MAT JOURNALS

Journal of Analog and Digital Communications
Volume 3 Issue 3

Design and Analysis of Compact SIW Bandpass Filter using DGS-DMS Technique for Satellite Applications

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DOI: http://doi.org/10.5281/zenodo.1465568

Abstract

This letter proposes a new compact substrate integrated waveguide based bandpass filter for satellite application. First SIW BPF is designed by tapered via transition to provide a smooth transition from microstrip line to SIW cavity with minimal reflection and better S_{11} performance. The stop band performance of the proposed filter is improved by introducing a two square head DGS connected by U-slot on the bottom ground plane which introduces transmission zeros in upper stopband. DMS is made by etching two horizontal slots on the top of the SIW cavity in order to provide finite passband and to suppress undesired harmonic response. The filter with center frequency of 7GHz and fractional bandwidth of 2.8% is developed on the Rogers substrate with dielectric constant of 3.5 and substrate thickness of 0.5mm. By combining the concept of DGS-DMS, the proposed filter exhibits very low insertion loss of 0.02dB, return loss >20dB and compact size. The structure is simulated and analyzed by using Advanced Design software.

***Keywords**: Substrate Integrated Waveguide (SIW), Bandpass Filter (BPF), Defected Ground Structure (DGS), Defected Microstrip Structure (DMS), Satellite application.*

INTRODUCTION

RF, microwave and millimeter wave circuits are widely used for high frequency applications. Among these bandpass filters are the most important and useful for many wireless communication systems. Compared with the conventional microstrip filters, a new technology known as substrate integrated waveguide is introduced, which is a non planar waveguide structure can be transformed into planar form and it can be easily integrated into any planar dielectric substrate such as printed circuit board(PCB) and low-temperature co-fired ceramic(LTCC). SIW structures have the advantage of low fabrication cost, low losses. Besides, SIW have better quality factor than conventional printed circuit board (PCB). Substrate integrated Waveguide can also integrate an advantage of both uniplanar rectangular waveguide and planar microstrip transmission line than the waveguides which has high ohmic losses. In [1] smooth transition is provided by using tapered via transition from microstrip line (planar structure) to SIW cavity with minimal reflection and has wider bandwidth. Due to the development of science and technology, multiband filters are having good practical and theoretical values. According to this, a dual band SIW BPF with good transmission performance is presented in [2]. An SIW cavity is loaded with CSRR by triple mode filter provides frequency response, out of band rejection and skirt selectivity [3]. Another technique called Defected Ground Structure (DGS)[4]for improving the upper stopband performance and provides high selectivity by using Slots or defects integrated on the ground plane of microwave planar circuits. Two passbands with transmission zero in the middle can be achieved by using resonant properties of CSRR and two dumbbell DGS [5]. By loading two stubs on both edges of the SIW cavity and loading DGS unit patters into quarter mode SIW to operate the waveguide below cutoff frequency [6]. Further to improve the filter performance DGS structures are analyzed and studied, by adopting three pairs of DGS structures are introduced to suppress the spurious passband ripples by assigning transmission zeros towards stopband response[7]. In [8], U-shaped slot has been realized to provide stopband rejection and to sharpen selectivity. DMS-DGS [9] based filter structure with stopband behaviors are used to suppress undesired harmonic response.

In this paper, a new compact SIW BPF using DGS-DMS technique is reported. DGS is made by etching two square heads connected by U-slot on the bottom ground plane to obtain better out-of band suppression. Further to improve the filter performance by introducing defects in the top of the SIW cavity called DMS (Defected Microstrip structure). The proposed filter using DGS-DMS techniques are used to provide good filtering response which is usable for satellite applications.

DESIGN AND ANALYSIS

SIW Filter Design

Conventional SIW BPF is synthesized by array of array of metalized via holes connected upper and lower metal plates of dielectric substrate. The geometrical parameters of the filter are diameter d, spacing between the via holes 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 microstrip feeding lines. The structure is developed on the Rogers substrate with relative permittivity of 3.5 and thickness of 0.5mm. The microstrip energy can be easily transformed by using tapered via transition. The microstrip to SIW transition is used to provide proper impedance matching and minimal reflection losses. The effective width and length of the SIW structures can be related by given formula

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

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

The resonant frequency of the desired passband can be given as

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

(2.3)

The spacing between the via holes and diameter should be kept minimum in order to radiation losses and leakage losses between the via holes, such that filter should satisfy the following condition, d/p>0.5, $d/W_{SIW}<0.4$. The SIW BPF is designed to achieve quality factor and it can be defined by using the given formula,

$$Q_e = \frac{f_0}{BW} \quad (2.4)$$

Where f_0 and BW are the resonant frequency and bandwidth of the filter respectively.

SIW BPF Design using DGS-DMS

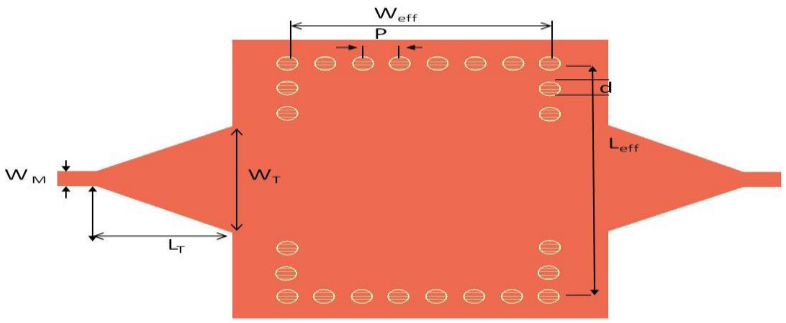
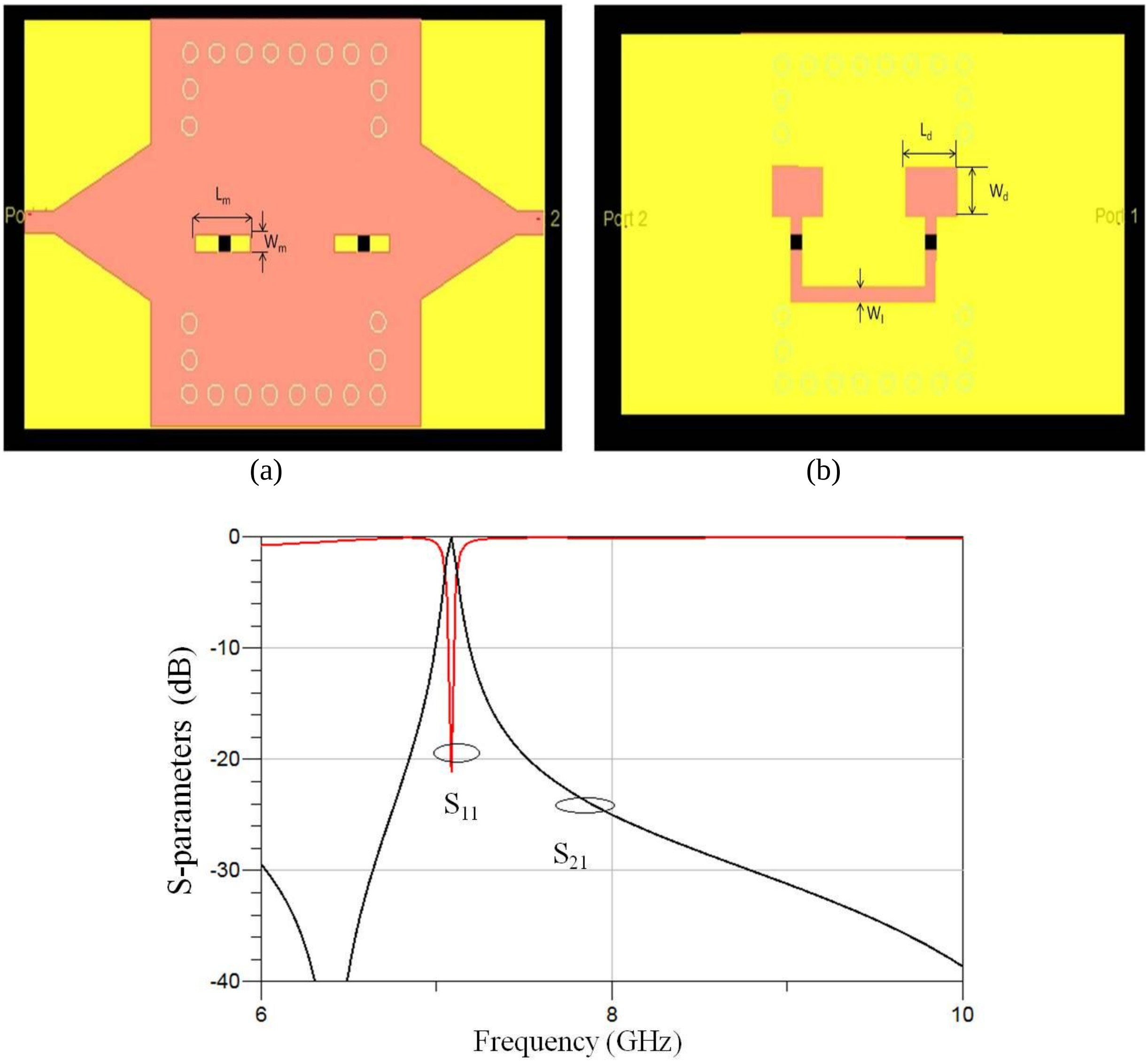


***Fig: 1.** Layout of the SIW cavity structure*

Fig.1 shows the layout of the proposed SIW cavity structure. The layout of the proposed SIW bandpass filter with DMS and DGS and its simulated S-parameters are shown in fig(2).The filter is designed by microstrip to SIW transition in order to reduce the leakage losses. Further optimization can be done by adding array of metallic via holes with diameter of 0.8mm on the SIW cavity.



(c)

Fig: 2. *Layout of the proposed filter. The geometrical parameters of the filter are* L_{eff}*=14mm,* W_{eff}*=16mm,*$W_{T=}$*6.1mm,*W_M*=0.9m,*L_T*=5.01m, d=0.8mm,P=1.4mm,* W_m *=0.64mm,* L_m *=2.8mm,* L_d *=2.8mm,* W_d*=2.2mm,* W_l*=0.73mm.. (a). Top view (b). Bottom view (c) Frequency response of the proposed filter*

Based on the proposed DGS structures, a non-uniform DGS unit is adopted to design the SIW bandpass filter. The shape of DGS proposed in this letter consists of a two square heads connected U-slot in the ground plane of the SIW cavity to further improve the stopband performance. The electric field distribution is more on the etched gap of the SIW structure, which eventually change the characteristics of transmission line such as line inductance and line capacitance. DGS are studied and adopted to suppress the spurious passband and to assign transmission zeros towards out of band signal. By using DGS there is a considerable improvement in passband ripple. Another technique called defected microstrip structure (DMS) is introduced by etching two horizontal rectangular slots in the middle of the conducting strips to provide the slow wave characteristics and to eliminate the undesired response in the desired frequency range. Similar to DGS, DMS increases the electrical length of the microstrip line and disturbs its current distribution which tends to increase the line inductance and capacitance. The DMS dimensions are chosen to obtain an optimum filter response.

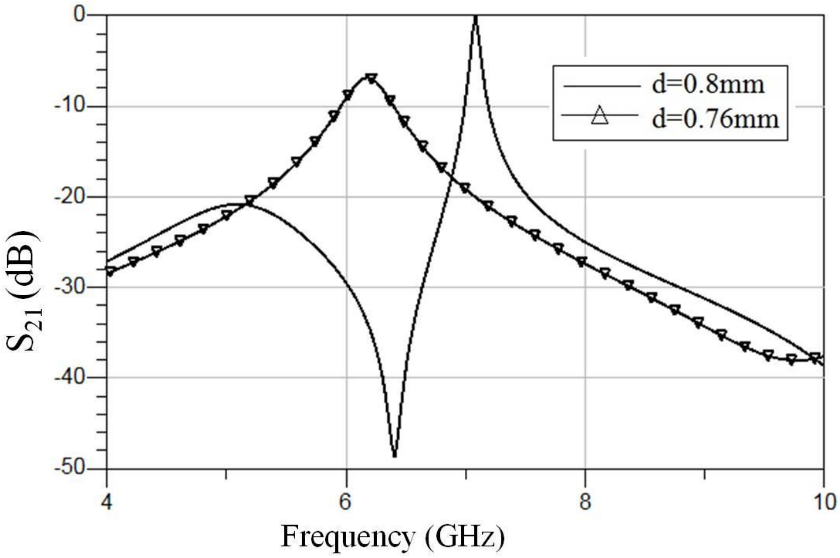


***Fig: 3.** Simulated frequency response of the proposed filter with two different via diameter*

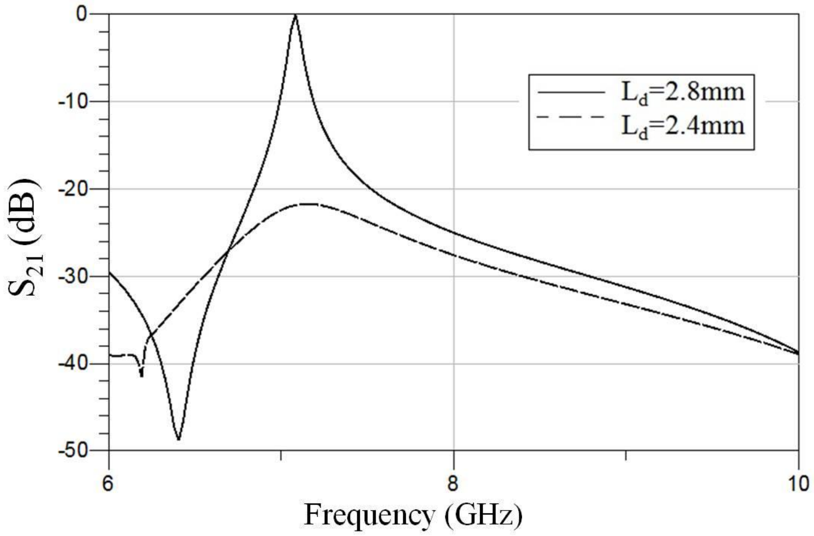


***Fig: 4.** Simulated S_{21} of the filter for varying length of DGS*

The simulated S_{21} is shown in fig.3. It can be seen that by reducing the via diameter the filter insertion loss gets minimum and also the passband gets shifted towards its lower frequency side. Fig.4 shows the simulated response of the filter by varying length of the DGS unit. It shows that by reducing the length of the DGS the

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condition of under coupling occurs with reduced insertion loss, such that the length of the DGS can be adjusted to optimized value to avoid under coupling in the filter response. In order to increase the out of band suppression, defected ground structure (DGS) can be applied to SIW. Further to improve the stopband performance the DMS can be applied on the top of the SIW cavity to produce finite passband and to obtain stopband attenuation upto -38dB. Fig.5 shows the simulated response of the proposed filter for varying length of DMS. From this it can be inferred that the passband of the filter moves towards its higher resonant frequency with its lower stopband attenuation gets reduced.

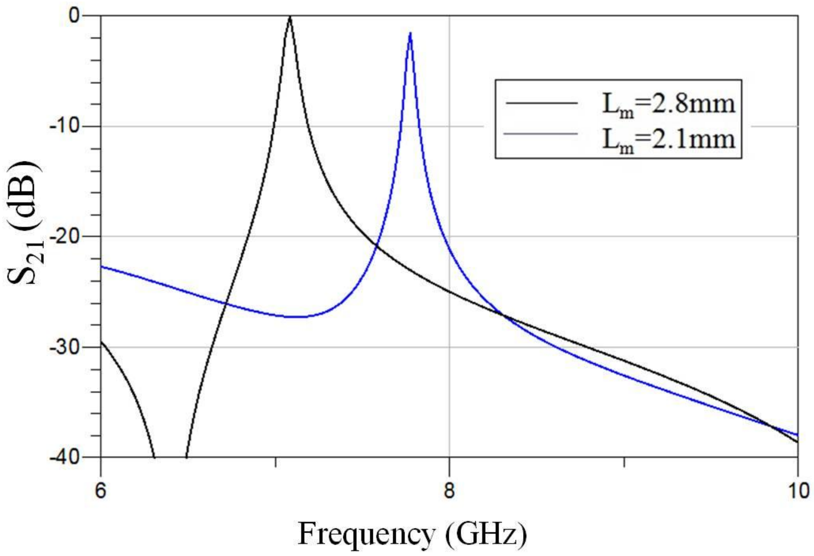

Fig: 5. *Simulated S_{21} of the filter for varying length of DMS*

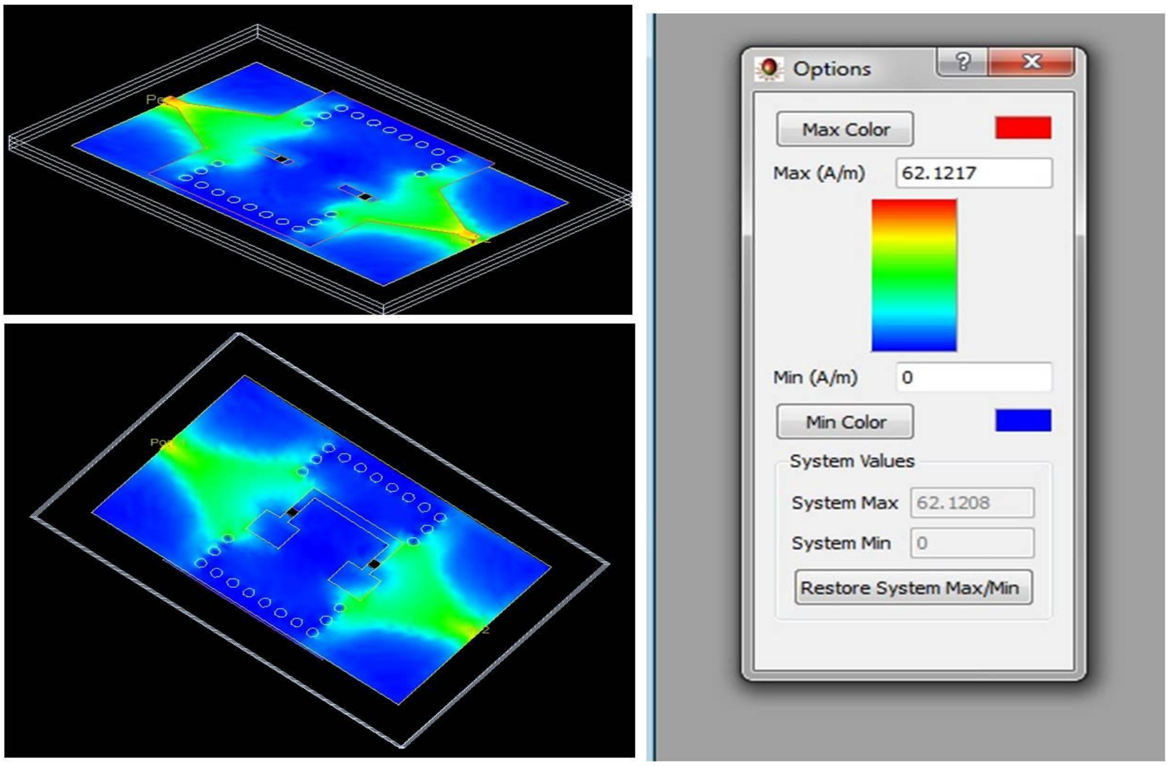

Fig: 6. *Field current distribution of the filter*

SIMULATED RESULTS

The proposed filter is developed on the Rogers substrate. The filter has total size of 26mm×16mm including input/output tapered microstrip lines. The 50Ω microstrip lines connected on both sides of the SIW cavity is used to produce a narrow bandwidth of the filter design. The results are verified using Advanced Design software(ADS) and the simulated results with center frequency of 7GHz, has insertion loss of 0.02dB, return loss of >20dB with 3-dB bandwidth of 2.8% and stopband attenuation is over 35dB/decade. The proposed filter has the advantage of lower insertion loss, good return loss and improved out of band rejection.

CONCLUSION

In this work, a novel DGS-DMS based SIW BPF is designed and analyzed. The structure with strong harmonic suppression has been presented based on the stopband behaviors of the DGS-DMS unit cells. The proposed filter shows lower insertion loss, good return loss and better stopband attenuation. The newly proposed DGS-DMS SIW BPF is more compatible and is used for satellite applications.

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Cite this article as:
Banu priya A, & Umma Habiba H. (2018). Design and Analysis of Compact SIW Bandpass Filter using DGS-DMS Technique for Satellite Applications. Journal of Analog and Digital Communications, 3(3), 7–13. http://doi.org/10.5281/zenodo.1465568

