International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 3 (2011) pp. 347-354

Analysis and Design of Microstrip High Pass Filters Using Artificial Neural Network

Vivek Singh Kushwah[1], Fanindra Mohan Sharma [2], G.S. Tomar[3]

[1] Amity School of Engineering and Technology, Bijwasan ,
New Delhi 110061, India
vskushwah@aset.amity.edu

[2] R.J.I.T, B.S.F. Academy, Tekanpur, ,
Gwalior, India
fmsharma@gmail.com

[3] MIR Labs,
Gwalior, India
gstomar@ieee.org

***Abstract*: Filters play an important role in many RF/Microwave applications [1] and are used to select or confine the RF/microwave signals within assigned spectral limits. Emerging applications such as wireless communications continue to challenge RF/microwave filters with ever more stringent requirements like higher performance, smaller size, lighter weight, and lower cost. Microstrip filters are always preferred over the lumped filters at higher frequencies. In this paper we present the design and analysis of Microstrip high pass Filter at cut-off frequency 1.5 GHz. Also an artificial neural network model to determine the Magnitude and Phase variations of scattering parameters (S-parameters) of these filters is proposed for various dimensions.**

Keywords: Microstrip High Pass Filters, ANN model, IE3D EM Simulation, S-parameters, Training Algorithm**.**

I. Introduction

A High pass filter has many attractive features, such as compact size, easy fabrication, high bandwidth and low radiation loss. Therefore, it acquires increased applications in microwave circuits [1]. The design of such filters can be achieved by using a method of synthesis based on the equivalent circuit model. However, the accuracy of the equivalent circuit model is not always good enough. High pass filter can also be designed and analysed by using electromagnetic (EM) simulators, such as IE3D .An EM simulator can model this high pass filter more accurately since it takes into account of the dispersion and mutual coupling effects ignored in an equivalent circuit model. However, EM simulation is often computational intensive and time consuming, especially for the design adjustment and optimization. Artificial neural networks (ANNs), are information processing systems with their design inspired by the studies of the ability of the human brain to learn from observations and to generalize by abstraction [15]. A neural network model for microwave device/circuit can be developed from measured/simulated microwave data, through a process called training once ANN architecture is set up. Once the ANN model is fully developed, the computation time is usually negligible and much faster than any single full-wave EM simulator. Though a considerable effort is required in developing an ANN model, it is worthy doing so if repeated design analysis and optimization are required. Neural-network techniques have been used for a wide variety of microwave applications such as embedded passives [3], transmission-line components [4]–[6], bends [8], coplanar waveguide (CPW) components [9], spiral inductors [10], FETs [12] amplifiers etc. An increased number of RF/microwave engineers and researchers have started taking serious interest in this emerging technology. The fact that neural networks can be trained to learn any arbitrary nonlinear input–output relationships from corresponding data has resulted in their use in a number of areas such as pattern recognition, speech processing, control, biomedical engineering etc. ANNs can also be applied to RF and microwave Computer-Aided Design (CAD) problems as well. This paper presents the design and analysis of Microstrip high Pass filters at cut-off frequency 1.5 GHz and proposes an artificial neural network model to determine the Magnitude and Phase variations of scattering parameters (S-parameters) of Microstrip high Pass filters for various dimensions. Performance of the proposed model is evaluated in terms of average and maximum estimated errors using different neural network training algorithms. Comparison of the results of the proposed model with that of EM simulated results has also been presented. The remainder of the paper is organized as follows: illustration of the design of microstrip high pass filter, discussion of the ANN models for the analysis of microstrip high pass filters, explanation of the experimental results and summary of the presented research work.

II. Design of optimum distributed high pass filters

High pass filters can be constructed from distributed elements such as commensurate transmission-line, commensurate network exhibits periodic frequency response. these filters are having wide-band applications. The Optimum Distributed High Pass Filters consists of shunt short-circuited stubs of electrical length θc at some specified frequency fc(cut-off frequency),separated by connecting links of electrical length 2θc.Although the filter consists of only n stubs, it has an insertion function of degree (2n-1) in frequency for having its high pass response has (2n-1) ripples. This compares with n ripples for an n-stub band pass (pseudo high pass) filter, therefore the stub filter of figure 1(a) will have a sharp cut-off, and may be argued to be optimum in this sense. Figure 1(b) illustrates the typical transmission characteristics of this type of filter where f is the frequency variable and θ is the electrical length, which is proportional to f, i.e.

$$\theta = \theta_c\left(\frac{f}{f_c}\right) \qquad (1)$$

for high pass applications, the filter has a primary pass band from θc to (π- θc) with a cut-off at θc. The harmonic pass bands occur periodically, centered at θ =3π\2, 5π\2… and separated by attenuation poles located at θ = π,2π,…..The filtering characteristics of the network in figure 1(a) can be described by a transfer function

$$\left|S_{21}(\theta)\right|^2 = \frac{1}{1+\varepsilon^2 F_N{}^2(\theta)} \qquad (2)$$

Where ε is the pass band ripple constant, θ is the electrical length as defined in (1),and F_N is the filtering function given by

$$F_N(\theta) = \frac{(1+\sqrt{1-x_c^2})T_{2n-1}\left(\frac{x}{x_c}\right) - (1-\sqrt{1-x_c^2})T_{2n-3}\left(\frac{x}{x_c}\right)}{2\cos\left(\frac{\pi}{2}-\theta\right)}$$

(3)

Where n is the number of short-circuited stubs,

$$x = \sin\left(\frac{\pi}{2}-\theta\right), x_c = \sin\left(\frac{\pi}{2}-\theta_c\right) \qquad (4)$$

And Tn(x) = cos (n $\cos^{-1}$x) is the chebyshev function of the first kind of degree n.

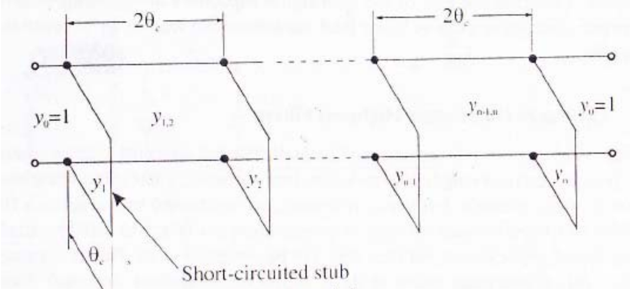

Figure 1(a). Optimum distributed high pass filter

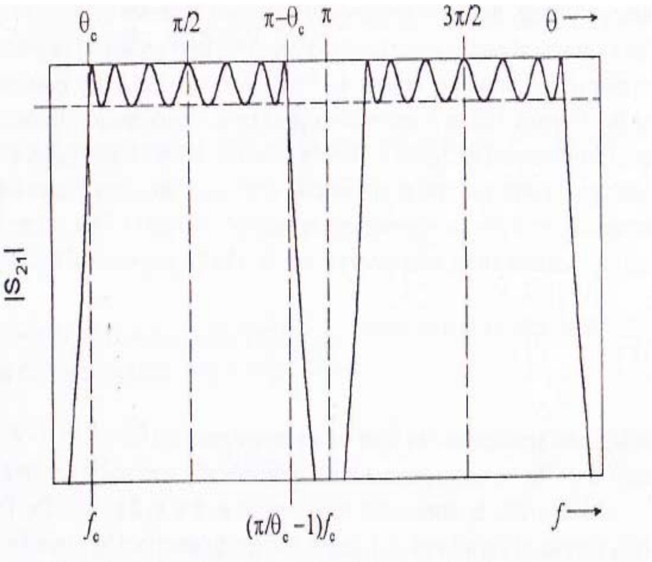

Figure 1(b). Typical filtering characteristics of the optimum distributed High Pass filter

Theoretically, this type high pass filter can have an extremely wide primary pass band as θc becomes very small, however, this may require unreasonably high impedance levels for short-circuited stubs. Table 1 tabulates some typical element values of the network in figure 1(a) for practical design of optimum high pass filters with two to six stubs and a pass band ripple of 0.1 db for θc = $25^{o,}$ 30^{o} and 35^{o}. Note that the tabulated elements are the normalized characteristic admittances of transmission line elements, and for given terminating impedance Zo the associated characteristic line impedances are determined by

$$Z_i = Z_O/y_i$$
$$Z_{i,i+1} = Z_0/y_{i,i+1} \qquad (5)$$

For designing such type of filter, let us consider the design of an optimum distributed high pass filter having a cut-off frequency fc=1.5 GHz and a 0.1 db ripple pass band up to 6.5 GHz. Referring to figure 1(b),the electrical length θc can be found from

$$\left(\frac{\pi}{\theta_c}-1\right)f_c = 6.5 \qquad (6)$$

This gives θc =0.589 radians or θc=33.75^{o}.Assume that the filter is designed with six shorted-circuited stubs. From table (1) we could choose the element values for n=6 and θc= 30^{o}, which will give a wider pass band, up to 6.5 GHz, because the smaller the electrical length at the cut off frequency, the wider the pass band. Alternatively we can find the element values for θc=33.75^{o} by interpolation from the element values presented in table 1. As an illustration for n=6 and θc=33.75^{o}, , the element value y_1 is calculated as follows:

$$y_1 = 0.35346 + \frac{(0.48096-0.35346)}{5}\times 3.75 = 0.44909$$

In a similar way the rest of element values are found to be
$y_{1,2}$ = 1.03446, y_2 = 0.63221, $y_{2,3}$=1.00443,
y_3=0.71313, $y_{3,4}$=0.99734.

The filter is supposed to be doubly terminated by Zo=50 ohms. using equation (5),the characteristic impedances for the line elements are Z_1=Z_6=111.3 ohms,Z_2=Z_5=79.1

ohms, Z_3=Z_4=70.1ohms, $Z_{1,2}$=$Z_{5,6}$=48.3ohms, $Z_{2,3}$=$Z_{4,5}$=49.8 ohms, and $Z_{3,4}$=50.1 ohms.

Table 1.
Element value of high pass filters with 0.1 dB ripple

n	θc degree	y_1	$y_{1,2}$	y_2	$y_{2,3}$	y_3	$y_{3,4}$
2	25	.15436	1.1348				
	30	.22070	1.1159				
	35	.30755	1.089				
3	25	.19690	1.120	.18			
	30	.28620	1.092	.30			
	35	.40104	1.053	.48			
4	25	.22441	1.111	.23	1.1036		
	30	.32300	1.078	.39	1.064		
	35	.44670	1.036	.60	1.015		
5	25	.24068	1.105	.27	1.093	.29	
	30	.34252	1.071	.43	1.050	.48	
	35	.46895	1.027	.66	.9988	.72	
6	25	.25038	1.101	.29	1.087	.33	1.08
	30	.35346	1.067	.46	1.043	.52	1.03
	35	.48096	1.023	.68	.9912	.77	.983

The filter is realized in microstrip on a substrate with a relative dielectric constant of 2.2 and a thickness of 1.57 mm. The initial dimensions of the filter can be easily estimated by using the microstrip design equations for realizing these characteristic impedances and the required electrical length at the cut off frequency, namely $\theta c = 33.75^{\circ}$ for all the stubs and $2\theta c = 67.5^{\circ}$ for all the connecting lines. The final filter design with all the determined dimensions is shown in Figure 2(a)**.**The design is verified by IE3D EM simulation. Figure 2(b) is the EM simulated performance of the filter.

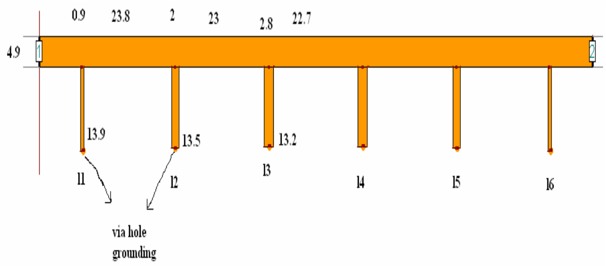

Figure 2(a). Layout of microstrip optimum high pass filter

IE3D Simulated results (Magnitude & Phase response are shown in figure 2(b) & 2(c).

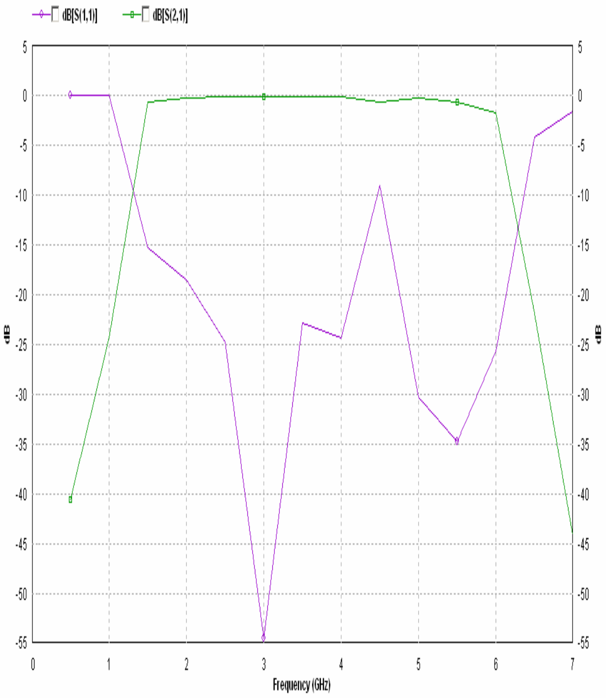

Figure 2(b). Magnitude Response of high pass filter when stub length is 2.8 mm

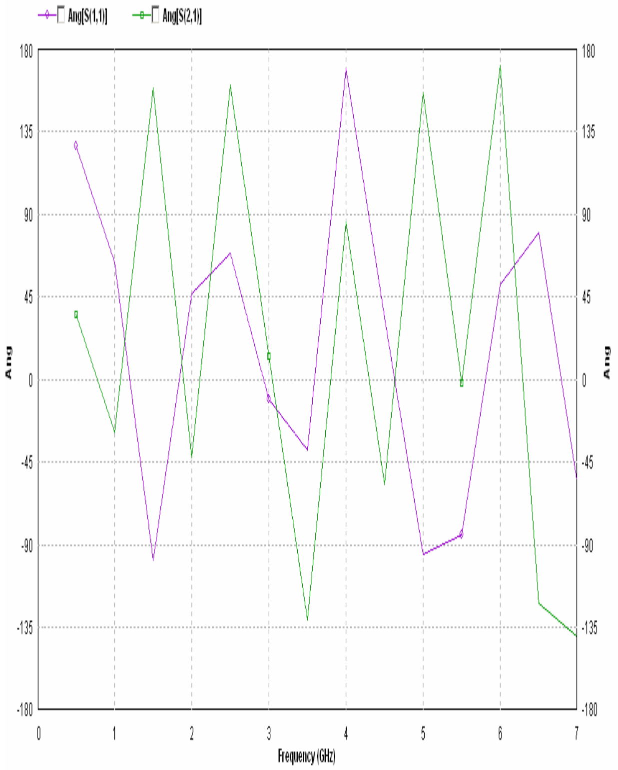

Figure 2(c). Phase response of high pass filter when stub length is 2.8 mm

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Table 2.
S-Parameters (Magnitude in dB, Phase in degrees)

Freq [GHz]	dB[S_{11}]	Ang[S_{11}]	dB[S_{21}]	Ang[S_{21}]
1.5	-15.28	-98.41	-0.6851	158.4
2	-18.54	46.31	-0.3303	-42.25
2.5	-24.83	68.8	-0.2345	160
3	-54.57	-10.8	-0.1808	12.44
3.5	-22.95	-38.18	-0.1708	-131.2
4	-24. 33	169.2	-0.1463	85.38
4.5	-9.06	33.34	-0.7437	-57.49
5	-30.31	-95.39	-0.3888	156.4
5.5	-34.82	-84.61	-0.7712	-1.982
6	-25.76	51.8	-1.853	170.7
6.5	-4.216	79.57	-21.95	-122.2

S-Parameters obtained after IE3D simulation are given in table 2, when stub length is 2.8 mm. From magnitude and phase response of high pass filter at cut off frequency 1.5 GHz, the magnitude and phase of S-Parameters at 1.5 GHz are given as.

Magnitude in db, S11= -15.28, S21= -0.6851

Phase in Degrees, S11= -98.41, S21= 158.4

Now keeping all other parameter constants, changes the length of stubs (l3=l_4 = 2.8 mm) and obtained the different responses for different dimensions.If stub length is varying , when length of stubs is 2.5 mm, then cutoff frequency will remain same but the S-parameters will be changed.

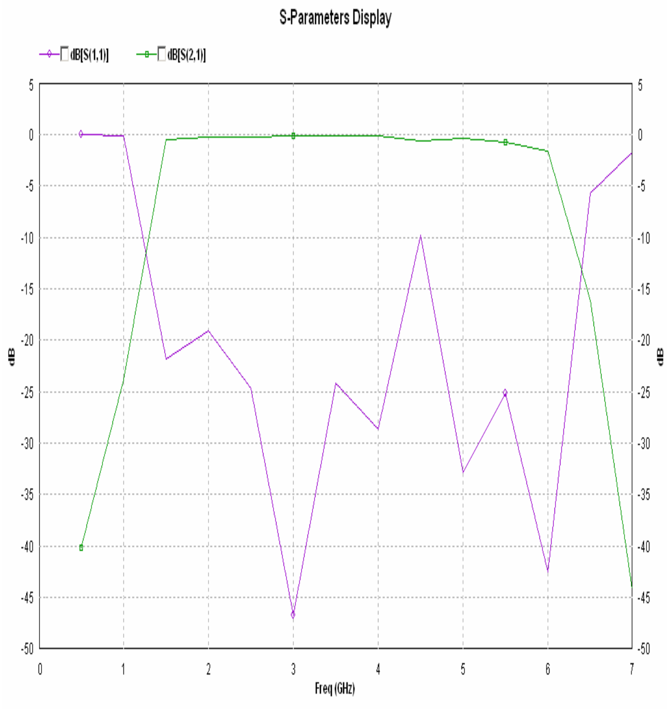

Figure 3(a). Magnitude response of high pass filter when stub length is 2.5mm

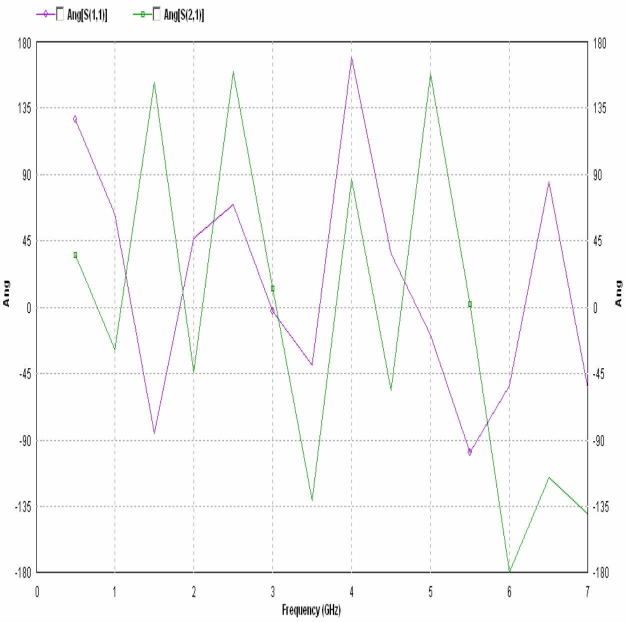

Figure 3(b). Phase response of high pass filter when stub length is 2.5 mm

If stub length (l_3,l_4) is 0.8 mm, then cutoff frequency will also remain same. The frequency responses are shown in figure 4(a) and 4(b).

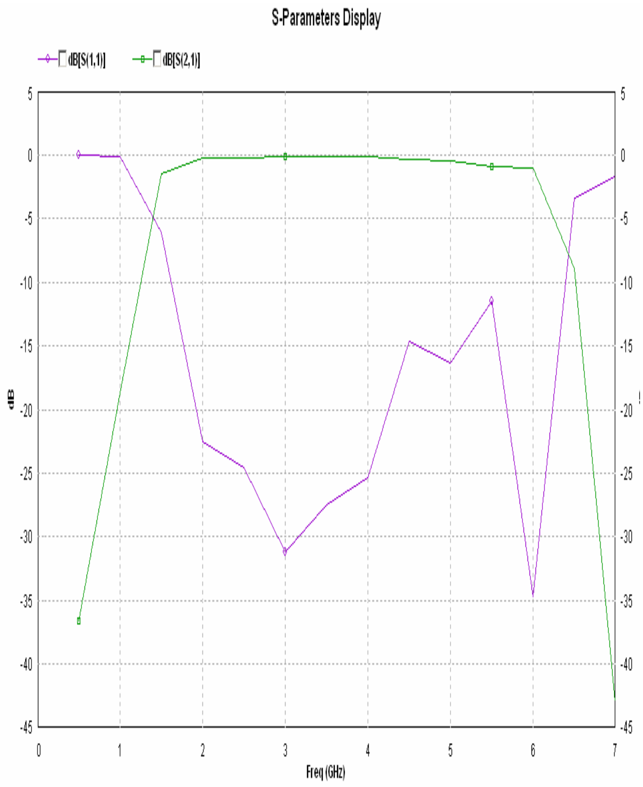

Figure 4(a). Magnitude response of high pass filter when stub length is 0.8 mm

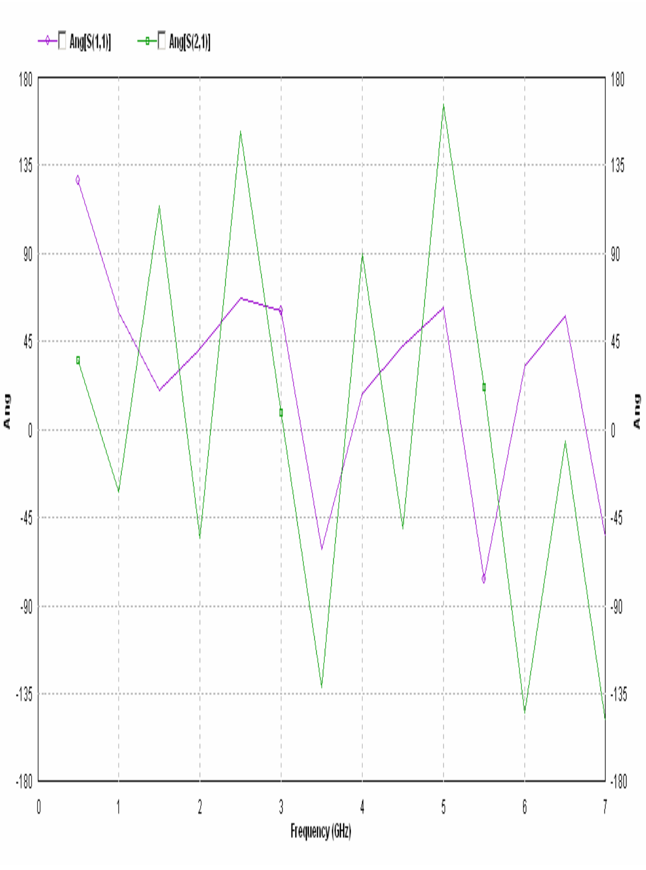

Figure 4(b). Phase response of high pass filter when stub length is 0.8 mm

If stub length (l_3,l_4) is 3.8 mm, then cutoff frequency will also remain same. S-parameters are summarised in the following table 3

Table 3.
S-Parameters (Magnitude in dB, Phase in degrees)

Freq [GHz]	dB[S_{11}]	Ang[S_{11}]	dBS_{21}]	Ang[S_{21}]
1.5	-6.744	-89.88	-1.846	177.9
2	-16.96	45.17	-0.3909	-36.87
2.5	-25.69	69.97	-0.2539	162.7
3	-38.95	131.1	-0.1939	13.06
3.5	-18.49	-40.59	-0.2199	-132.2
4	-15.7	161.9	-0.2522	81.79
4.5	-6.705	23.33	-1.243	-61.59
5	-16.48	-142.9	-0.5548	151.1
5.5	-21.3	47.69	-1.039	-16.7
6	-7.602	-2.118	-5.051	128.7
6.5	-2.8	68.57	-39.75	-78.77

Magnitude and phase responses are shown in figure 5(a) and 5(b).

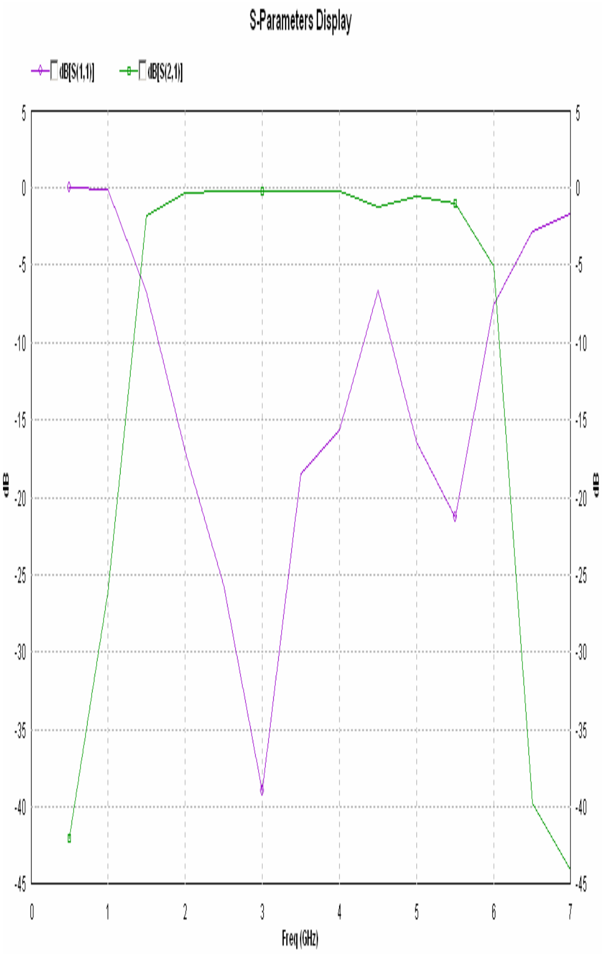

Figure 5(a). Magnitude response of high pass filter when stub length is 3.8 mm

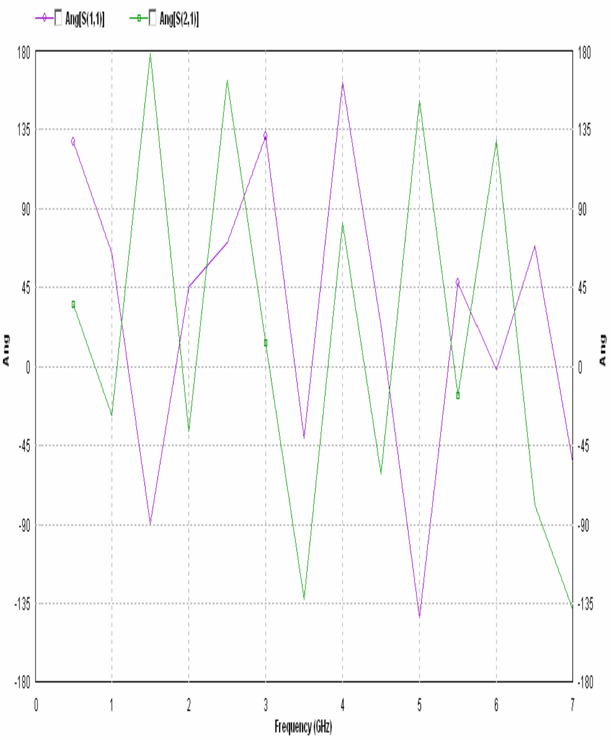

Figure 5(b). Phase response of high pass filter when stub length is 3.8 mm

IE3D Simulated results for calculating the magnitude and phase of S-Parameters are summarized in the table 4

Table 4.
IE3D Simulated results

Inputs		Targets(S-Parameters)IE3D			
Stub length (mm)	Stub length (mm)	Magnitude (dB)		Phase/Angle (Degree)	
(l3)	(l4)	S11	S21	S11	S21
0.8	0.8	-6.109	-1.506	20.23	114.2
1.8	1.8	-14.96	-0.525	31.37	136.8
2.2	2.2	-24.86	-0.4579	1.756	145.6
2.5	2.5	-21.8	-0.5246	-85.78	152.1
2.8	2.8	-15..28	-0.6851	-98.41	158.4
3.8	3.8	-6.744	-1.846	-89.88	177.9
4.8	4.8	-4.028	-3.295	-79.57	-168.9
5.8	5.8	-2.793	-4.669	-72.4	-160.1
6.8	6.8	-2.2	-5.75	-68.31	-154.5
7.8	7.8	-1.881	-6.539	-65.67	-150.9

III. ANN models for the analysis of microstrip high pass filters

ANN represents a every effective modelling technique, especially for data sets having non-linear relationships

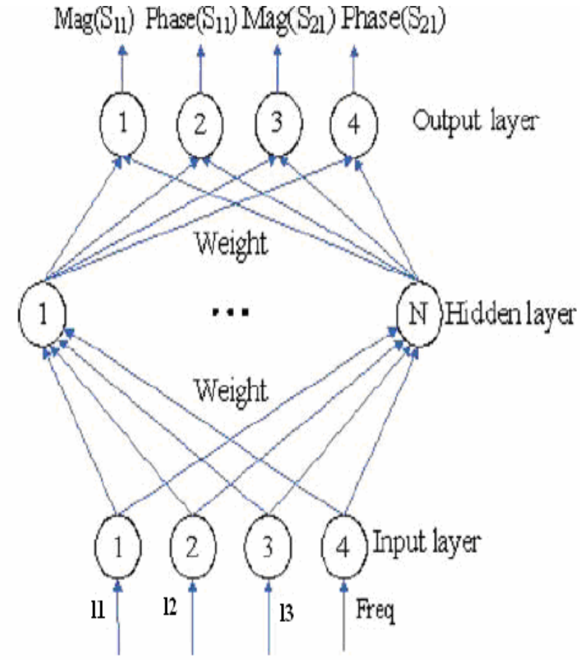

Figure 6. Neural model for calculating Magnitude\Phase of S-parameters of Microstrip high Pass Filter

ANN represents a promising modelling technique, especially for data sets having non-linear relationships that are frequently encountered in engineering. In the course of developing an ANN model, the architecture of ANN and the learning algorithm are the two most important factors. ANNs have wide range of structures and architectures. The architecture selected for a particular model implementation depends on the problem to be solved. The ANN architecture used in this paper is shown in Figure 6 which consists of an input layer, an output layer and one hidden layer. It is utilizing the back propagation training. The hidden layer incorporates nonlinear activation functions, and allows modelling of complex input/output relationships between multiple inputs and multiple outputs. Inputs and output are connected by different sets of weights. Training of the ANN model can be accomplished by adjusting these weights to give the required response. ANN model development starts with selecting, analysing, and manipulating data. The model considers how to divide the data into separate training and test sets. The input-output pairs are normalized by scaling them between the ranges of -1 to 1. This helps prevent the activation values from becoming too large and the occurrence of neuron saturation during training. The ANN model learns relationships among sets of input/output data which are characteristic of the filter under consideration. First, the input vectors of the training dataset are presented to the input neurons and output vectors are computed. ANN outputs are then compared to the known outputs 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 neural network. These error derivatives are then used to update the weights for neurons in the model. Training process completes until errors are low as much as possible than the given required values. In order to develop an ANN model for this filter, a number of EM simulations need to be performed first. The training was conducted by using a combination of the Conjugate-Gradient and Back Propagation methods until the difference between the training data and the output from the ANN model has reached less than 1%.. The parameters (length of stub and frequency) are represented to the filter response -output vector, which is represented by the dB form of scattering parameters. The variation ranges of input parameters are listed in Table 2 The training data has been obtained in the EM simulation over a cut off frequency of 1.5 GHz. S-Parameters obtained after the training are given in table 5:

Table 5.
ANN Trained results

Inputs		Targets(S-Parameters)ANN			
Stub length (mm)	Stub length (mm)	Magnitude (dB)		Phase/Angle (Degree)	
(l3)	(l4)	S11	S21	S11	S21
0.8	0.8	-6.0881	-1.405	-36.785	147.5
1.8	1.8	-15.029	-0.9448	-36.785	147.5
2.2	2.2	-24.843	-0.6115	-36.785	147.5
2.5	2.5	-20.855	-0.392	-36.785	147.5
2.8	2.8	-16.365	-1.4479	-36.785	147.5
3.8	3.8	-7.1927	-3.5836	-36.785	147.5
4.8	4.8	-3.7534	-4.3878	-71.487	-158.59
5.8	5.8	-2.5116	-4.6725	-71.487	-158.6
6.8	6.8	-2.0872	-4.7712	-71.487	-158.6
7.8	7.8	-1.941	-4.8052	-71.487	-158.6

IV. Results and Discussion

Training graph obtained after ANN training of samples for Magnitudes of S-Parameters is shown in figure 7.it is clear from the graph that error minimizes from 10^2 to 10^0 .

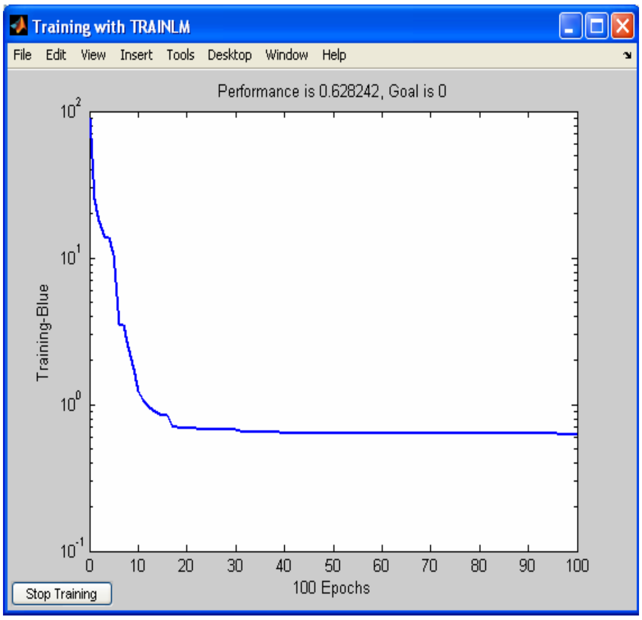

Figure 7. ANN Training Graph Results for Magnitude of S-Parameters

Training graph obtained after ANN training of phase samples of S-Parameters is shown in figure 8.

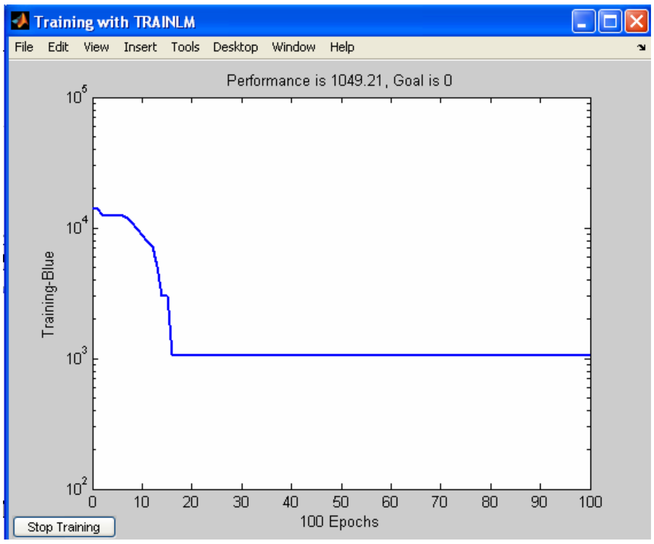

Figure 8. ANN Training Graph Results for Phase of S-Parameters

Figure 7 and 8 represents the minimization of error as far as possible, so that accurate results are obtained after ANN training .Table 2 and 3 shows the comparison between the data obtained from the EM simulation and ANN trained data for the filter. Comparison between the ANN model's output with that of the equivalent circuit model, can be defined in terms of root mean square error:

$$\sqrt{\sum_{K=1}^{N}\frac{(S_{ij}^{EM}-S_{ij}^{Mol})^2}{N}}$$

Where N is the sampled point number, S_{ij}^{EM} and S_{ij}^{Mol} are the EM simulated S parameters and the modelled S parameters, respectively.

V. Conclusion

This paper presents the application of artificial neural networks to the design of a high filter. It has shown that the developed ANN model for the considered filter can be as accurate as an EM simulator and also computational efficient when conducting a massive and repetitive design analysis. Accurate and simple neural models are presented to compute the S-parameters of Microstrip high Pass filter for the required design specifications and trained by using different learning algorithms to obtain better performance and faster convergence with a simpler structure. It was shown that the accuracy of the neural models trained by Feed forward Back Propagation algorithm are found to be suitable for Microstrip high pass filter for magnitude and phase response of S-parameters respectively.

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Author Biographies

Vivek Singh Kushwah received his B.E. degree from Institute of Technology and Management, Rajiv Gandhi Technical University, India in 2005 and M.Tech. degree from Madhav Institute of Technology and Science, Rajiv Gandhi Technical University, India in 2007 respectively. He is now Working as a Assistant Professor in the Electronics and Communication Engineering Department, Amity School of Engineering and Technology, New Delhi, India since 2007. He is doing his Ph.D. work in Microwave Filters from Rajiv Gandhi Technical University, India. His areas of interests include Artificial Neural Networks, Microstrip Antenna, R.F. and Microwave Filters

Fanindra Mohan Sharma has received his Bachelors of Engineering in Electronics Engineering and Masters of Technology In Microwave Engineering from Reputed University of India .Presently he is working as an Assistant Professor in department of Electronics in RJIT, Border Security Force Academy, Tekanpur, Gwalior, India since 2007 and having overall teaching and research experiences of about 06 years. His areas of interest towards research are Microstrip Filters, Resonators and Antenna.

Geetam Singh Tomar (M'03), received UG, PG and Ph.D. degrees in Electronics Engineering from reputed universities of India. Presently he is with Malwa Institute of Technology and Management as Principal of the Institute and as advisor R&D with MPCT Gwalior. He has more than 23 years of experience in industry and academics. His research experience is in the field of air interface, ad hoc networks, Sensor Networks. He is with MIR Labs (USA), India part and actively working on research projects in the field of underwater communication. He is associated with many IEEE conferences around the world as conference chair and committee member. He is also chief editor of three international journals.