A Dual-band Substrate Integrated Waveguide (SIW) Band Pass Filter for scientific Radar applications

Aman Kumari[1, 2], Arun Kumar[1], Dhirendra Kumar[3]
[1]*Department of Electronics and Communication Engineering, IFTM University, Moradabad, India*
[2]*Maharaja Surajmal Institute of Technology, Delhi, India*
[3]*Department of Electronics and Communication Engineering, RKGIT, Ghaziabad, India*

Abstract—In this paper, a dual-band Substrate Integrated Waveguide bandpass filter is proposed for 45.5 GHz to 52.5 GHz and 60 GHz to 62.5 GHz band. SIW is a linear periodic arrangement of metallic vias or holes which are embedded along the side walls of waveguide. Dual-band Substrate Integrated Waveguide filter is a three pole filter and with multiple transmission zeros. The Substrate Integrated Waveguide (SIW) is designed by inserting metallic vias along the side walls of the substrate with adequate spacing and diameter. A parametric study by varying the vias geometry is presented with vias diameter as 0.10mm, 0.12mm and 0.18 mm. The return loss and insertion loss of the proposed filter are better that 15dB and 1.18dB respectively at 0.12 mm, which is the improved result as compared when the vias diameter is 0.10 mm and 0.18 mm. The fractional bandwidth obtained is 8.9% in 45.5 GHz to 52.5 GHz band and 4 % from 60 GHz to 62.5 GHz band respectively. The proposed filter is suitable for use in scientific RADAR applications.

Keywords—*Substrate Integrated Waveguide; Dual-Band, Band Pass Filter; Transmission zeros; radar*

I. INTRODUCTION

The investigation in the field of wireless communications has led to a vast development in the design of RF circuits and has been more inclined on the miniaturization of these circuits. Earlier for transmission of signals in circuits the traditional transmission lines metallic waveguides were used for guiding the electromagnetic energy. The rectangular waveguides being non-planar and bulkier are expensive and voluminous [1]. The more viable option developed in 1998 is Substrate Integrated Waveguide (SIW). Substrate Integrated waveguide are designed with cylindrical vias embedded in the substrate. SIW technology is used vastly in design of active and passive devices such as antennas, filters [2] etc. SIW technology can be fabricated on a printed circuit board (PCB) offering wide commercial applications in radar imaging and biomedical devices [3]. This SIW technology is also used in circuits and components such as filters, oscillators, power dividers [7],[8],[9] etc. Substrate Integrated Waveguide (SIW) filters are one of the advanced filters that offer high performance as compared to conventional waveguide filters. SIW filters have a high quality factor and compact size that is conformable with planar circuits. It requires low cost for fabrication. SIW technology uses standard PCB or Low temperature co-fired ceramic (LTCC) process for designing and offers an attractive solution for minimized volume of the circuits that can be integrated with planar circuits on the same substrate [4],[5],[6]. SIW technology uses metallic vias to limit the propagation region. These vias are embedded in the substrate with spacing such that losses are minimized. Microstrip lines are used to realize SIW structures with planar circuits. Dual band filters have two pass bands with two different centre frequencies [10]. Cascading a broadband filter and a band stop filter is constructed in [11],[12]. But these designs have high insertion loss and large size. In [13],[14] dual-band filter is realized by introducing transmission zeros among a passband filter. It uses dual- resonance structures or step impedance resonators [15],[16]. By using SIW valuable research has been done in the field of dual-mode filters [18], half mode filter [19] or dual-band filter [20]. Dual-band filters are mostly used in wireless communications. In this paper, a dual-band three pole filter in 45.5 GHz to 52.5 GHz and from 60 GHz to 62.5 GHz band is proposed. This dual- band SIW filter can be deployed for millimeter- wave radar in scientific research.

II. DESIGN OF SIW FILTER

SIW structure is a progression between microstrip and dielectric filled waveguide (DFW). SIW is a linear periodic arrangement of metallic vias or holes which are embedded along the side walls of waveguide. SIW structure supports the propagation of quasi transverse electric (TE) modes. The cut off frequency of the rectangular waveguide is [22]

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

Where f_c is the cut off frequency, m and n are the mode numbers, *c* is the speed of light, a and b are the broader and narrower dimensions respectively. For TE_{10} mode which is considered to be the dominant mode, the cut off frequency is given as [22]:

$$f_c = \frac{c}{2a} \quad (2)$$

The effective length of the dielectric filled waveguide is given as

$$a_d = \frac{a}{\sqrt{\varepsilon_{eff}}} \quad (3)$$

Once dimension "a_d" of dielectric filled waveguide is determined, design equation for the SIW correlating width a_s is given as

$$a_s = a_d + \frac{d^2}{0.95c} \quad (4)$$

Where c is the separation between vias. Proposed filter is designed using Computer Simulation Technology Microwave Studio which uses finite element method (FEM) techniques.. The designed filter is a dual band pass filter with frequency 45.5 GHz to 52.5 GHz and in 60 GHz to 62.5 GHz. The designed filter has best response when the diameter of the vias of the substrate integrated waveguide filter is 0.12 mm. The figure 1 shows the design of the filter. ROGERS RT5880 has been used as the substrate with height of 0.762 mm and relative permittivity $€_r$ of 2.2. Table 1 shows the tabular dimensions of the geometry of the filter. By increasing the diameter of vias the poles shift towards right with better return loss when the d is 0.12 mm,

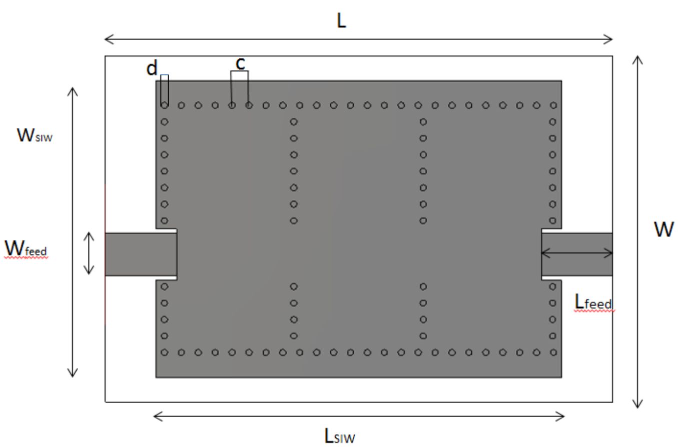

Fig.1: Structure of the designed SIW dual band filter

Table 1. Parameters of the designed dual band SIW filter

Case	L (mm)	L_{SIW} (mm)	W (mm)	W_{feed} (mm)	L_{feed} (mm)	d (mm)	C (mm)
I	30	24	21	2.55	4.22	0.10	1
II	30	24	21	2.55	4.22	0.12	1
III	30	24	21	2.55	4.22	0.18	1

Where L is the length of filter, L_{SIW} is the length of SIW, W is the width of filter, W_{feed} is the width of feed lines, L_{feed} is the length of feed lines, d is the diameter of vias and c is the center to center separation between vias. The width of SIW is considered to be 16 mm.

III. SIMULATION OF FILTERS

A full wave Electromagnetic simulation software CST Microwave Studio is used for design optimization and simulation. Figure 2 shows S_{11} (Return loss) of the designed dual band filter by varying the changing the diameter of the vias. It has been observed that the dimensions of the vias critically affect the return loss.The return loss when the diameter of the vias is 0.10 mm in 45.5 GHz to 52.5 GHz band is 32 dB and in 60 GHz to 62.5 GHz band it is 35 dB. Then diameter of the vias when increased to 0.12 mm the return loss is improved 53 dB in 45.5 GHz to 52.5 GHz band and 30 dB in 60 GHz to 62.5 GHz band. The return loss is increased when the diameter of the vias is further increased to 0.18 mm. The return loss in 60 GHz to 62.5 GHz band is 39 dB and 36 dB. Insertion losses for the three different vias dimensions is shown in figure 3. The insertion loss when p is 0.10, 0.12 and 1.28 are 1.23 dB, 1.18 dB and 1.34 dB in 45.5 GHz to 52.5 GHz band whereas it is 1.7dB,1.4dB, 0.8dB respectively in 60 to 62.5 GHz band. The 3 dB bandwidth of the dual band filter is 4.5 GHz and 2.5 GHz in the two bands. The fractional bandwidth is 8.9 % and 4.09 % in 45.5 GHz to 52.5 GHz and 60 GHz to 62.5 GHz respectively. The return and insertion loss are better when vias diameter (p) is 0.12 mm. Figure 4 shows the return and insertion loss of the best response by considering with p = 0.12 mm. The return loss is better than 15 dB in 45.5 GHz - 52.5 GHz and 18 dB in 60 GHz - 62.5 GHz.

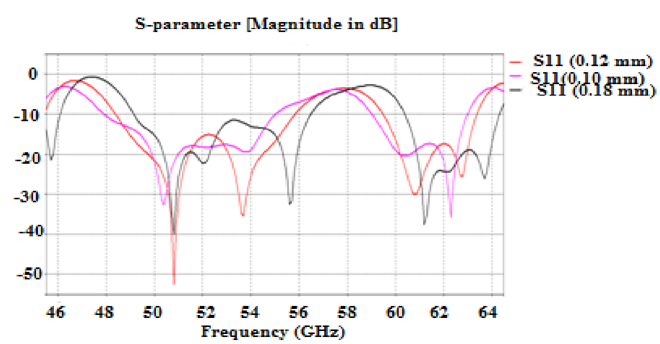

Fig.2: Return loss of the designed SIW dual band filter for different vias dimensions

The proposed filter response is better than as obtained by Guo-Hui et al. [10].

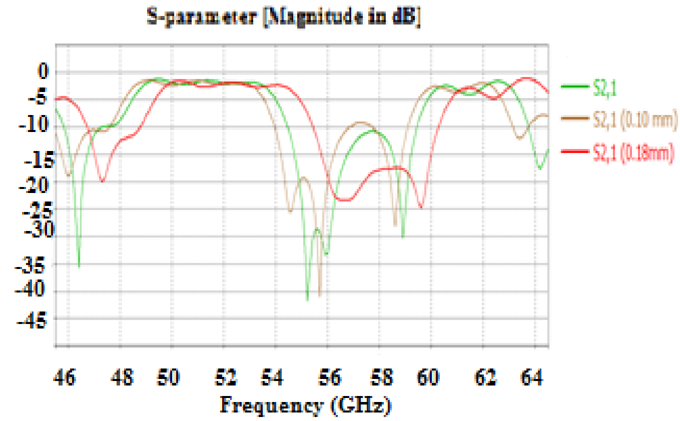

Fig.3*:* Insertion loss of the designed SIW dual band filter for different vias dimensions

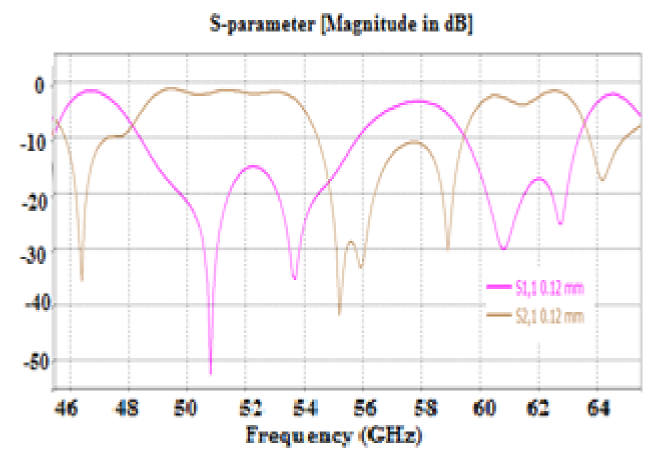

Fig.4*:* Insertion loss and return loss of the SIW dual band pass filter for vias diamter 0.12mm

The power flow is shown in figure 5 across the dual band pass filter. Most of the power is transmitted from port1 to the other port 2 when the ports are perfectly matched. Various modes propagation occurs inside the structure. In a guided-wave structure when a mode is established the surface currents are then established. The SIW can be regarded as a special rectangular waveguide with a series of vertical slots on the sidewalls and the slots cut along the direction of current flowing. Slots are etched to increase the energy fed to the structure. The energy coupled to the SIW structure is controlled by both the length and position of slot. The appropriate slot allocation modifies the fractional bandwidth (FBW) from 1% to 15%. Energy is magnetically coupled from feed line into SIW resonator. So in order to achieve maximum bandwidth co-planar waveguides are inserted in the SIW structure from both input and output end.

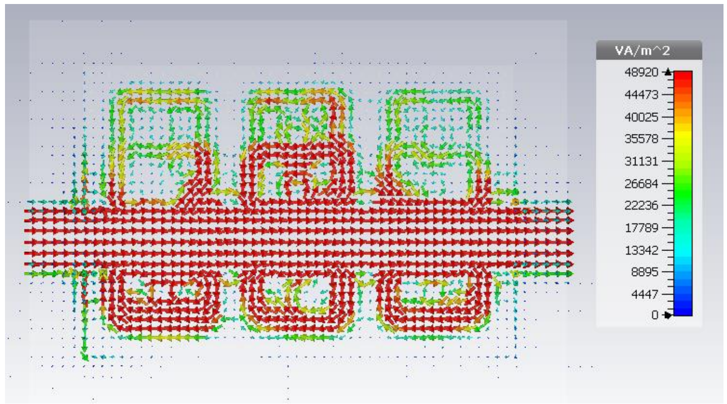

Fig.5*:* Power flow across the SIW dual band pass filter with vias diamter 0.12mm

IV. CONCLUSION

In this paper, a dual-band Substrate Integrated Waveguide bandpass filter is proposed. Based on parametric study, it has been investigated that the return and insertion losses of the SIW filter are critically affected when the diameter of the vias is varied. The dual-band filter is designed in frequency range from 45.5 GHz to 52.5 GHz and 60 GHz to 62.5 GHz. It has 3 poles in each band and multiple transmission zeros. The proposed filter has better response when the vias diameter is 0.12mm with insertion loss of 0.18dB and return loss of 53dB. The dual-band filter can be used for millimeter wave RADAR applications in scientific research.

V. REFERENCES

[1]. Hemendra Kumar, Ruchira, Jadhav," A Review on Substrate Integrated Waveguide and its Microstrip Interconnect" *IOSR Journal of Electronics and Communication Engineering (IOSRJEC)* Volume 3, Issue 5 , pp. 36-40 Sep. – Oct. 2012.

[2]. Shigeki, F. Waveguide Line (in Japanese). Japan Patent 06-053. pp.711, Feb. 25, 1994.

[3]. Mizuno, K., Wagatsuma, Y., Warashina, H., Sawaya, K., Sato, H., Miyanaga, S., Yamanaka, Y. Millimeter-wave imaging technologies and their applications. In IEEE International Vacuum Electronics Conference, IVEC '07,pp. 15-17 May 2007.

[4]. K. Wu, D. Deslandes, and Y. Cassivi, "The substrate integrated circuits – a new concept for high-frequency electronics and optoeletronics*", presented at Telecommunications in Modern Satellite, Cable and Broadcasting Service,* 2003. TELSIKS 2003. 6th International Conference on, vol. 1, Pages:P-III - P-X. Oct. 1-3, 2003.

[5]. D. Deslandes and K. Wu, "Single-substrate integration techniques for planar circuits and waveguide filters", *IEEE Trans. Microwave TheoryTech*., vol. 51, no.2, pp. 593-596, Feb. 2003.

[6]. D. Deslandes, K. Wu, “Integrated Microstrip and Rectangular Waveguide in Planar Form”, *IEEE Microwave wireless ComponentLetters*, vol. 11, no.2, pp. 68-70, Feb. 2001.

[7]. Y. Cassivi, and K. Wu,”Low cost microwave oscillator using substrate integrated waveguide cavity”, *Microwave and Wireless Components and Guided Wave Letters*, vol.13, pp.48-50, Feb.2003,.

[8]. S. Germain, D. Deslandes, and K. Wu, “Development of substrate integrated waveguide power dividers”, Electrical and Computer Engineering,2003,*IEEE CCECE2003. Canadian Conference on*, vol. 3, pp1921-1924,May 4-7, 2003,.

[9]. D. Deslandes, K. Wu,“Millimeter-wave substrate integrated waveguide filters”, Electrical and Computer Engineering, *IEEE CCECE Canadian Conference* , vol. 3, pp.1917-1920, May 4-7, 2003,

[10]. Guo-Hui Li, Xiao-Qi Cheng, HaoJian, Huan-Ying Wang,*”*Novel High-Selectivity Dual-Band Substrate Integrated Waveguide Filter with Multi-Transmission Zeros” *Progress In Electromagnetics Research Letters,* Vol. 7,pp. 7-12, 2014.

[11]. Huang, C. L. and C. L. Pan, “Dual-band multilayer ceramic microwave bandpassfilter for applications in wireless communication," *Microwave and Optical Technology Letters*, Vol. 32, No. 5,pp. 327-329, 2002.

[12]. Tsa, L. C. and C. W. Hsue, “Dual band bandpass Filters using equal-length coupled-serial-shunted lines and Z-transform technique," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 52, No. 4, pp. 1111-1117, 2004.

[13]. Lee, J., M. S. Uhm, and I. B. Yom, A dual-pass band Filter of canonical structure for satellite applications, "*Microwave and Wireless Components Letters*, Vol. 14, No. 6, pp. 271-273, 2004.

[14]. Lenoir, P., S. Bila, F. Seyfert, D. Baillargeat, et al., Synthesis and design of asymmetrical dual-band bandpass Filters based on equivalent network simplification*," IEEE Transactions on Microwave Theory and Technique*s, Vol. 54, No. 7, pp. 3090-3097, 2006.

[15]. Velazquez-Ahumada, M. D. C., J. Martel-Villagr, F. Medina, and F. Mesa, Application of stub loaded folded stepped impedance resonators to dual band Filter design*," Progress In Electromagnetics Research,*Vol. 102, pp. 107-124, 2010.

[16]. Lee, C. H., I. C. Wang, and C. I. G. Hsu, Dual-band balanced BPF using quarter wavelength stepped-impedance resonators and folded feed lines*," Journal of Electromagnetic Waves andApplications,* Vol. 23, pp.17-18, 2441-2449, 2009.

[17]. Weng, M.-H., S.-K. Liu, H.-W.Wu, and C.-H. Hung, A dual-band bandpass Filter having wide and narrow bands simultaneously using multilayered stepped impedance resonators*," Progress In Electromagnetics Research Letters*, Vol. 13, pp. 139-147, 2010.

[18]. Huang, T. H., C. S. Chang, and H. J. Chen, Simple method for a K-band SIW Filter with dual- mode quasi-elliptic function response*," Microwave and Optical Technology Letters,* Vol. 49, No. 6, pp. 1246-1248, 2007.

[19]. Zhang, X. C., J. Xu, Z. Y. Yu, et al., C-band half mode substrate integrated waveguide (HMSIW) Filter," *Microwave and Optical Technology Letters,* Vol. 50, No. 2,pp. 275-277, 2008.

[20]. Chen, J., B. Wu, L. W. Jiang, and C. H. Liang, A compact hexagonal dual-band substrate integrated Waveguide Filter based on extracted-pole technique*," Microwave and Optical Technology Letters,* Vol. 53, No. 3, pp.562-564, 2011.