Chapter-5

THE BAND STOP FILTERS

5.1 INTRODUCTION

A band stop filter (BSF) also known as band reject filter can be defined as a network that passes most frequencies unaltered and attenuates those in a specific range to very low levels. A special kind of band stop filter is the notch filter (or wave trap) which is a narrowband band stop filter.

In the recent days researchers all over the world took keen interest to develop different planar band stop filters which are compact in size by employing defective ground, coupled resonators, microstrip line with spiral resonators cut on the line etc [110], [151]-[158]. This chapter presents various BSF structures developed using planar technology using fractals to achieve compact size. Design of a band stop filter using defected microstrip structure by etching open square ring has been presented in [110]. Few structures of band stop filter have been presented using the defective ground with mushroom structures in [151]. It uses a multilayer structure to achieve compactness. Another compact microstrip band stop filter based on defective ground structure (DGS) has been proposed by Rehman et. al. [152], where coupled DGS resonators are used on the ground plane. A tapered small sized electromagnetic band gap microstrip filter structure is proposed and implemented in [153]. This structure is comprised of a main 1-D microstrip EBG structure and two auxiliary EBG structures arranged in a compact configuration. The spiral resonators also are used to design a band stop filter [154]. In which an array of spiral resonators etched on the axis of the microstrip line are used to provide stop band characteristics. This microstrip band stop filter can be implemented with very small size. A parallel coupled band stop filter is presented in [155] where a double negative coupled transmission line is used. A compact band stop filter is proposed in [156] where a meander spurs line and pair of capacitively loaded stubs is used. A 10GHz band stop microstrip filter has been presented in [157]
using the excitation of magnetostatic surface wave in a pattern Ni$_{78}$Fe$_{22}$ ferromagnetic film. An innovative compact microstrip line left-handed dual mode notch band stop filter is presented [158], showing that the size of the band stop filter can be significantly reduced by employing the left-handed metamaterials. In [159] a compact microstrip band stop filter with extended stop band is proposed using both quarter wave length and stepped impedance resonators.

In this chapter different band stop filter topologies have been proposed using fractal to achieve compactness in comparison with the same class of filter topologies available in literatures.

5.2. WIDE BAND STOP FILTER USING FRACTAL LINES

A band stop filter may be designed by using the shunt quarter-wavelength (at the mid-stop band frequency) long open-circuited stubs separated by a quarter wave length long (at the mid-stop band frequency) transmission line [1] - [3], [148]. The basic structure of the optimum band stop filter [2], [149], [150], is based on the open circuited transmission line stub network as depicted in figure (5.1). Filtering characteristics of this filter entirely depend on the design of characteristic impedances $Z_i$ for the open-circuited stubs, characteristic impedances $Z_{i,i+1}$ for the transmission line elements and two terminating impedances $Z_A$ and $Z_B$ [2].

![Fig.5.1 Transmission line network representation of open stub band stop filter.](image)
The design equations are given here for easy reference from [2]. The synthesis of the ladder network shown in figure (5.1) is based on following transfer function given by equation (5.1).

\[ |S_{21}(f)|^2 = \frac{1}{1+\varepsilon^2 A_n^2(f)} \]  

(5.1)

Where \( \varepsilon \) is the pass band ripple constant and \( A_n \) is the filtering function represented by the following:

\[ A_n(f) = R \left[ \frac{t}{t_c} \right]^n \left[ \frac{t \sqrt{1-t^2}}{t_c \sqrt{1-t_c^2}} \right] - C_n \left[ \frac{t}{t_c} \right]^n \left[ \frac{t \sqrt{1-t^2}}{t_c \sqrt{1-t_c^2}} \right] \]  

(5.2)

Where \( t \) and \( t_c \) are the Richards' transform variables which are given by

\[ t = j \tan \left( \frac{\pi}{2} f \right) \]  

(5.3)

\[ t_c = j \tan \left( \frac{\pi}{4} (2 - \text{FBW}) \right) \]  

(5.4)

The fractional band width of the filter is defined as:

\[ \text{FBW} = \frac{f_2 - f_1}{f_0} \times 100\% \]  

(5.5)

where \( f_0 \) is the mid-band frequency of the band-stop filter. \( B_n(x) \) and \( C_n(x) \) used in equation (5.2) are the Chebyshev functions of the first and second kinds respectively of order \( n \) and are expressed as:

\[ B_n(x) = \cos(n \cos^{-1} x) \]  

(5.6)

\[ C_n(x) = \sin(n \cos^{-1} x) \]  

(5.7)

The impedances \( Z_A, Z_B, Z_i \) and \( Z_{i,i+1} \) are defined as:
\[ Z_A = Z_B = Z_0 \]
\[ Z_i = Z_0 / g_i \]
\[ Z_{i,j+1} = Z_0 / J_{i,j+1} \]

(5.8)

Where \( g_i \) and \( J_{i,i+1} \) are the element values of the lowpass prototype and admittance inverters respectively. An optimum microstrip band-stop filter with three open-circuited stubs and a fractional bandwidth \( \text{FBW} = 100\% \) at a mid-band frequency \( f_0 = 3 \) GHz is designed. By considering a pass band return loss of \(-20\)dB, which corresponds to a ripple constant \( \varepsilon = 0.1005 \). For optimized filter the normalized element values are taken from [2] which are \( g_1 = g_3 = 0.94806 \), \( g_2 = 1.67311 \), and the impedance inverters \( J_{1,2} = J_{2,3} = 0.56648 \). The filter is designed to match 50 ohm terminations. Therefore \( Z_0 = 50 \) ohms, and from equation (5.8) we determine the electrical parameters for the desired filter network. The parameters values so obtained are given below:

\[ Z_A = Z_B = 50 \text{ ohms} \]
\[ Z_1 = Z_3 = 52.74 \text{ ohms} \]
\[ Z_2 = 29.88 \text{ ohms} \]
\[ Z_{1,2} = Z_{2,3} = 88.26 \text{ ohms} \]

The lengths and widths of the corresponding microstrip line open stubs are determined by using the equation from (2.5) to (2.7). The BSF so obtained is shown in figure (5.2) along with their dimensional values. The width of the microstrip lines connected with two open ended stubs are 0.45mm and width of the 50 ohm microstrip line is 1.82mm.
Fig. 5.2 Microstrip BSF with optimum design with $a = 0.3\,\text{mm}$, $b = 2.3\,\text{mm}$, $W = 15.15\,\text{mm}$, $L=15.5\,\text{mm}$.

The Kotch fractal structure discussed in section 2.3 and shown in figure (2.4) is applied in the structure shown in figure (5.2). The filter with fractal lines is depicted in figure (5.3). In the modified filter the length $L$ has been reduced to $L/2$ by using fractal. So the total reduction in length $15.5\,\text{mm}$ has been achieved.

Fig. 5.3 band stop filter with fractal lines.

The simulated results of the scattering parameters $S_{11}$ and $S_{21}$ of modified BSF of figure (5.3) are compared with that of the filter of figure (5.2) are shown in figures (5.4) and (5.5) respectively. From the comparison it is evident that the S-parameters of the filter shown in figure shown in figure (5.2) have not been altered by using Kotch fractal but the length has been reduced by 42%. The proposed filter of figure (5.3) is fabricated using photolithographic technique. The fabricated structure is shown in figure (5.6). The experimental $S_{11}$ and $S_{21}$ parameters are compared with that of the
simulated values and shown in figure (5.7) and (5.8) respectively. A Very good agreement has been observed between the simulated and experimental results.

Fig.5.4 Comparison of S11 parameters of notch filter with and without Fractal Structure.

Fig.5.5 Comparison of S21 parameters of notch filter with and without Fractal Structure.
Fig. 5.6 Fabricated structure of proposed band stop filter.

Fig. 5.7 Comparison of Measured and Simulated values of $S_{11}$ parameters.

Fig. 5.8 Comparison of Measured and Simulated values of $S_{21}$ parameters.
5.3 FRACTAL SHAPED BAND STOP FILTER

The band stop filter designed in this section is based on the fractal structure as shown in figure (5.9). In this structure fractal shape is applied on the horizontal line. The order of the fractal curve applied here has the order half. The self similarity of the structure can be visualized from the figures (5.9 a, b and c). The figure (5.9a) is a line of length L which has been modified in first iteration as shown in figure (5.9b) and the similar structures are again made on the horizontal lines in second iterations as shown in the figure (5.9c).

The fractal structure shown in figure (5.9) is applied on the quarter wave length (at the center frequency of the stop band) long open circuited stubs of the band stop filter. The band stop filter with quarter wave length open
circuited stubs is shown in figure (5.10). The widths of the lines are based on the concept of fractal shape i.e. the width of the 50 ohm line is $w$ can be determined by equations (2.5) to (2.7) and $w_1 = w/2$ and $w_2 = w_1/2$ and the total lengths equal to $(l_1 + l_2 + l_3 + l_4 = \lambda_g/4)$. Where $l_1$, $l_2$, $l_3$, $l_4$ are the lengths of the line as shown in figure (5.10), and $\lambda_g$ is the wavelength of corresponding medium at the center frequency of stop band. The distance between the open stubs are less than the quarter wave length. The appropriate length may be calculated using the simulation software. The values of all the dimensions are determined for the stop band with center frequency of 2.5GHz. The structure shown in figure (5.10) is simulated using IE3D simulation software. The simulated $S_{11}$ and $S_{21}$ parameters are given in figure (5.11).

![Fig. 5.10 BSF (structure-1) with quarter wave length long with $l_1=6.91$mm, $l_2=5.82$mm, $l_3= 3.91$mm, $l_4=2.13$mm.](image)

![Fig.5.11 S-parameters of the structure-1.](image)
For the proposed filter the horizontal length is reduced by 3.13mm and the vertical size is reduced by 10.95mm as compared with the conventional design using open circuited stubs for the same center frequency. The structure-1 gives a response with a shifted center frequency as 2.7GHz which can be adjusted by modifying the structure of (5.10) by applying the horn of the length $l_3 + l_4$ as shown figure (5.12). This structure is simulated and the results of the $S_{11}$ and $S_{21}$ parameters are shown in figure (5.13).

![Fig.5.12 Band Stop Filter with the fractal structure (structure-2).](image)

![Fig.5.13 Simulated S-parameters of structure-2.](image)

The comparison of the results of $S_{11}$ and $S_{21}$ are shown in figures (5.14) and (5.15) respectively.
Fig. 5.14 Comparison of $S_{11}$ parameters of Structure-2 with Structure-1.

Fig. 5.15 Comparison of $S_{21}$ parameters of the Structure-2 with Structure-1.

From this comparison it can be observed that the stop band and pass band responses of both structures are same but desired center frequency of the structure-1 is having 0.2GHz shift which is compensated with the modification in the structure-1 by putting the horn as shown in structure-2. The structure-2 thus follows the fractal geometry shape. The fabricated structure is shown in figure (5.16).
Fig. 5.16 Fabricated structure of the BSF with fractal shape.

Fig. 5.17 Comparison of $S_{11}$ of measured and simulated values.
The design methodology has been validated from the measured results of the designed structure of band stop filter. The comparison of scattering parameters $S_{11}$ and $S_{21}$ are shown in figures (5.17) and (5.18) respectively. An excellent matching between measured and simulated result is obtained.

5.4. BAND REJECT FILTER USING TRIANGULAR PATCH RESONATOR

In this section a compact wide band stop filter is designed using the triangular patch resonators with open circuited stubs. To get the band stop response from the low pass filter structure shown in figure (2.37) is modified by placing two open stubs at a distance of about a quarter wave length long of the center stop band frequency as shown in figure (5.19). The dimensions of the open stubs are determined using the conventional technique [1]-[3].
The designed microstrip filter is fabricated using the substrate with dielectric constant 3.2 and height 0.762mm and shown in figure (5.20). The simulated and measured values of scattering parameters are compared and the $S_{11}$ and $S_{21}$ parameters are shown in figures (5.21) and (5.22) respectively.
A good agreement between measured and simulated results may be observed from the results shown in figures (5.21) and (5.22). The deviation about 0.2 GHz of the center frequency of the stop band in measured and
simulated $S_{21}$ parameters can be seen, it may be due to imperfection in fabrication.

5.5 CONCLUSIONS

This chapter discusses the compact design techniques of the band stop filters. A band stop filter is designed using the open stubs and made compact by 42% by a modification of fractal structure as shown in figure (5.3). The compactness has been achieved by unaltering the original response of the filter, it is evident from the figures (5.4) and (5.5). In another structure of self symmetry is designed as shown in figure (5.12). A good response of rejection is achieved in the desired range of frequency. The fabricated structure is shown in figure (5.16). The measured and simulated scattering parameters are compared in figures (5.17) and (5.18) respectively. The response of this filter is depicted in figures (5.13). Band stop filter is designed using the open stubs in the triangular patch low pass filter. The structure is very compact and can be visualized from figure (5.20). Good agreement between simulated and measured scattering parameters $S_{11}$ and $S_{21}$ has been observed from the figures (5.21) and (5.22) respectively.