ISSN 2320 - 2599
Volume 6, No. 1, January – February 2017
International Journal of Microwaves Applications
Available Online at http://www.warse.org/IJMA/static/pdf/file/ijma04612017.pdf

A Ka-Band Bandpass filter with Cylindrical Cavity Resonators using a Substrate Integrated Waveguide (SIW)

Aman Kumari[1,2*], Dhirendra Kumar[3] and Arun Kumar[1]
[1]Department of Electronics and Communication Engineering, IFTM University, Moradabad, India.
amandahiya@msit.in
[2]Maharaja Surajmal Institute of Technology, Delhi
[3]Department of Electronics and Communication Engineering, RKGIT, Ghaziabad,India.
dhirendra_007@rediffmail.com

ABSTRACT

A Ka-band Substrate Integrated Waveguide (SIW) 2-poles bandpass filter with metalized cylindrical cavities is proposed for satellite communications and closed range RADARS. The proposed filter inherits the bandpass characteristics of conventional waveguide and bandstop features of periodic structures. Hence, a Substrate Integrated Waveguide filter is designed with linear array of metallized cylindrical cavities implanted inside the same substrate along the side walls and inside the substrate in periodic pattern . A bandpass filter with passband of 38.7–40.5 GHz is designed on a single-layer Rogers RT/Duroid 5880 substrate. Simulated results exhibit insertion loss better than 29 dB and return loss less than 0.1 dB.

Key words: Substrate Integrated Waveguide(SIW), mm-wave circuits, cylindrical cavity resonators, Ka-band, bandpass filter, satellite communications.

1. INTRODUCTION

In last few decades different types of periodic structures have been developed. Structures like Electromagnetic Band gap (EBGs) and Defected Ground structures (DGS) are also common. As millimeter band is wide and can have many profitable capitalization [1]. As the development in RF front ends for millimeter wave circuits there has been a trend to design compact and good performance components to achieve the appropriate results. Filters are the crucial part of the RF front ends and also for millimeter wave systems [7]. At millimeter wave frequencies conventional methods for designing filters such as using microstrip line filters, conventional rectangular waveguides do not show optimum response [2]-[5]. SIW (Substrate Integrated Waveguide) filters provide the best solution for millimeter waves systems. SIW is designed with linear array of metallized cylindrical holes known as posts are implanted inside the same substrate along the side walls of substrate. The SIW technology is passed into various microwaves and millimeter wave devices such as active circuits, antennas and a convenient system for millimeter wave wireless system .Various SIW filters to surpass the losses like signal integrity and cross coupling are proposed [6]. The main issue of passive filtering is adopted by SIW, in other filtering methods such as RLC filters, metallic rectangular waveguides , microstrip lines are not capable of contributing to required response. To add more, these components are cumbersome, heavy to use, thus increasing the production cost to be used for satellite loads. SIW filters provide the quick fix solution as they are easily manufactured on a planar microwave substrate printed circuit board. Other aspects like high quality factor, reduced losses and size also contribute to the wide use of SIW in RF and millimeter circuits [7]. Various broadband SIW bandpass filters designed with cavity resonators such as circular and elliptical cavities [10],coaxial cavity [11] and triangular cavities [8] are proposed with different bandwidths. Several state of the art filter, such as dual-and triple-mode waveguide filters, dielectric resonator filters [11]-[14], high-temperature superconductor filters [15]-[16] are proposed. A narrow bandpass filter using low temperature co-fired (LTCC) technology in Ka-band is designed [17]. In this paper, a bandpass filter with cylindrical cavity resonators in Ka-Band using a Substrate Integrated Waveguide (SIW) technology is proposed at 38.6 Ghz center frequency. The designed filter is suitable for use in communication satellites and close range target RADARS.

2. 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. Microstrip lines and coplanar waveguides (CPWs) integrated to SIW as feed lines. These are transition systems to connect easily with other circuits. When boundary conditions are applied to a section of SIW, a cavity resonator is obtained. The resonant frequency is given by :

$$f_{mon} = \frac{c}{2\sqrt{E_{eff}}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \quad (1)$$

Where m, n represents the mode number, E_{eff} is the effective permittivity, a and b are width and height of rectangular waveguide, c is the speed of light in free space respectively. Various electromagnetic field distributions along with their modes determine the resonant frequencies. Where m and n are mode numbers. $TE_{10}$is said to be dominant mode, hence cutoff frequency f_c, of dominant mode TE_{10} is given as:

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

Now, if we fill the air filled space with dielectric material then it is converted into dielectric filled waveguide, then due to the effect of dielectric material embedded inside the waveguide the effective width get changed. Dielectric filled waveguide width a_d is given as **:**

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

Where ϵ_{eff} is the effective dielectric constant. Once dimension a_d of dielectric filled waveguide is determined, design equation for the SIW correlating width , a_s is given as:

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

Where d represents vias diameter, p is the pitch length or center to center separation between the vias. When a device is operating in millimeter–wave frequency range, three loss mechanisms occur in SIW structure. SIW structure exhibit conductor losses, dielectric losses and radiation losses. These losses are minimized by changing various geometrical parameters such as substrate thickness and spacing [16]. There are certain design conditions to minimize the losses [8]:

$$d/p \geq 0.5 \quad (5)$$

$$d/s < 0.4 \quad (6)$$

$$d < 0.2\lambda_g \quad (7)$$

where λ_g is guided wavelength and s is the separation between two arrays. Hence the pitch length should be kept small to reduce conductor losses and diameter of post is made optimum to control radiation losses. Dielectric losses can be minimized by proper choice of the substrate. The proposed SIW filter prototype is designed with roughly estimated parameters. A full wave electromagnetic simulation is used to simulate and optimize the filter prototype. Ultimately, the following empirical design formulae are derived to design the proposed SIW band pass filter.

$$\boldsymbol{We} = \frac{\mathbf{0.004 * 10^{-3} c}}{\boldsymbol{f_c \sqrt{\epsilon_r}}} \quad (8)$$

$$L_e = 1.1 * W_e + 2d \quad (9)$$

$$W_f = 1.1 * W_e \quad (10)$$

Using above design equations the structure length and width is proposed. The most effective and influential response is achieved by inserting metallic holes in periodic topology with specific diameter and adequate spacing along the horizontal and vertical dimensions inside the structure along with the side walls as the design specifications given in equations 5, 6 and 7. The proposed SIW filter is formed by a rectangular substrate embedded between two metallic layers with cylindrical metallic vias arranged in a serial manner, which act as the resonating structures on the sidewalls as shown in figure 1. Cylindrical cavity resonators which are arranged vertically down, split the waveguide in different sections, each section individually providing a high resonant Q- cavity. The electromagnetic energy is confined through these cavity resonators from input port to output port. The substrate used is ROGERS RT5880 with relative permittivity 2.2, loss tangent 0.009. A co-planar waveguide is used to excite the filter structure. The width of the waveguide is adjusted to provide the maximum coupling of energy from both sides of the structure and provide sharp skirt characteristics.

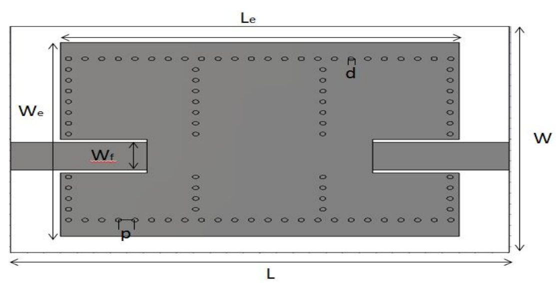

Figure 1: Substrate Integrated waveguide structure

The exploded view of the filter is shown in figure 2. The exploded view represents the top metal layer, ground metal layer, substrate, cylindrical vias and feed lines. Geometrical dimensions for the filter are mentioned in table 1 using above given design considerations.

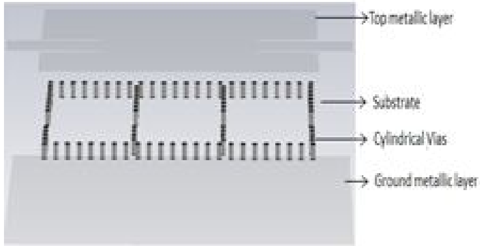

Figure 2: Exploded view of SIW bandpass filter structure

Table 1: Geometrical dimensions for the bandpass filter

Length of structure (L)	30 mm
Width of structure (W)	21 mm
Distance between two vias(p)	1mm
Thickness of Copper Conductor	0.017mm
Thickness of Substrate	0.762mm
Diameter of via(d)	0.5mm
Length of top metallic layer (Le)	24mm
Width of top metallic layer (We)	16mm
Width of feedline (Wf)	2.5mm

3. SIMULATION OF FILTER

Simulation of filter is done by full wave electromagnetic computer simulation technology. Various parameter studies have been made to get the desired performance around 39 GHz. The proposed filter is designed for 38.7 GHz to 40.5 GHz in Ka-band.

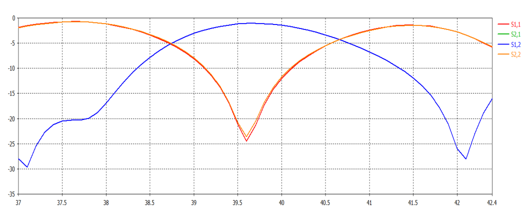

Figure 3: Bandpass Filter response of SIW structure depicting Insertion loss and return loss

The proposed filter is better in response in comparison with the bandpass filter designed in Ka-band [17]. Frequency response for the proposed filter is shown in figure 3. The return loss of the filter is better than 29 dB and the insertion loss is better than -0.1 dB.

4. CONCLUSION

In this paper, a bandpass filter with cylindrical cavity resonators in Ka-band using a substrate integrated waveguide (SIW) technology is proposed. The center frequency is considered at 39.6 Ghz. The simulated results exhibit a return loss less than 29 dB and insertion loss better than 0.1 dB over the pass band and offers a fractional bandwidth of 6%. The proposed SIW structure is suitable for use in satellite communications and closed range target RADARS.

REFERENCES

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

[2] X.-P. Chen and K. Wu. **Substrate integrated waveguide filters: Practical aspects and design considerations**,IEEE Microwave Magazine, vol. 15, pp. 75–83, Nov 2014.

[3] A. E. Atia and A. E. Williams**. Narrow-bandpass waveguide filters,** IEEE Trans. Microw. Theory Tech., vol. 20, no. 4, pp. 258-265, Apr.1972.

[4] R.J.Camero. **General coupling matrix synthesis methods for Chebyshev filtering functions,** IEEE Trans. Microw.Theory Tech., vol.47, no.4, pp. 433-442, Apr. 1999.

[5] R. Levy, R. V. Snyder, and G. Matthaei. **Design of Microwave Filters**, IEEE Trans. Microw. Theory Tech., vol 50, no. 3, pp. 783-793, Mar. 2002.

[6] Zhang-Cheng Hao. Wei Hong. **Compact Super-Wide Bandpass Substrate Integrated Waveguide (SIW) Filters**, IEEE Trans. Microwave Theory Tech., vol. 53, pp. 2968-977, Sept. 2005.

[7] Jixin Chen, Pinpin Yan, and Wei Hong. **A Ka-band Receiver Front End Module,** APMC 2010 Proc., pp. 535-537, Dec. 7- 10, 2010.

[8] Yu Lin Zhang, Wei Hong, Ke Wu, Ji Xin Chen, and Zhang Cheng Hao. **Development of Compact Bandpass Filters with SIW Triangular Cavities,** APMC 2005 Proc., pp. 535-537, Dec. 4-7, 2005.

[9] G. Lastoria, G. Gerini, M. Guglielmi, and F. Emma. **CAD of triple-mode cavities in rectangular waveguide,** IEEE Microw. Guided W., vol. 8, pp. 339-341, Oct. 1998.

[10] Hong Jun Tang, Wei Hong, Ji-Xin Chen, Guo Qing Luo, and Ke Wu. **Development of Millimeter-Wave Planar Diplexers Based on Complementary Characters of Dual-Mode Substrate Integrated Waveguide Filters With Circular and Elliptic Cavities**, IEEE Trans. Microwave Theory Tech., vol. 55, pp. 776-782, April 2007.

[11] Miguel`A.S´anchez-Soriano. **Compact Dual-Mode Substrate Integrated Waveguide Coaxial Cavity for Bandpass Filter Design**, IEEE Microwave and Wireless Components Letters, vol. 26, pp. 386-388, 2016.

[12] Xiao-Ping Chen, Ke Wu, Zhao-Long Li. **Dual-Band and Triple-Band Substrate Integrated Waveguide Filters With Chebyshev and Quasi-Elliptic Responses,** IEEE Trans. MicrowaveTheory Tech., vol. 55, pp. 2569-2577,December 2007.

[13] M. Guglielmi, P. Jarry, E. Kerherve, O. Roquebrun, and D. Schmitt**. A new family of all-inductive dual-mode filters**, IEEE Trans. Microw. Theory Tech., vol. 49, pp. 1764-1769, Oct. 2001.

[14] K. L. Wu**. An optimal circular-waveguide dual-mode filter without tuning screws**, IEEE Trans. Microw. Theory Tech., vol. 47, pp. 271-276, Mar. 1999.

[15] I.B.Vendik,V.V. Kondratiev, D. V. Kholodniak, S. A. Gal'chenko, A. N. Deleniv, M. N. Goubina, A. A. Svishchev, S. Leppavuori, J. Hagberg, and E. Jakku. **High-temperature superconductor filters: modeling and experimental investigations,** IEEE Trans. Appl. Supercon., vol. 9, pp. 3577-3580, Jun. 1999.

[16] M. F. Sitnikova, I. B. Vendik, O. G. Vendik, D. V. Kholodnyak, P. A. Tural'chuk, I. V. Kolmakova, P. Y. Belyavskii, and A. A. Semenov. **Modeling and experimental investigation of microstrip resonators and filters based on High-Temperature Superconductor films,** Tech. Phys. Lett., vol. 36, pp.862-864, Sep. 2010.

[17] B. G. Choi, , M. G. Stubbs**. A Ka-Band Narrow Bandpass Filter Using LTCC Technology,** IEEE Microwave and Wireless Components Letters, Vol. 13, NO. 9, September 2003.