Enhanced Performance of Substrate Integrated Waveguide Bandstop Filter using Circular and Radial Cavity Resonator

M. N. Husain, G. S. Tan, K. S. Tan
Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya 76100, Melaka, Malaysia
drmohdnor@utem.edu.my
gansiang@student.utem.edu.my
tankim@utem.edu.my

Abstract—Circular and Radial SIW cavity resonators are proposed to enhance the performance of SIW bandstop filter. Prior to this research work, rectangular cavity resonator was used to produce bandstop response. The design of the circular and radial SIW bandstop filters are done by directly coupling circular and radial cavity resonators to the SIW line. The SIW bandstop filters are designed to operate at X-band and implemented on Rogers RO4350 substrate with a thickness of 0.508mm. Simulated and measured results show good bandstop responses and thus useful in microwave bandstop filter design.

Keyword-Bandstop Filter, Substrate Integrated Waveguide, Cavity Resonator, Stopband Bandwidth

I. INTRODUCTION

Bandstop filter plays an important role in attenuating unwanted signal in microwave communication systems. The currents trend of miniaturization and integration leads towards the use of planar transmission lines such as microstrip and stripline rather than conventional waveguide [1]. Defected ground structure has been used on microstrip filter to design a bandstop filter [2]. Defected microstrip structure has been used to design bandstop filter [3]. Recently, defected microstrip structure and defected ground structure are utilized to produce miniaturized dual-band bandstop filters [4]. Uniplanar double spiral resonant cells bandstop filter has been shown to have a high rejection but has been designed for broad stopband [5]. Substrate integrated waveguide was first proposed by Pilote, Flanik and Zaki with the title of waveguide filter having a layered dielectric structure [6]. Substrate integrated waveguide has the advantages of low insertion loss, high Q-factor and can be implemented in planar form. SIW is formed by two periodic rows of metallic via hole on a dielectric substrate [7].

Only a few research papers on bandstop filters were done using SIW technique. A multiple SIW bandstop filter had been designed by transversal coupling network [8]. SIW cavity resonator separated by unity impedance inverters had been used to design a single bandstop filter [9]. Further to that, a single bandstop filter had been designed by directly coupling three cavity resonators to SIW line [10]. Even and odd predistortion technique was presented to design a SIW bandstop filter [11]. Another design had used an impedance inverter network connected across a two-port network SIW bandpass filter to function as a bandstop filter [12]. Bandstop filter has also been designed based on a dual-band bandstop filter topology [13].

Prior to this research, only rectangular cavity resonator structure was used in the design of SIW bandstop filter while SIW circular cavity filter had been used for bandpass filter design [14-15]. In this paper, circular and radial cavity resonators are design incorporated for the bandstop filters. The bandstop filters are designed by coupling SIW cavity resonators to a SIW line to produce broad passband and bandstop response. However, the rectangular cavity resonator bandstop filter is also fabricated for comparison.

II. SIW BANDSTOP FILTER DESIGN

A. Substrate Integrated Waveguide Transmission line design

SIW line functions as a waveguide in transmitting the input signal to the load. In SIW structure, only TE_{M0} modes can be excited and extracted in the structure, thus, TM modes do not exist in the SIW structure [16]. The lower passband cutoff frequency for the SIW line is the corresponding resonant frequency f_c. Therefore, effective width of the SIW line W_{eff} can be determined [7] by:

$$f_{c(TE10)} = \frac{c}{2\sqrt{\varepsilon_r}} \cdot \left(W - \frac{d^2}{0.95 \cdot p} \right)^{-1} \tag{1}$$

$$W_{eff} = W - \frac{d^2}{0.95 \cdot p} \tag{2}$$

where W is the width of the SIW line, d is the diameter of the metallic via holes and p is the spacing between the via holes.

The diameter d and the spacing between the via holes p are determined by using a set of design rules for the substrate integrated waveguide [16-18] given as:

$$d < p < 2d \tag{3}$$

$$d < \lambda_g/5 \tag{4}$$

$$p/\lambda_c < 0.25 \tag{5}$$

where λ_c is the cutoff wavelength and λ_g is the guide wavelength.

The bandstop filters are designed to operate at X-band. So, a lower resonant frequency for the SIW line is preferred to obtain a good passband response along the band. 6GHz is the selected resonant frequency and the W_{eff} length of 13.06mm is obtained.

B. Coupling of the cavity resonator to SIW line

The coupled position of the resonator to SIW line is determined to get strong electric field intensity coupling between cavity resonator and SIW line. The position of the resonator is placed at 19.59mm from the input of the SIW line to the centre of the cavity resonator. The input width of the cavity resonator for the three designs is set at 8.3mm which is the adequate width for the three designs to operate and function.

C. Configuration of the resonators

For the rectangular cavity resonator, there are two critical parameters which are the width, represented by *a* and the length, represented by *b* that affect the bandstop response. While for the circular cavity resonator, the two critical parameters are the radius and the length of the circle represented by *r* and *l* respectively that affect the bandstop response. As for the radial cavity resonator, there are three parameters, the span degree, the radius and the coupling length of the radial represented by *rd*, *r* and *l* respectively. Fig. 1, Fig. 2 and Fig. 3 show the configuration of the rectangular, circular and radial cavity resonator SIW bandstop filter design.

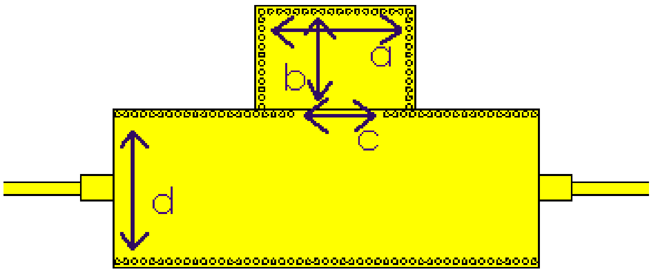

Fig. 1 Configuration of rectangular cavity resonator SIW bandstop filter

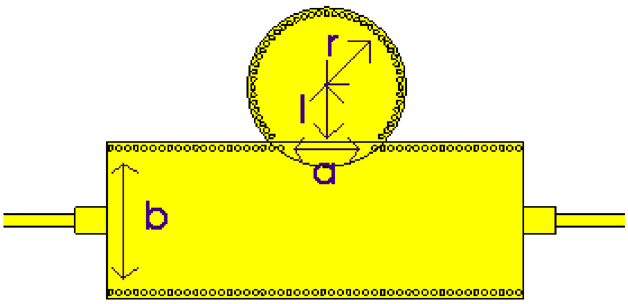

Fig. 2 Configuration of circular cavity resonator SIW bandstop filter

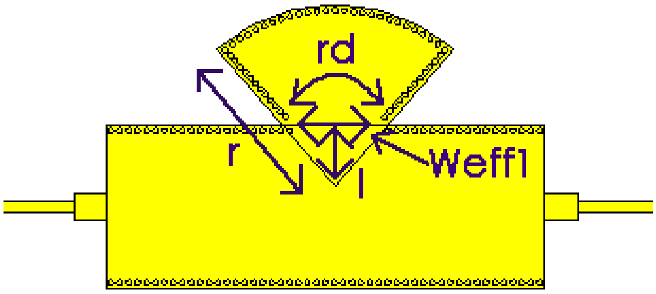

Fig. 3 Configuration of radial cavity resonator SIW bandstop filter

III. SIMULATION RESULTS

The simulations are carried out to investigate the performance produced by each resonator. These are done by varying the value of one parameter while the rest of the dimensions are being kept constant. The analyses of the performances are based on the centre stopband frequency, 3dB stopband bandwidth, attenuation and average insertion loss. 3dB stopband bandwidth is a crucial parameter for any bandstop filter design [19].

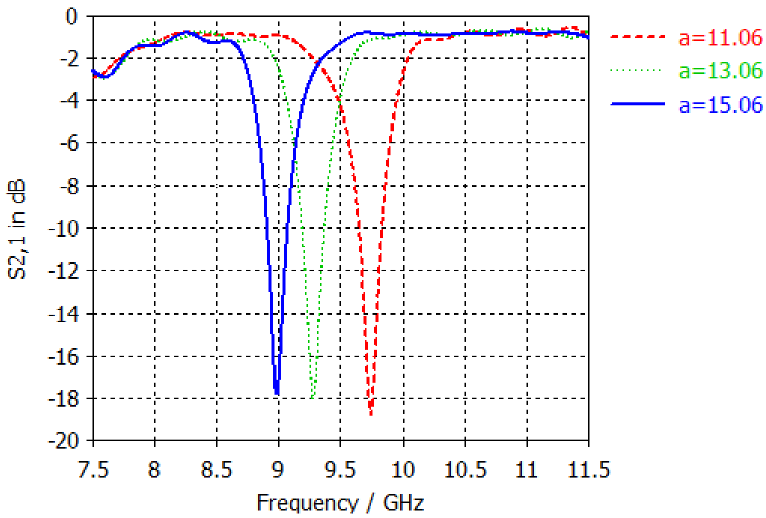

Fig. 4 Frequency response of variation of *a* for rectangular cavity resonator with dimensions *b*=9mm, *c*=8.3mm, and *d*=13.06mm

TABLE I

Frequency response of variation of *a* for rectangular cavity resonator with dimensions *b*=9mm, *c*=8.3mm, and *d*=13.06mm

a(mm)	**Center Stopband Frequency (GHz)**	**3dB Stopband Bandwidth (MHz)**	**Attenuation (dB)**	**Average insertion loss (dB)**
11.06	9.75	559	-18.7	-1.2
13.06	9.27	511	-18.0	-1.2
15.06	8.99	498	-17.7	-1.3

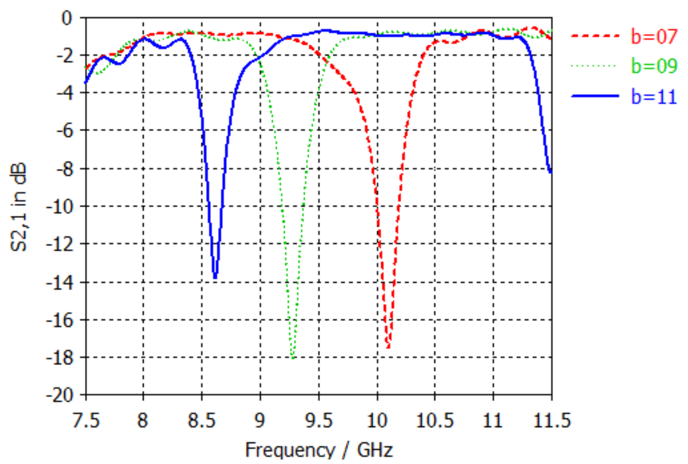

Fig. 5 Frequency response of variation of *b* for rectangular cavity resonator with dimension *a*=13.06mm, *c*=8.3mm, and *d*=13.06mm

TABLE II
Frequency response of variation of *b* for rectangular cavity resonator with dimension *a*=13.06mm, *c*=8.3mm, and *d*=13.06mm

b (mm)	**Center Stopband Frequency (GHz)**	**3dB Stopband Bandwidth (MHz)**	**Attenuation (dB)**	**Average insertion loss (dB)**
7	10.10	664	-17.5	-1.3
9	9.27	511	-18.0	-1.2
11	8.62	397	-13.9	-1.4

For the rectangular cavity resonator, the width *a* and length *b* are investigated and the results are shown in Fig. 4, Fig. 5, Table I and Table II. The results show that an increase in the width *a* resulted in a decrease in the centre stopband frequency, stopband bandwidth and attenuation. Similarly, the increase in the length *b* indicates a decrease in the centre stopband frequency and stopband bandwidth but not the attenuation. There is peak attenuation at certain length, in this case at 9mm.

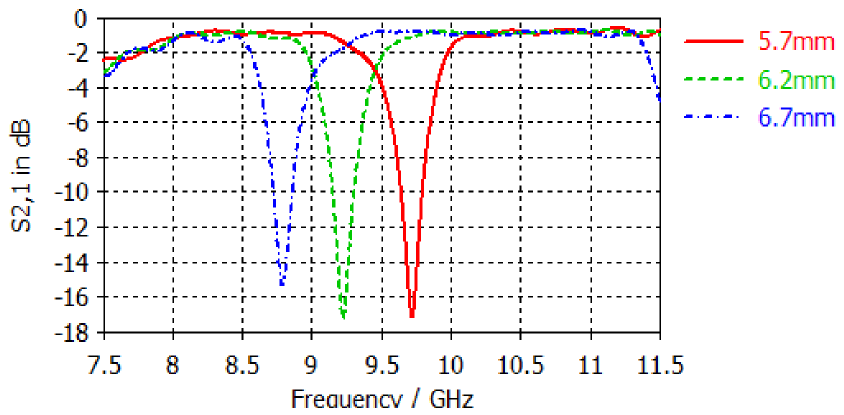

Fig. 6 Frequency response of variation of radius of circular cavity resonator with dimension *a*=8.3mm, *b*=13.06mm and *l*=5mm

TABLE III
Frequency response of variation of radius of circular cavity resonator with dimension *a*=8.3mm, *b*=13.06mm and *l*=5mm

Radius *r* (mm)	**Center Stopband Frequency (GHz)**	**3dB Stopband Bandwidth (MHz)**	**Attenuation (dB)**	**Average insertion loss (dB)**
6.7	8.78	434	-15.4	-1.3
6.2	9.22	450	-17.4	-1.3
5.7	9.72	477	-17.1	-1.3

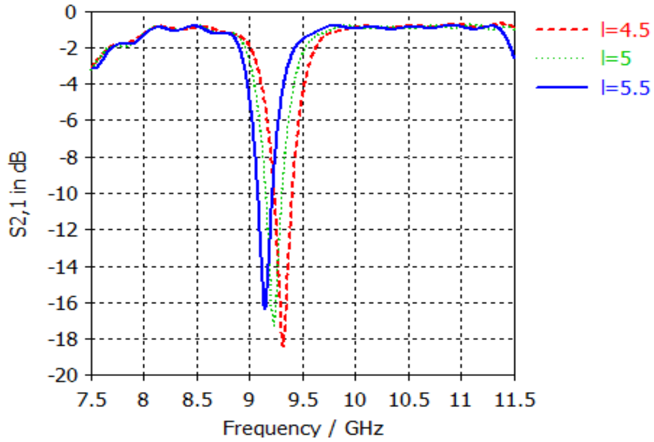

Fig. 7 Frequency response of variation of *l* of the circular cavity resonator with dimension of *a*=8.3mm, *b*=13.06mm, and *r*=6.2mm.

TABLE IV
Frequency response of variation of *l* of the circular cavity resonator with dimension of *a*=8.3mm, *b*=13.06mm, and *r*=6.2mm.

Length *l* (mm)	**Center Stopband Frequency (GHz)**	**3dB Stopband Bandwidth (MHz)**	**Attenuation (dB)**	**Average insertion loss (dB)**
5.5	9.15	413	-16.3	-1.3
5	9.22	450	-17.4	-1.3
4.5	9.31	490	-18.5	-1.3

For the circular cavity resonator, radius *r* and length *l* are investigated and the results are shown in Fig. 6, Fig. 7, Table III and Table IV. The results show that an increase in the radius *r* and length *l* resulted in a decrease in the centre stopband frequency, stopband bandwidth and attenuation. Parameter *r* has the most effect on the centre stopband frequency so it has to be determined first in each design. However the length *l* has the most effect in stopband bandwidth, so it can be used to optimize the bandstop response.

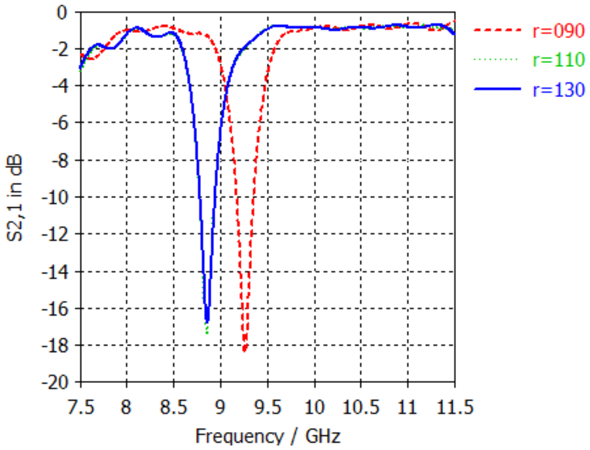

Fig. 8 Frequency response of variation of degree of radial cavity resonator with dimension *r*=14.7mm, *l*=6mm, and *Weff1*=8.3mm

TABLE V
Frequency response of variation of degree of radial cavity resonator bandstop filter with dimension *r*=14.7mm, *l*=6mm, and *Weff1*=8.3mm.

Degree *rd*	**Center Stopband Frequency (GHz)**	**3dB Stopband Bandwidth (MHz)**	**Attenuation (dB)**	**Average insertion loss (dB)**
90	9.26	507	-18.5	-1.3
110	8.85	502	-17.4	-1.4
130	8.85	490	-16.9	-1.4

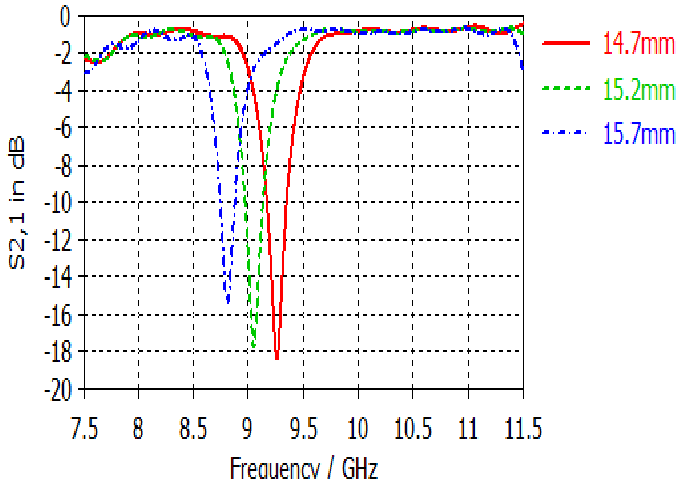

Fig. 9 Frequency response of variation of radius of radial cavity resonator with dimension *rd*=90°, *l*=6mm, *Weff1*=8.3mm

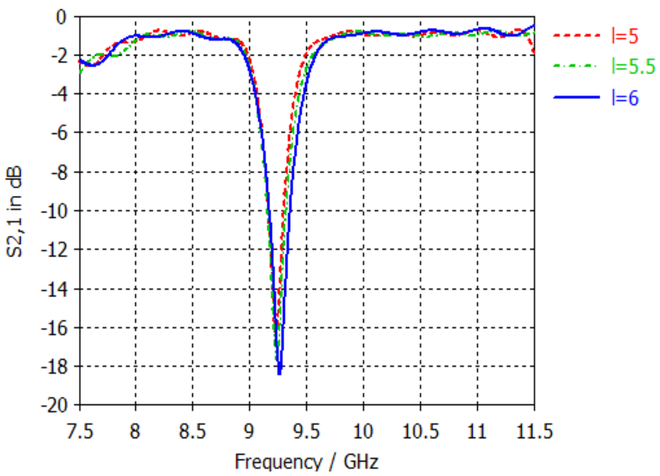

Fig. 10 Frequency response of variation of centre of radial cavity resonator with dimension *rd*=90°, *r*=14.7mm, and *Weff1*=8.3mm

For the radial cavity resonator, the radius *r*, degree of radius *rd* and length *l* are investigated and the results are shown in Fig. 8, Fig. 9, Fig. 10, Table 5, Table 6 and Table 7.The increase of radius *r* and degree *rd* result in a decrease in the centre stopband frequency and stopband bandwidth, while an increase in the length *l* gives an increase in the centre stopband frequency and stopband bandwidth. Radius, *r* is the most crucial parameter as it has the most influence in the bandstop response. The degree *rd* can be used to control the centre stopband frequency as it influences the centre stopband frequency without much effect on stopband bandwidth and attenuation. The length *l* can be used to control stopband bandwidth without much effect on centre stopband frequency.

TABLE VI
Frequency response of variation of radius of radial cavity resonator with dimension *rd*=90°, *l*=6mm, *Weff1*=8.3mm

Radius *r* (mm)	**Center Stopband Frequency (GHz)**	**3dB Stopband Bandwidth (MHz)**	**Attenuation (dB)**	**Average insertion loss (dB)**
14.7	9.26	507	-18.5	-1.3
15.2	9.09	459	-17.2	-1.3
15.7	8.80	425	-15.4	-1.3

TABLE VII
Frequency response of variation of centre of radial cavity resonator with dimension *rd*=90°, *r*=14.7mm, and *Weff1*=8.3mm

Separation of the center of radius *l* (mm)	Center Stopband Frequency (GHz)	3dB Stopband Bandwidth (MHz)	Attenuation (dB)	Average insertion loss (dB)
6	9.26	507	-18.5	-1.3
5.5	9.23	464	-17.7	-1.3
5	9.23	402	-16.3	-1.3

IV. MEASUREMENT RESULTS

The rectangular, circular and radial cavity resonator SIW bandstop filters are fabricated on RO4350 substrate using standard PCB process to verify the simulation results. The substrate relative permittivity constant is 3.48 with 0.5mm thickness and has a loss tangent of 0.0037. The diameter of the metallic holes is 0.5mm. The separation between the metallic holes is 0.3mm. Figure 11, Figure 12 and Figure 13 show the fabricated rectangular, circular and radial SIW bandstop filter respectively.

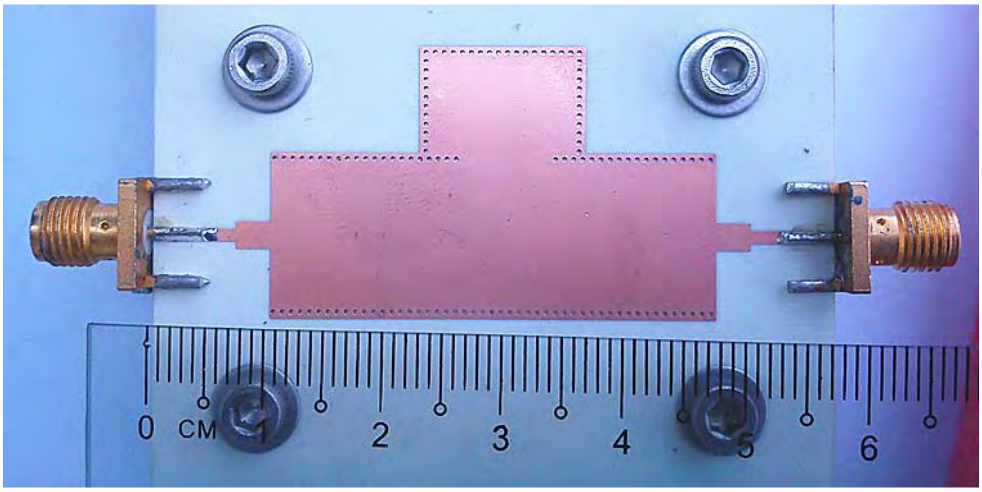

Fig. 11 Fabricated rectangular SIW bandstop filter

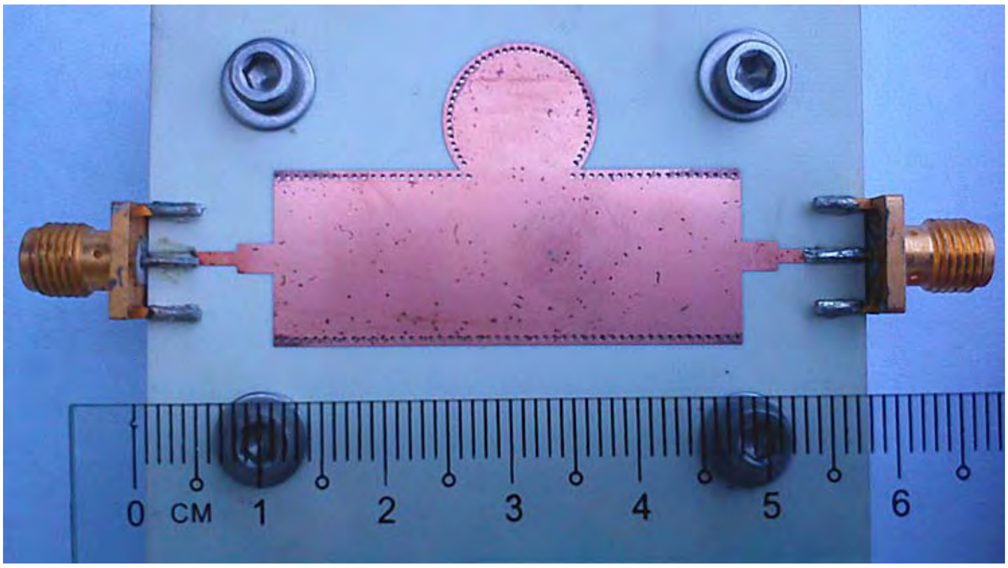

Fig. 12 Fabricated circular SIW bandstop filter

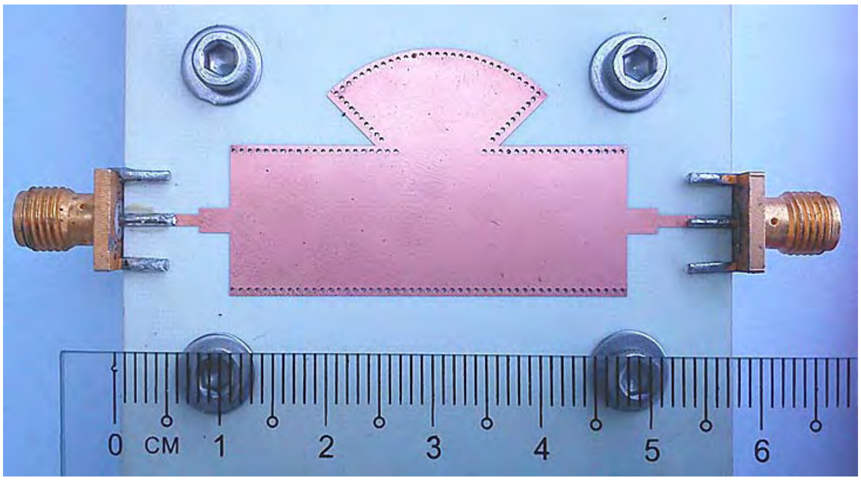

Fig. 13 Fabricated radial SIW bandstop filter

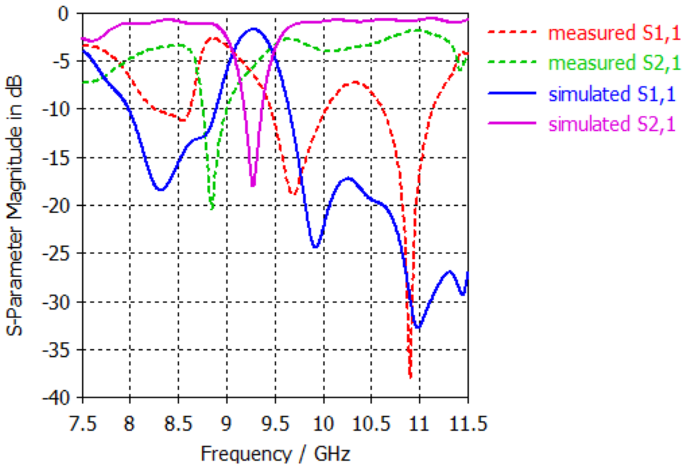

Fig. 14 Comparison between simulated and measured rectangular cavity resonator SIW bandstop filter

Figure 14, Figure 15 and Figure 16 show the comparison between simulated and measured frequency response. The results show that there is shift in the centre stopband frequency for all the three designs. The frequency shifts for the three designs are around 400MHz. The shift is mainly caused by the variation of dielectric permittivity between simulated and fabricated substrate. The increase in insertion loss and attenuation for both simulated and measured reveals the correlation between the two parameters. Thus, the simulation and measured results are in agreement with each other. The insertion loss is mostly caused by the transition loss from microstrip line to SIW.

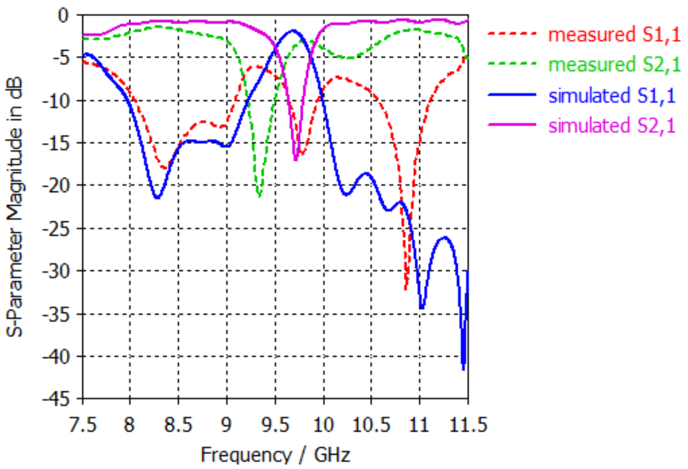

Fig. 15 Comparison between simulated and measured circular cavity resonator SIW bandstop filter

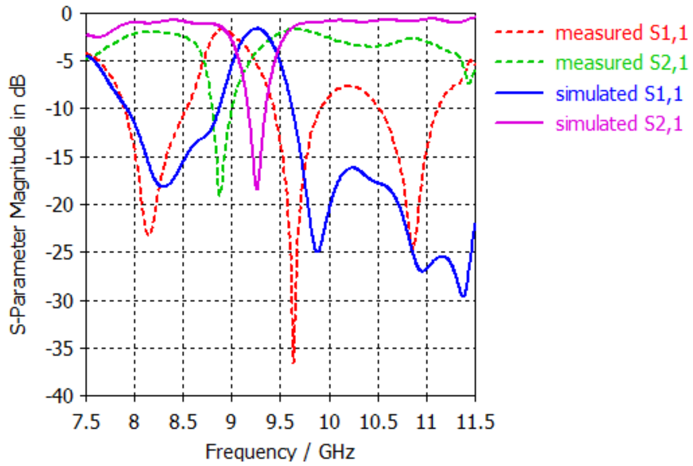

Fig. 16 Comparison between simulated and measured radial cavity resonator SIW bandstop filter

TABLE VIII
Comparison between simulated and measured rectangular, circular and radial cavity resonator SIW bandstop filter

Resonator	Simulation			Measurement		
	Centre stopband frequency (GHz)	Attenuation	Insertion loss	Centre stopband frequency (GHz)	Attenuation	Insertion loss
Rectangular	9.27	-18.0	-1.2	8.84	-19.9	-3.2
Circular	9.72	-17.4	-1.2	9.33	-21.4	-3.2
Radial	9.26	-18.5	-1.3	8.88	-19.1	-2.7

V. Conclusion

The circular and radial cavity resonators SIW bandstop filters are introduced in this paper. Both cavity resonators are able to produce the bandstop response. Comparing to rectangular cavity resonator, circular cavity resonator shows a better 3dB stopband bandwidth response while radial cavity resonator shows a slightly improvement in the attenuation and the 3dB stopband bandwidth. Frequency shift is observed between the simulated and measured results. The shift of the centre stopband frequency for the three designs is towards the lower stopband frequency. This research clearly shows that the rectangular cavity resonator, the circular cavity resonator and the radial cavity resonator SIW bandstop filters can be developed. They demonstrate good performance as bandstop filters at X-Band but each of their optimization has to be compromised.

Acknowledgment

I would like to thank UTeM and Exploratory Research Grant Scheme (ERGS) for their sponsorship on this research.

References

[1] K. S. Chin and C. K. Lung, "Miniaturized microstrip dual-band bandstop filters using tri-section stepped impedance resonators," Progress In Electromagnetics Research C, Vol. 10, 37-48, 2009.

[2] Yu-Hao Hsu, Chung-Hao Tsai,and Tzong-Lin Wu, "A new bandstop filter using artificial defected ground structures with compact size and low radiation" 978-1-4244-6867-6/10 2010 IEEE

[3] J. K. Xiao and W. J. Zhu, "New defected microstrip structure bandstop filter," Progress In Electromagnetics Research Symposium Proceedings, Suzhou, China, Sept. 12-16, 2011 pp. 1471-1474

[4] Jun Wang, Huansheng Ning, Qingxu Xiong, Minquan Li, and Lingfeng Mao, "A novel miniaturized dual-band bandstop filter using dual-plane defected structures," Progress In Electromagnetics Research, Vol. 134, 397-417, 2013

[5] Ke Lu, Guang-Ming Wang, He-Xiu Xu, "Compact and sharp-rejection bandstop filter using uniplanar double spiral resonant cells," Radioengineering, Vol. 20, No 2, June 2011, pp.468-471

[6] Pilote, A.J., K.A. Leahy, B. A. Flanik, and K. A. Zaki, "Waveguide filters having a layered dielectric structure," U.A. Patent, No.5382931, Jan.1995.

[7] Y. Cassivi, L. Perregrini, P. Arcioni, M. Bressan, K. Wu, and G. Conciauro, "Dispersion Characteristics of Substrate Integrated Rectangular Waveguide." IEEE Microwave and Wireless Components Letters, vol. 12, no.9, September 2002, pp.333-335

[8] Han S.H., Wang X.L., Fan Y. "Analysis and Design of Multiple-Band Bandstop Filters," Progress in Electromagnetics Research, PIER 70,297 - 306, 2007

[9] Badrul Hisham Ahmad and Ian. C. Hunter, “Design and Fabrication of a Substrate Integrated Waveguide Bandstop Filter,” Proc. Of the 38th European Microwave Conference Amsterdam. 40-42 2008.

[10] Badrul Hisham Ahmad, Ian c. Hunter, " Substrate Integrated Waveguide Bandstop Filter", Journal of Telecommunication, Electronic and Computer Engineering, Vol 2, No. 1, January - June 2010

[11] Z. Zakaria, Ian. C. Hunter "Substrate Integrated Waveguide Filters based on Even- and Odd-Mode Predistortion Technique," Journal of Telecommunication, Electronic and Computer Engineering (JTEC), UTeM(2011): 61-71

[12] A. Badrul Hisham, M. N. Husain, K.S.Tan, "A Novel Hybrid Notch (HN) Substrate Integrated Waveguide(SIW) Bandstop Filter." Journal of Telecomunication, Electronic and Computer Engineering, (JTEC), UTeM 2.2 (2010): 13-17.

[13] Fei Yang, Hong-xi Yu, Xin-yang He, Ying Zhou and Rui-zhu Liu, "Multiple-band Filter Design and Substrate Integrated Waveguide Filter Realization," In Microwave Symposium Digest (MTT), 2012 IEEE MTT-S International (pp. 1-3). IEEE

[14] H. J. Tang, W. Hong, Z. C. Hao, J. X. Chen and K. Wu, "Optimal design of compact millimetre-wave SIW circular cavity filters," Electronics Letters 15th September 2005 Vol. 41 No.19

[15] Chuanyun Wang, Xiaoyan Zhang, Xuehui Guan, Jing Wan and Haiwen Liu, "A novel substrate integrated waveguide circular cavity bandpass filter loaded with complementary split ring resonator," 978-1-4244-5708-3/10 2010 IEEE pp. 1690-1692

[16] D. Deslandes, K. Wu, "Accurate modeling, Wave Mechanisms, and Design Cinsideration of a Substrate Integrated Waveguide." IEEE Trans. on Microwave Theory and Techniques, 2006, vol. 54, no. 6, pp. 2516-2526.

[17] K. Wu, Dominic Deslandes, and Yves assivi, "The Substrate Integrated Circuits - A New Concept for High-Frequency Electronic and Optoelectronics." TELSIKS 2003, October 1-3,2003.

[18] F. Xu, K. Wu, "GUided-Wave and Leakage Characteristics of Substrate Integrated Waveguide", IEEE Transactions on Microwave Theory and Techniques, Vol. 53, NO 1, 66-73, January 2005

[19] Hong, J. S. and M. J. Lancaster, Microstrip Filters for RF/Microwave Applications, John Wiley & Sons, New York, 2001.