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Comparative analysis of different via used on Substrate Integrated Waveguide

Karan Mahajan, Sourabh, Rajat Arora

***Abstract*—For the next coming decade Substrate Integrated Waveguide (SIW) technology is the most auspicious candidate for the implementation of millimeter-wave (mm-wave) integrated circuits. In this paper, the design and modeling of substrate integrated waveguide (SIW) using different vias has been analyzed and designed to investigate the effect of changing of vias on the SIW on its operating parameters. Parameters that have been evaluated in this work are electric field, return losses and the transmission gain. Printed circuit board (PCB), is used as dielectric substrate to evaluate the results in the frequency domain of 6 to 10 GHz. The FEM based designing and simulation software is used.**

Index Terms— Substrate integrated waveguide, finite element method, return loss, different vias.

I. Introduction

From the last few years, there is rapidly increase in interest for SIW based antennas. The development in the area of small integrated radio frequency (RF) systems takes the scaling of waveguides to micron level [1]. There are various configurations have been presented: the first SIW antenna was designed using four slots SIW array operation which was operating at 10 GHz, and that was obtained by etching the longitudinal slots in the top metal surface of an SIW [2]. To design microwave and millimeter wave components and subsystems Substrate integrated waveguide (SIW) technique has been developed [3]. The main advantage of SIW over conventional metallic waveguides, are high power Capacity, high Q-factor, high selectivity, cutoff frequency characteristic [4]. SIW also consists of the advantage of low profile, light weight, conformability to planar or curved surfaces, and easy integration with planar circuits [5]. The benefits of SIW used in high frequency applications, microstrip devices are not much capable, and because wavelength at high frequencies are small, microstrip device manufacturing requires very tight tolerances [6]. At high frequencies waveguide devices are preferred; however their manufacturing process is difficult [7]. Dielectric filled waveguides are the fundamental building blocks of integrated circuits. Dielectric filled waveguide is transformed to substrate integrated waveguide (SIW) by the help of vias for the side walls of the waveguide. Because at the sidewalls, there are vias transverse magnetic (TM) modes do not exist; TE10 therefore is the dominant mode [8]. As the operational frequency increases, in the planar microstrip line efficiency various losses occur, mainly at bends and discontinuities apart from its inherent conductor losses [9]. The increase in frequency and gain is accompanied with the decrease of radiation efficiency due to the inherent losses on the microstrip feeding network [10]. The common connection between waveguide and the planar circuits is to provide via transitions with a simple matching geometry between both structures, and also to provide a compact and low-cost platform [11]. In this paper, three different SIW based antenna using different vias has been designed using finite element method based design software. The S- paramaters and electric field were estimated while simulation and the design analysis for the proposed SIW structures is presented in the next section. The design methodology, results and discussions are proposed and discussed in the subsequent sections.

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Karan Mahajan PG Student, Dept. of ECE, Sri Sai College of Engineering & Technology, Badhani Pathankot India.
Sourabh, Assistant professor, Dept. of ECE, Sri Sai College of Engineering & Technology, Badhani Pathankot India.
Rajat Arora PHD Student, Dept. of ECE, GNDU Amritsar, India.

II. Mathematical analysis of SIW

The structure of SIW devices can be used as a dielectric filled waveguide (DFW). For TE10 mode, the thickness of the substrate is not important, because it does not affect the cut off frequency of the waveguide. Therefore the substrate can be of any thickness; it only affects the dielectric loss [12].

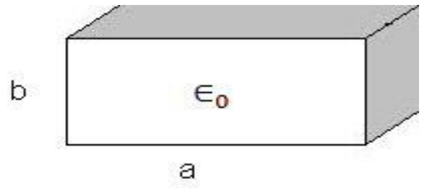

Fig 2: Dimension definition of rectangular waveguide

the cut off frequency for a rectangular waveguide, of arbitrary mode is found by the following formula:

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

where:
c: speed of light
m, n: mode numbers
a, b: dimensions of the waveguide

For TE10 mode, in simplest form f_c can also written as

$$f_c = \frac{C}{2a}$$

For DFW with same cut off frequency, dimension ad" is found by:

$$a_d = \frac{a}{\sqrt{\epsilon_R}}$$

After considering the SIW width dimension "a" for the DFW, the design equations for SIW are used.

$$a_s = a_d + \frac{d^2}{0.95p}$$

where
d: diameter of the via
p: pitch (distance between the vias)

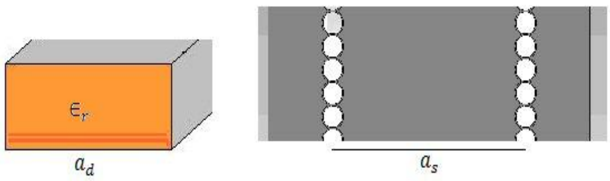

Fig 3: Dimensions for DFW and SIW

for designing of SIW the following two conditions are required

$$d < \frac{\lambda_g}{5}$$
$$p < 2d$$

Where λ_g is the (guided wavelength)

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{\epsilon_R (2\pi F)^2}{c^2} - \left(\frac{\pi}{a}\right)^2}}$$

The TE10 mode is the fundamental mode of SIW. The equivalent width between the two rows of metallic vias is W and spacing between neighboring via hole is taken S. The diameter of metalized via hole of SIW is taken as D, The equivalent width of the SIW can be expressed as follows

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

Therefore, the propagation constant $\beta(W)$ of the SIW can written as

$$\beta(W) = \sqrt{\omega^2 \mu \varepsilon - \left(\frac{\pi}{W_{eff}}\right)^2}$$

the propagation constant β is determined by the width W of SIW completely for given D, S, , ω , ε, and μ.

III. Design and Analysis

Figure 4 shows the structure of SIW consisting of the top and bottom metal planes of a substrate and two parallel rectangular hollow vias on the substrate.

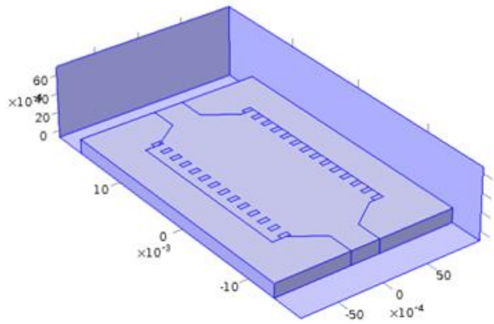

Fig. 4 designed Structure of rectangular SIW

In this paper three different designs, are used taking different vias on the SIW. PCB has been taken as substrate with relative permittivity 3.38 and relative permeability 1.

The dimensional parameters selected for the proposed design is shown in table 1.

Table 1: Dimensional parameters selected for SIW design

Parameter	Value
Substrate thickness	15 mm
Substrate length	35 mm
Substrate width	12.5 mm
Feed line length	30 mm
Feed line width	3.2 mm
Radius of via	0.5 mm

IV. Results and Discussions

In this section, we will highlight the essential comparison related to different conducting vias in the rectangular waveguide. Fig. 5 shows the meshing design of using different vias in rectangular SIW waveguide structures. Normal meshing is used in the SIW structure to avoid the computational load. The maximum element size selected is 0.0054508. The design of SIW was simulated on the computational machine having 3.4 GHz processor speed.

The electric field generated while computing the results for different vias in the SIW structure are shown in figure 6. Fig. 6(a) shows the simulated result for electric field for circular vias in SIW structure, while fig. 6(b), and 6(c) shows the radiations due to electric field generated for vias in SIW structure taken as square, and rectangular.

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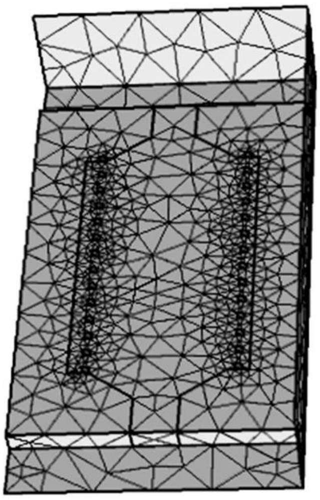

Fig.5. Meshed design of the proposed model.

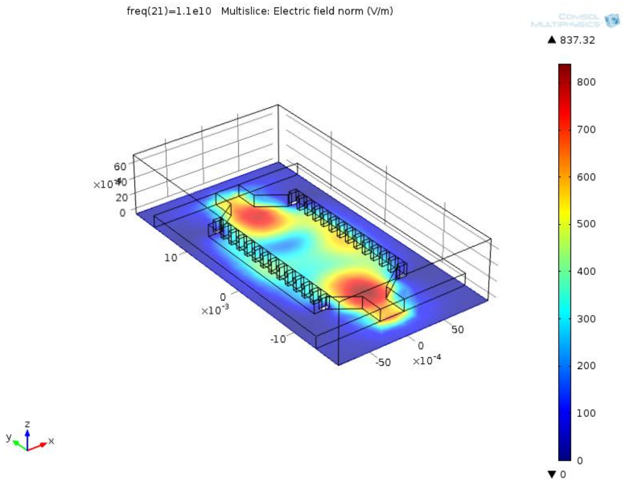

Fig. 6(c) Electric field for rectangular vias

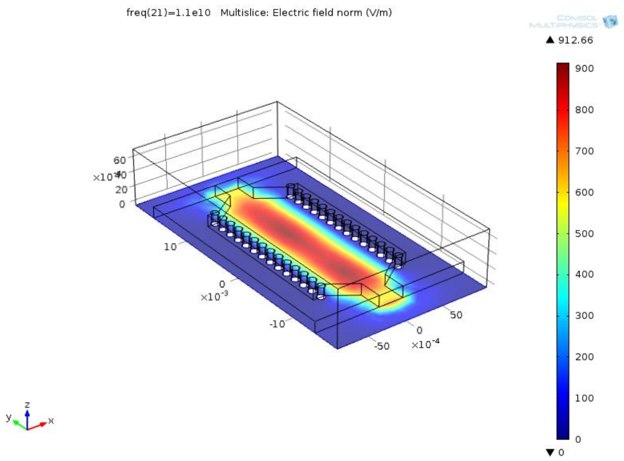

Fig. 6(a) Electric field for circular vias

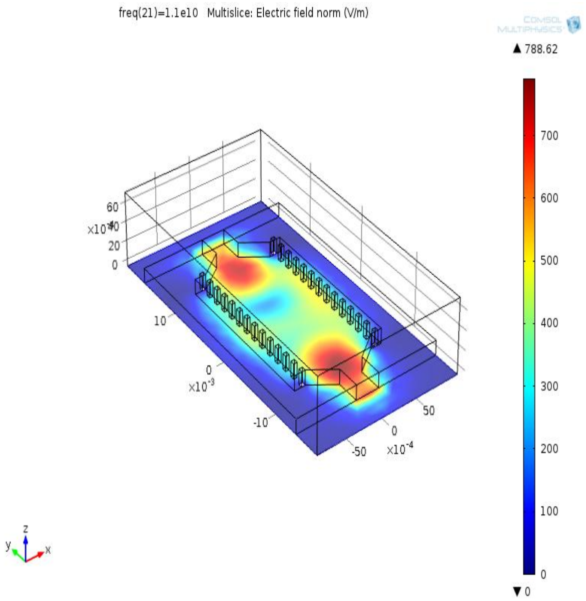

Fig. 6(b) Electric field for square vias

From the bar line adjacent to these graphs it is clear from the above figures that the maximum value (912.6 V/m) of electric field is for circular vias while for square vias contains minimum value (788.62 V/m), and For rectangular vias it contains the maximum value of electric field is 837.92 V/m respectively. Generally to radiate effectively the return loss value of antenna should be -10 dB in the plot of return loss (dB) versus frequency (GHz). Figure 7(a) (b) (c) shows the return loss (dB) versus frequency (GHz) plot for substrate integrated waveguide (SIW) antenna using different conducting hollow vias on the substrate of substrate integrated waveguide. Return losses or input reflection coefficient (S11) and the forward transmission gain (S21) were plotted for all the vias contained in a substrate in the substrate integrated waveguide.

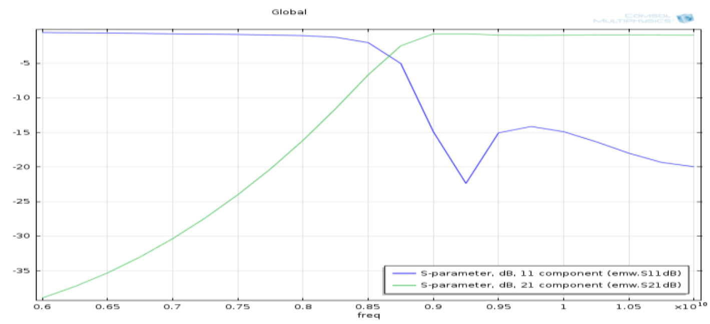

Fig. 7 (a) Return loss vs frequency for circular vias

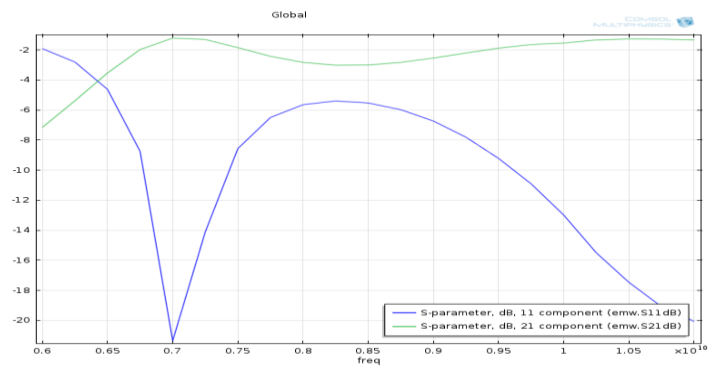

Fig. 7 (b) Return loss vs frequency for square vias

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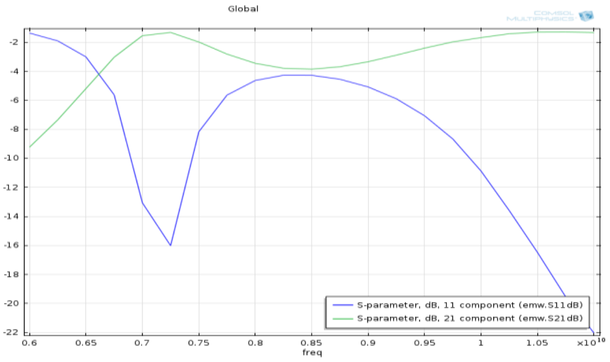

Fig. 7 (c) Return loss vs frequency for rectangular vias

Fig. 6(a) shows the S11 and S21 parameter w. r. t. frequency plot for circular vias. Dip in the return loss is observed at 9.25 GHz and transmission gain increases upto 9 GHz and then saturates. Correspondingly, return loss and transmission gain for square and rectangular vias are also plotted from Fig. 7(b) to 7(c). In case of square vias transmission gain remains varied for the whole frequency band but shows maxima at the resonant frequency (7 GHz). While in the case of rectangular vias Return loss is found at 7.25 GHz frequency and transmission gain shows dips of -24 dB, -22 dB, and -16 dB at frequencies 9.25 GHz, 7 GHz, and 7.25 GHz respectively.

V. CONCLUSION

This paper has presented an overview of substrate integrated waveguide technology, and effect of different vias on the substrate integrated waveguide technology. To evaluate the effect of vias, three different vias on substrate such as circular, square and rectangular were used in the experiment. S-parameters such as return loss and transmission gain were calculated for frequency ranging from 6 GHz to 10 GHz. It can be concluded that the SIW works efficiently at around 6-10 GHz for square and rectangular vias

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