A Compact Low Pass Filter Design with a Fan-Shaped Defected Ground Structure for Broad Stopband

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Abstract

The aim of the paper is to acquire low pass filter with broad stopband frequency characteristics. To achieve this, a novel fan-shaped defected ground structure (DGS) is presented and compared with other conventional simple DGS units such as square, circular and elliptical. Furthermore, effects of slot length variation of the novel DGS unit are analyzed. Finally, top side of the structure is modified adding several impedance lines to the center of the microstrip line to obtain broad stopband. Designed filter is quite compact with a dimension of 20 mm x 14 mm x 1.27mm. Simulations of design procedure are achieved with ANSYS HFSS and SONNET.

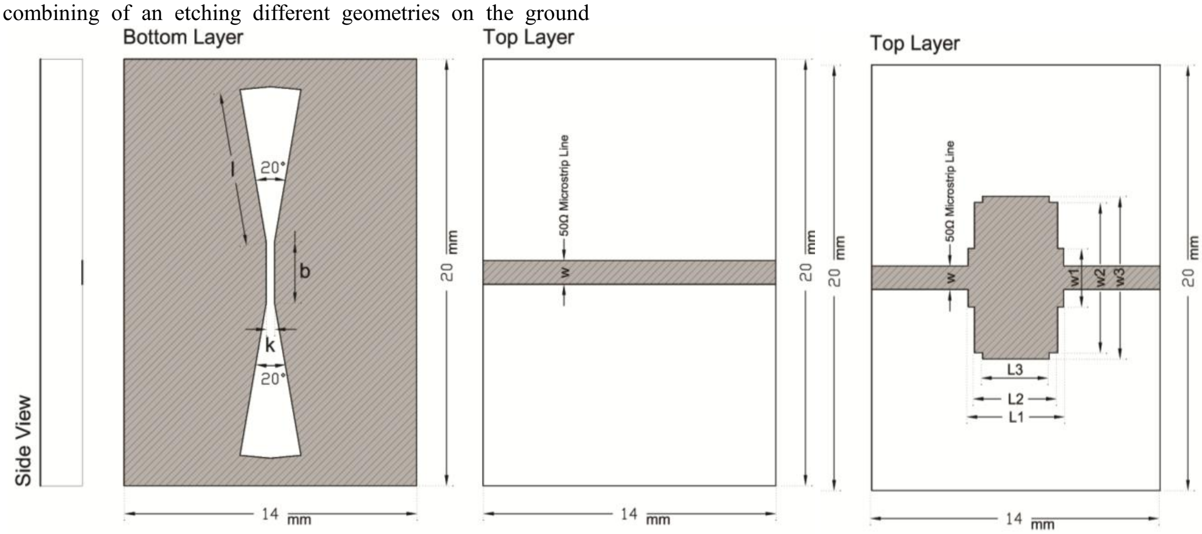
1. Introduction

During the recent years, there has been a growing attention on defected ground structures (DGSs) for microwave and millimeter-wave applications [1]-[2]. In 1999, a dumbbell shape defect on metallic ground plane of a microstrip line was used in [3] to obtain stopband in C and X-bands and it was called as "Photonic Bandgap (PBG) unit structure". A term of "Defected Ground Structure" was firstly proposed to literature in [4].

A microstrip defected ground structure can be defined as combining of an etching different geometries on the ground plane to obtain desired frequency characteristics, such as cut-off, resonant frequencies and harmonic suppression. The research areas of DGSs are grown up to microstrip antennas [5], power dividers [6], filters [1], [7], [8]. Designing low pass filter has some critical parameters such as good transmission in passband, high insertion loss in stopband, sharper rejection or improved sharpness factor and high selectivity to acquire proposed design.

In literature, not only simple DGS geometries like square dumbbell [9], circular dumbbell [10], arrow head dumbbell [11], V-shaped [12], H-shaped [12], spiral-shaped [13], but also complex DGS geometries such as split ring resonator [14], fractals [15] are available. These structures can be used for uniform and non-uniform cascaded DGSs or periodic structures.

In this study, a low pass filter with a fan-shaped dumbbell DGS is presented. Firstly, metallic ground plane of a microstrip line is etched with a fan-shaped dumbbell DGS. This fan-shaped DGS structure is compared with other conventional simple DGS geometries such as circular dumbbell, square dumbbell and elliptic dumbbell with the same areas. Secondly, slot length *b* of fan-shaped dumbbell DGS (see Fig. 1) is analyzed to observe the effect on scattering parameter $|S_{21}|$ of the design. Finally, there has been added several capacitive lines to acquire broad stopband. Full-wave EM simulations are performed in HFSS [16] and SONNET [17]. Simulation results show that both EM simulations are consistent with each other.



(a) (b)

Fig. 1. a) A fan-shaped dumbbell DGS unit (*l*=7.25mm, *b*=2.87 mm, *k*=0.4mm) b) Top view of the designed filter (W= 1.19 mm, L_1= 4.6 mm, L_2=4 mm, L_3=3.2 mm, W_1=2.74mm, W_2=7.1 mm, W_3=7.6 mm).

2. Fan-Shaped Dumbbell DGS Unit

The proposed fan-shaped dumbbell DGS and its dimensions are shown in Fig. 1. Microstrip line has 50 Ω characteristic impedance with 1.19 mm width and fan-shaped dumbbell type pattern is etched on the ground plane.

2.1. Comparison of Different DGS Units

Different conventional DGS geometries in the available literature such as circular dumbbell, square dumbbell, elliptic dumbbell and proposed fan-shaped dumbbell DGS are demonstrated in Fig. 2.

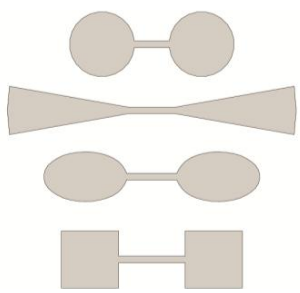


Fig. 2. Different DGS units.

All filters with different DGS structures given in Fig. 2 are designed by Arlon AD1000 substrate, which has relative dielectric constant of 10.2 and thickness of 1.27mm. The width and length of the Arlon AD1000 substrate are 14mm and 20mm respectively. Fig. 3 shows the simulated $|S_{21}|$ dB of the four filters which have the same etched areas. Cutoff, resonant frequencies and sharpness factor of each DGS unit are given in Table 1.

It is shown in Fig. 3, fan-shaped structure has lower cutoff and resonant frequency values than the other simple structures. -3dB bandwidth of circular head DGS structure is greater than other types. It means that fan-shaped DGS unit can be used for lower passband applications with respect to the other DGS units.

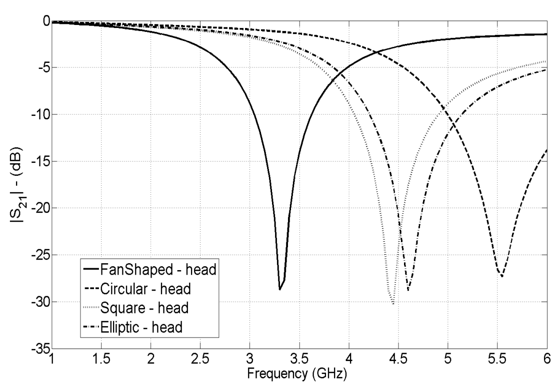


Fig. 3. Simulated $|S_{21}|$ parameters of different DGS units.

Table 1 shows that fan-shaped dumbbell DGS unit has slightly better sharpness factor than three different DGS units when they have the same defect area.

Table 1. Cutoff, resonant frequencies and sharpness factor of different DGS Units.

DGS Unit	f_c [GHz]	f_0 [GHz]	f_c/f_0
Fan-shaped Dumbbell	2.52	3.3	0.7636
Elliptic-shaped Dumbbell	3.51	4.6	0.7630
Circular-shaped Dumbbell	4.19	5.55	0.7549
Square-shaped Dumbbell	3.39	4.45	0.7617

2.2. Parametric Analysis of Fan-Shaped DGS Unit

To explain the effects of different dimension of fan-shaped DGS, slot length *b* is varied from 1mm to 5mm. Figure 4 shows the simulated $|S_{21}|$ parameters of fan-shaped DGS for different *b* values. Increasing of *b* from 1mm to 5mm reveals that cutoff and resonant frequency values shift towards to lower frequencies.

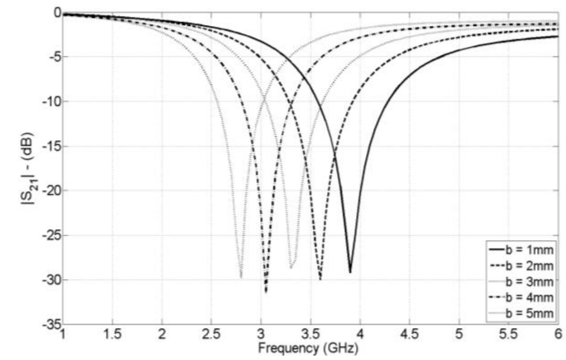


Fig. 4. Simulated $|S_{21}|$ parameters for different b values.

3. Low Pass Filter Design with a Fan-Shaped DGS

In this section, a designed low pass filter with a fan-shaped DGS is presented in Figure 1(b). Filter size is also quite compact which has 20 mm x 14 mm x 1.27 mm dimensions. In order to obtain broad stopband at higher frequency band and improved sharpness factor value, a design procedure with three steps are applied to microstrip DGS structure as shown in Fig. 1.

(i) Two capacitive lines (W_2 x (L_2-L_3)) with the same dimensions are added to the microstrip line.

(ii) To achieve improved $|S_{21}|$ in stopband, another impedance line (W_3 x L_3) is added to the middle of the two capacitive lines.

(iii) One more impedance line (W_1 x (L_1-L_2)) is inserted to the center of the microstrip line.

3. Simulation Results

HFSS simulation results are given in Fig. 5 for different cases shown in Fig. 1(b). A microstrip line with a fan-shaped DGS unit has not only low pass frequency characteristic but also a transmission from 4 GHz to 10.8 GHz. All other three filters have similar low pass characteristics except for -3dB cutoff and resonant frequency values. When two impedance lines are added to the microstrip line with the same DGS as shown in Fig. 5, -15dB attenuation characteristic is obtained which is better than straight microstrip line without capacitive lines. However narrow transmission peak at the neighborhood of -3 dB occurs from 7.2 GHz to 8.3 GHz.

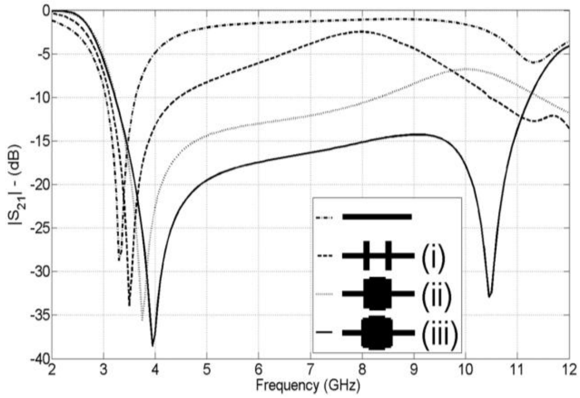


Fig. 5. Simulated $|S_{21}|$ parameters of different cases.

To obtain $|S_{21}|$<-15dB, one more impedance line is added to second case of filter (step (i)). In step (ii), improved stopband characteristic is achieved compared to step (i). In final step (iii) designed filter includes symmetric capacitive lines shown in Fig. 5 and has 3.2 GHz cutoff frequency and 3.95 GHz resonant frequency respectively. Sharpness factor value of final filter is increased to 0.81 due to described modifications through proposed design procedure. As shown in Fig. 6, designed filter has the optimum design results and gives rise to broad stopband ($|S_{21}|$<-15dB) supporting from 3.4 GHz to 10.8 GHz.

SONNET and HFSS are two different EM platforms used different numerical solution methods such as Method of Moments and Finite Element Method. On the other hand, circuit model extraction of any microstrip structure is a good method to validate your design. Extraction circuit model of proposed design is given in Fig.6. Before the measurement processes, it has been shown that comparing the results of two different EM simulation programs and one circuit simulation step with AWR provides designers to control their design correctly. So SONNET EM and AWR circuit simulation results of final filter are given together with HFSS results in Fig. 7 for verification purposes. As depicted in Fig. 7, the magnitude of S_{21} parameters are consistent with HFSS, SONNET EM simulators and AWR circuit simulator. In addition, phase of S_{21} parameters of both HFSS and SONNET EM simulations are in good agreement with each other in Fig. 8.

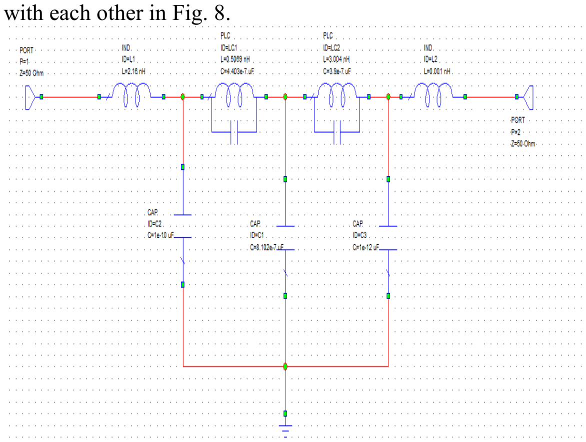


Fig. 6. Circuit model of designed filter.

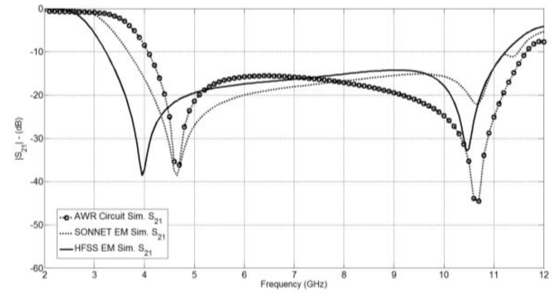


Fig. 7. Simulated $|S_{21}|$ parameters of designed filter.

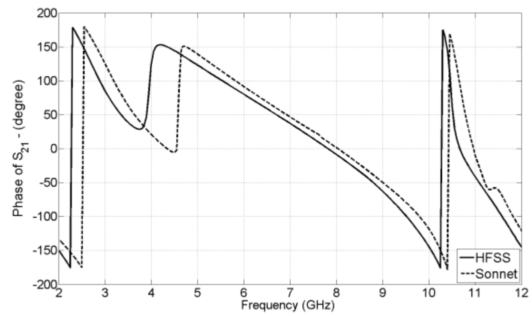


Fig. 8. Phase of simulated S_{21} of designed filter.

4. Conclusion

In this paper, a low pass filter with a novel fan-shaped dumbbell DGS is presented and compared with conventional simple DGSs such as circular dumbbell, square dumbbell, elliptic dumbbell. Parametric analysis of novel DGS unit is achieved and effects on cutoff and resonant frequencies are investigated as shown in Fig. 4. Numerical results are validated in HFSS and SONNET design environments. A compact low pass filter is designed with a fan-shaped defected ground structure and remarkable broad stopband between 3.4 GHz and 10.8 GHz is obtained together with relatively improved sharpness factor.

5. References

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