SIW-DGS based bandpass filter

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Abstract: In this article, substrate integrated waveguide (SIW) based bandpass filter for radar application is presented. In the proposed design, bandpass response is achieved by combining SIW structure with dumbbells shaped defected ground structure (DGS) cells. Simulation of the proposed structure is carried out using commercial software Ansoft High Frequency Structure Simulator (HFSS). Frequency tuning is also carried out by changing the dimension of DGS. Moreover, equivalent circuit of the proposed filter has been derived and lumped circuit elements have been calculated using the circuit simulator in Keysight Advanced Design System (ADS) software. The measured return loss of 12.36 dB and insertion loss of 0.77 dB with 3 dB fractional bandwidth (FBW) of 5.71% at the center frequency of 7 GHz. Good agreements are observed between the experimental and the simulation results. Proposed filter will be utilized in the developed frequency modulated continuous wave radar system at CSRTC for the suppression of harmonics.

Keywords: Substrate Integrated Waveguide (SIW), Defected Ground Structure (DGS), Filters, slow wave behavior

1. INTRODUCTION

The microstrip lines and metallic waveguides are widely used for the designing of RF and Microwave components from decades as they are highly efficient electromagnetic performance with fewer losses. Power handling capacity is less and losses are more in microstrip lines, while waveguides are bulky and expensive [1, 2]. Nowadays, SIW technology attracts many researchers in the field of electromagnetic and microwave communication due to high power handling capacity, low insertion losses, light weight, low fabrication cost and efficient high frequency characteristics. Conventional SIW structure contains dielectric substrate embedded with two linear arrays of metalized vias connecting the upper and lower metallic plates. This technology provide the advantages of waveguide like low insertion losses and high power handling capacity along with demanding properties of microstrip lines like low-cost, small size and easy fabrication [3,4]. In the proposed structure, bandpass filter using SIW structure and dumbbell shaped DGS is presented for the radar application. DGS is periodic or non periodic unit cell etched on the bottom metallic surface of planar circuit boards. This intentionally modification in ground plane enhance the performance of the circuit. DGS has inherent resonant properties and act as low pass filter. So, the combination of SIW cavity with dumbbells shape DGS behave as a bandpass filter.

2. DESIGN AND ANALYSES

2.1 Design of conventional SIW structure

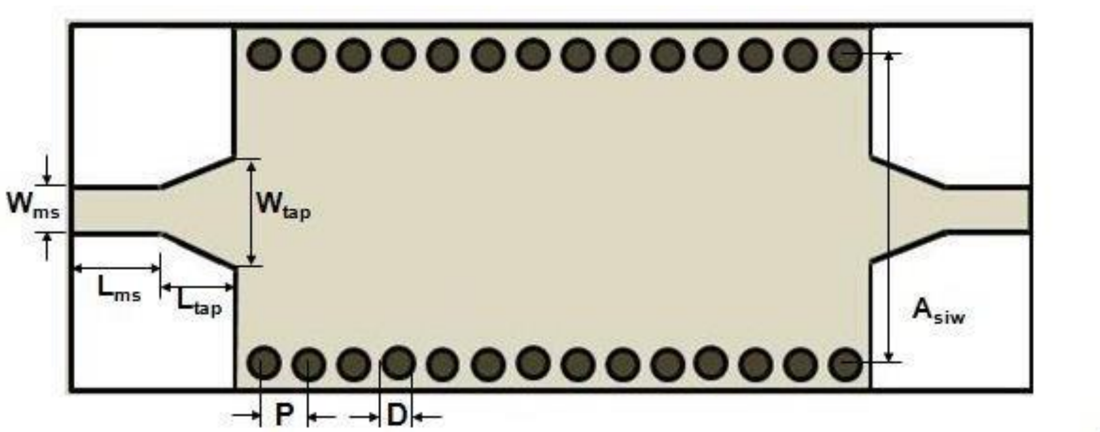
Initially, basic SIW structure has been designed as shown in fig. 1(a). Equivalent width and length of the SIW structure are derived using following equations to determine the cut-off frequency of SIW structure in TE10 mode, which were derived in [3-5].

$$f_{cTE10} = \frac{Co}{2\sqrt{\varepsilon_r}}\left(a - \frac{4R}{0.95P}\right)^{-1} \tag{1}$$

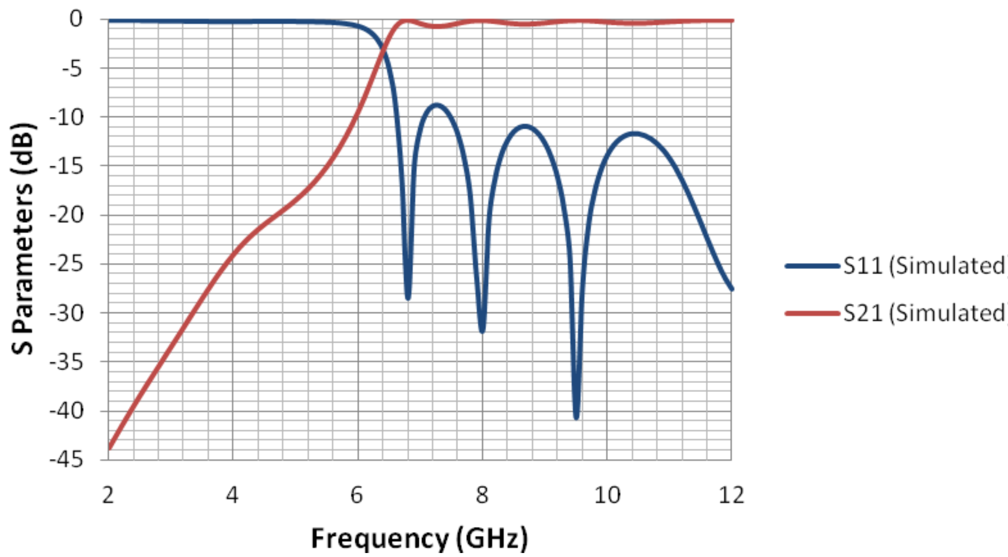
$$W_{eff} = W_{SIW} - \frac{D^2}{0.95P} \tag{2}$$

$$L_{eff} = L_{SIW} - \frac{D^2}{0.95P} \tag{3}$$

The dimensions of the designed filter are given in table 1. The simulated result of the SIW filter is as shown in fig. 1(b). Here, the cutoff frequency of the filter is at about 6.8 GHz with the insertion loss of 0.5dB within the desirable operating frequency band of 6.8 GHz to 12 GHz with good high pass performance.



(a)



(b)

Figure 1 (a) the basic SIW Structure (b) simulated S-parameter results.

Table 1: Dimensions of the proposed filter shown in figure 1(a).

Parameter	Values in mm
Diameter of Via (D)	1.08
Pitch of Via (P)	1.20
Width of SIW (A_{siw})	15.8
Width of Microstrip (W_{ms})	1.56
Length of Microstrip (L_{ms})	3.10
Width of Taper (W_{tap})	3.58
Length of Taper (L_{tap})	4.90

In order to achieve band pass response, filter can be realized with different structures like complementary split ring resonators (CSRRs), defected ground structure (DGS) and SIW resonant cavity [7–11].

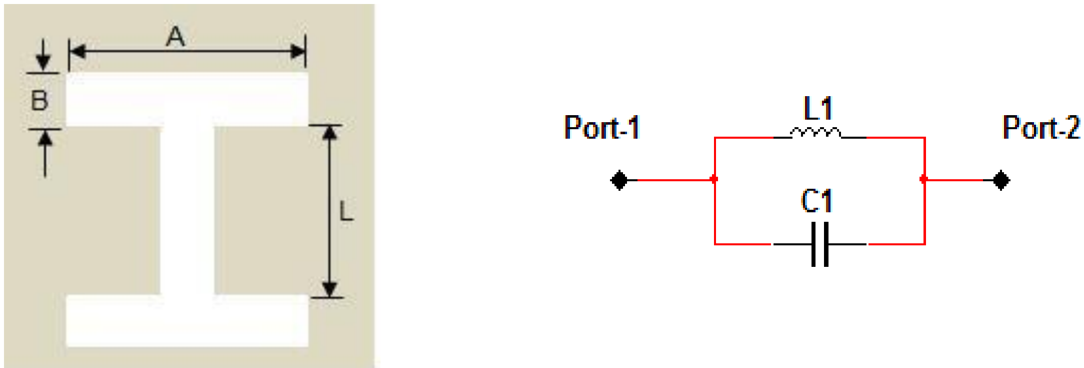
2.2 Modeling of DGS structure

DGS is realized by etching off dumbbell shape in the bottom ground plane, which changes the shielded current distribution and propagation of the electromagnetic waves through the. substrate layer. DGS cell has good bandstop characteristic [6, 8]. The equivalent circuit of the dumbbell shape DGS considered as combination of parallel capacitance (C) with the series inductance (L). The inductance of the DGS structure can be easily calculated using prototype values of the butterworth response as given in various references [1, 2]. Layout of the dumbbell shaped DGS structure is shown in figure 2(a). The equivalent circuit of the elliptic shape DGS can be explained as modeled as a parallel LC circuit as shown in figure 2(b).

$$C = \frac{\omega_c}{2Z_0(\omega_0^2 - \omega_c^2)} \quad (4)$$

$$L = \frac{1}{4(\pi f_0)^2 C} \tag{5}$$

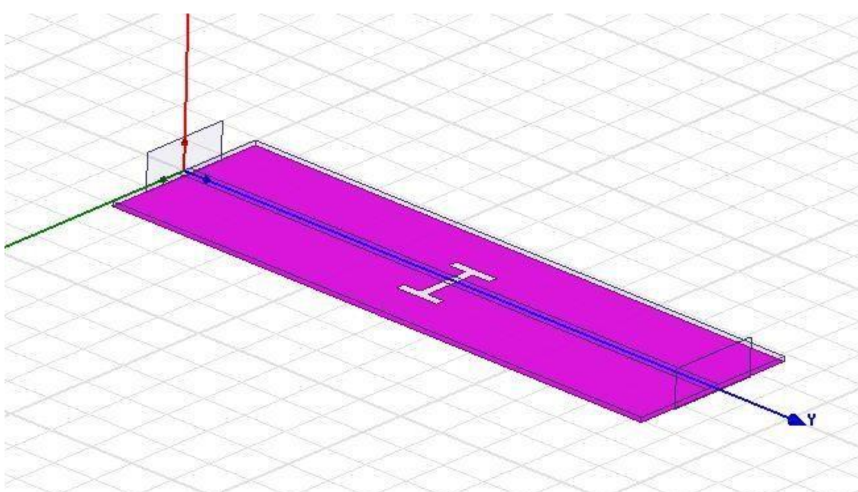
Where, ω0 is the angular resonance frequency, ωc is the 3-dB cutoff frequency and Z0 is the characteristic impedance.



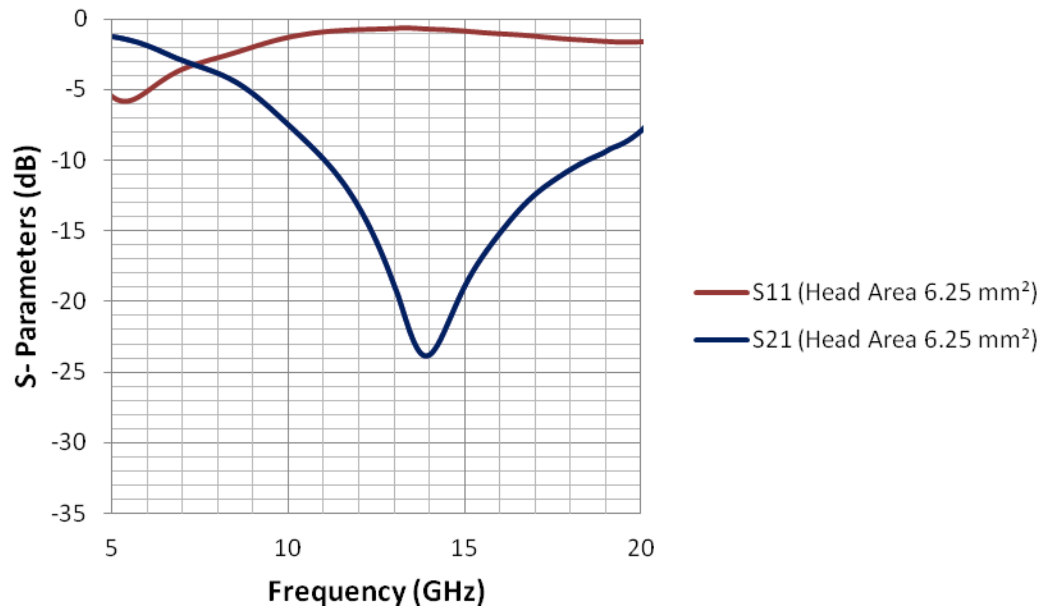
(a) (b)

Figure 2 (a) layout of elliptic shaped DGS cell and (b) LC equivalent circuit

In order to do the modeling of DGS structure, dumbbells shaped defect is created on the ground plane of the microstrip line as shown in the figure 3 (a). Initially, single dumbbells shaped DGS is applied on the ground plane of the 50 Ω microstrips (MS) line. The etched gap was kept to 0.2 mm and the etched area of head was set to 2.5 mm. The simulation result of the proposed DGS unit cell shows the response similar to single-pole Butterworth-type low-pass response, which has 3-dB cutoff frequency at 7.3 GHz and attenuation pole location is at 14 GHz as shown in the figure 3 (b). Moreover, circuit simulation has been carried out Advanced Design System (ADS) software, obtained simulation results are as shown in figure 4 (b).

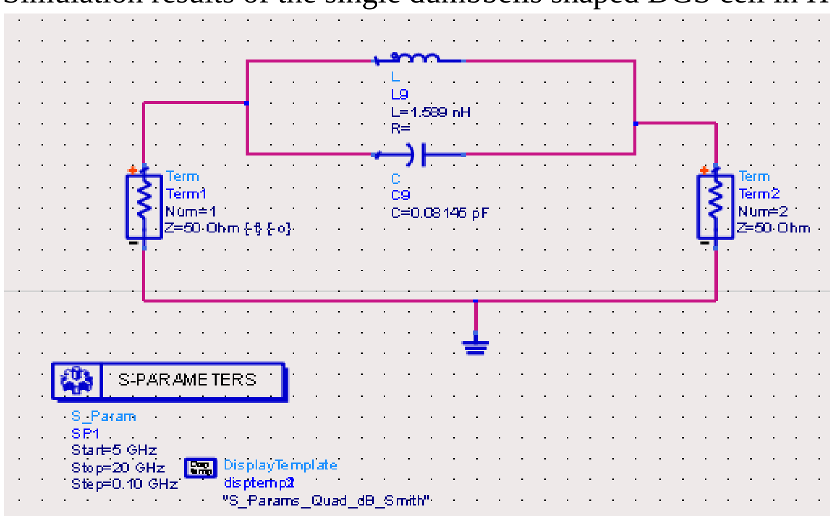


(a)

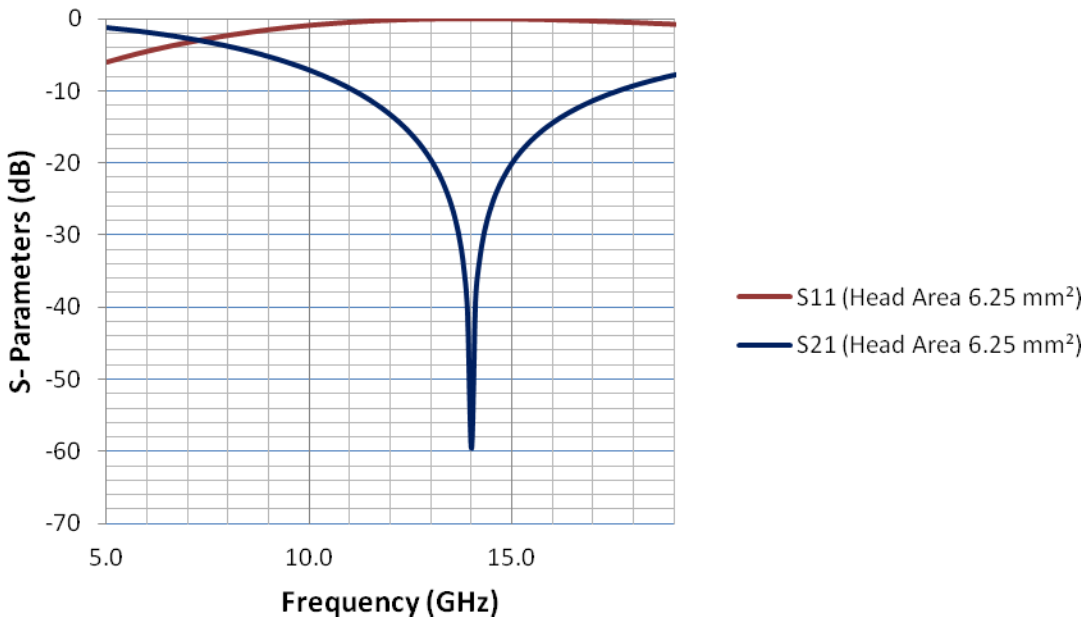


(b)

Figure 3 (a) Single dumbbells shaped DGS on MS line and
(b) Simulation results of the single dumbbells shaped DGS cell in HFSS



(a)



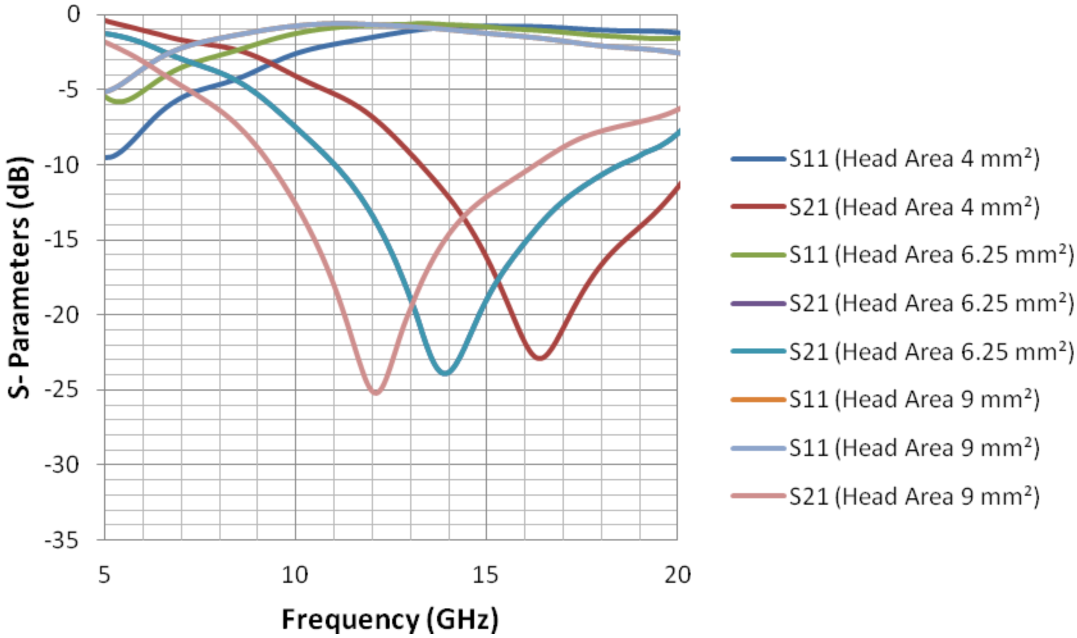
(b)

Figure 4 (a) LC equivalent circuit and (b) Simulation results of the single dumbbells shaped DGS cell in ADS

To investigate the influences of physical dimension on frequency characteristics elliptic lattice dimension and the etched gap of the DGS cell is varied. Effect of the elliptic lattice and the etched gap dimension on the frequency characteristics, simulation of DGS cell has been carried out using HFSS software.

(a) Effect of DGS head dimension

To observe the effect of the area of the head on the frequency characteristics, size of the head was varied while gap (g) of elliptic shaped was kept constant. It was observed that as the area of the head is increased, the inductance of the LC circuit increases and the cutoff frequency decreases, as shown in figure 5 (a). Obtained equivalent-circuit parameters with constant gap (g) equal to 0.2 mm for the DGS cell has been tabulated in table 2. Moreover, circuit simulation has been carried out Advanced Design System (ADS) software, obtained simulation results are as shown in figure 5 (b).



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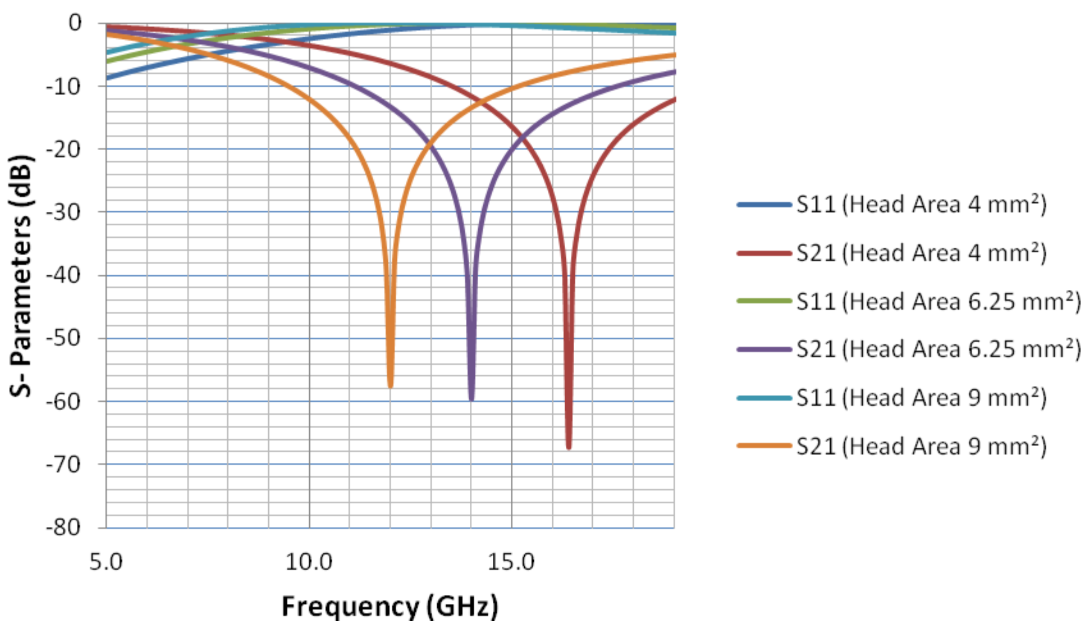


(b)

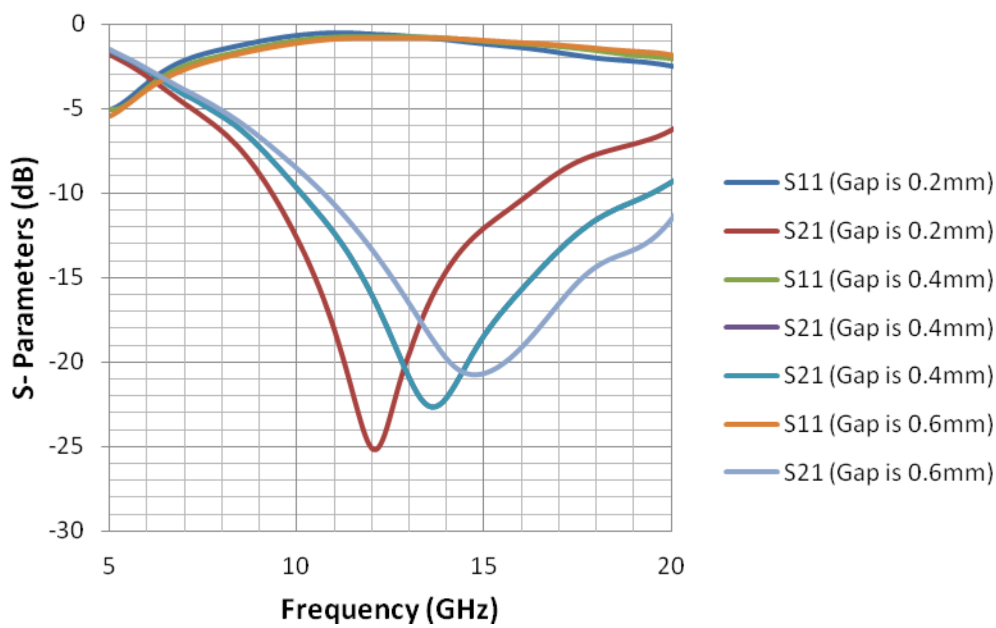
Figure 5 Simulation results with constant gap (g) = 0.2 mm (a) S-Parameters obtained in HFSS (DGS structure simulation) and (b) S-Parameters obtained in ADS (circuit simulation)

Table 2: Equivalent-circuit parameters for the DGS cell (gap (g) kept constant to 0.2 mm).

Parameters	DGS Head Area is 4 mm²	DGS Head Area is 6.25 mm²	DGS Head Area is 9 mm²
Inductance (nH)	1.138	1.589	1.884
Capacitance (pF)	0.0828	0.0814	0.0935
Cutoff Frequency (GHz)	9.4	7.3	6.2
Attenuation pole location (GHz)	16.4	14	12

(b) Effect of the gap distance

Similarly, to observe the effect of the gap on the frequency characteristics, size of the gap (g) was varied while size of head of elliptic shaped was kept constant. It was observed that as the gap of the DGS cell is increased, the capacitance of the LC circuit decreases and the cutoff frequency increases, as shown in figure 6 (a). Obtained equivalent-circuit parameters with constant head size equal to 2.5mm x 2.5 mm (a x b) for the DGS cell has been tabulated in table **3.** Moreover, circuit simulation has been carried out Advanced Design System (ADS) software, obtained simulation results are as shown in figure 6 (b).



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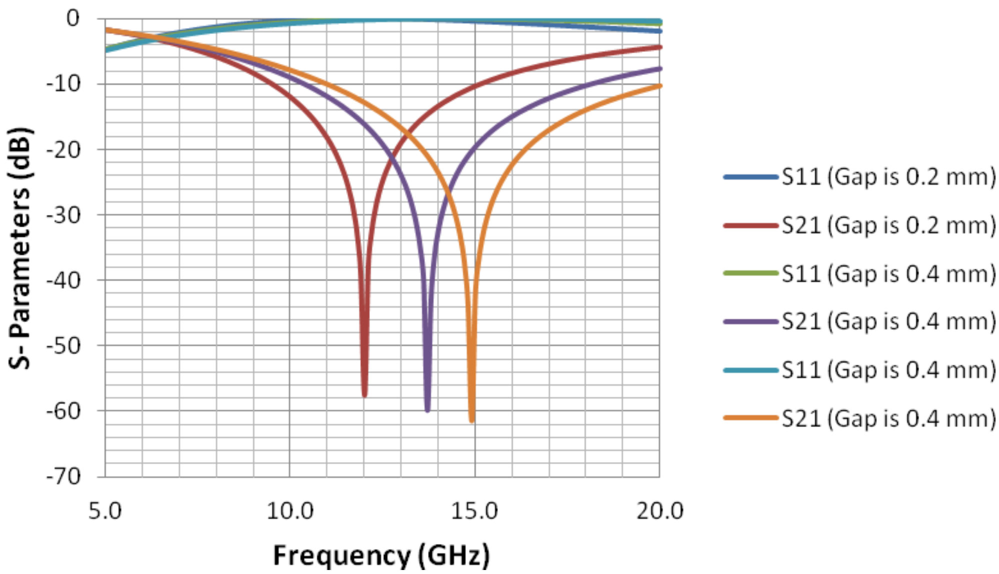


(b)

Figure 6 Simulation results with constant area = 9 mm² (a) S-Parameters obtained in HFSS (DGS structure simulation) and (b) S-Parameters obtained in ADS (circuit simulation)

Table 3: Equivalent-circuit parameters for the DGS cell (area of head kept constant to 9 mm²).

Parameters	**DGS Gap is 0.2 mm**	**DGS Gap is 0.4 mm**	**DGS Gap is 0.6 mm**
Inductance (nH)	1.884	1.990	1.985
Capacitance (pF)	0.0935	0.0667	0.0575
Cutoff Frequency (GHz)	6.2	6.3	6.5
Attenuation pole location (GHz)	12	13.7	14.9

2.3 Design of SIW-DGS Bandpass filter

In order to achieve band pass response, filter can be realized with different structures like complementary split ring resonators (CSRRs), defected ground structure (DGS) and SIW resonant cavity [8–14]. As the DGS structures has low insertion loss, wide stop band response and simple design. Thus DGS has been utilized for the design and development of the band pass filter. As observed in section 2.2, single DGS cell shows frequency response similar to the single pole Butterworth low pass filter. In order to achieve sharp roll off three DGS cells has been utilized to achieve the band pass response. Proposed structure is shown in figure 7. It has been observed that when DGS is applied to the SIW structure, variation in the phase is fast (slow-wave behavior) below the resonant frequency and slow phase variation in the phase is slow above the resonant frequency as shown in fig. 8.

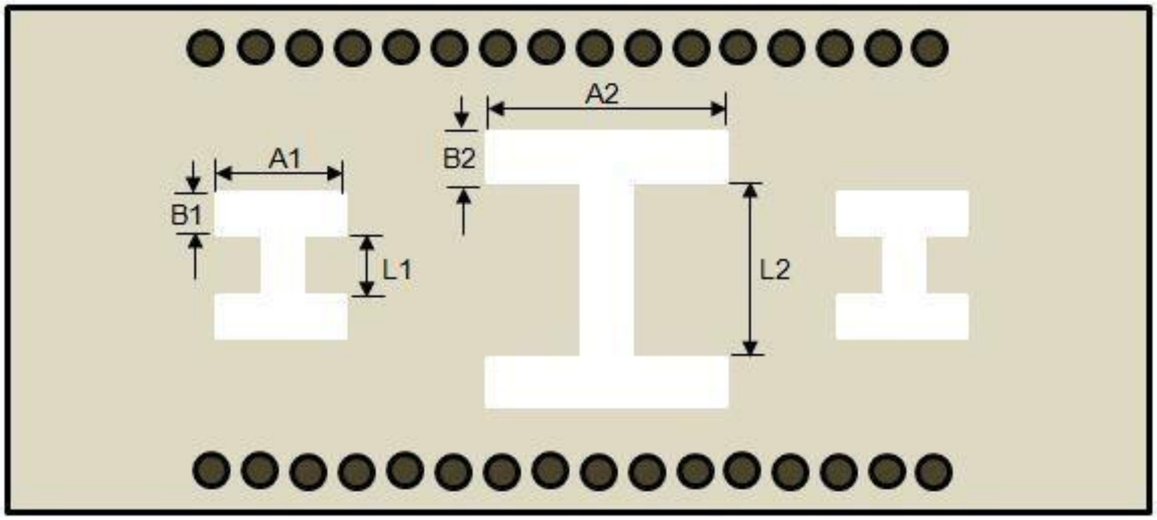


Figure 7 Bottom view of the proposed SIW Structure

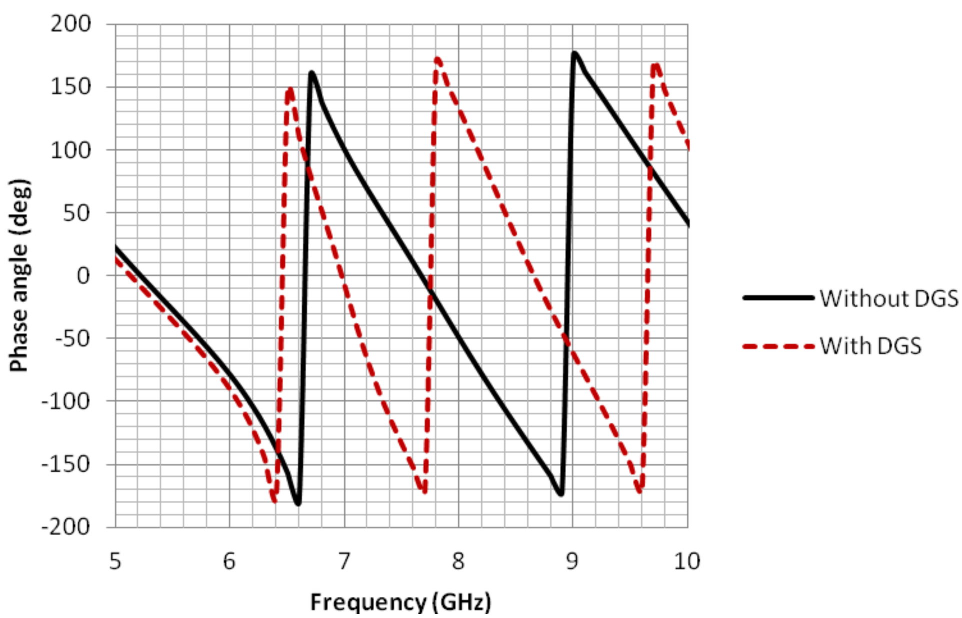


Figure 8 Simulated phase angle with and without DGS.

Upper cutoff frequency of the pass band can be changed by changing the length of the dumbbell shaped DGS. As we increase or decrease the length of the DGS structure, value inductance is increased or decreased, which is ultimately change the cutoff frequency of the structure. Transmission and reflection coefficients for the different length of the dumbbell shaped DGS has been observed. Fig. 9 shows the simulation results of the transmission and reflection coefficient. A relative detail of Fig. 9 is tabulated in Table 4.

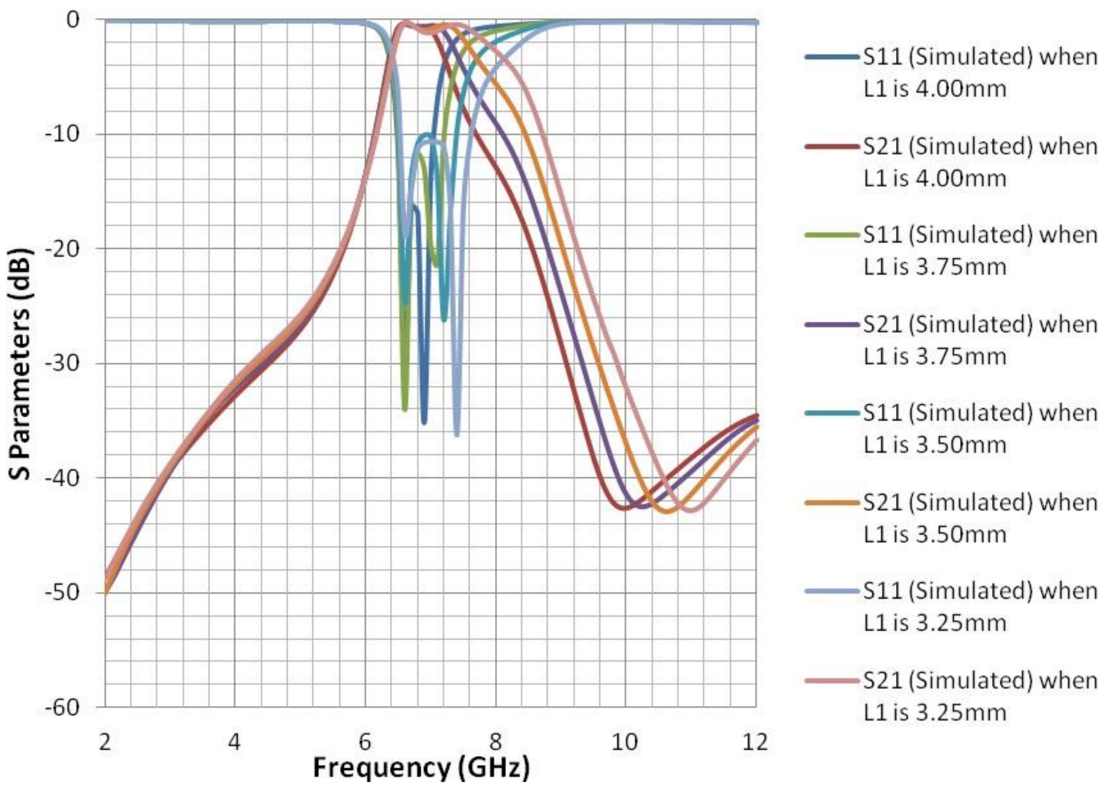


Figure 9 Simulated S-parameter results of frequency tuning by changing the length of DGS.

Table 4: Obtained results by changing the length of DGS

Length of Dumbbell Shaped DGS (L1 in mm)	3 dB fractional bandwidth (FBW) (%)	Insertion Loss in (dB)	Return Loss in (dB)
4	5.71	-0.2 to -0.7	>-10
3.75	8.45	-0.2 to -0.7	>-10
3.5	11.11	-0.2 to -0.7	>-10
3.25	13.69	-0.2 to -0.7	>-10

Equivalent circuit of the proposed filter is shown in the fig. 10. In the proposed structure, via-walls can be modeled as inductive post [9, 10] and dumbbell shape DGS can be modeled as a parallel LC circuit [8]. The lumped circuit elements have been calculated using the circuit simulator in Keysight Advanced Design System (ADS) software. Full wave simulated response, circuit simulated response and measured response of the proposed structure is shown in the fig 12.

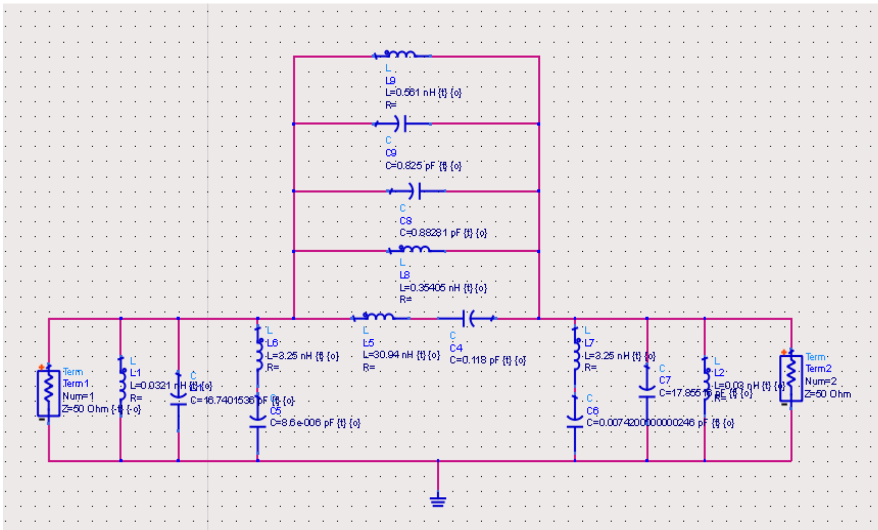
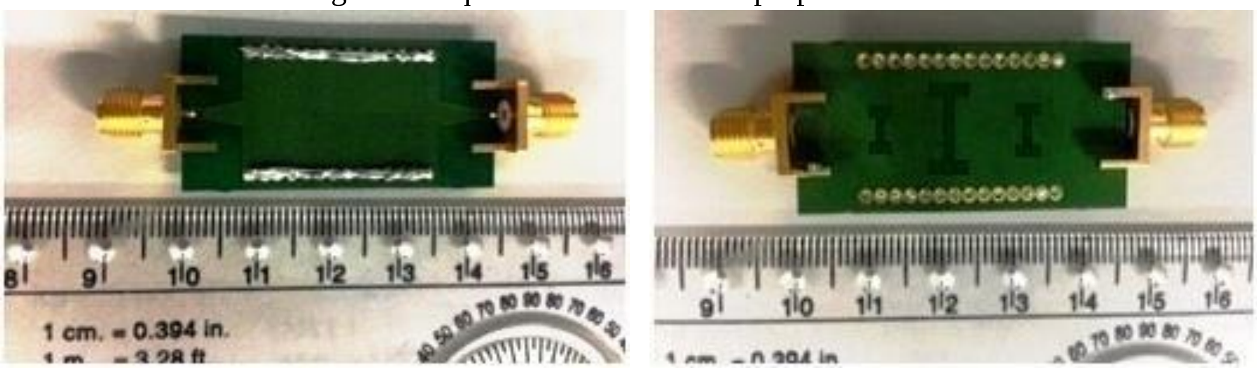


Figure 10 Equivalent circuit of the proposed filter



(a) (b)

Figure 11 Fabricated Structure (a) top view (b) bottom view

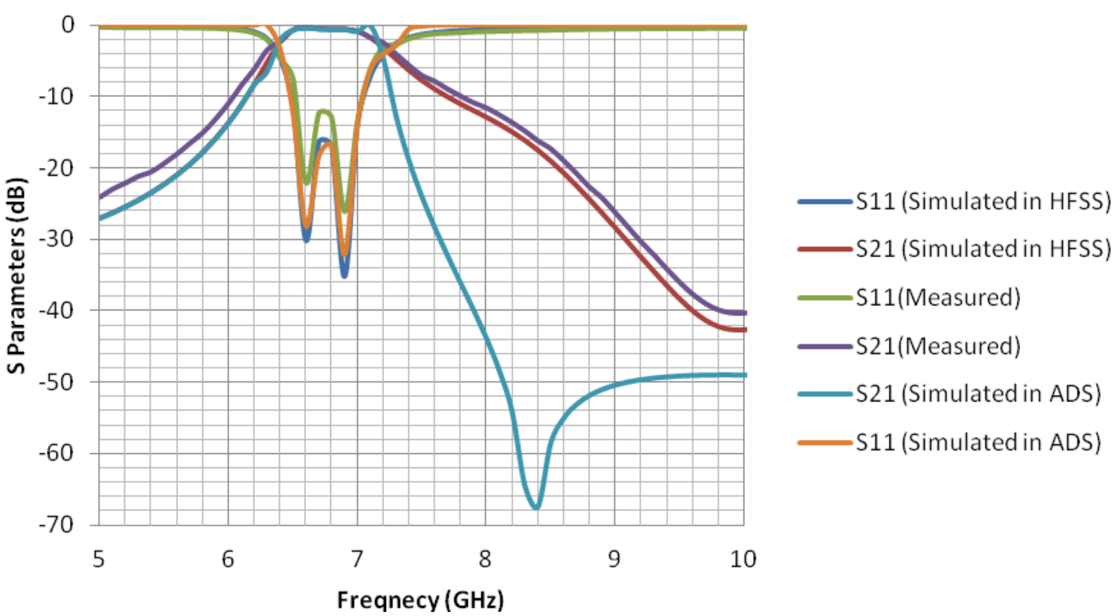


Figure 12 Simulated and measured response of the proposed filter

3 RESULTS AND DISCUSSION:

The proposed bandpass filter is fabricated on the dielectric material RT duroid 5880 with the dielectric constant ε_r=2.2, dissipation factor tanδ=4 x 10^{-4} and height h= 0.508 mm. The photograph fabricated structure of the proposed filter is as shown in figure 11 (a) and (b). Size of the proposed structures excluding feeding line is 43mm x 21mm (1.48 λg x 0.72 λg), where λg is guided wavelength at centre frequency of 7 GHz. Keysight N5245A vector network analyzer is utilized for the measurement of the of the proposed structure. The simulated and measured s-parameters results of the proposed filter are as shown in figure 12. Excellent agreement has been observed between simulation and measurement results. The measured return loss is 12.36 dB and insertion loss of 0.77 dB with 3 dB fractional bandwidths of 5.71 % at 7 GHz.

4 CONCLUSIONS

In this article, SIW based bandpass filter is proposed. In our design three dumbbell shaped DGS cells is etched on the ground plane of the SIW cavity. A proposed structure was fabricated and tested. A good agreement is observed between the simulated results and measured results. The measured insertion loss is less than 0.8 dB and the return loss is better than 12 dB in the operating frequency band. Frequency tuning is also demonstrated with the variation in the 3 dB fractional bandwidths from 5.71 % to 13.69%, user can configured frequency of the filter according to the required band of frequency. Moreover, proposed structure is also useful for some other microwave application like terrestrial microwave links, satellite communication, radar etc.

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