Optimum Design of Microstrip Band-Stop Filters Using Artificial Neural Network (ANN)

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Abstract

This paper presents a design approach for a optimum Microstrip Band-Stop filters by using the artificial neural network (ANN) modeling technique. Important dimensions of the filter layout are used to capture critical input-output relationships in the ANN model. This paper presents the design and analysis of Microstrip Band-Stop Filter at central frequency 1.8 GHz which provides improved bandwidth and insertion loss of -52.8 dB. Also an artificial neural network model to determine the Magnitude variation of scattering parameters (S-parameters) of these filters is proposed for various frequencies. Once fully developed, the ANN model has been shown to be as accurate as an EM simulator and much more efficient computationally in the design. The simulation is done using the commercial software IE3D 14.1.

Keywords

Microstrip Band Stop Filters, Open Stubs, ANN Model, IE3D EM Simulation, S-Parameters, Training Algorithm.

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Introduction

Band-Stop filters are widely used in many microwave and millimeter-wave systems to reject undesired frequencies and pass the desired frequencies[1]. A Band-stop filter has many attractive features, such as compact size, easy fabrication, large bandwidth and very high insertion loss. Therefore, it acquires increased applications in mobile communication and microwave circuits[1]. Active devices, such as oscillators and doublers generally use the Band-Stop filters to suppress spurious harmonics. The design of such filters can be achieved by using a method of synthesis based on the equivalent circuit model. 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], vias[7], coplanar waveguide (CPW) components[9], spiral inductors[10], FETs[11,12] 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 application 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[13,14,16]. This paper presents the design and analysis of Microstrip Band-Stop filters at center frequency 1.8 GHz with an extremely narrow stop-band and very high insertion loss and an artificial neural network model is proposed to determine the Magnitude variation of scattering parameters (S-parameters) in Microstrip Band-Stop filters for various dimensions.

Design of Optimum Microstrip Band-Stop Filters

Band-Stop filters can be constructed from microstrip line[15,17]. These filters are having narrow-band and wide-band applications. Figure 1 is a transmission line network of a band-stop filter with open-circuited stubs, where the shunt quarter-wavelength, open-circuited stubs are separated by unit elements (connecting lines) that are a quarter wavelength long at the mid-stop-band frequency. Filtering characteristics of the filter then entirely depends on design of characteristic impedances Z_i for the open-circuited stubs, and characteristic impedances $Z_{i,i+1}$ for the unit elements, as well as two terminating impedances Z_A and Z_B.

This type of filter can be designed to have any stop-band width. This type of bandstop filter may be designed using a design procedure as described[1]. The design procedure starts with a chosen ladder-type lowpass prototype (i.e., with Chebyshev response, etc.). f_0 is the mid-band frequency of the corresponding band-stop filter, and FBW is the fractional bandwidth of the band-stop filter defined by

$$\mathrm{FBW} = \frac{f_2 - f_1}{f_0} \tag{1}$$

f_1 and f_2 are the band-edge frequencies. Element values of optimum bandstop filters for 3-pole ($n = 3$) open circuited stubs are given in table 1[1].

The tabulated elements are the normalized admittances, and for a given reference impedance Z_0, the line impedances are determined by

$$\begin{aligned} Z_A = Z_B &= Z_0 \\ Z_i &= Z_0/g_i \\ Z_{i,i+1} &= Z_0/J_{i,i+1} \end{aligned} \tag{2}$$

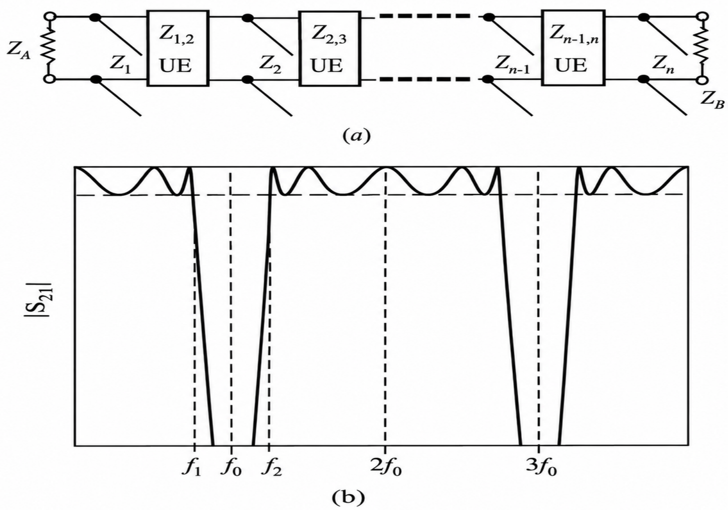

Figure 1. Band-stop filter with open-circuited stubs. (a) Transmission line network representation. (b) Frequency characteristic defining midband frequency f_0 and band edge frequencies f_1 and f_2 ($f_1 < f_0 < f_2$)

Table 1. Element values of optimum bandstop filters for $n = 3$ and Passband ripple constant (ε) = 0.1005

FBW	$g_1 = g_3$	g_2	$J_{1,2} = J_{2,3}$
0.3	0.16318	0.26768	0.97734
0.4	0.23016	0.38061	0.92975
0.5	0.37754	0.63292	0.83956
0.6	0.46895	0.79494	0.78565
0.7	0.56896	0.97488	0.73139
0.8	0.67986	1.17702	0.67677
0.9	0.80477	1.40708	0.62180
1.0	0.94806	1.67311	0.56648
1.1	1.11601	1.98667	0.51082
1.2	1.15215	2.06604	0.49407
1.3	1.37952	2.49473	0.43430
1.4	1.67476	3.05136	0.37349
1.5	2.07059	3.79862	0.31262

An optimum microstrip bandstop filter with three open-circuited stubs ($n = 3$) and a fractional bandwidth FBW = 0.5 at a midband frequency $f_0 = 1.8$ GHz will be designed. From Table 1, we obtain the normalized element values $g_1 = g_3 = 0.3774$, $g_2 = 0.63292$, and $J_{1,2} = J_{2,3} = 0.83956$. The filter is designed to match 50 Ω terminations. Therefore, $Z_0 = 50$ ohms, and from equation (2) we determine the electrical design parameters for the filter network representation.

$$Z_A = Z_B = Z_0 = 50\,\Omega$$
$$Z_1 = Z_3 = 132.43\,\Omega$$
$$Z_2 = 78.998\,\Omega$$
$$Z_{1,2} = Z_{2,3} = 59.55\,\Omega$$

Here Z_1, Z_2, Z_3 are Stub line impedance and Z_0, $Z_{1,2}$ and $Z_{2,3}$ are Connecting line impedance. For microstrip design, we use a commercial substrate Duroid (RT/D 6006) with a relative dielectric constant of 6.15 and a thickness of 1.27 mm. Using the microstrip design equations[1,6], the microstrip line width W and guided quarter-wavelength $\lambda_{g0}/4$ at 1.8 GHz for each of the above determined line impedances are found and listed in Table 2.

Table 2. Microstrip design parameters for a 3-pole optimum Microstrip band-stop filter

Line Impedance	Line width W(mm)	Quarter guided wavelength $L = \lambda_{g0}/4$(mm)
Z_1 & Z_3	$W_1 = W_3 = 0.13$	21.36
Z_2	$W_2 = 0.66$	20.58
$Z_{1,2}$ & $Z_{2,3}$	$W_{1,2} = W_{2,3} = 1.35$	20.06
Z_A & Z_B	$W_0 = 1.87$	

The final layout of optimum microstrip band-stop filter design is shown in Figure 2(a).

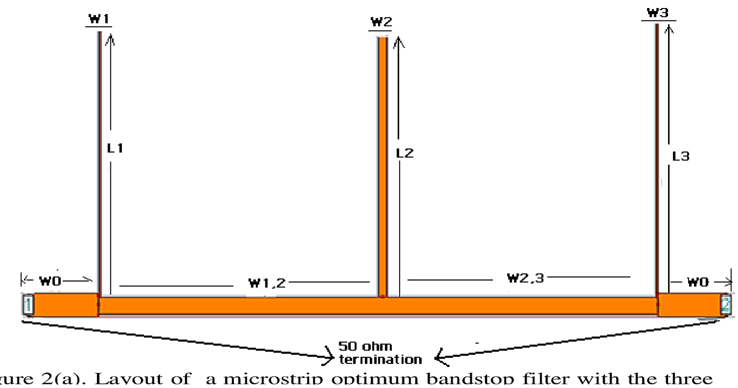

Figure 2. Layout of a microstrip optimum bandstop filter with the three open-circuited stubs on a substrate with a relative dielectric constant of 6.15 and thickness 1.27 mm

3-D geometry of microstrip optimum bandstop filter with the three open-circuited stubs is shown in below figure 2(b).

Photograph of the fabricated microstrip optimum bandstop filter with the three open-circuited stubs is shown in figure 2(c).

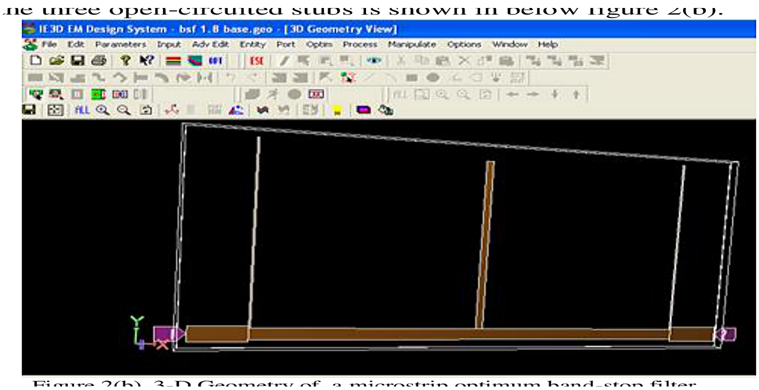

Figure 3. 3-D Geometry of a microstrip optimum band-stop filter

Figure 4. fabricated microstrip optimum bandstop filter

Implementation and Results

The full-wave EM simulated performance of this designed microstrip optimum band-stop filter is illustrated in Figure 3(a).

Return-loss and insertion-loss expressed in terms of S-parameters (S_{11}, S_{21}). Magnitude of S-parameters is summarized in table 3 which is represented in dB form.

Figure 3(b) represents the measured response of microstrip optimum bandstop filter with the help of Vector Network Analyser.

Now changing the dimensions of open circuited Stubs, quarter guided wavelength and microstrip line width, S-parameters are obtained for different frequencies. If microstrip Line Width $W_1 = W_3 = 0.63$ mm. and keeping quarter guided wavelength and Line width W_2 remain same. Then following frequency response of the Band-Stop filter will be obtained as shown in figure 4.

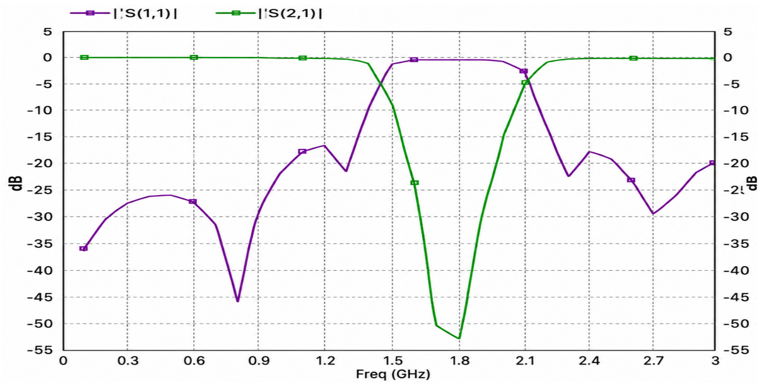

Figure 5. full-wave EM simulated performance of the microstrip optimum bandstop filter

Table 3. S-Parameters (Magnitude in dB)

Freq[GHz]	dB[S(1,1)]	dB[S(2,1)]
0.1	-36.12	-3.675e-002
0.2	-30.44	-4.061e-002
0.3	-27.61	-4.563e-002
0.4	-26.24	-5.043e-002
0.5	-26.06	-5.352e-002
0.6	-27.3	-5.42e-002
0.7	-31.24	-5.369e-002
0.8	-45.95	-5.626e-002
0.9	-28.79	-6.991e-002
1	-21.81	-0.1046
1.1	-17.96	-0.1637
1.2	-16.51	-0.2202
1.3	-21.59	-0.2085
1.4	-9.991	-0.8548
1.5	-1.172	-8.441
1.6	-0.3367	-23.62
1.7	-0.2832	-50.26
1.8	-0.2857	-52.8
1.9	-0.3244	-30.49
2	-0.5622	-15.3
2.1	-2.644	-4.801
2.2	-12.98	-0.6597
2.3	-22.49	-0.2635
2.4	-17.81	-0.2497

Now changing the line width of W_2 and keeping quarter guided wavelength, line width W_1 and $W_3 = 0.13$ (constant). If $W_1 = W_3 = 0.13$ mm. and $W_2 = 1.66$ mm. Then following results are obtained as shown in figure 5.

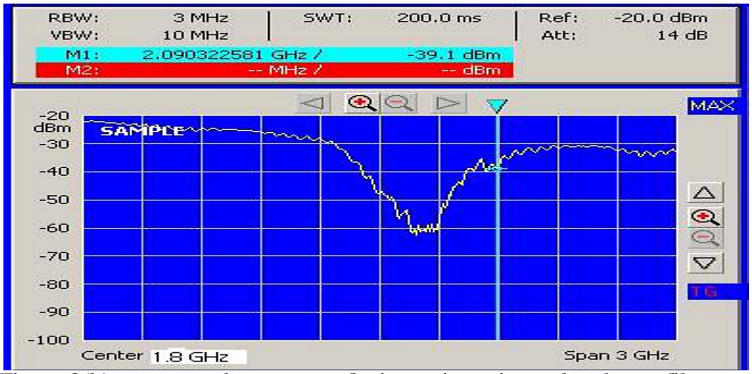

Figure 6. measured response of microstrip optimum band-stop filter

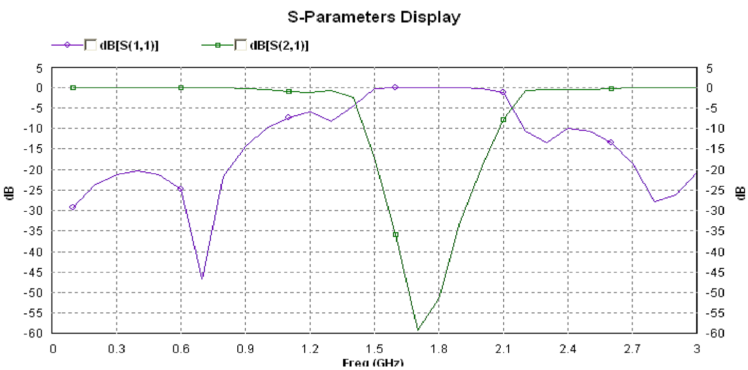

Figure 7. Magnitude response of Band-Stop filters when width W_1 is 0.63 mm.

Magnitude of S-parameters in dB form is summarized in table 4.

If line width $W_1 = W_3 = 0.13$ mm. and line width $W_2 = 1.16$ mm. Then following results are obtained as given in figure 6.

Corresponding S-parameters are mentioned in table 5.

If $W_1 = W_3 = 0.13$ mm. and $W_2 = 2.16$ mm. Then following results are obtained as shown in figure 7.

Corresponding S-parameters are mentioned in table 6.

If $W_1 = W_3 = 0.13$ mm. and $W_2 = 2.66$ mm. Then following results are obtained as shown in figure 8.

Corresponding S-parameters are mentioned in table 7.

If $W_1 = W_3 = 0.13$ mm., $W_2 = 3.66$ mm., Then following results are obtained as shown in figure 9.

Corresponding S-parameters are mentioned in table 8.

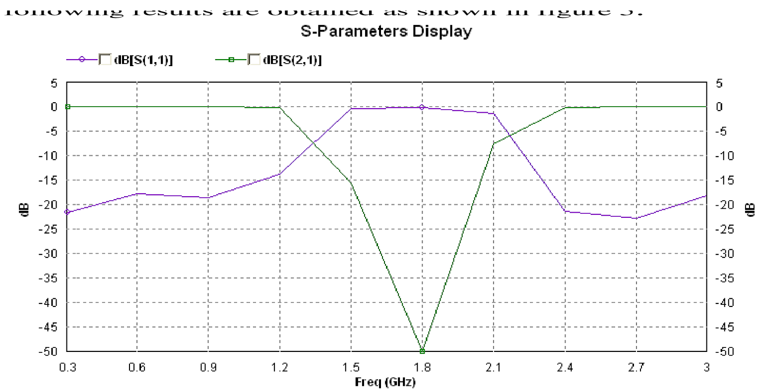

Figure 8. Magnitude response of Band-Stop filter when width W_2 is 1.66 mm.

Table 4. S-Parameters (Magnitude in dB)

Freq[GHz]	dB[S(1,1)]	dB[S(2,1)]
0.3	-21.67	-5.855e-002
0.6	-17.74	-0.1223
0.9	-18.53	-0.1305
1.2	-13.86	-0.3324
1.5	-0.4442	-15.63
1.8	-0.2854	-49.81
2.1	-1.411	-7.613
2.4	-21.44	-0.2257
2.7	-22.74	-0.1292
3	-18.27	-0.138

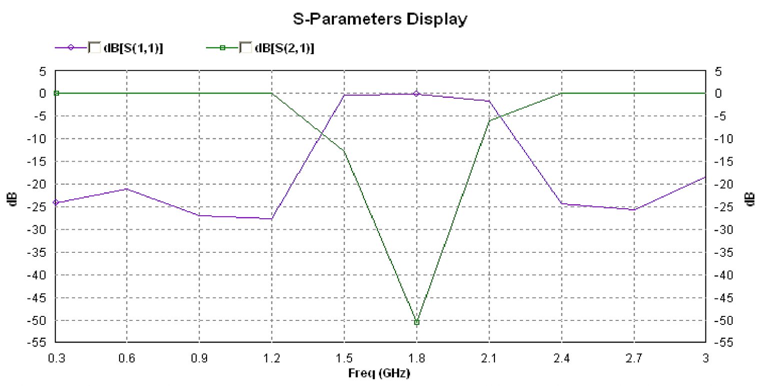

Figure 9. Magnitude response of Band-Stop filter when width W_2 is 1.16 mm

Table 5. S-Parameters (Magnitude in dB)

Freq[GHz]	dB[S(1,1)]	dB[S(2,1)]
0.3	-24.22	-5.487e-002
0.6	-21.23	-8.001e-002
0.9	-27.06	-7.491e-002
1.2	-27.8	-0.1398
1.5	-0.5929	-12.94
1.8	-0.2852	-50.49
2.1	-1.862	-6.247
2.4	-24.5	-0.1944
2.7	-25.79	-0.1148
3	-18.62	-0.1318

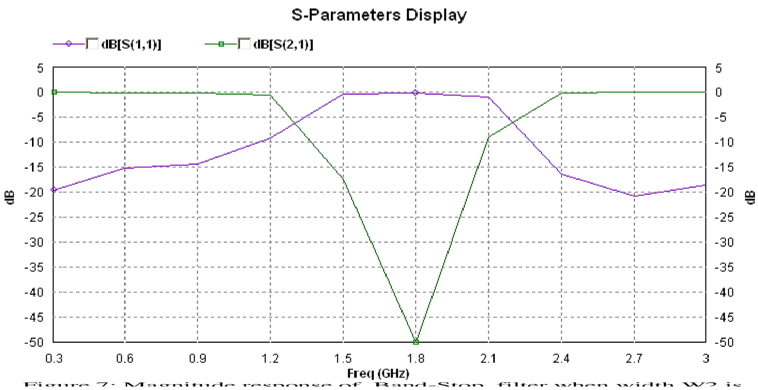

Figure 10. Magnitude response of Band-Stop filter when width W_2 is 2.16 mm

Table 6. S-Parameters (Magnitude in dB)

Freq[GHz]	dB[S(1,1)]	dB[S(2,1)]
0.3	-19.65	-8.691e-002
0.6	-15.23	-0.1827
0.9	-14.35	-0.2357
1.2	-9.162	-0.7369
1.5	-0.3834	-17.48
1.8	-0.285	-49.81
2.1	-1.095	-9.04
2.4	-16.36	-0.3203
2.7	-20.87	-0.1469
3	-18.67	-0.1351

If $W_1 = W_3 = 0.13$ mm and $W_2 = 4.66$ mm. Then following results are obtained as shown in figure 10.

The S-parameters obtained after EM simulation are mentioned in table 9.

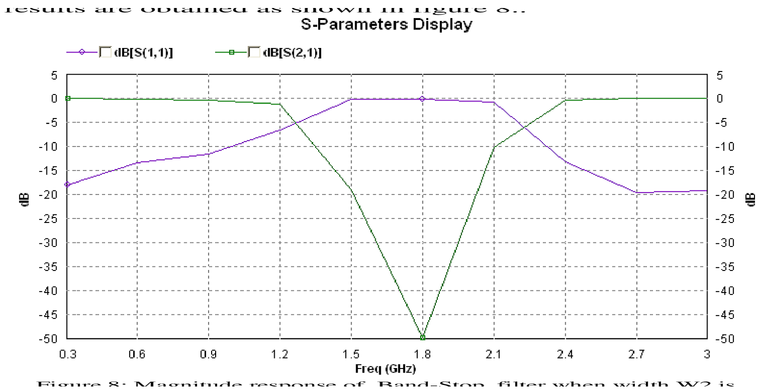

Figure 11. Magnitude response of Band-Stop filter when width W_2 is 2.66 mm.

Table 7. S-Parameters (Magnitude in dB)

Freq[GHz]	dB[S(1,1)]	dB[S(2,1)]
0.3	-18.05	-0.1089
0.6	-13.35	-0.258
0.9	-11.68	-0.3832
1.2	-6.567	-1.289
1.5	-0.3485	-19.02
1.8	-0.2847	-49.78
2.1	-0.9134	-10.18
2.4	-13.26	-0.4557
2.7	-19.58	-0.1651
3	-19.3	-0.1303

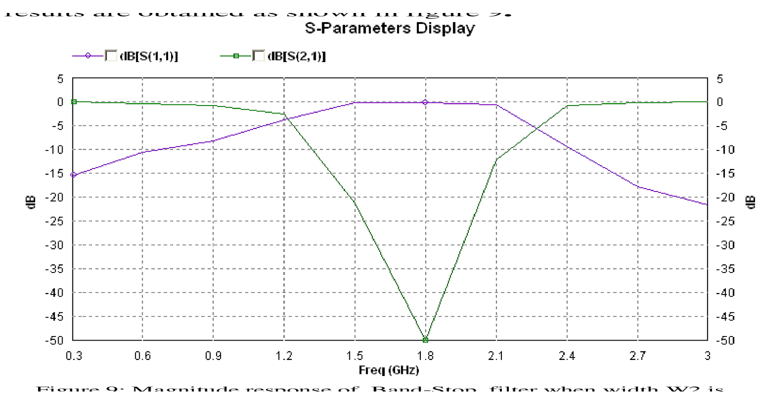

Figure 12. Magnitude response of Band-Stop filter when width W_2 is 3.66 mm.

Table 8. S-Parameters (Magnitude in dB)

Freq[GHz]	dB[S(1,1)]	dB[S(2,1)]
0.3	-15.52	-0.1649
0.6	-10.59	-0.4532
0.9	-8.286	-0.7871
1.2	-3.872	-2.58
1.5	-0.3146	-21.28
1.8	-0.2838	-49.98
2.1	-0.6915	-12.2
2.4	-9.361	-0.8479
2.7	-17.86	-0.2032
3	-21.54	-0.1177

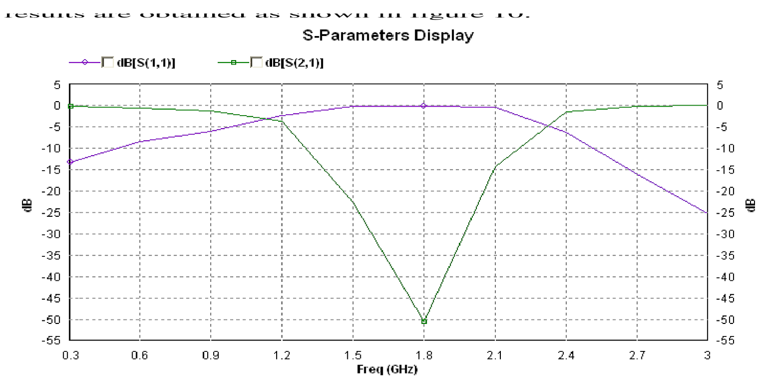

Figure 13. Magnitude response of Band-Stop filter when width W_2 is 4.66 mm.

Table 9. S-Parameters (Magnitude in dB)

Freq[GHz]	dB[S(1,1)]	dB[S(2,1)]
0.3	-13.45	-0.244
0.6	-8.502	-0.7236
0.9	-6.089	-1.332
1.2	-2.567	-3.894
1.5	-0.302	-22.69
1.8	-0.2825	-50.62
2.1	-0.5409	-14.41
2.4	-6.473	-1.533
2.7	-16.19	-0.2601
3	-25.43	-0.1123

If $W_1 = W_3 = 0.13$ mm., $W_2 = 5.66$ mm., Then following results are obtained: Corresponding S-parameters are mentioned in table 10.

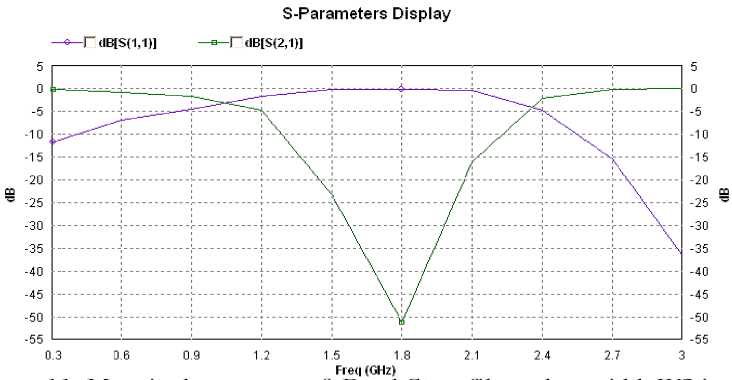

Figure 14. Magnitude response of Band-Stop filter when width W_2 is 5.66 mm.

Table 10. S-Parameters (Magnitude in dB)

Freq[GHz]	dB[S(1,1)]	dB[S(2,1)]
0.3	-11.9	-0.3342
0.6	-7.065	-1.019
0.9	-4.762	-1.887
1.2	-1.94	-4.92
1.5	-0.2982	-23.45
1.8	-0.2811	-51.26
2.1	-0.4583	-16.25
2.4	-4.805	-2.299
2.7	-15.44	-0.3054
3	-36.52	-0.1145

In Band-stop filter, If changing only the line width W_2 of open circuited stubs and keeping quarter guided wavelength, line width W_1 and W_3 constant. Then For cutoff frequency $f_c = 1.8$ GHz, following IE3D simulated results obtained in terms of S-Parameters and are given in table 11.

Table 11. IE3D Simulated results

INPUTS (Width of Stubs) in mm.		TARGETS/OUTPUTS (S-Parameters) in dB.	
$W_1 = W_3$(mm.)	W_2(mm.)	S_{11}(dB)	S_{21}(dB)
0.13	0.66	-0.2857	-52.8
0.13	1.16	-0.2852	-50.49
0.13	1.66	-0.2854	-49.81
0.13	2.16	-0.285	-49.81
0.13	2.66	-0.2847	-49.78
0.13	3.66	-0.2838	-49.98
0.13	4.66	-0.2825	-50.62
0.13	5.66	-0.2811	-51.26

ANN Models for the Analysis of Microstrip Band-Stop Filter

The ANN architecture used in this paper is shown in Figure 12 which consists of an input layer, an output layer and one Hidden layer. It is utilizing the back propagation training[4]. The hidden layer incorporates nonlinear activation functions, and allows modeling of complex input/output relationships between multiple inputs and multiple outputs[13]. 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 desired response. ANN outputs are compared to the known outputs and then the errors are calculated.

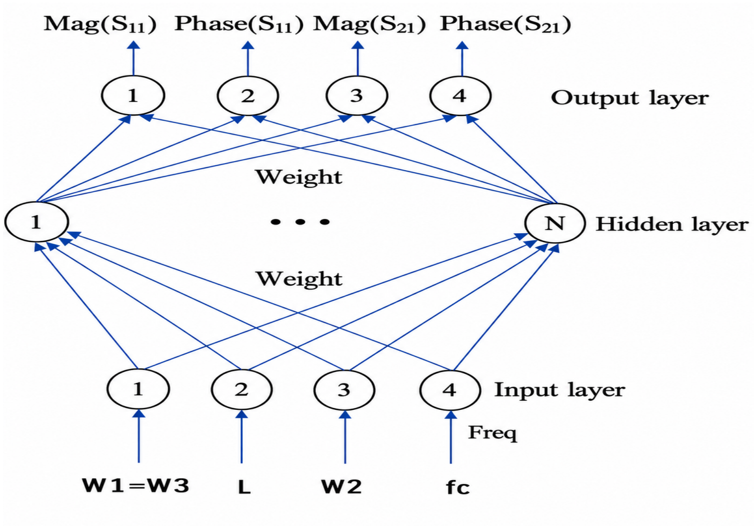

Figure 15. Neural model for calculating Magnitude\Phase of S-parameters of Microstrip Band-Stop Filter

Training process continues until errors are minimized as much as possible than the given prescribed values[14]. In order to develop an ANN model for this filter, a number of EM simulations need to be performed first. The width of microstrip line, quarter guided wavelength and frequency are taken as the input parameters whereas scattering parameters are represented as the filter response -output parameters, which is represented in terms of dB. The variation ranges of input parameters are listed in Table 11. The training data has been obtained in the EM simulation over a cutoff frequency of 1.8 GHz. S-Parameters obtained after the ANN training are given in table 12.

Results and Discussion

Training graph obtained after ANN training of samples for Magnitudes of S-Parameters is shown in figure 13.

Figure 13 shows that training performs in 32 epochs and error minimized from 10^3 to 10^{-4}. It represents that error is minimized as far as possible, so that the accurate results are obtained after ANN training. Table 11 and 12 represents the comparison between the data obtained from the EM simulation and ANN trained data for the filter.

Table 12. ANN Trained results

INPUTS (Width of Stubs) in mm.		TARGETS/OUTPUTS (S-Parameters) in dB.	
$W_1 = W_3$(mm.)	W_2(mm.)	S_{11}(dB)	S_{21}(dB)
0.13	0.66	-0.28573	-52.8
0.13	1.16	-0.2851	-50.49
0.13	1.66	-0.28491	-49.8116
0.13	2.16	-0.28488	-49.7877
0.13	2.66	-0.28483	-49.8052
0.13	3.66	-0.28438	-49.9747
0.13	4.66	-0.28265	-50.6211
0.13	5.66	-0.28094	-51.2597

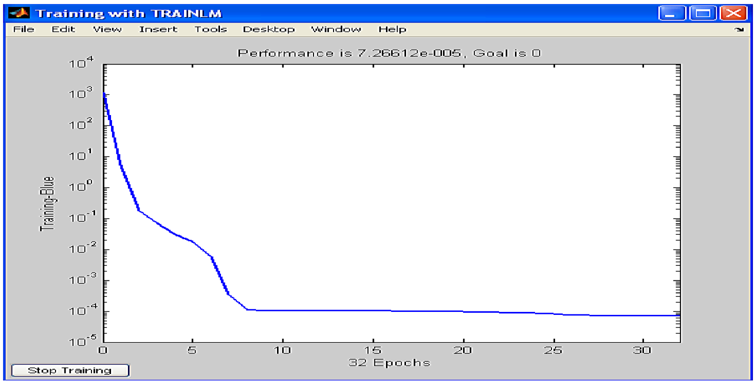

Figure 16. ANN Training Graph Results for Magnitude of S-Parameters

Conclusion

This paper presents the application of artificial neural networks to the design of a Microstrip Band-Stop filter at the center frequency 1.8 GHz with high insertion loss. Simulated and measured results are matched well. It has presented that the developed ANN model for the considered filter can be as accurate as an EM simulator and also it is more computational efficient when conducting a massive and repetitive design analysis. Accurate and simple neural models are presented to compute the S-parameters of Microstrip Band-Stop filter for the required design specifications and trained by using different learning algorithms to obtain better performance and faster convergence with a compact structure.

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