A dual-purpose Substrate Integrated Waveguide (SIW) Wideband Bandpass Filter

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***Abstract*—**This paper presents a dual-purpose Substrate Integrated Waveguide (SIW) structure. The structure can be used as wideband bandpass filter as well as high gain antenna. The proposed filter is designed by inserting metallic cylindrical holes in periodic topology in both horizontal and vertical directions inside the substrate along with the side walls. The simulation and parametric evaluation of the filter is carried out by Computer Simulation Technology (CST) Microwave studio suite. The performance evaluation and parametric study shows that insertion of metallic holes inside the structure in periodic topology with optimum diameter and adequate spacing led to wide bandwidth bandpass filter and high gain antenna. The bandpass performance of proposed filter exhibit a insertion loss better than 0.7 dB and return loss less than 28 dB at around 96 GHz center frequency with 14.6% fractional bandwidth. The proposed structure is suitable for use in millimeter-wave applications.

***Keywords*—** *Millimeter-wave; Dual purpose Substrate Integrated Waveguide (SIW); Bandpass filter; Periodic topology; High gain Antenna.*

I. INTRODUCTION

For high-quality millimeter-wave and microwave communication systems, there is a great need to deploy low cost, low weight, small size, high capacity and of good performance characteristics filters. Conventional waveguide filters using metallic waveguides, co-axial lines and circular waveguides exhibit low loss, high reliability and high power handling capability. But filters designed using these waveguides are bulky, costly and difficult to integrate with other planar and non-planar circuits. Various planar circuits include microstrip lines and co-planar waveguides (CPWs) also exhibit low cost, small size and good integration with other planar circuits. However, sometimes these filters are unable to provide desired performance. To meet the desired requirements of high performance and low cost, special type of filters have been designed known as Substrate Integrated Waveguide (SIW) filters. SIW inherits many advantages such as low cross talk, low loss, high capacity, light weight, high quality factor and easy integration with other planar circuits [1]. SIW is designed with linear array of metallic cylindrical holes embedded along the side walls of substrate. Cylindrical holes also known as vias are of certain radius and adequate spacing. This leads to guided wave structure and electromagnetic waves are well confined along two parallel walls. The SIW planar circuits behave like waveguide [2] [3]. So all concepts of waveguide theory can be implemented on SIW circuits. SIW technique has been applied to various microwave circuits including power dividers [4], antennas [5], diplexers [6], couplers [7], filters [8][9] etc. The technique is more attractive for designing high frequency antennas and filters design. Many papers are published to demonstrate the properties and capacities of Substrate Integrated Waveguide (SIW) filters. More focus is made on making the size compact and achieving steep skirt characteristics of SIW filter. In order to reduce the size of circuit, substrate integrated waveguide (SIW) filters using various multilayered low temperature co-fired ceramic(LTCC) technology [12], printed circuit boards (PCB) process, folded SIW cavities (half folded and double folded) [13], meta-material resonators such as complementary split ring resonators(CSRRs) [11] and complementary spiral resonators(CSRs), defected ground structure (DGS) [10] etc are designed. Filters in ultra wide band and high frequency range are also investigated. In this paper a dual purpose Substrate Integrated Waveguide (SIW) structure is proposed which can be configured both as wide band bandpass filter centered at 96 GHz as well as high gain antenna at 100 GHz frequency. The structure is designed by inserting metallic holes in periodic topology embedded inside the substrate along horizontal and vertical directions along with the side walls.

II. THE PROPOSED FILTER DESIGN

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 whose fractional bandwidth is about 15%.

$$W = \frac{0.016 * 10^{-3} c}{f_c \sqrt{\epsilon_r}} \quad (1)$$

$$L_e = 4.8 * W \pm 2d \quad (2)$$

Using above design equations the structure length and width is proposed. fc is considered as the center frequency of a rectangular waveguide filter with dielectric material, fc of dominant TE mode is given by Pozar M. David [14]:

$$f_c = \frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (3)$$

Where m and n are mode number, c is the speed of light in free space, a is considered as length and b is width of a rectangular waveguide. TE10 said to be dominant mode, hence cutoff frequency fc, of dominant mode TE10 is given as

$$f_c = \frac{C}{2a} \quad (4)$$

Dielectric filled waveguide width “ad” is given as

$$a_d = \frac{a}{\sqrt{\varepsilon_{eff}}} \quad (5)$$

Where $\epsilon_{r\ eff}$ is the effective dielectric constant. Once dimension "a" of dielectric filled waveguide is determined, design equation for the SIW correlating width, as is given by K.wu. et.al. [15].

$$a_s = a_d + \frac{d^2}{0.95P} \quad (6)$$

Where d represents vias diameter, p is the pitch length or center to center separation between the vias.

III. LOSS MINIMISATION

First, When a device is operating in millimeter–wave frequency range, three loss mechanisms can occur in SIW structure. SIW structure exhibits 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

$$d/p \geq 0.5 \quad (7)$$

$$d/c < 0.4 \quad (8)$$

$$d < 0.2\,\lambda_g \quad (9)$$

where λg is guided wavelength. Guided wavelength is given by Pozar M. David [14]:

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{\omega^2 \epsilon_r - (\frac{\pi}{W})^2}{c^2}}} \quad (10)$$

Where ϵ_r is the relative permittivity of substrate. The pitch length should be kept small to reduce conductor losses and diameter of post is made optimum to control radiation losses as leaky waves. Dielectric losses can be minimized by proper choice of substrate. The proposed filter is designed by embedding metallic vias on whole top layer of substrate in periodic pattern to achieve wide band response at 96 GHz center frequency is shown in Figure 1. The inserted periodic patterns allow various electric and magnetic coupling mechanisms inside the structures.

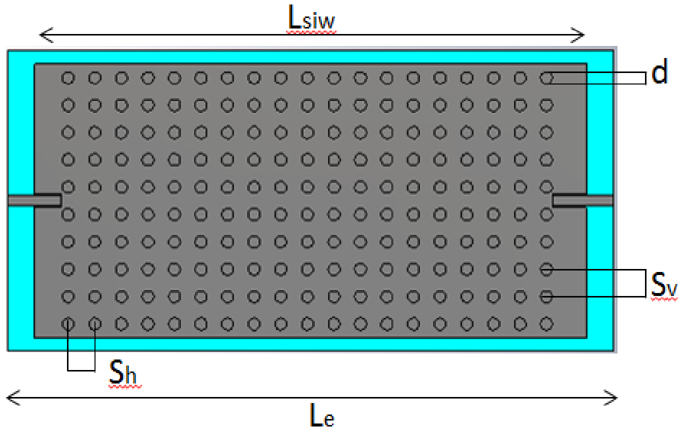

Fig. 1. Substrate Integrated Waveguide (SIW) structure

IV. THE PARAMETRIC EVALUATION AND SIMULATION OF FILTER

The parametric evaluation and simulation of filter is done by computer simulation technology (CST) microwave studio suite. Various parameter studies have been made to get the desired performance around 96 GHz. The most effective 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. The SIW structure is designed by using a substrate with relative permittivity, ϵ_r of 2.2 and height of 0.762 mm. The proposed filter structure is excited by open-ended microstrip lines in various topologies. Slots are etched to increase the energy fed to the structure and for minimizing transition loss. The input fed 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 used in the SIW structure. The optimum dimensions of proposed SIW bandpass filter structure are obtained by using mathematical equations given above in proposed filter design. Various parametric values obtained are given in Table 1.

Table 1 Parametric values of Substrate Integrated Waveguide (SIW) structure

Parameter	L_{siw}	L_e	W_{siw}	S_h	S_v	D
Values(mm)	36	40	20	2	2	0.775

Where L_e is the effective length of the filter, L_{siw} is the length of SIW, W_{siw} is the width of structure, S_h and S_v is center to center separation between vias along horizontal and vertical directions respectively and d is the diameter of vias.

A. EFFECT OF CHANGE IN VIA DIAMETER ON BANDPASS FILTER RESPONSE

Table 2 shows the effects of changing the vias diameter on Bandpass filter responses including return loss, insertion loss, 3-dB bandwidth and fractional bandwidth. It is proved from the studies that if the diameter of vias is kept small, then there will be low losses both return as well as insertion loss.

Table 2 comparison table showing change in responses by changing vias diameter

Diameter of Vias (mm)	S_{11} Return loss (dB)	S_{21} Insertion loss (dB)	3 dB Bandwidth (GHz)	Center frequency (f_c)	Fractional bandwidth (FBW)
0.44	45.4	0.4	9	100.5	8.9%
0.46	47.4	0.4	15	94.2	15.9%
0.45	54.6	0.2	15	94.2	15.9%

Comparison graph of return losses (S11) by varying the vias diameters is depicted in Figure 2 and insertion losses (S21) is depicted in Figure 3. It is observed that 0.45 mm is the optimum diameter of vias for better response which is shown in Figure 4.

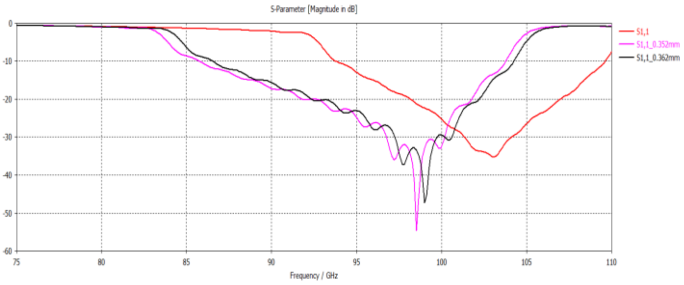

Fig. 2. Substrate Integrated waveguide bandpass filter depicting S11 (return loss) by varying diameters of vias

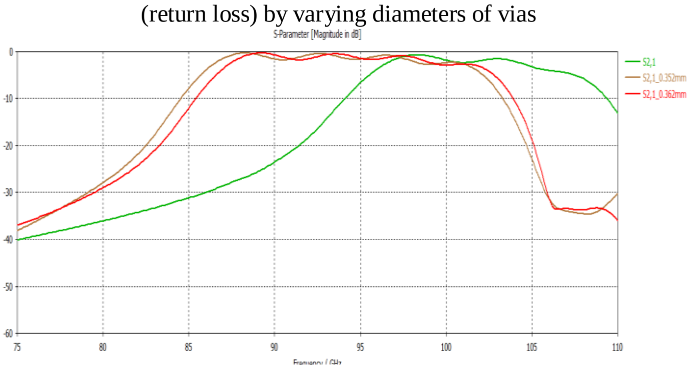

Fig. 3 Substrate Integrated waveguide bandpass filter depicting S21 (Insertion loss) by varying diameters of vias.

Figure 4 illustrates the proposed prototype of Substrate Integrated Waveguide (SIW) bandpass filter response in terms of S_{11}, S_{12}, S_{21}, S_{22} parameters. S_{11} represents the return loss better than 28 dB whereas insertion loss, S_{21} better than 0.7 dB. The 3dB bandwidth of filter obtained is 14 GHz centered around 96 GHz. The proposed substrate integrated waveguide (SIW) bandpass filter shows an improvement in response as reported by H. L. Kao et.al. [17].

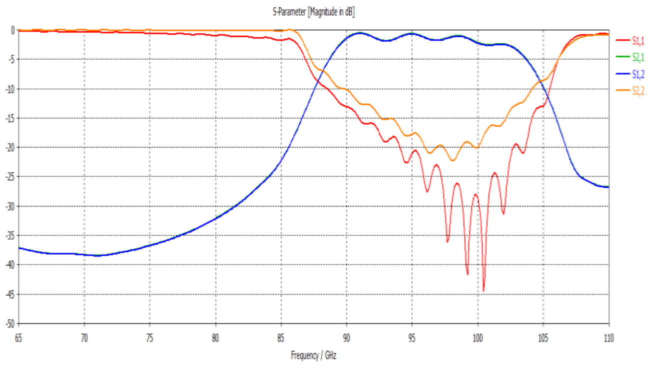

Fig. 4: Substrate Integrated Waveguide (SIW) structure illustrating Bandpass Filter response

V. SIMULATION OF ANTENNA

The SIW structure shown in figure 1.behaves as band pass filter as the response is depicted in figure 5. The same structure behaves like antenna also when simulated using single feed line as shown in figure 5. The farfield radiation plot by the given structure is shown in figure 6. The far field pattern of antenna depicts high gain of 11.15 dB at 100 GHz frequency.

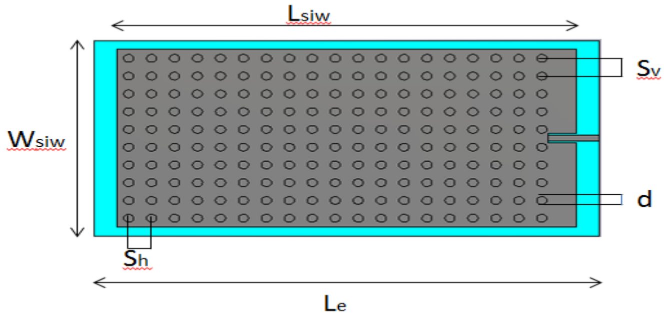

Fig 5: Substrate Integrated waveguide structure as Antenna with Co-planar waveguide feed line

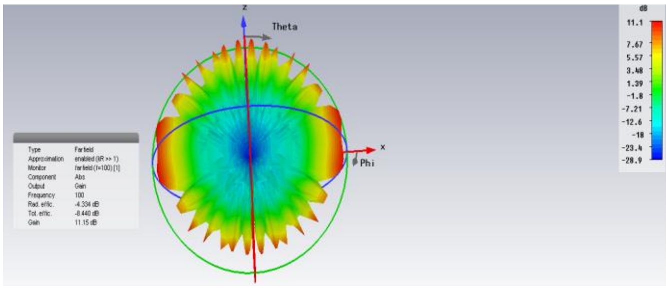

Fig 6: Substrate Integrated Waveguide (SIW) structure as high gain Antenna depicting the Radiation Pattern

VI. CONCLUSION

In this paper a dual purpose Substrate Integrated Waveguide (SIW) structure is proposed which can be configured both as wide band bandpass filter centered at 96 GHz as well as high gain antenna at 100 GHz. The structure is designed by inserting metallic holes in periodic topology inside the substrate in both horizontal and vertical directions along with the side walls. The simulated results exhibit a return loss better than 28 dB and insertion loss better than 0.7 dB over the pass band and offers 3dB bandwidth of 14 GHz with 14.6% fractional bandwidth. Parametric study reveals that insertion of vias inside the substrate in periodic topology with microstrip feed lines have successfully led to wide bandwidth filter performance and sharp skirt characteristics.The periodic topology of structure also successful in achieving high gain antenna. The proposed SIW structure is suitable for use in millimeter-wave applications.

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