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Parametric study of different shapes-slotted substrate integrated waveguide for wideband applications

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***Abstract*— On the way to design Substrate Integrated Waveguide Bandpass Filter (SIW-BPF) for wideband applications a parametric study of the slot geometry etched on a SIW structure is the preliminary step to design such filter.**
Three different structures, namely, H-Slotted, T-Slotted, and U-Slotted SIW is investigated in order to examine the effect of altering different geometrical parameter of the unit on its response. H-Slotted Electromagnetic Band Gap (EBG) shows the highest Fractional Band Width (FBW), which is about 90% compared to the others, consequently it could be used to design a wideband SIW-BPF.

Keywords—Bandpass filter (BPF); substrate integrated waveguide (SIW); electromqgnetic band gap structure (EBG); Wideband; High Frequency Electromagnetic Field Simulation (HFSS).

I. INTRODUCTION

Most of the modern communication systems bring about the requirement of compact size, low cost, and low profile while maintaining high performance and by guaranteeing a vertical roaming between different applications.

Microwave filters are key components in modern communication systems. Different microwave components have been used in the design of microwave filters such as transmission lines, micro-strip, coplanar waveguide (CPW) and rectangular waveguide. However, they do not satisfy the requirement of modern communication systems and they are not suitable for easy integration. Substrate integrated waveguide (SIW), also named Laminated has been used in microwave and millimeter-wave component design as described by others [1–4].

Compared to conventional waveguide, SIW based components are of low cost fabrication, compact size, and present an easy integration with other microwave and millimeter-wave components, which they are assured by keeping the same advantages of the rectangular waveguide [5].

Recently, electromagnetic band gap (EBG) which was only used in photonic application, started to become popular in other microwave and millimeter-wave application, and thus, they started to be used in the design of microwave and millimeter-wave components such as filters [6].

In a previous work, an S-Slotted EBG based SIW-BPF was designed and showed a fractional bandwidth of 7.31% [7]. Another U-Slotted EBG based SIW-BPF was presented in a different report, which showed a fractional bandwidth of 42% [8]. The necessity to extend the bandwidth is a dire need. A comparative parametric study between H-, U- and T-slotted EBG is performed in the current work. Therefore, the alteration of different geometrical parameters of the unit's effect on its response is also examined.

This paper is structured as follows: Section 2 presents the theory of SIW Structure and EBG. In Section 3, the effect of H-, U- and T-Slotted cells on the SIW structure performance is discussed. Finally, Section 4 is dedicated to the conclusion.

II. THEORICAL BACKGOUND

A. Substrate Integerd Waveguide (SIW)

SIW is a periodic structure based on a dielectric substrate with linear arrays of metallic vias [10, 11]. The studies of microwave components based on SIW such as filters showed that SIW presents a very promising performance in the design of microwave and millimeter-wave components. The SIW must be free from any radiation loss and in order to ensure that, the effects of the spacing S and the diameter D was investigated [5], and the design rules for SIW was fixed as follows:

$$\frac{S}{D} < 2 \quad and \quad \frac{D}{W} < \frac{1}{5}\,\frac{0.1D^2}{W} \tag{1}$$

Following this rule and based on analysis, we can see that the performance of SIW is the same as a conventional rectangular waveguide. However, the SIW presents a compact size with an equivalent width Weff compared with the conventional rectangular waveguide. Equations of the effective width and the cutoff frequency have been presented in [12] and [13], as follows

$$W_{eff} = W - \frac{1.08D^2}{S} + \frac{0.1D^2}{W} \quad (2)$$

$$F_{TE10} = \frac{c}{2Weff * \sqrt{\varepsilon r}} \quad (3)$$

From this, realization methods of an SIW can be based on a conventional rectangular waveguide, and by means of (2) and (3) the SIW structure parameter design is obtained. The design procedure is summarized as follows:

- Step 01: Select $\frac{S}{D} < 2$
- Step 02: Select $\frac{D}{W} < \frac{1}{5}$
- Step 03: Calculate W*eff* according to the operating frequency by solving (3).
- Step 04: Calculate W by solving (2).
- Step 05: Calculate D and S according to $\frac{D}{W} < \frac{1}{5}$ and $\frac{S}{D} < 2$

B. *Electromagnetic Band Gap (EBG)*

When an electromagnetic wave is transmitted, an echo dispersion occurs in a periodic medium structure. The complex structure, which presents this characteristic, is named electromagnetic bandgap structures-EBG.

The size and occurrence of the bandgap structure are the basic parameter in the EBG structure application. Relative permittivity of the medium and the size of EBG cell control the bandstop characteristic of EBG.

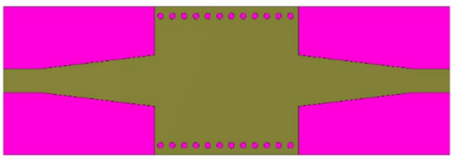

Fig.1. Configuration of conventional SIW.

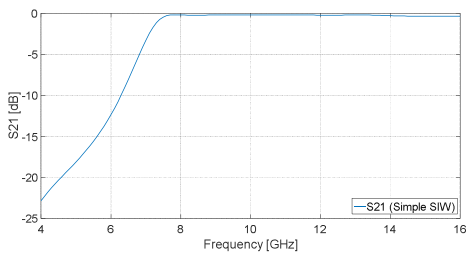

Fig.2. Simulated results of S-Parameter (Simple SIW)

III. ANLYSIS OF DIFFERENTSHAPES SLOTTED SIW

Different shapes slotted SIW circuits are examined. One dimension each time is varied while the other dimensions are kept constant to realize the influence of that parameter on the overall performance of the structure.

The geometrical dimensions of each structure under study are depicted in Fig.3.

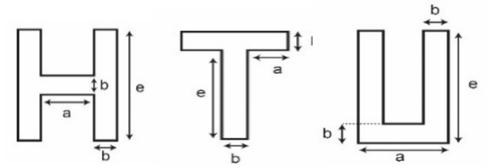

Fig.3. H-, U- and T-Slotted Structures.

A. *H-Sloted Structure:*

The starting geometrical values of the H-shaped slotted SIW is listed in Table I.

TABLE I. STARTING GEOMETRICAL VALUES OF THE H-SHAPED SLOTTED SIW

a	***b***	***e***
2.4mm	0.9mm	5.8mm

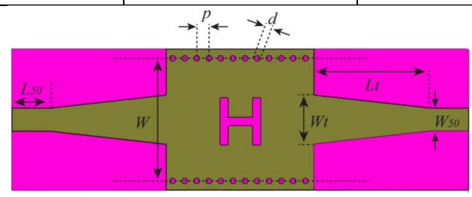

Fig.4. Configuration of H-Slotted SIW

The impact of altering the *a*, *e*, and *b* dimensions are listed in Tables II, III, IV respectively. Our simulation results show that decreasing the *a* and *e* parameters increases the FBW, as shown in Figs. 5 and 6. Furthermore, the decrease in the *b* parameter decreases the FBW, as depicted in Fig. 7.

TABLE II. EFFECT OF THE PARAMETER (A)

Changing Parameter	*Frequency Bandwidth*	*Center Frequency*	*FBW*
a1 (2.4mm)	[7.38GHz – 17.35GHz]	12.36 GHz	80.66%
a2 (2.2mm)	[7.39GHz – 17.49GHz]	12.44 GHz	81.18%
a3 (2.0mm)	[7.39GHz – 17.77GHz]	12.58 GHz	82.51%

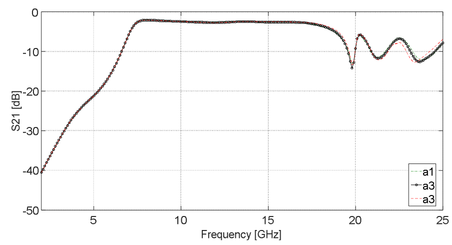

Fig.5. S21 [dB] Simulated results for H-slotted SIW with varied 'a'

TABLE III. EFFECT OF THE PARAMETRE (E)

Changing Parameter	*Frequency Bandwidth*	*Center Frequency*	*FBW*
e1 (5.8mm)	[7.38GHz – 17.35GHz]	12.36 GHz	80.66%
e2 (4.8mm)	[7.35GHz – 19.30GHz]	13.32 GHz	89.71%
e3 (3.8mm)	[7.31GHz – 19.46GHz]	13.38 GHz	90.80%

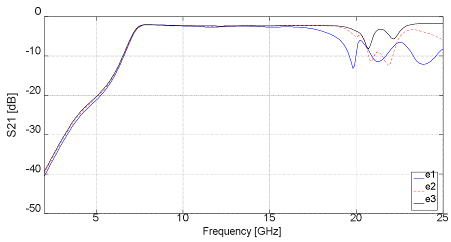

Fig.6. S21 [dB] Simulated results for H-slotted SIW with varied 'e'

TABLE IV. EFFECT OF THE PARAMETRE (B)

Changing Parameter	*Frequency Bandwidth*	*Center Frequency*	*FBW*
b1 (0.9mm)	[7.35GHz – 17.35GHz]	12.35 GHz	80.97%
b2 (0.8mm)	[7.37GHz – 17.24GHz]	12.30 GHz	80.24%
b3 (0.7mm)	[7.35GHz – 17.00GHz]	12.17 GHz	79.29%

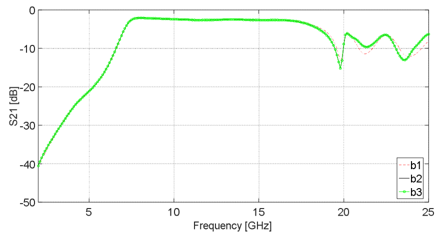

Fig.7. S21 [dB] Simulated results for H-slotted SIW with varied 'b'

B. U-Sloted Structure :

The starting geometrical values of the U-shaped slotted SIW is listed in Table V.

TABLE V. STARTING GEOMETRICAL VALUES OF THE U-SHAPED SLOTTED SIW

a	*b*	*e*
2.4mm	0.9mm	5.8mm

The impact of altering the *a*, *e*, and b dimensions are listed in Tables VI, VII, VIII respectively. For this slotted shaped structure, decreasing the *a* and *e* parameters increases the FBW as shown in Figs. 8 and 9. Furthermore, the decrease in the b parameter decreases the FBW as depicted in Fig. 10.

TABLE VI. EFFECT OF THE PARAMETER (A)

Changing Parameter	*Frequency Bandwidth*	*Center Frequency*	*FBW*
a1 (2.4mm)	[7.33GHz – 9.60GHz]	8.46 GHz	26.83%
a2 (2.2mm)	[7.35GHz – 9.96GHz]	8.65 GHz	30.17%
a3 (2.0mm)	[7.38GHz – 10.42GHz]	8.9 GHz	34.15%

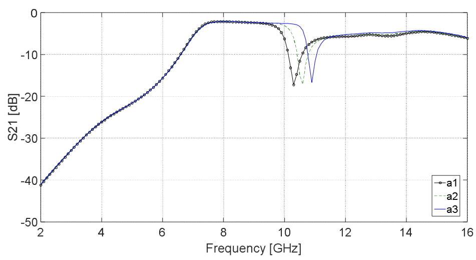

Fig.8. S21 [dB] Simulated results for U-slotted SIW with varied 'a'

TABLE VII. EFFECT OF THE PARAMETRE (E)

Changing Parameter	*Frequency Bandwidth*	*Center Frequency*	*FBW*
e1 (5.8mm)	[7.33GHz – 9.60GHz]	8.46 GHz	26.83%
e2 (4.8mm)	[7.33GHz – 11.54GHz]	9.43 GHz	44.64%
e3 (3.8mm)	[7.31GHz – 12.93GHz]	10.12 GHz	55.53%

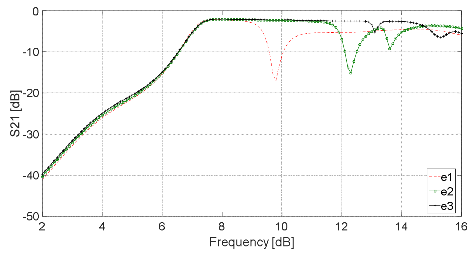

Fig.9. S21 [dB] Simulated results for H-slotted SIW with varied 'e'

TABLE VIII. EFFECT OF THE PARAMETRE (B)

Changing Parameter	*Frequency Bandwidth*	*Center Frequency*	*FBW*
b1 (0.9mm)	[7.33GHz – 9.60GHz]	8.46 GHz	26.83%
b2 (0.8mm)	[7.29GHz – 9.30GHz]	8.29 GHz	24.24%
b3 (0.7mm)	[7.26GHz – 9.00GHz]	8.13 GHz	21.40%

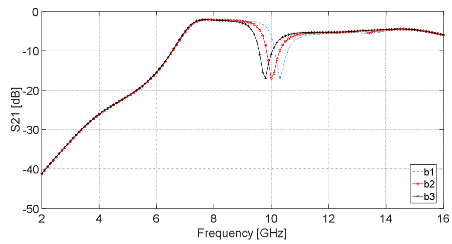

Fig.10. S21 [dB] Simulated results for U-slotted SIW with varied b'

C. T-Sloted Structure :

The starting geometrical values of the U-shaped slotted SIW is listed in Table IX.

TABLE IX. STARTING GEOMETRICAL VALUES OF THE T-SHAPED SLOTTED SIW

a	*b*	*e*
2.4mm	0.9mm	5.8mm

The impact of altering the *a*, *e*, and *b* dimensions are listed in Tables X, XI, and XII respectively. For the T-shaped slotted, the simulation results shows a different pattern, decreasing *a* parameter reduce the FBW (Figs.11). In addition, *e* and *b* parameters, reduction, increase FBW as shown in Figs. 12 and 13.

TABLE X. EFFECT OF THE PARAMETER (A)

Changing Parameter	*Frequency Bandwidth*	*Center Frequency*	*FBW*
a1 (2.4mm)	[7.37GHz – 9.51GHz]	8.44 GHz	25.35%
a2 (2.2mm)	[7.37GHz – 9.60GHz]	8.48 GHz	26.29%
a3 (2.0mm)	[7.37GHz – 9.69GHz]	8.53 GHz	27.19%

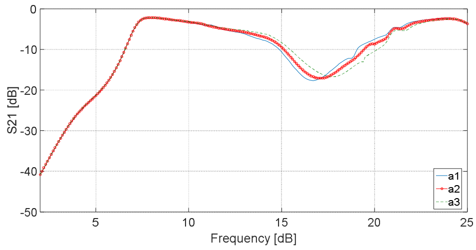

Fig.11. S21 [dB] Simulated results for H-slotted SIW with varied 'a'

TABLE XI. EFFECT OF THE PARAMETRE (E)

Changing Parameter	***Frequency Bandwidth***	***Center Frequency***	***FBW***
e1 (5.8mm)	[7.36GHz – 9.51GHz]	8.43 GHz	25.50%
e2 (4.8mm)	[7.32GHz – 11.08GHz]	9.2 GHz	40.86%
e3 (3.8mm)	[7.30GHz – 15.93GHz]	11.61 GHz	74.33%

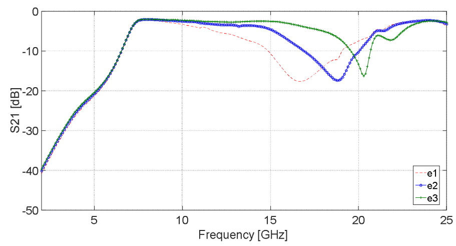

Fig.13. S21 [dB] Simulated results for H-slotted SIW with varied 'e'

TABLE XII. EFFECT OF THE PARAMETRE (B)

Changing Parameter	***Frequency Bandwidth***	***Center Frequency***	***FBW***
b1 (0.9mm)	[7.36GHz – 9.51GHz]	8.43 GHz	25.50%
b2 (0.8mm)	[7.34GHz – 9.49GHz]	8.41 GHz	25.56%
b3 (0.7mm)	[7.33GHz – 9.52GHz]	8.42 GHz	26%

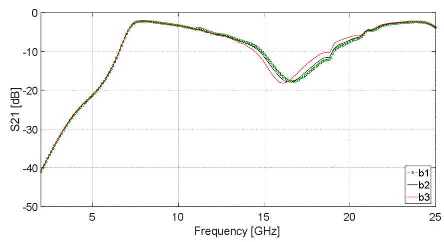

Fig.12. S21 [dB] Simulated results for H-slotted SIW with varied 'b'

CONCLUSION

In this paper, three units EBG cells (H-, U- and T-slotted) etched on a SIW are studied through geometric parametric comparison, aiming to design a Substrate Integrated Waveguide Bandpass Filter (SIW-BPF) for wideband applications. Our work, unequivocally, reveals that H-slotted EBG has the widest FBW, which is about 90% compared to T- and U- slotted EBG, suggesting the advantage of using H-slotted EBG in the design of wideband SIW-BPF.

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