Wideband Bandpass Substrate Integrated Waveguide (SIW) Filter for C Band Application

Amrita Dixit, Ashok Kumar, Ashok Kumar, and Arjun Kumar

Abstract This paper presents a substrate integrated waveguide (SIW) filter using electromagnetic band gap (EBG) structure. The periodic EBG structure is etched on the top metal surface of SIW cavity. These periodic structures create a slow wave effect on the filter performance to achieve wide pass band at lower frequency in a small compact size. In the proposed design, Rogers 4350 is used as a dielectric material with the permittivity(ε_r) of 3.48 and thickness 1.524 mm. The simulated results obtained by HFSS 19.1 has a broadband from 3.25 to 6.94 GHz with the bandwidth of 3.38 GHz in C band used for satellite communication. The insertion loss is less than 0.5 dB and return loss is better than 18 dB. The size of filter is 48 × 10 mm^2. The fractional bandwidth (FBW) of proposed filter is 68%.

Keywords Substrate integrated waveguide (SIW) filter · Wideband bandpass (WB-BPF) filter · Electromagnetic band gap (EBG)

1 Introduction

In present time modern communication systems for mobile and satellite applications required a high-performance RF/microwave filters with some important characteristics in terms of weight, cost, insertion loss, quality factor and power handling capability and it is a challenging task to meet all these requirements. SIW technique is growing candidate to fulfil all these requirements in past few decades. SIW technique is a transition of non-planar technology to planar technology. Using this technique, various RF components can be designed such as antenna[1], filter [2], diplexer [3, 4] power divider [5] etc. Microwave bandpass filter (BPF) is the most

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important component in wireless communication systems because it can control the spectrum of signals and reduce the interference problem.

U.S. federal communications commission (FCC) authorized the unlicensed use of ultra-wideband (UWB, from 3.1 to 10.6 GHz) for a variety of applications so wideband band pass filters are highly required in wireless communication systems. To design a wideband bandpass filter using SIW technique can be done with the help of various topologies to achieve required band of frequency. These topologies are electromagnetic band gap structures (EBGs) [6], defected ground structures (DGSs) [7–9], perforated sections (PSs) [10, 11] or different types of resonators including split ring resonators (SRRs) [12–15]. For the band pass behaviour of SIW filter, we can combine its characteristics as a high pass and a stop band characteristic as discontinuity. A bandpass filter with fractional bandwidth greater than 20% is known as wideband bandpass filter. In this paper, the fractional bandwidth is 68%, and it is in C band that can be used for satellite communication.

The SIW filter is based on dielectric filled waveguide shown in Fig. 1 with the difference of metal via as the side wall of waveguide to confine the electric field within the waveguide. The cut-off frequency of dielectric filled waveguide is shown in Eq. (1) [17].

$$f_c = \frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \tag{1}$$

For the fundamental mode TE_{10} the frequency is

$$f_c = \frac{c}{2a} \tag{2}$$

The width of dielectric filled waveguide is calculated by Eq. (3)

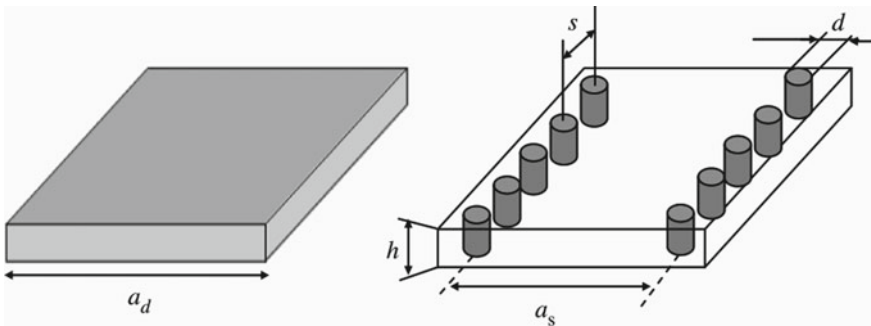$$a = \frac{a_d}{\sqrt{\varepsilon_r}} \tag{3}$$

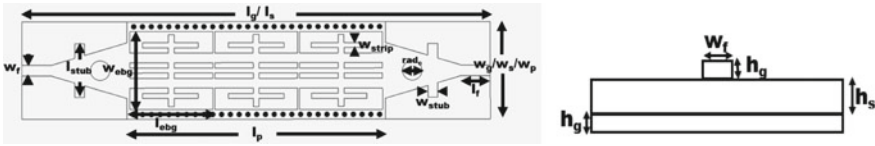**Fig. 1** Dielectric filled waveguide with SIW configuration. [16]

Fig. 2 Top and side view of proposed SIW filter with its dimension

From the Ref. [18] the SIW width is calculated by Eq. (4)

$$a_s = a - \frac{d^2}{0.95s} \tag{4}$$

In order to reduce, the radiation loss and return loss due to gap between via the following condition are required for SIW filter [18] shown in Eqs. (5) and (6), where d is the diameter of via and s is the pitch, i.e. distance between two via.

$$d \leq \frac{\lambda g}{5} \tag{5}$$

$$s \leq 2d \tag{6}$$

2 Proposed Wideband SIW Filter Configuration

As shown in Fig. 2 the SIW transmission line structure is a basic requirement of proposed wide band bandpass filter, which is constructed using a series of metallic via in the side structure with metal top and bottom. SIW structure is a transition of non-planar technology to planar technology. In this paper, SIW with EBG structure have been mixed to provide wideband filter at low frequencies. The present design is in the form of transmission line structure in which EBG structure is created by etching the periodic structure on the top metal layer of substrate. Figure 2 shows the top and side view of proposed design with all the parameters. All dimensions are shown in Table 1. The dielectric substrate used in the designing of filter is Rogers 4350 with the dielectric constant $\varepsilon_r = 3.48$, a loss tangent $\tan \delta = 0.004$ and the thickness is 1.524 mm. The overall dimension of filter is 48×10 mm^2.

3 Evolution of Proposed Design

In the above design, the loss less transmission line shown as $\beta = \omega(LC)^{1/2}$, where L and C are the series inductance and shunt capacitance. In this EBG structure, a slow

Table 1 All dimensions of proposed SIW WB-BPF

S. No.	Parameter	Dimension (mm)	S. No	Parameter	Dimension (mm)
1	l_g	48	8	l_f	3
2	w_g	10	9	w_f	1.1
3	h_g	0.07	10	l_{ebg}	8.5
4	l_p	26.5	11	w_{ebg}	8
5	w_p	10	12	l_{stub}	5.5
6	h_s	0.508	13	w_{stub}	1
7	d/s	0.25/0.8	14	Circle-rad	1

wave effect is generated due to increase in series inductance and shunt capacitance. As the evolution of design is started with the simple structure without any horizontal strips so the losses are more. When the horizontal strips are added in the design better response can be achieved because the periodic EBG structure create a simple L-C parallel resonant circuit shown in Fig. 3. The value of capacitance and inductance can be controlled by the number of horizontal thin lines and gap between the lines which can produce a stop band with a certain width. This stop band produces a wide pass band at low frequency. For improving the roll-off rate an open stub is used and finally a circle is etched in the tapered feed section to reduce the losses and increasing the bandwidth. In Fig. 4, the evolution of proposed filter is shown. The result of all designs is compared in Fig. 5 as return loss and Fig. 6 as insertion loss. It is easily identified that in a simple design without strips and open stub losses are very high and roll off rate in also very poor.
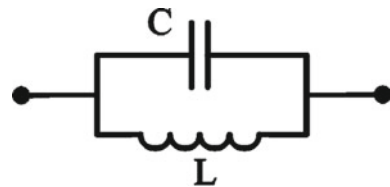
Fig. 3 L-C parallel resonant circuit

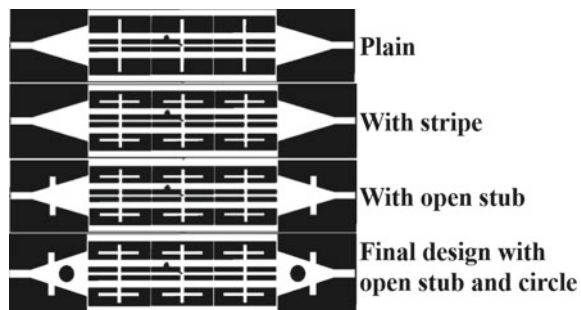**Fig. 4** Evolution of proposed SIW Filter
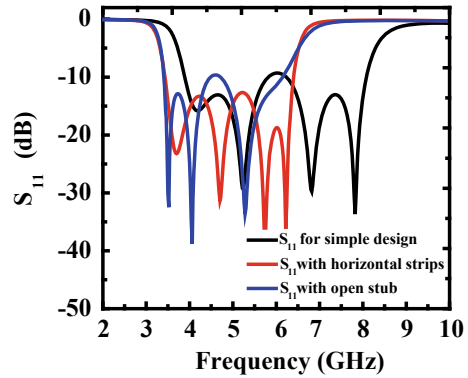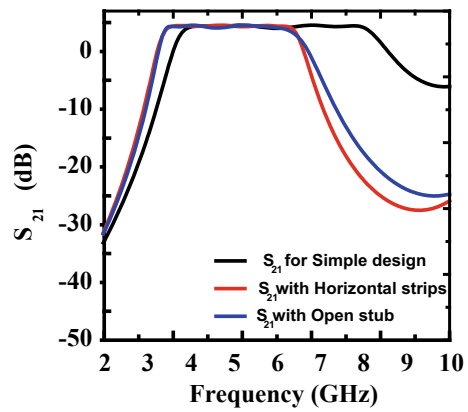
Fig. 5 Return loss of all designs

Fig. 6 Insertion loss of all designs

4 Result and Discussion

A wideband SIW BPF was designed in this paper with the help of periodic EBG structure, the initial specifications are shown in Table 1. Figure 7 shows the final simulation result of proposed design in which the insertion loss is less than 0.5 dB and the return loss is better than 18 dB. The proposed design is simulated using HFSS 19.1. The proposed design has a group delay of 0.46 ns in the passband which is very small as compared to previous published work shown in Fig. 8.

The result of proposed design is compared with the published work for the validation in Table 2. It is observed in this table that the fractional bandwidth (FBW) is 68% for the proposed design, whilst in other designs it is maximum 61%. The insertion loss is also very low for proposed design.

Fig. 7 Return loss and
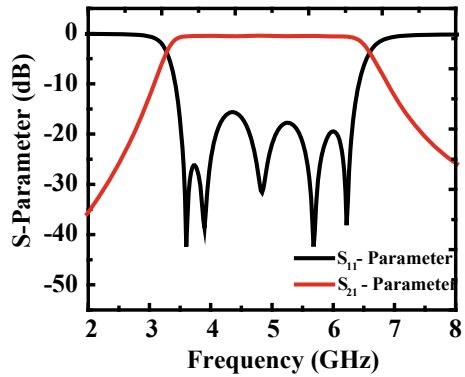insertion loss of proposed
design
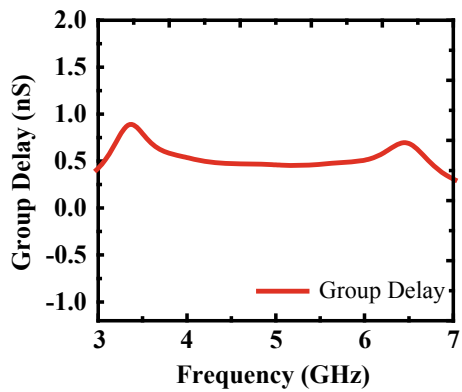

Fig. 8 Group delay of
proposed design

Table 2 Comparison between the designed SIW WB- BPF with other SIW BPF implemented using
EBG, DGS and resonators

References	Type-No. of cell	Design method	f_O (GHz)	FBW (%)	IL (dB)	RL (dB)	Size ($\lambda_O \times \lambda_O$)
[6]	EBG-11	Periodic structure	12.2	61.2	1.3	10	0.52 × 1.24
[19]	DGS-4	Band pass resonator	5.88	5.1	1.38	15	0.42 × 2.05
[20]	DGS-2	Band pass resonator	4.9	9.2	1.1	18	0.39 × 0.39
[21]	DGS-3	Stop band resonator	10	23	1.2	20	0.22 × 0.45
[11]	PS-5	Band pass resonator	3.65	17.7	1.31	18	0.21 × 0.98
This Work	EBG-3	Periodic structure	4.95	68	0.5	16	0.11 × 0.52

5 Conclusion

A wideband bandpass substrate integrated waveguide (SIW) filter using periodic electromagnetic band gap (EBG) structure has been designed and simulated in this paper. The proposed design has a broad band extends from 3.25 GHz to 6.94 GHz with the bandwidth of 3.38 GHz and a centre frequency of 5 GHz. The group delay is 0.46 nS in the passband. Due to the mixed feature of EBG and SIW a compact wideband band pass filter is designed with the fractional bandwidth (FBW) of 68%. This passband is coming in C band used for satellite communication.

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