Design of SIW Bandpass Filter using DGS-DMS Technique for 5G Applications

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Abstract
A novel SIW bandpass filter based on the combination of DGS (Defected Ground Structure) and DMS (Defected Microstrip structure) is proposed. Their excellent defected characteristics are verified through the simulated results. The proposed filter is designed by etching a dumbbell shaped DGS in the ground plane of the SIW cavity in order to improve the stopband performance. Defected Microstrip structure (DMS) is made by etching a single or double slots to create a finite passband, rejection band and slow wave characteristics. The filter is fed using microstrip to SIW transition technique over a material with dielectric constant of 3.5 and thickness of 0.5mm. Additionally to a sharp cutoff, the filter exhibits simple design, low insertion loss of 0.5dB and it achieves rejection bandwidth with overall 28dB attenuation from 26GHz to 28GHz. Utilizing this concept, SIW BPF of 27.4GHz center frequency with 7.2%fractional bandwidth at -3dB has been implemented for the application of 5G spectrum bands. The structure has been simulated using Advanced Design Software (ADS).

***Index Terms:** Bandpass filter, Substrate integrated waveguide (SIW), Defected ground structure (DGS), Defected microstrip structure (DMS), dumbbell DGS (DB-DGS)*

INTRODUCTION

High performance, low cost bandpass filters plays an important role in microwave and millimeter wave communication systems. Among these substrate waveguide filter [1] has attracted much interest due to its low loss, low fabrication cost, size, power handling and its structure tolerance. Substrate selection is more important for the electrical or physical performance of SIW filter than that of microstrip/coplanar waveguide (CPW) filter. A smooth transition is provided by using tapered via transition from microstrip line (planar structure) to SIW cavity with minimal reflection and has wider bandwidth (2). In order to improve the upper stopband performance and provides high selectivity by using Slots or defects integrated on the ground plane of microwave planar circuits are referred to as Defected Ground Structure(DGS)(3). By using the unique resonant properties of CSRR and a pair of dumbbell DGS (4), two pass bands with transmission zero in the middle have been achieved. In (5), Micro strip filters also designed by loading dumbbell DGS (DB-DGS) on metal strips. Another emerging technique called defected micro strip structure (DMS) [6] which exhibits slow wave properties and rejecting microwaves at certain frequencies. Single or multiple resonant slots has been introduced to obtain a stop band within pass band in [7]. In [8-9], combination of DGS and DMS is used to provide wide out of band rejection and desired filtering response.

This paper presents the design of SIW band pass filter using DGS-DMS technique. The Performance of microstrip transmission line can be improved by introducing slots in the microstrip structure. The dumbbell DGS (DB-DGS) which is etched on the bottom ground plane to improve stop band performance. The DGS along with DMS technique is used to obtain band pass filtering response which is usable for 5G spectrum applications.

THEORY AND DESIGN ANALYSIS
SIW FILTER DESIGN

An SIW is inherently a dielectric-filled synthesized rectangular waveguide with periodic metalized via holes or slot arrays connected to the upper and lower metal plates. There are several vital parameters need to be considered like diameter of the via holes d, spacing between the metallic vias p, length of the microstrip transmission line L_m, width of the microstrip transmission line W_m, Effective length of the SIW L_{eff} and effective width of the SIW W_{eff}. The SIW structure consists of SIW cavity, microstrip tapered transition and a 50Ω microstrip transmission line. The microstrip energy can be easily transformed to SIW by using planar tapered transition. In order to increase the effectiveness of electrical feeding, a microstrip line connected to the SIW cavity via tapered transition. This equivalent width is the effective width of the SIW and it is calculated as follows,

$$W_{eff} = W_{SIW} - \frac{d^2}{0.95p} \quad (2.1)$$

$$L_{eff} = L_{SIW} - \frac{d^2}{0.95p} \quad (2.2)$$

The resonant frequency of the desired passband can be given as

$$f_0 = \frac{c_0}{\epsilon_r}\sqrt{\left(\frac{1}{W_{eff}}\right)^2 + \left(\frac{1}{L_{eff}}\right)^2} \quad (2.3)$$

The cutoff frequency for the SIW can be calculated as,

$$f_c = \frac{c}{2\epsilon_r} w_{eff} \quad (2.4)$$

Where, c is the velocity of light in vacuum. In this case, the geometric size of the SIW is designed by using equation (2.1).

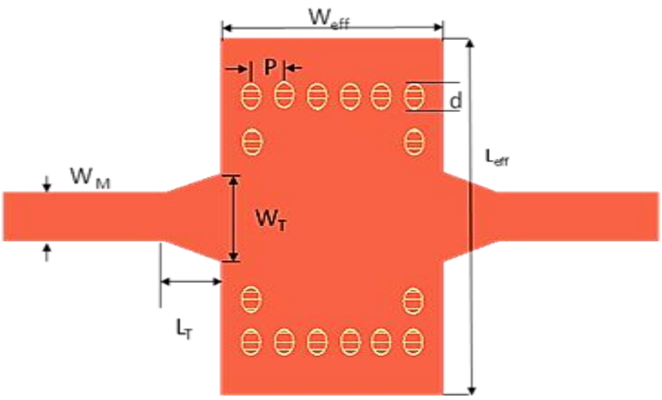


***Fig: 1.** Layout of the SIW BPF*

Increasing the spacing between the via holes, p which leads to increase in the leakage loss. The diameter of the via holed should be kept small in order to avoid the radiation loss. The design parameters of array of vias are optimistically calculated as,

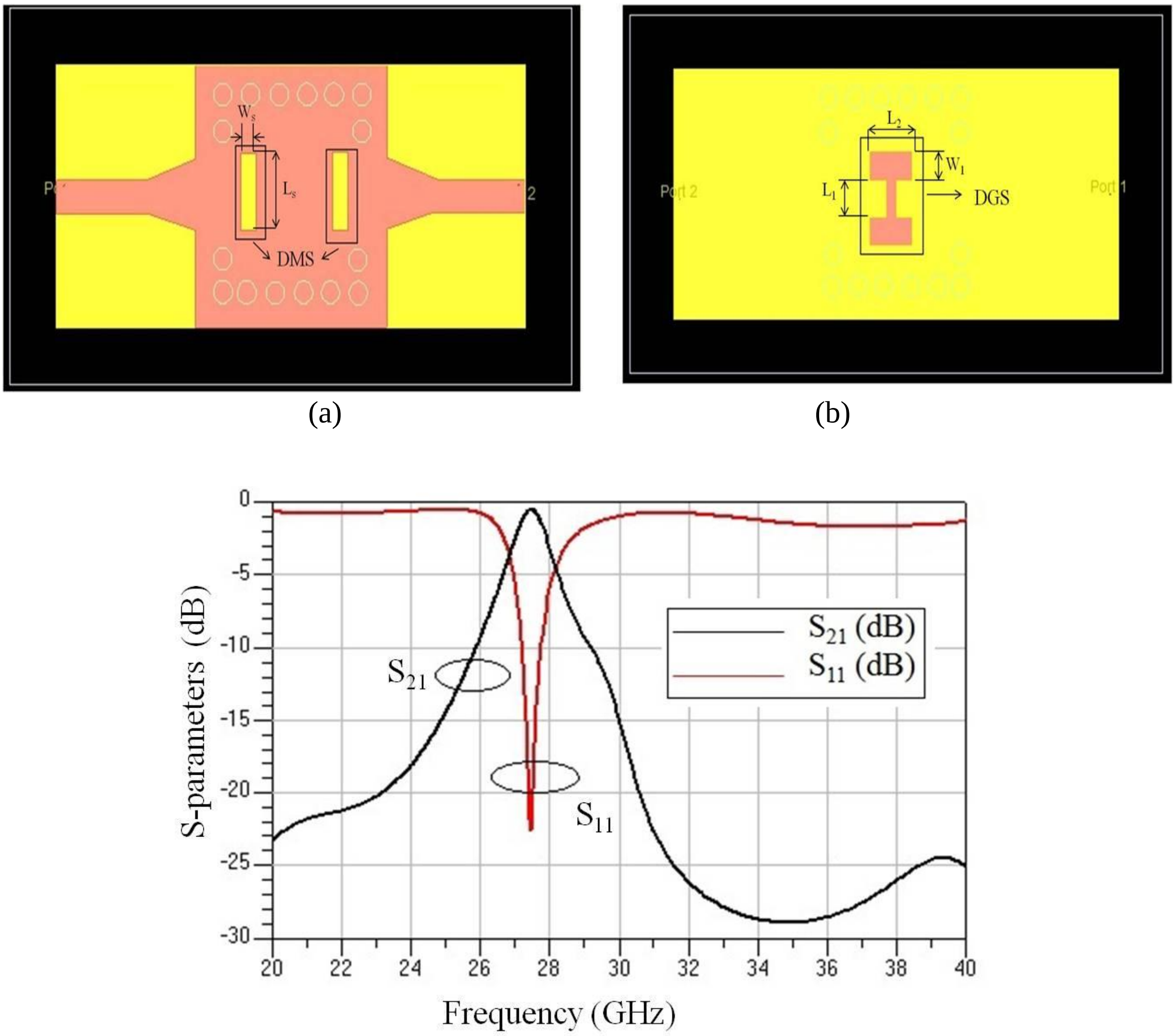
$d/p > 0.5$ (2.5)

$d/W_{SIW} < 0.4$ (2.6)

From this the diameter of via hole is 0.5mm. In the conventional SIW structure, dumbbell DGS is etched on the bottom metal plate to improve the upper stop band performance and two vertical slots are introduced on the top metal plate of the SIW cavity to achieve the out of band rejection.

DESIGN OF SIW BPF USING DGS-DMS

Fig.2 shows the layout of the proposed SIW BPF using DGS-DMS technique. The microstrip line connected to the SIW cavity is tapered via transition in order to minimize the leakage losses and to provide smooth transition and proper impedance matching between microstrip line and SIW structure.



(a) (b)

(c)

Fig: 2. *Layout of the proposed filter. The filter dimensions are L_{eff}=5.5mm, W_{eff}=5mm,$W_{T=}$1.5mm,W_M=0.8m,L_T=1.2m, d=0.4mm,P=0.75mm, W_s =0.4mm, L_s =1.6mm, L_1 =0.8mm, W_1=0.6mm, L_2=1.2mm.(a). Top layer (b). Bottom layer (c). Frequency response of the proposed SIW BP*

Further optimization can be done by adding two horizontal rows of metallic vias with diameter of 0.5mm in the SIW BPF design. The electromagnetic energy is distributed mainly on the center of the SIW cavity. By this radiation loss can be suppressed and in the same way quality factor can be improved. The filter is designed by etching dumbbell DGS (DB-DGS) in the center of the bottom ground plane of SIW structure to improve stopband performance as the DGS creates a transmission zero which increases out of band rejection. Further to improve the rejection band the defected microstrip structure (DMS) is introduced by creating two vertical slots on the top metal plate of the microstrip structure to obtain desired bandpass filtering response. The DMS is an attractive solution for achieving finite pass band, rejection band and slow-wave characteristics. The slow wave factor over the microstrip is increased since the current distribution in the microstrip line is perturbed due to the trajectory followed around the slot line which introduces high line inductance and capacitance of the microstrip line. In order to investigate the frequency characteristics of the filter structure, it is simulated by using Advanced Design Software (ADS). The structure is developed on the Rogers substrate with dielectric constant of 3.5 and thickness of 0.5mm.

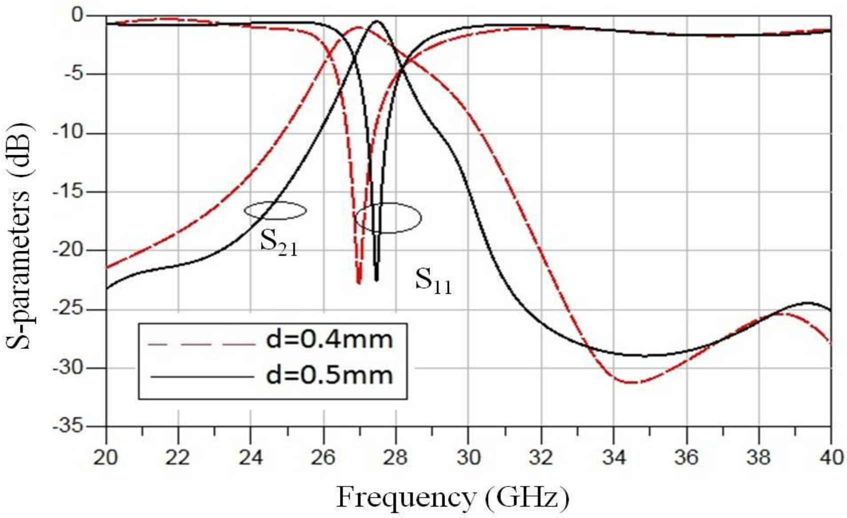


Fig: 3. *Simulated response of the SIW BPF for different via diameter*

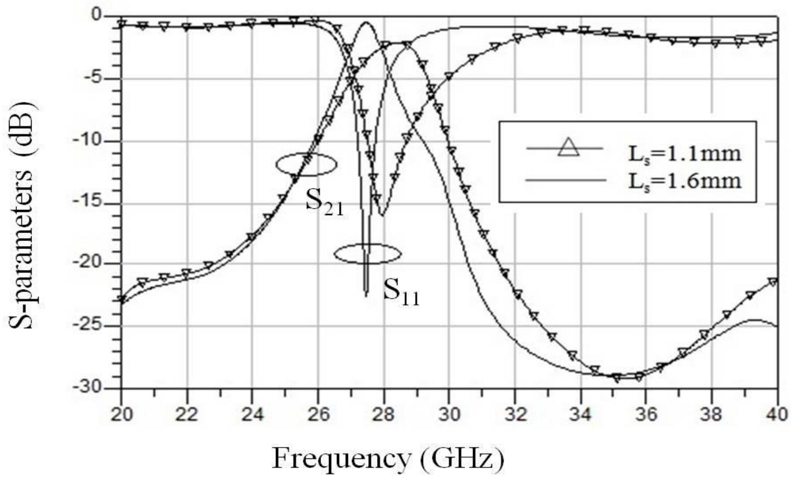


Fig: 4. *Simulated results of proposed filter for different length of DMS slot*

Fig.3 shows simulated frequency response of the proposed filter for different via diameter. It can be seen that by decreasing the via diameter the resonant frequency shifts towards its lower frequency side with wide out of band rejection. By increasing the length of the DMS slot there is an upper frequency shift with lower passband attenuation and return loss gets improved is depicted in fig.4.

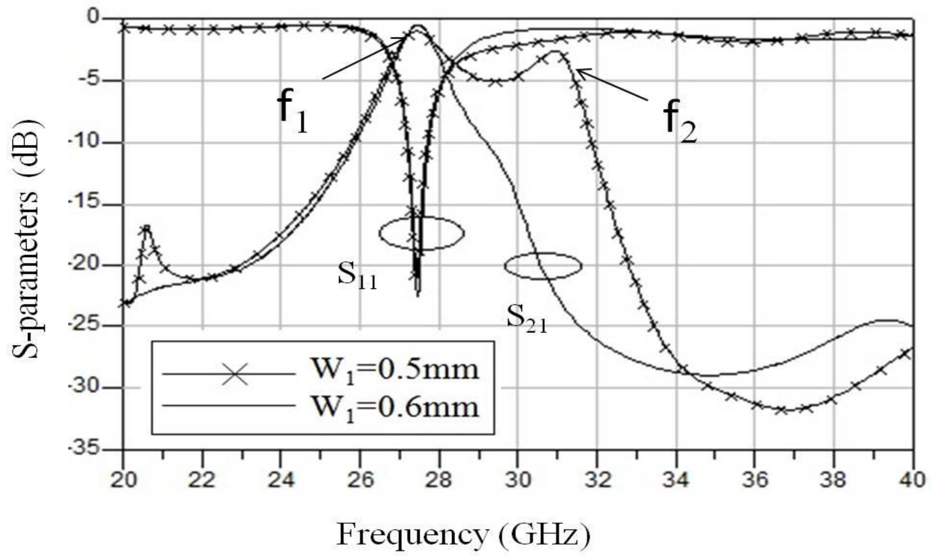


***Fig: 5.** Simulated S-parameters of the filter for different width of dumbbell DGS (DB-DGS)*

In Fig.4 it can be inferred that the dumbbell DGS width can be increased in order to avoid over coupling in the filter frequency response and two peak frequencies occurs by decreasing the width of DGS can be neglected.

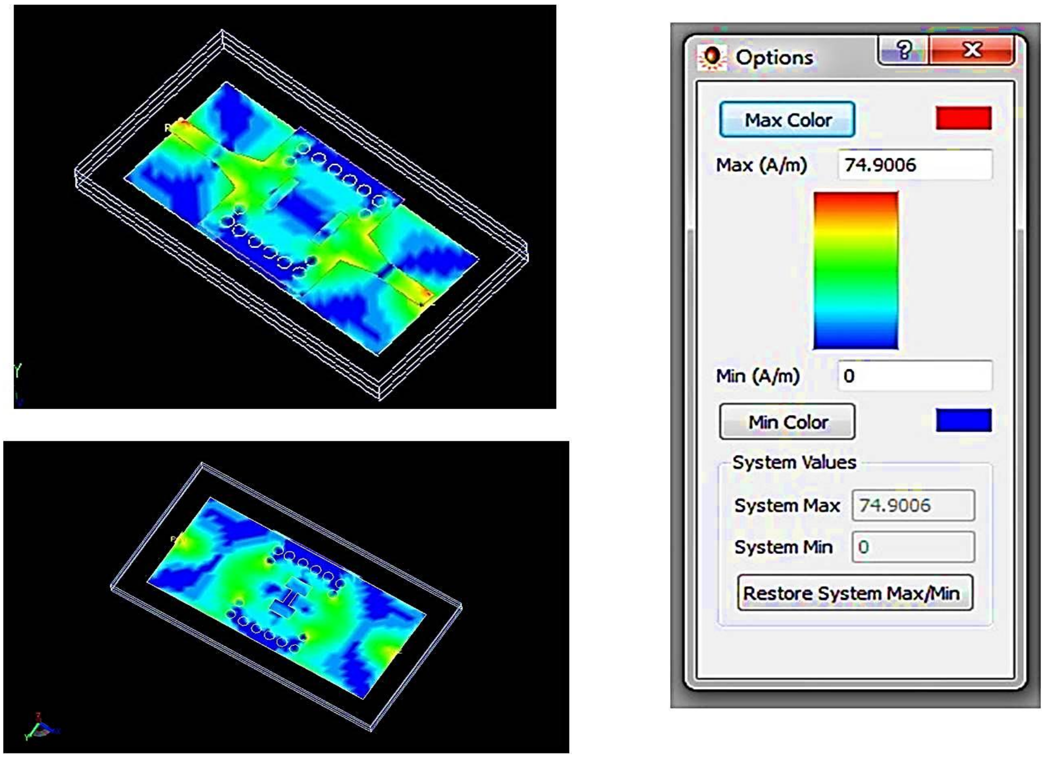


***Fig: 6.** Surface current density of filter*

RESULTS AND DISCUSSION

The proposed SIW BPF with dumbbell DGS (DB-DGS) on the bottom ground plane and two vertical slots on the top metal plane with size of 11mm×5mm including input/output tapered microstrip line to minimize impedance matching and reflection loss between microstrip to SIW structure. The simulated results with center frequency of 27.4GHz have insertion loss of 0.5dB, return loss of >20dB with 3-dB bandwidth of 7.2% and stopband attenuation is over 28dB/decade. It can be seen that the simulated filter provides good performance in the stop band rejection and the pass-band insertion loss and smaller in size.

CONCLUSION

In this paper, SIW BPF using DGS and DMS techniques is designed and simulated. The filter with center frequency of 27.4GHz and it is applicable for 5Gspectrum band applications. The proposed filter possesses better stopband characteristics due to the presence of dumbbell DGS in the SIW structure and also finite passband can be achieved by adding two vertical slots on the top metal plane called defected microstrip structure (DMS). The proposed full mode SIW BPF design has the advantage of low insertion loss, compactness, good return loss and better out of band rejection.

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