exp (2A) - 2) \quad (3)$$

Where $A= (Zo / 60)\ \{(\varepsilon r+1)/2\}^{0.5} + [(\varepsilon_r + 1) / (\varepsilon_r - 1)]\ \{0.23 + 0.11/ \varepsilon_r \}$

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The effective dielectric constant can be found by the following formula

$$\varepsilon_{re} = (\varepsilon_r+1)/2 + [(\varepsilon_r - 1)/2]\,[(1+12\,h / w)^{-0.5}] \quad (4)$$

The electrical lengths of inductors and capacitors sections of the transmission line are obtained from following formula (5), (6).

$$\beta l = Z_o L / Z_{high} \quad (5)$$

$$\beta l = C Z_{low} / Z_0 \quad (6)$$

Where β is the phase constant, transmission line physical lengths is represent as l . Z_{high} is the inductive impedance and Z_{low} is the capacitive impedance of the transmission lines. By using above formulas we designed a third order stepped impedance LPF as shown in fig. 1 and fig. 2 shows the simulated result of filter

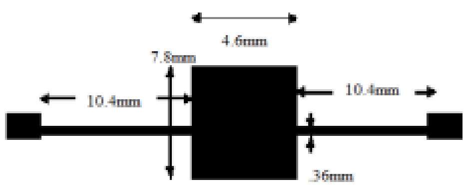

Fig. 1 The designed LPF

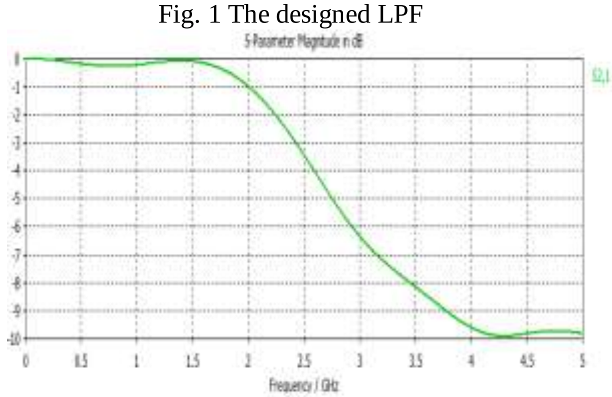

Fig. 2 Simulated Result of low pass filter

In Stepped impedance microstrip low-pass filter, if varying only the length of high impedance line (l_L) and keeping all other parameters remain same. Then following CST simulated results received in terms of cutoff frequency f_c and are summarized in table1

Table 1: CST Simulated Results

S.No.	INPUTS (length of high and low impedance line in mm.)		Target/Output
	Length of capacitive elements(mm)	***Length of inductive elements(mm)***	***Cutoff frequency in GHz***
1	4.6	4	4.09
2	4.6	5	3.65
3	4.6	6	3.32
4	4.6	7	3.02
5	4.6	8	2.84
6	4.6	9	2.63
7	4.6	10	2.48
8	4.6	11	2.36

III. ANN MODEL FOR THE ANALYSIS OF LOW PASS FILTER

The ANN model used in this paper is suggested in Fig. 3 which comprises of three layers. i.e. an input layer, an output layer and one hidden layer. Inputs and output layers of neurons are interconnected by different sets of weights. Training of the neural model can be achieved by adjusting these weights to give the desired response [6]. ANN responses are compared to the known outputs and then the respective errors are calculated simply.

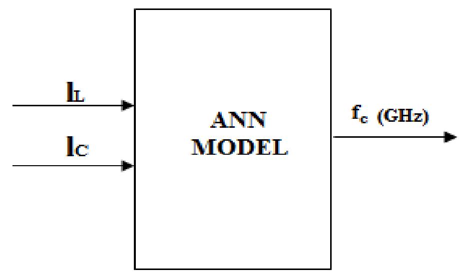

Fig. 3 Analysis ANN Model

In this paper we use three different neural networks namely, feed forward back propagation (FFBP), cascaded forward back propagation (CFBP) and Non-linear autoregressive exogenous (NARX). In order to evaluate the performance of proposed FFBPANN, CFBPANN and NARXANN based models for the design of LPF , simulation results are obtained using CST Software and generated 80 input-output training patterns and 9 inputs-output test patterns to validate the model. The network has been trained for a specified range having inductive length is in the range of $4\text{mm} \le l_L \le 12$ mm.

IV. TRAINING AND TESTING THROUGH ANN

Firstly, feed forward back propagation neural network is used for training of stepped impedance low pass filter as this is widely used neural network architecture. The training function which we use to analyze this network are trainlm. Trainlm training function updates weight and bias values according to Levenberg-Marquardt optimization.

After training the network by input and output data and then testing it with the sample data we obtain the desire output from ANN. Results obtain from CST and ANN is shown in Table 2 and error which occur is shown in next column followed by MSE (Mean Square Error).

Table 2 Comparison of results of CST software and FFBP ANN for cutoff frequency calculation

S.No.	f_c in GHz (CST)	f_c in GHz (FFBP)	Error	MSE
1	4.09	4.0858	0.0042	0.00001764
2	3.65	3.657	-0.007	0.000049
3	3.32	3.3345	-0.0145	0.0002102
4	3.02	3.0094	0.0106	0.00011236
5	2.84	2.8384	0.0016	0.00000256
6	2.63	2.6323	-0.0023	0.00000529
7	2.48	2.4735	0.0065	0.00004225
8	2.36	2.3623	-0.0023	0.00000529
9	2.25	2.2552	-0.0052	0.00002704

Cascaded forward back propagation algorithm is used to train the proposed neural network. This is similar to feed forward networks but include a connection from the input and every previous layer to the following layer. Results obtain from CST and ANN is shown in Table 3 and error which occur is shown in next column followed by MSE (Mean Square Error).

Table 3 Comparison of results of CST software and CFBP ANN for cutoff frequency calculation

S.No.	f_c in GHz (CST)	f_c in GHz (CFBP)	Error	MSE
1	4.09	4.0869	0.0031	0.00000961
2	3.65	3.6432	0.0068	0.00004624
3	3.32	3.3276	-0.0076	0.00005776
4	3.02	3.0186	0.0014	0.00000196
5	2.84	2.8378	0.0022	0.00000484
6	2.63	2.6288	0.0012	0.00000144
7	2.48	2.4772	0.0028	0.00000784
8	2.36	2.3637	-0.0037	0.00001369
9	2.25	2.2543	-0.0043	0.00001849

Non-linear autoregressive exogenous (NARX) is a nonlinear autoregressive model which has exogenous inputs. Results obtain from CST and ANN is shown in Table 4 and error which occur is shown in next column followed by MSE (Mean Square Error).

Table 4 Comparison of results of CST software and NARX ANN for cutoff frequency calculation

S.No.	f_c in GHz (CST)	f_c in GHz (CFBP)	Error	MSE
1	4.09	4.0366	0.0534	0.00285156
2	3.65	3.6506	-0.0006	0.00000036
3	3.32	3.3308	-0.0108	0.0001166
4	3.02	3.0096	0.0104	0.00010816
5	2.84	2.8306	0.0094	0.00008836
6	2.63	2.6268	0.0032	0.00001024
7	2.48	2.4786	0.0014	0.00000196
8	2.36	2.3551	0.0049	0.00002401
9	2.25	2.2694	-0.0194	0.00037636

The MSE is calculated by averaging the total sum of all the square errors of the respective network.

Table 5 Comparison of the MSE of all the three networks

Name of the ANN	FFBP	CFBP	NARX
MSE	0.00005240	0.00001798	0.00039751

V. RESULT

When we trained proposed neural network by using feed forward back propagation algorithm we noticed that network is trained in 2 sec with 85epochs to achieve minimum Mean Square Error (MSE). Fig. 4 shows the performance plot of the developed neural network model using FFBP algorithm.

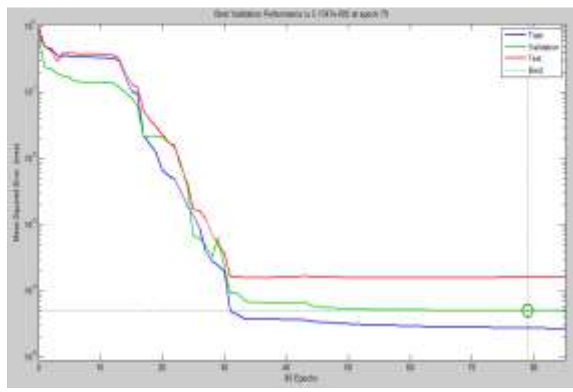

Fig. 4 performance plot of FFBPANN

CFBP based neural network is trained in 1 sec with 6 epochs to achieve minimum Mean Square Error (MSE). Fig. 5 shows the performance plot of the developed neural network model using CFBP algorithm.

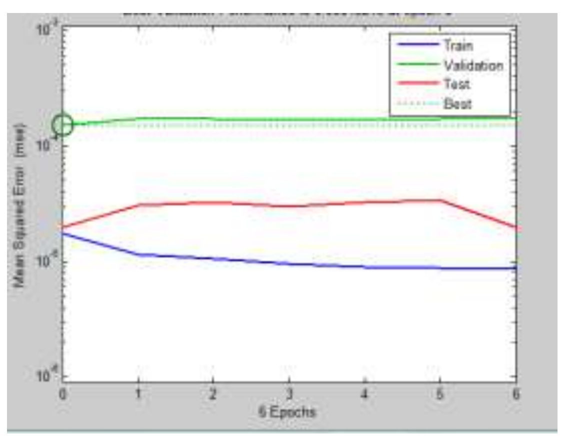

Fig. 5 performance plot of CFBPANN

NARX based neural network model is trained with 6 epochs to achieve minimum Mean Square Error (MSE). Fig. 6 shows the performance plot of the developed neural network model using NARX algorithm.

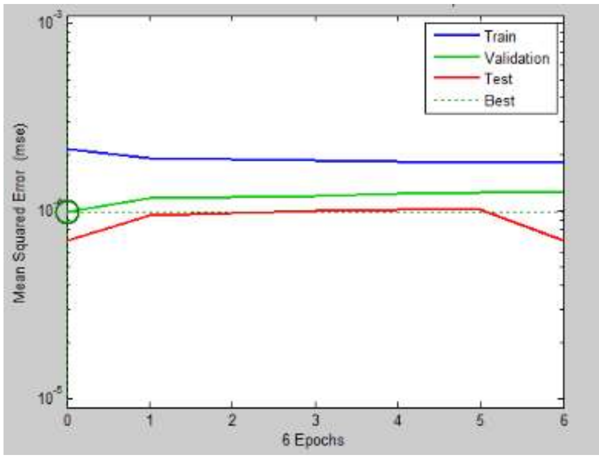

Fig. 6 performance plot of NARXANN

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