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Planar and Angular Modified Substrate Integrated Waveguide (SIW) Filter with Electromagnetic Bandgap(EBG) Structures

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Planar and Angular Modified Substrate Integrated Waveguide (SIW) Filter with Electromagnetic Band-Gap (EBG) Structures

S. Moitra [α], R. Dey [σ] & H. Kumar [ρ]

Abstract- Designing of 180° linear full mode substrate integrated waveguide(FMSIW) filter and a new type of FMSIW filter bent with 90° angle have been proposed in this paper with a new type of Electromagnetic bandgap structure, etched on the PEC surface (upper layer) of the main structures to obtain the bandpass characteristics. Insertion loss is effectively low for both (180° FMSIW and 90° bent FMSIW) filters due to this distinct type of EBG structures. Outcomes of Parametric analysis of the EBG structures have also been studied and presented in graphical form. Entire experiments have been done with Neltec (NH-9320), the dielectric constant of 3.2 and thickness of 0.8 mm. Proposed filters in this paper are used for microwave Ku band applications. Both bandpass filters are compact in size, low in cost and easy to fabricate. Moreover, 90° bent filters are more convenient in use where the linear filters are restricted.

Keywords: 180° linear FMSIW filter, 90° bent FMSIW filter, Ku-band, insertion loss (IL), EBG structure.

I. Introduction

Rapid development in planer components is a result of growing interest in the field of wireless component design. An effective approach in designing passive microwave component is the substrate integrated waveguide (SIW) technology. In SIW dielectric material is sandwiched between two metal conducting plates and series of vias are inserted in the other two sides thus forming a rectangular waveguide-like structure modified in planer form [1]. SIW inherits almost all of the advantages of conventional rectangular waveguide like low insertion loss, high power handling capability in the microwave band and high-quality factor. Most of the properties of SIW like dispersion characteristics, propagation constant and field pattern are similar to that of waveguide counterparts. Several passive components like antennas, filters, power dividers and couplers are designed in the recent past using the manifold benefits of SIW. Several filters [2], couplers [3], oscillators [4], slot array antennas [5], six-port circuits [6], and circulators [7] are proposed since then.

In this paper, a conventional(linear) and a 90° bent full mode SIW (FMSIW) bandpass filter embedded with new type of Electromagnetic Bandgap Structures are proposed, which exhibits the bandpass property of the microwave Ku-band.

For designing high Q-factor and low loss filters, SIW which is realized by metallic vias on low loss substrates through printed circuit board is proved to be a useful technology [8]-[10]. In SIW fabrication process takes place with using two rows of conducting cylindrical vias embedded in a dielectric substrate that connects two parallel metal plates, and permit the implementation of a classical rectangular waveguide components in planar form, along with several printed passive circuitry, active devices and antennas as shown in Fig. 1.

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II. Design Equations

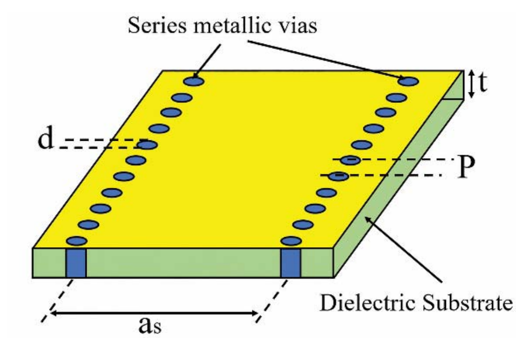

Fig. 1: Layout of Basic SIW structure realized on a dielectric substrate (a_s=effective width of SIW section, p=center to center gap between vias 'pitch', d=diameter of metallic vias and t=thickness of dielectric material).

The basic design formulations for designing an SIW filter are as follows:

$$a_s = a_d - \frac{d^2}{0.95p} \qquad \text{………..} (1)$$

where, a_s is the separation between via rows (center to center), a_d is the width of the structure, d is the diameter, p is the pitch (as shown in Figure 1). The cut-off frequency of the SIW can be obtained by the following relation.

$$f_c = \frac{c}{2\varepsilon_r . a_s} \qquad \text{………..} (2)$$

Where c is the velocity of light in vacuum.

III. Designing of 180° Bent FMSIW Bandpass Filter

a) 180° FMSIW Filter Design Without EBG Structures

Fig 2. and Fig 3. shows the basic 180° FMSIW structure used in designing the bandpass filter and the high pass characteristic of the basic structure respectively.

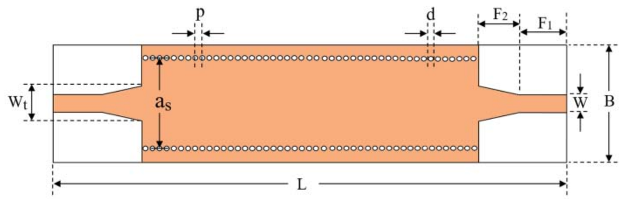

Fig. 2: Basic structures of 180° FMSIW filter (All dimensions are in mm).

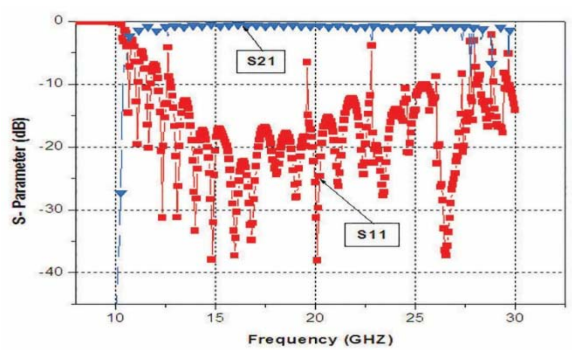

Fig. 3: Scattering Parameters of basic 180° FMSIW filter as designed on a substrate dielectric constant of 3.2 and 0.8mm thickness.

b) 180° FMSIW Filter Design With EBG Structures

The basic 180° FMSIW structure which is shown in Fig 2. acts as a high pass transmission line section. Tapered section between micro strip feed line and SIW section [14] avoids the impedance mismatch and designed as for 50Ω impedance matching. In this paper, implementation of introduced new type of EBG structures on the linear (180°) FMSIW filter creates additional resonance within the structure. Thus a considerable stop band attenuation arises in the range of Ku band with a transmission band of minimum insertion loss. The parametric analysis of EBG elements on the 180° FMSIW structure shows that the magnitude and frequency of the stop band attenuation is highly dependent on the dimension of the EBG elements. Fig 4. and Fig 5. shows the EBG loaded 180° FMSIW filter and its transmission characteristics respectively. Basic dimensional calculations can be obtained from [8].

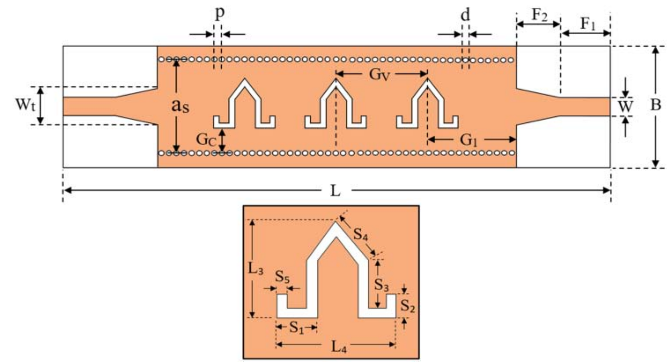

Fig. 4: 180° FMSIW bandpass filter with EBG realized on a dielectric substrate

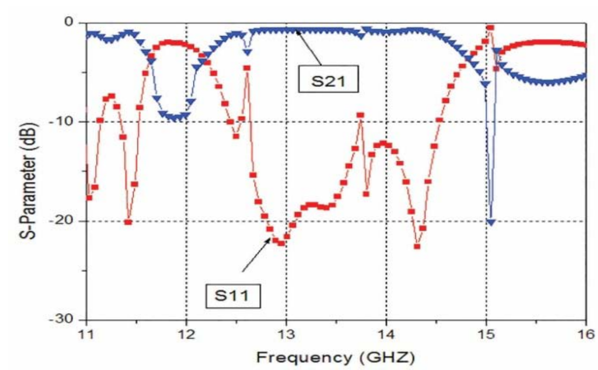

Fig. 5: Scattering Parameters of 180° FMSIW filter with EBG slots as designed on a substrate dielectric constant of 3.2 and 0.8mm thickness.

Introduction of EBG in 180° FMSIW results in production of transmission zero at around 15.04GHz, which complies the range of microwave Ku-band. The range of obtained passband is from 12.44 GHz to 14.53GHz with a minimum insertion loss of 0.71 dB. The E-field of the 180 FMSIW bandpass filter is shown in Fig 6

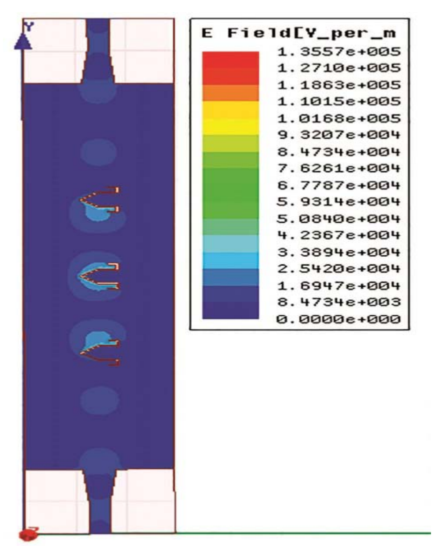

Fig. 6: E-Field distribution of EBG loaded 180° FMSIW bandpass Filter at 13.5 GHz.

Table 1: Dimensions of the 180° FMSIW filter.

Sl No.	Parameters	Without EBG Structure (mm)	With EBG Structure (mm)
1.	L	80 mm	80 mm
2.	t	0.8 mm	0.8 mm
3.	W	2.1 mm	2.1 mm
4.	B	14.6 mm	14.6 mm
5.	Wt	3.22 mm	3.2 mm
6.	F1	5 mm	5 mm
7.	F2	5 mm	5 mm
8.	d	0.6 mm	0.6 mm
9.	P	1 mm	1 mm
10.	as	8.6 mm	8.6 mm
11.	H	3 mm	3 mm
12.	S1	–	1 mm
13.	S2	–	1 mm
14.	S3	–	1.8 mm
15.	S4	–	1.2 mm
16.	S5	–	0.2 mm
17.	L3	–	4.29 mm
18.	L4	–	4 mm
19.	Gv		13.86 mm

Table 2: Performance of FMSIW Filter.

Parameters	180° FMSIW with EBG
Insertion Loss	0.66
Transmission Bandwidth	2.59 GHz
S11 (dB)	>10
S21 (dB)	<1.3
Lower Cut-off frequency ‘f_L’	12.12 GHz
Higher Cut-off frequency ‘f_L’	14.71 GHz

IV. Designing of 90° Bent FMSIW Bandpass Filter

a) 90° FMSIW Filter Design Without EBG Structures

In this paper, transformation of 180° FMSIW into 90° FMSIW structure was provided. For better transmission, greater bandwidth and low insertion loss the outer via series have been additionally bent in two points P_1 and P_2 by 45°. These 90° FMSIW structures exhibit similar properties with TE_{10} mode of propagation as in SIW. Fig 7. and Fig 8. shows the basic 90° FMSIW structure used in designing the bandpass filter and the high pass characteristic of the proposed structure respectively.

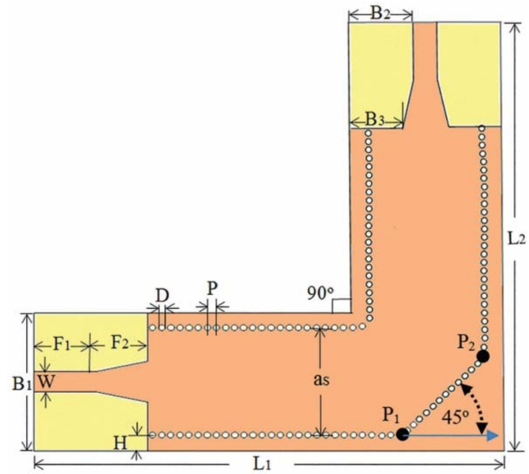

Fig. 7: Basic structures of 90° FMSIW filter (All dimensions are in mm).

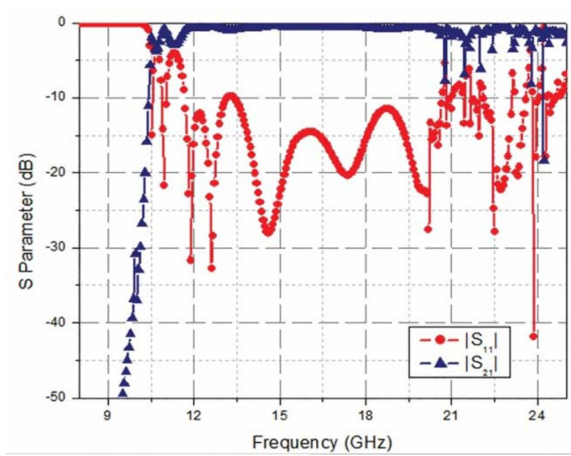

Fig. 8: Scattering Parameter of 90° FMSIW filter as designed on substrate dielectric 3.2 and thickness of 0.8mm.

a) 90° FMSIW Filter Design with EBG Structures

In this section, we have induced the EBG structures in the basic 90° FMSIW structure. In the middle section of the basic structure extra resonance will produce for bending of via rows. Thus, for etching the EBG structure denoted with ‘M’ in the middle region effective result will produce in terms of band width and isolation in microwave Ku band region as shown in Fig 10. Fig 9. and Fig 10. defines the EBG loaded 90° FMSIW BPF and its transmission characteristics respectively. E-field of FMSIW bandpass filter is shown in Fig.11.

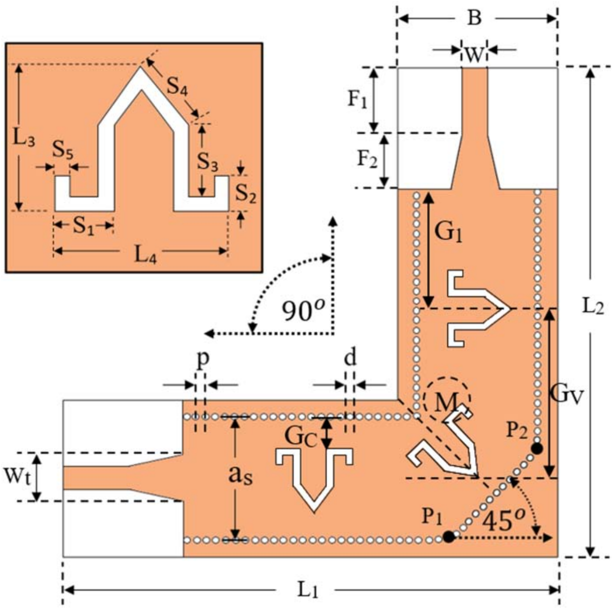

Fig. 9: 90° FMSIW bandpass filter with EBG realized on a dielectric substrate.

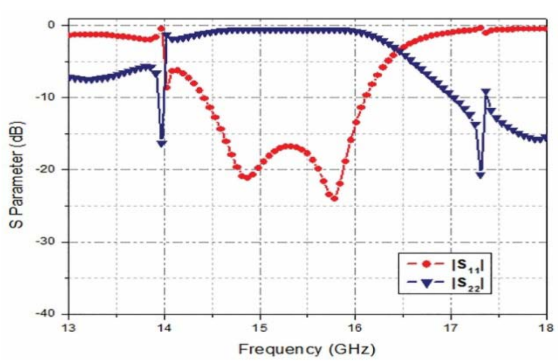

Fig. 10: S-Parameter of 90° FMSIW bandpass Filter with EBG.

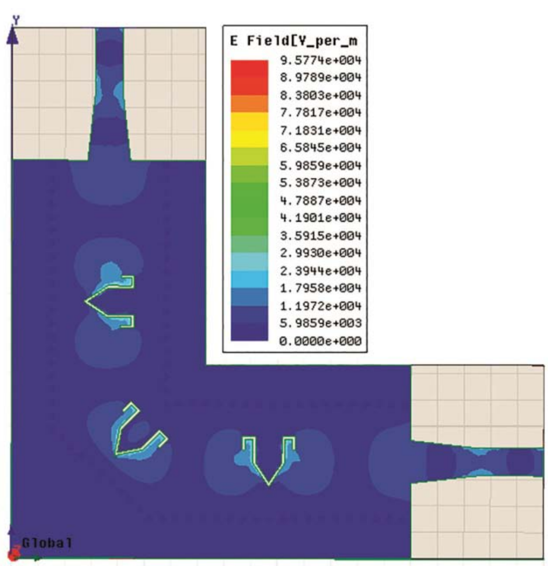

Fig. 11: E-Field of 90° FMSIW bandpass filter(15.5 GHz) with EBG realized on a dielectric substrate.

Table 3: Dimensions of the 90° bent FMSIW filter.

Sl No.	Parameters	Without EBG Structures (mm)	With EBG Structures (mm)
1.	L1	40 mm	40mm
2.	L2	40 mm	40 mm
3.	t	0.8 mm	0.8 mm
4.	W	2.1 mm	2.1 mm
5.	B	14.6 mm	14.6 mm
6.	Wt	3.22 mm	3.2 mm
7.	F1	5 mm	5 mm
8.	F2	5 mm	5 mm
9.	D	0.6 mm	0.6 mm
10.	P	1 mm	1 mm
11.	as	8.6 mm	8.6 mm
12.	H	3 mm	3 mm
13.	S1		1 mm
14.	S2		1 mm
15.	S3		1.8 mm
16.	S4		1.2 mm
17.	S5		0.2 mm
18.	L3		4.29 mm
19.	L4		4 mm
20.	Gv		7.9 mm

Bending of 180° FMSIW bandpass filter to 90° FMSIW filter results in the production of transmission zero at around 17.31GHz with a transmission bandwidth lies in the range of microwave Ku-band. The range of obtained passband is from 14.61GHz to 15.97GHz with a minimum insertion loss of 0.58 dB.

Table 4: Performance of 90° bent FMSIW Filter.

Parameters	90° FMSIW with EBG
Insertion Loss	0.58
Transmission Bandwidth	1.36 GHz
S11 (dB)	>15
S21 (dB)	<1.3
Lower Cut-off frequency 'f_L'	13.97 GHz
Higher Cut-off frequency 'f_U'	17.31 GHz

V. Parametric Analysis of EBG Structures

Microwave bandpass filter requires productive analysis of the technique to make the design effective. Several useful parameters of EBG elements are varied and the output is studied in details in this paper. Effective size of the EBG elements 'S_5' and the distance between successive EBG elements 'G_v' are studied. These parameters are found to have significant effect over the insertion loss, transmission band and isolation of the filter configurations.

a) Parametric Analysis of EBG Structures Induced In 180° FMSIW Band Pass filter

The effect of varying the distance of the EBG section 'G_v' with the transmission bandwidth is shown in Fig 10. It has been observed that the transmission bandwidth increases when the variation of distance takes place from 13.65mm to 13.75mm but the bandwidth decreases as we increase the distance between the EBG structures up to 13.95mm.

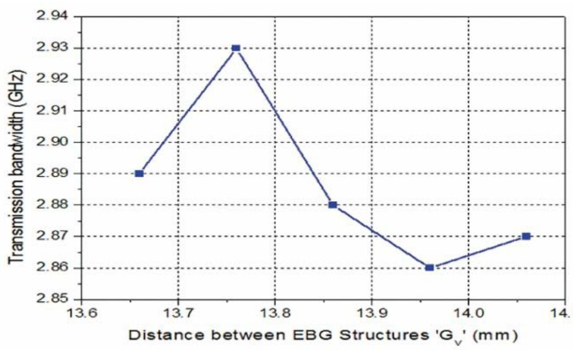

Fig. 12: Distance between EBG structures vs. Transmission Bandwidth of 180° FMSIW filter.

The distance vs. Stop band attenuation of the EBG structures is also studied to achieve greater control over the passband and loss characteristics. Fig 11. represents the variation which conveys that the stop band decreases from 16.59dB to 9.3dB as the distance increases from 13.66mm to 13.76mm but after 11.76mm the stop band attenuation increases with varying the distance by 0.1mm.

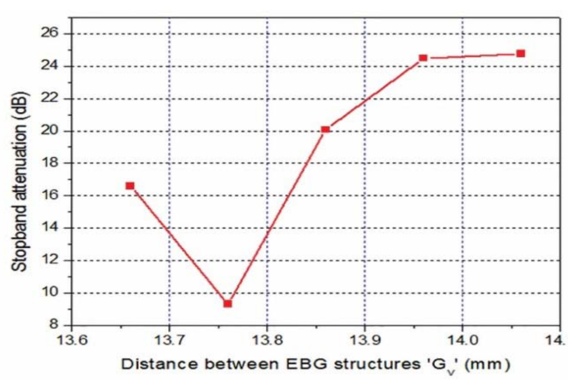

Fig. 13: Distance between EBG structures vs. Stop Band Attenuation of EBG structure of 180° FMSIW Filter.

The size of the EBG structures 'S_5' is also varied to achieve the size of EBG structure vs. transmission bandwidth and size of EBG structure vs. stop band attenuation graph to obtain greater control over passband and loss characteristics. Fig 12. shows the Size of EBG structure vs. Transmission bandwidth of EBG element. A clear observation is there that the transmission bandwidth slightly decreases when the size of the EBG element increases from 0.1mm to 0.2mm and again increases by small value when the size is increased to 0.3mm and gradually decreases as the size increases by 0.4mm.

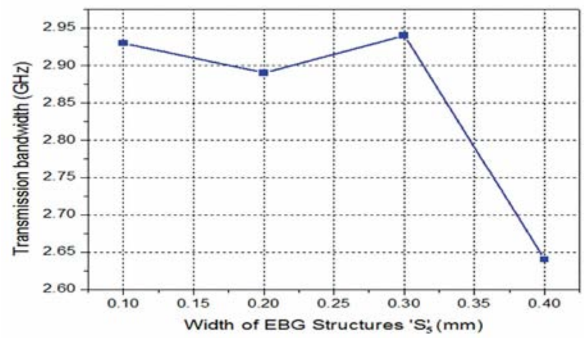

Fig. 14: Size of EBG structures vs. Transmission Bandwidth of 90° FMSIW Filter.

Fig 13. defines the size of EBG structures vs. Stop band attenuation. A clear observation is there that the stop band attenuation increases as the size increases from 0.1mm to 0.2mm but decreases as the size of EBG structure increased further.

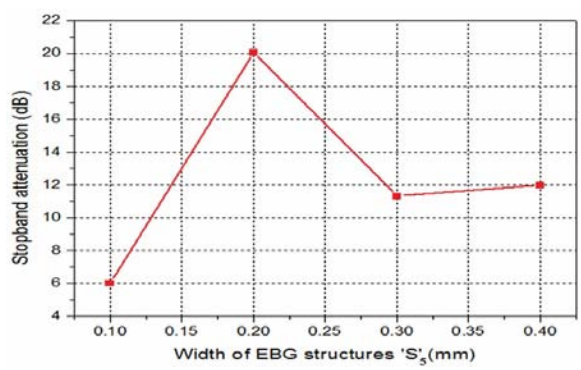

Fig. 15: Size of EBG structures vs. Stop Band Attenuation of 90° FMSIW Filter.

a) Parametric Analysis of EBG Structures Induced In 90° bent FMSIW Band Pass filter

The effect of varying the distance of the EBG section 'G_v' with the transmission bandwidth is shown in Fig 14. It has been observed that the transmission bandwidth is constant in a distance from 11.58mm to 11.61mm but the bandwidth decreases by 0.05 GHz as the distance increases to 11.62mm.

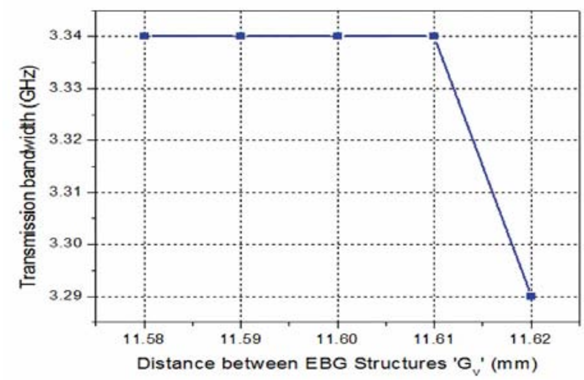

Fig. 16: Distance between EBG structures vs. Transmission Bandwidth of 90° FMSIW filter.

The distance vs. Stop band attenuation of the EBG structures is also studied to achieve greater control over the passband and loss characteristics. This variation is there in Fig 15. which shows that the stop band decreases from 28.63dB to 20.64dB as the distance increases from 11.58mm to 11.59mm but after 11.60mm the stop band attenuation increases with distance varying with 0.01mm.

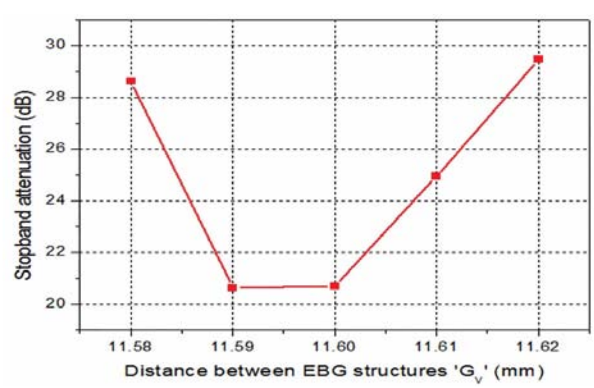

Fig. 17: Distance between EBG structures vs. Stop Band Attenuation of EBG structure of 90° FMSIW Filter.

The size of the EBG structures ‘S_5’ is also varied to achieve the Size of EBG structure vs. Transmission bandwidth and size of EBG structure vs. Stop band attenuation graph to achieve greater control over pass band and loss characteristics. Fig 16. shows the size of EBG structure vs. transmission bandwidth of EBG element. It can be reveals that the transmission bandwidth increases when the size of the EBG elements raises from 0.2mm to 0.3mm.

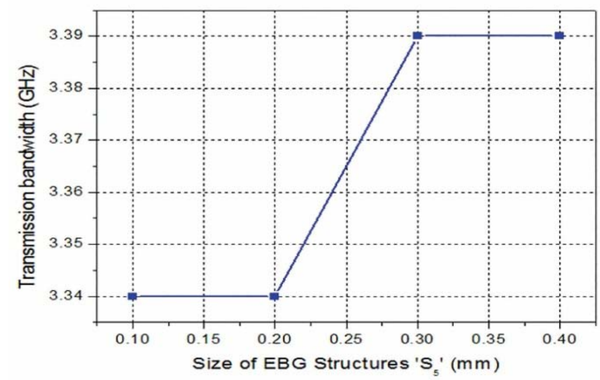

Fig. 18: Size of EBG structures vs. Transmission Bandwidth of 90° FMSIW Filter.

Fig 17. represents the variation graph of the Size of EBG structures and Stop band attenuation. It can be observe that the stop band attenuation decreases from 0.1mm to 0.2mm but increases as the size of EBG structure increases from 0.2mm to 0.4 mm.

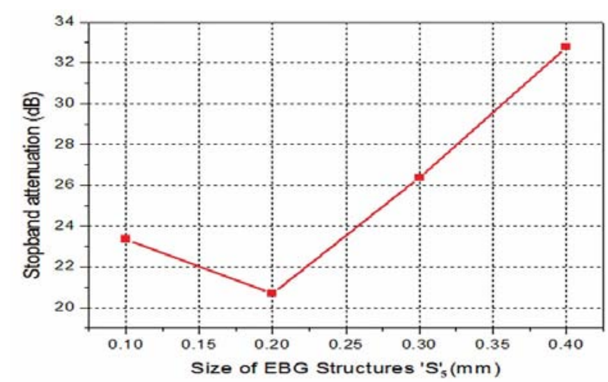

Fig. 19: Size of EBG structures vs. top Band Attenuation of 90° FMSIW Filter.

Table 2. and Table 4. represents simulated outcomes of the linear (180°) and 90° bent FMSIW filters respectively. Based on the parametric analysis presented in this paper, successfully achieves good filter performance like minimum loss and high isolation property.

VI. Conclusion

In this article, a brief discussion is there for obtaining the bandpass characteristics of 180° FMSIW filter and 90° FMSIW filter. 180° FMSIW filter loaded with EBG structures bent down to 90° and analyzed the bandpass characteristics for obtaining the desired passband. Bending of 180° FMSIW filter to 90° FMSIW filter and implementation of EBG structures on both designs are found to serve the purpose quite effectively. For better understanding, a detailed presentation for the analyses of several useful parameters of the EBG elements is there. Additionally, with bending the linear filter, length has been decreased. Thus, 90° bent filters are more flexible than linear 180° filters regarding the use and bandpass characteristics. Distance and size of

EBG elements can be chosen to achieve a better result. In future, both filters can be used for such applications (radar and remote sensing operations) which complies the range of Ku band. Moreover, 90° bent filters have the advantage to minimize the space complexity using its bending strategy and novel passband characteristics. Both designs are simple and easy to fabricate in the presence of advanced fabrication technology.

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