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SIW Band-Pass Filter using Dumbbell Shaped DGS Structure

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***Abstract*— In this study, a bandpass filter utilizing Substrate Integrated Waveguide (SIW) is reported. In the suggested design, square-shaped defective ground structure (DGS) cells are combined with SIW structure to achieve bandpass response. The proposed structure was simulated using a 3D frequency domain electromagnetic structure solver the Ansoft High Frequency Structure Simulator (HFSS). It has been done to analyze three various shapes of DGS cells: square, circular, and rectangular. Moreover, altering the DGS's dimension is another way to tune the frequency. Structure is built on the dielectric substance RT duroid 5880 to test the performance of the suggested bandpass filter. At the 7.1 GHz center frequency, the observed insertion loss and return loss and are 1.34 dB and 24.54 dB respectively, with fractional bandwidth (FBW) (3.0 dB) of 4.68%. The findings of the simulations and the experiments show good agreement.**

***Index Terms*— Substrate integrated waveguide (SIW), SFCW Radar, defected ground structure (DGS) and insertion loss.**

I. INTRODUCTION

Substrate-integrated waveguide (SIW) technique is recent state-of-art technology, in which composition includes dielectric material sandwiched between top and bottom copper layers, dielectric material is rooted with array of two linear metallic vias linking top and bottom copper layers. The SIW configuration presents the benefits of the conventional waveguides such as less insertion-loss, high power conducting capability and high Q (quality factor). Furthermore, SIW also demonstrate the benefits of microstrip-lines like lightweight, inexpensive manufacturing and easy to integrate [3-4]. [4-6]. In the anticipated configuration, bandpass filter with SIW structure and square dumbbell shaped DGS is reported. DGS is engraved on the bottom metallic surface and consists of periodic or nonperiodic unit cells. DGS functions as a low pass filter and has high band rejection characteristics. Therefore, the SIW cavity and dumbbell-shaped DGS work together to provide a bandpass filter. Police currently use X, Ku, K, and Ka band frequencies to determine the target vehicle's speed [3]. The developed Step Frequency Continuous wave (SFCW) traffic radar system will make use of the proposed filter to measure the target vehicle's speed by identifying changes in the reflected signals frequency brought on by the Doppler Effect.

II. DESIGN AND SIMULATION

The SIW structure in this design is constructed using the RT duroid 5880 dielectric material, which has a height of 0.508 mm and a relative permittivity of 2.2. Ansoft HFSS software is used for all simulations and fine

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optimizations of the planned structure.

A. Designing of SIW structure

The electro-magnetic behavior of the SIW is analogous to the metallic waveguide. The Cut-off frequency in the $TE_{1,0}$ mode, the resultant length and width of the SIW can be estimated using following equation (1), (2) and (3) correspondingly, which is mentioned in [4-6].

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

$$W_{eff} = W_{SIW} - \frac{D^2}{0.95P} \quad (2)$$

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

Table 1 lists the size of the anticipated SIW filter, illustrated in Figure 1(a), as determined using Equations (1), (2), and (3).

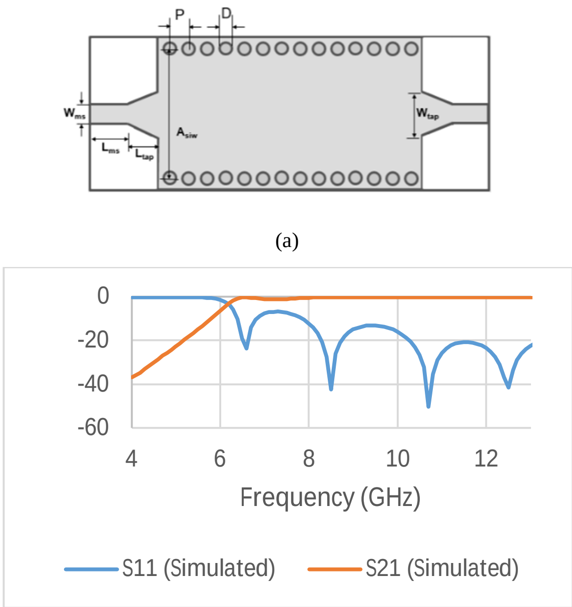


Fig 1. (a) Simple SIW Configuration (b) Simulation S-parameter results.

TABLE I: THE SIW STRUCTURE DIMENSIONS

Parameter	Values in mm
Via Diameter(D)	1.10
Via Pitch (P)	2.00
SIW Width (A_{siw})	8.10
Microstrip line Width (W_{ms})	1.58
Microstrip line Length (L_{ms})	3.20
Taper Width (W_{tap})	3.60
Taper Length (L_{tap})	5.00

The simulated S-parameter result of the SIW filter is displayed in Figure 1(b). The results obtained indicate that the traditional SIW structure is designed to function as a high pass filter with a cutoff frequency of 6.2 GHz and an insertion loss of 0.45 dB within the desired operating frequency region.

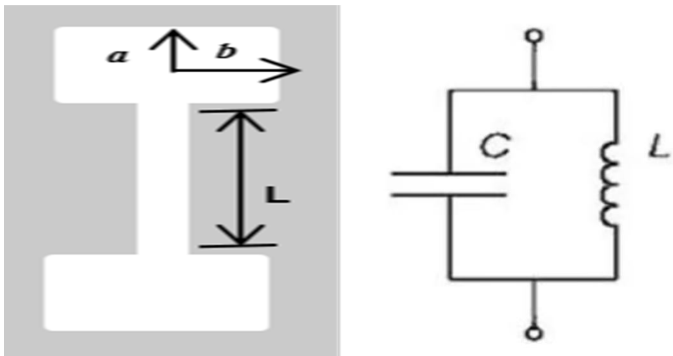
B. Investigation of dumbbell shaped DGS

DGS is achieved in the proposed bandpass filter by engraving a dumbbell-shaped area in the ground bottom layer. DGS modifies the substrate layer propagation of electromagnetic waves and shielded current distribution. Below the resonant frequency, DGS exhibits slow wave behavior (phase variation is quick), while above the resonant frequency, phase variation is sluggish. It also has a strong band rejection property [9]. At a specific frequency, the DGS cell exhibits a bandgap characteristic that is mostly caused by a finite attenuation pole. Investigation is also done into the connection between the dimensions of the DGS cell and attenuation pole frequency. Many researches have recently focused on and verified DGS act as a low pass filter for wide stop band performance [14–16]. DGS is achieved in the proposed bandpass filter by engraving a dumbbell-shaped area in the bottom ground layer. DGS modifies the shielded current distribution, and substrate layer propagation of electromagnetic waves. Below the resonant frequency, DGS exhibits slow wave behavior (phase variation is quick), while above the resonant frequency, phase variation is sluggish. It also has a strong band rejection property [9]. At a specific frequency, the DGS cell exhibits a bandgap characteristic that is mostly caused by a finite attenuation pole. Investigation is also done into the connection between the dimensions of the DGS cell and the attenuation pole frequency. Many researches have recently focused on and verified DGS act as a low pass filter for wide stop band performance [14–16].

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

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

Where, ω_c is the 3-dB cutoff frequency, Z_0 is the characteristic impedance and ω_0 is the angular resonance frequency.

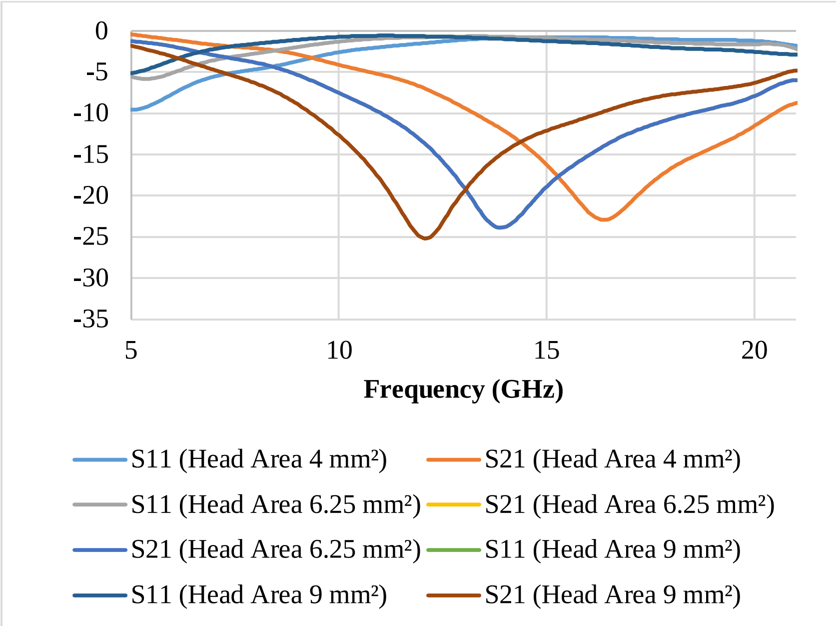


(a) (b)

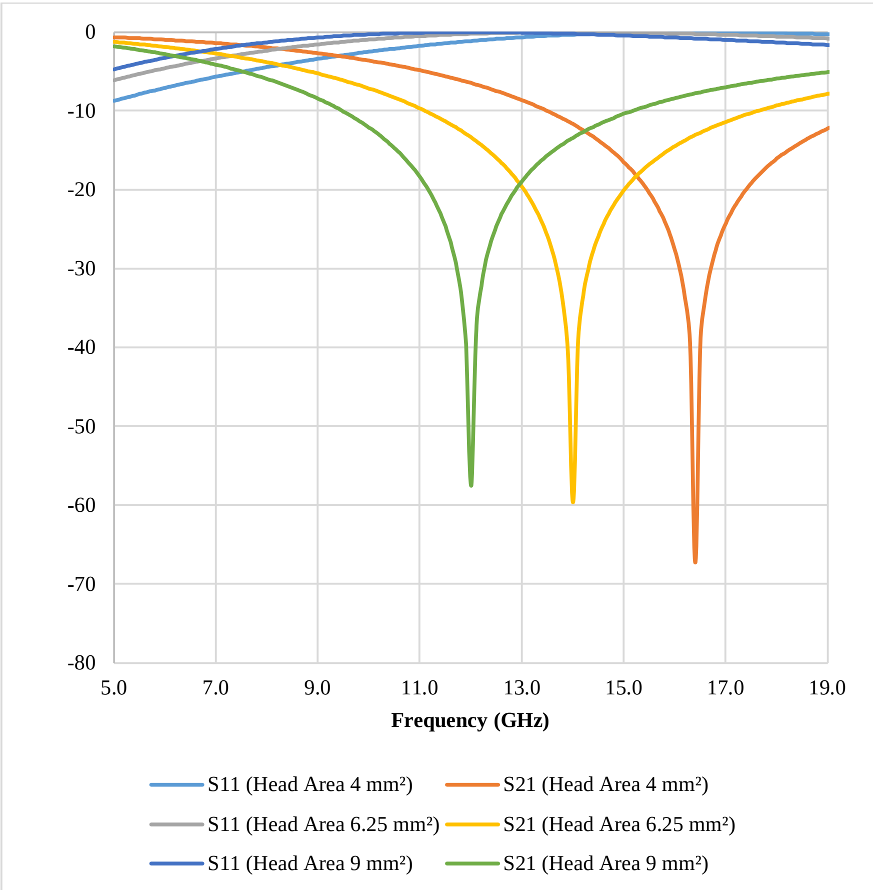
Fig. 2. (a) Design of square shaped DGS cell and (b) Equivalent LC circuit of DGS cell

Figure 3 depicts the results of a simulation of the DGS structure using HFSS in order to evaluate the frequency features of the DGS cell. Results from simulations indicate a response resembling that of a single pole Butterworth low pass filter. A study on the impact of the DGS cell's head area and gap on frequency features has been done in order to better understand how the DGS cell affects frequency characteristics. The head size was changed while the square shape's gap (g) was maintained in order to investigate how the head's area affected the frequency characteristics. It was discovered that as the head area grows, the LC circuit's inductance rises and the cutoff frequency falls, as illustrated in figure 3(a). Table 2 lists the obtained equivalent-circuit values for the DGS cell with a constant gap (g) of 0.25 mm.

A circuit simulation was also carried out using the Advanced Design System (ADS) software; the outcomes are presented in figure 3(b). To explore the influence of the gap on the frequency behaviour, the size of the gap (g) was altered whereas the size of the square-shaped head was left unaltered. It was discovered that as the DGS cell's gap is extended, the cutoff frequency rises and the LC circuit's capacitance falls, as presented in figure 4(a). The equivalent-circuit parameters for the DGS cell with a constant head size of 2.5mm x 2.5mm (a x b) are shown in Table 3. Circuit simulation was also carried out utilizing the ADS software. The results of the simulation that was run are presented in figure 4(b).

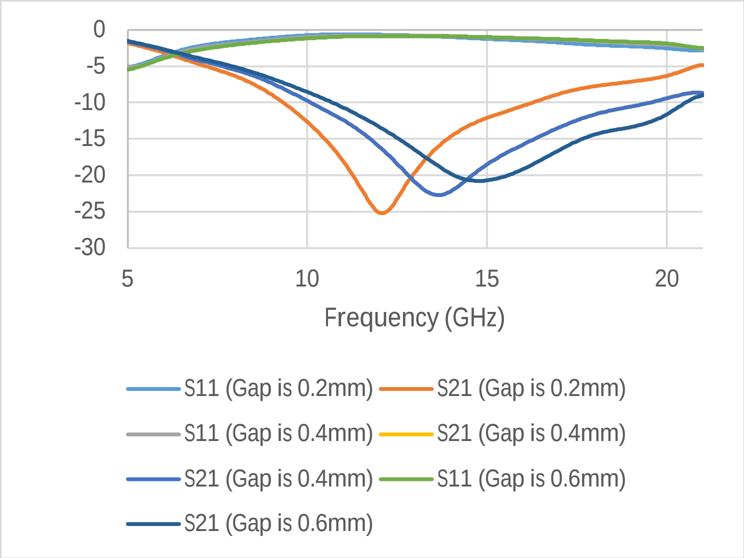


(a)

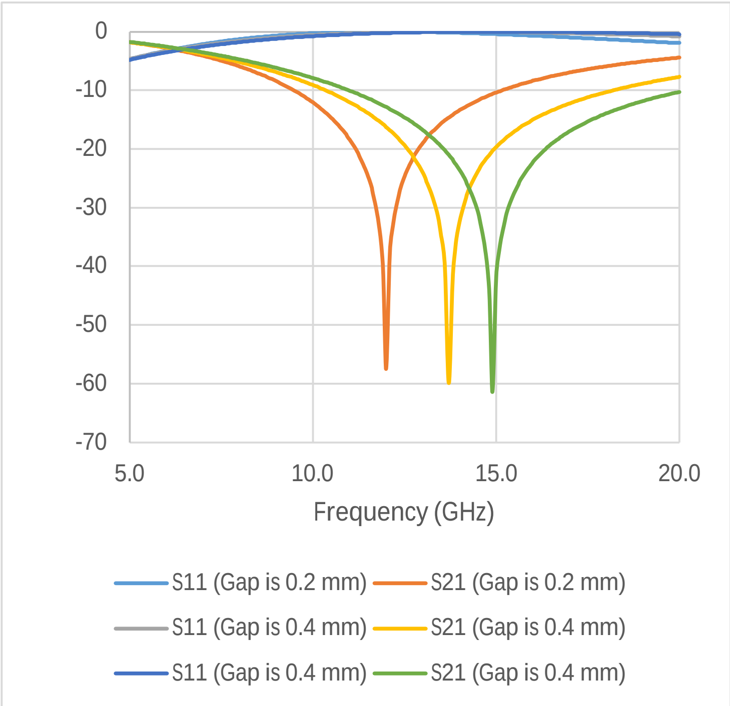


(b)

Fig. 3. S-Parameters simulated results with constant gap (g) = 0.25 mm (a) acquired in HFSS (DGS structure simulation) and (b) acquired in ADS



(a)



(b)

Fig. 4. Simulated S-Parameters results with fixed area = 6.25 mm² (a) acquired in HFSS and (b) acquired in ADS

TABLE II: OBTAINED RESULTS WITH CONSTANT GAP (G) TO 0.25 MM).

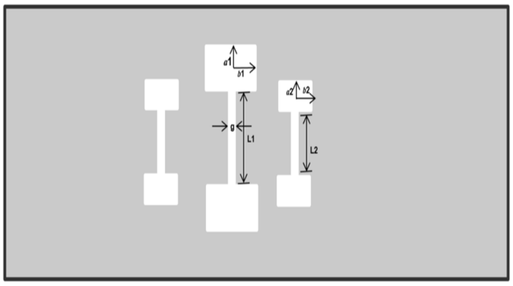
	DGS-head size is 4 mm²	DGS-head size is 6.25 mm²	DGS-head size is 9 mm²
Capacitance (pF)	0.0625	0.0921	0.0998
Inductance (nH)	1.285	1.492	1.423
Cutoff Frequency (GHz)	9.35	7.25	6.25
Attenuation pole (GHz)	16.35	13.9	11.9

TABLE III: OBTAINED RESULTS WITH CONSTANT AREA OF HEAD OF 6.25 MM²

	Gap in DGS is 0.2 mm	Gap in DGS is 0.4 mm	Gap in DGS is 0.6 mm
Capacitance (pF)	0.0895	0.0732	0.0655
Inductance (nH)	1.765	1.855	1.854
Cutoff Frequency (GHz)	6.25	6.35	6.45
Attenuation pole (GHz)	12.1	13.6	15

III. DESIGNING OF BANDPASS FILTER

Conventional SIW structure provides high pass response, as seen in figure 1(b). Numerous approaches, including SIW resonant cavities, complementary split ring resonators (CSRRs) and defective ground structures (DGS) have been used to achieve band pass response [8–14]. Because it offers a wide stop band response, a low insertion loss, and a straightforward design, bandpass filters with DGS structures are frequently utilized. DGS has thus been used in the creation and design of the band pass filter. The frequency response of a single DGS cell resembles that of a single pole Butterworth low pass filter, as was seen in section 2.2. Three DGS cells have been used to accomplish the band-pass response and sharp roll off. A comparison of the three different DGS structure types—rectangular, circular, and square—has been done. These three different forms of DGS cells have slots that are L1= 4.5 mm, L2= 2.5 mm, and g= 0.4 mm wide. Square shapes with a1 = 2.5 mm, b1 = 2.5 mm, a2= 1.5 mm, and b2 = 1.5 mm are substituted with rectangular shapes with a1 = 1.5 mm, b1= 2.5 mm length. a2 = 1 mm, b2 = 2 mm, and a circular with r1 = 1.6 mm and r2 = 1 mm of radius. Figure 5(a) shows the proposed filter that makes use of the DGS structure. The same characteristics are present in all three variations of the DGS structure, as presented in figure 5(b). Table 2 presents the results for the DGS structures: rectangular, circular, and square.



(a)

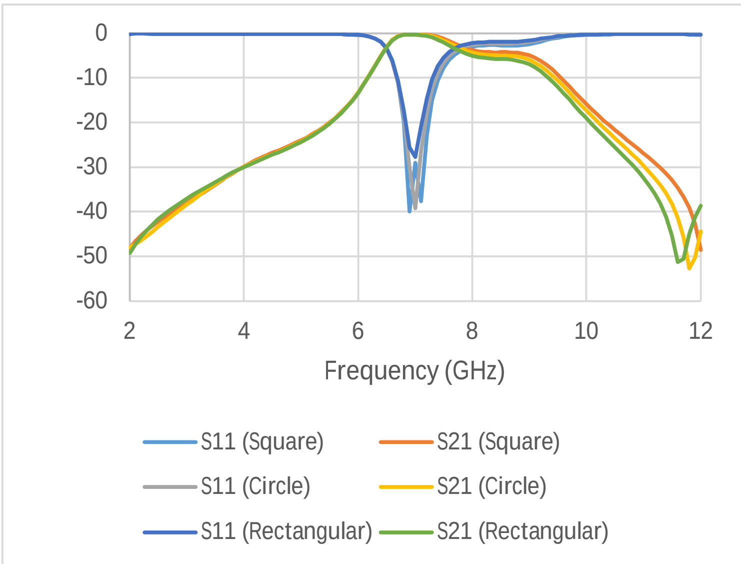
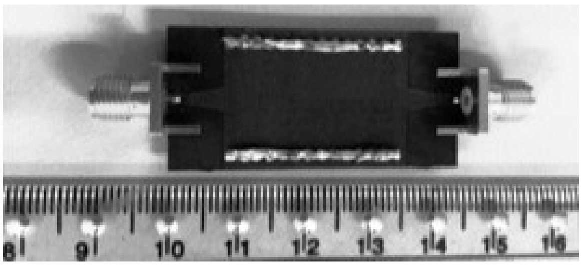
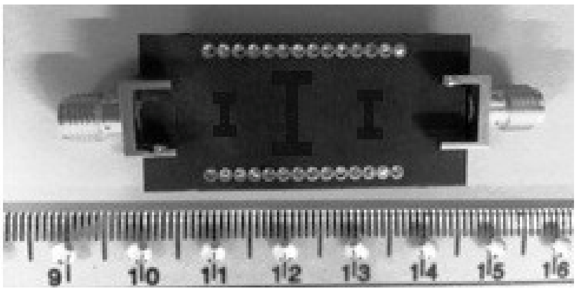


Fig. 5. (a) the anticipated filter configuration and (b) Simulated S-parameters results of DGS cell of rectangular, circular and square shape.

By altering the length of the rectangular-shaped DGS, the upper cutoff frequencies of the pass-band can be altered. Value inductance increases or decreases as the length of the DGS cell changes, changing the structure's cutoff frequency in the process. The rectangular-shaped DGS's transmission and reflection coefficients for various lengths have been observed. Figure 5 displays the transmission and reflection coefficient simulation findings. Table 3 contains a relative detail of Figure 3 in tabular form.



(a)



(b)

Fig. 6. Prototype Structure of anticipated filter (a) top view (b) bottom view

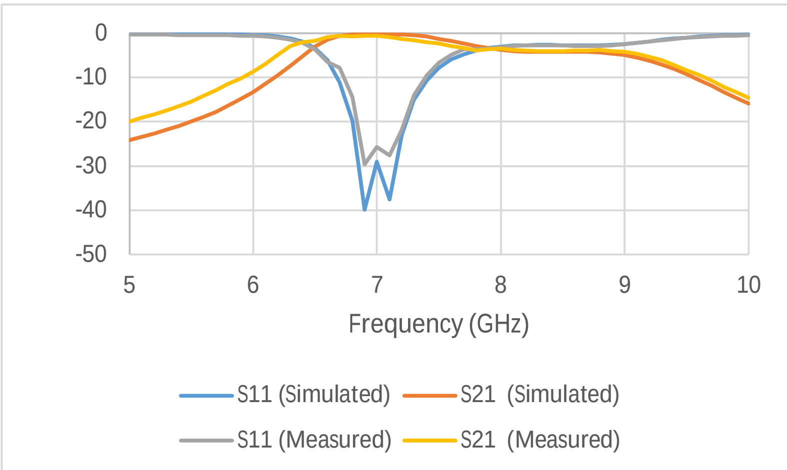


Fig 7: Simulated and measured results of the proposed filter

IV. Results and Discussion

The RT duroid 5880 dielectric material having a relative permittivity of 2.2, a height of 0.508 mm, and a dissipation factor of 4 x 10^{-4}, is used to construct the suggested bandpass filter. Figure 6(a) and (b) depict the constructed structure used in the photograph. The proposed structures measure 42 mm by 20 mm (1.38 λg by 0.68 λg), where λg is the guided wavelength at a center frequency of 7.1 GHz. A vector network analyzer (VNA) is used to measure the proposed structure. Figure 7 displays the results of the suggested filter's simulation and measurement of the s-parameters. The proposed filter, it has been found, offers less insertion loss plus return loss more than 25 dB. The findings of the simulation and the measurements are consistent. At 7.1 GHz, a 3 dB fractional bandwidth of 4.68% results in a measured return loss of 24.54 dB and an insertion loss of 1.34 dB.

V. Conclusions

This study presents a band-pass filter using SIW technology. On the ground plane of the SIW cavity, three DGS cells with square shapes are etched in our design. A suggested structure was created and put to the test. Results that are measured and those that are simulated agree. In the frequency band of operation, the measured insertion loss is better than 1.22 dB, and the measured return loss is more than 25 dB. The user can tune the frequency of the filter as per the needed frequency band by varying the 3 dB fractional bandwidths in the range of 4.6% to 6.2%, which also serves as a demonstration of frequency tuning. Additionally, the anticipated structure is helpful for various other microwave applications, including radar, satellite communication, and terrestrial microwave communications.

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