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Design and Analysis of Substrate Integrated Waveguide (SIW) for High Frequency Applications

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Abstract*:** ***In this paper, substrate integrated waveguide has been designed and analyzed for high frequency applications. As high frequency suffers attenuation due to metal waveguide, atmospheric attenuation and Rain fade etc.A improved waveguide method is adapted known as Substrate Integrated Waveguide. SIW is transition between micro-strip antenna and Dielectric filled Waveguide antenna. SIWs are planar structures so they can be fabricated over PCBs and can be easily integrated with supplementary transmission lines. In the study, the different parameters like electric field generated, transmission gain and return loss is evaluated. Results are calculated over a frequency ranging from 6 GHz to 11 GHz.

Index Terms*: *Substrate Integrated Waveguide; Vias; EHF or VHF; design SIW; Transmission

I. INTRODUCTION

In Era of Faster data transfer with better reliability, 5G is under test which make use of millimeter wave also known as mmW or mm Wave which consents higher data rates upto 10 Gbps. mmW are the waves having frequency ranges from 30 GHz to 300 Ghz wedged between microwave and infrared waves. These waves are also known as Extremely High Frequency (EHF) or Very High Frequency (VHF) waves. Millimeter wave communication is currently used for fixed links between cell towers which are generally known as Blackhaul. But on limitations side, due to shorter wavelength the mmW suffers from various attenuations like atmospheric attenuation and absorption by gases in environment. These are also affected by rain and humidity, which reduces its signal strength and range [12]. Substrate Integrated Waveguide (SIW) is a planar structure contrived having two rows of metallic vias linking upper and lower metallic ground planes and dielectric substrate which acts as a High Pass Filter. SIW when compared with traditional waveguides cavity, it brings various advantage of low profile, small fabrication tolerance also easier integration with microstrip circuit. On the other hand if related with microstrip resonators, it exhibits advantages of easier integration with heat sink, self packaging and tiny radiation loss specifically for mm-Waves. SIW resonator is completely compatible with PCB and Low Temperature Co-fired Ceramic (LTCC).Also SIW structures have benefits of very low production cost, they are compact in size.

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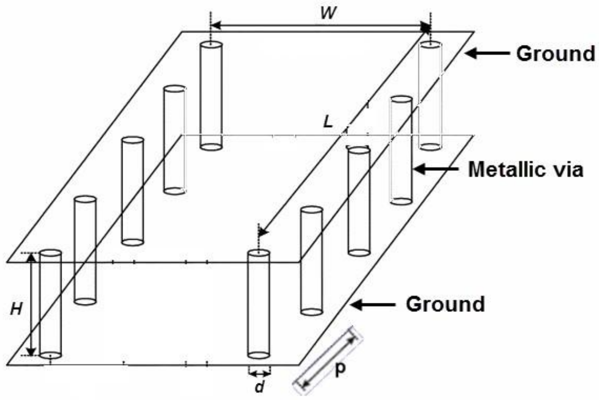

Fig. 1: Structure of Substrate Integrated Waveguide

II. DESIGN PARAMETERS

A. Design

First, The Vertical Perfect Conductor walls are formed by metallic Vias inside a dielectric substrate which can be easily unified with other elements of the system on a single substrate platform without tuning. Horizontal walls are made up from metallic layers of substrate. The length, width and height of the cavity are given by *L*, *W* and *H* respectively. The diameter of the vias are given by *d* and spacing between the vias is denoted by *p*. the spacing of the vias should be less than half guided wavelength of the high frequency equation[4]. Because of the vias at the sidewalls TM mode does not exist Only TE mode is dominant mode and is considered. [3]

B. Cutoff frequency of waveguide for SIW

For TE mode to be considered, the dimension "b" is not much important as it does not affect the cut off frequency of the waveguide [8].

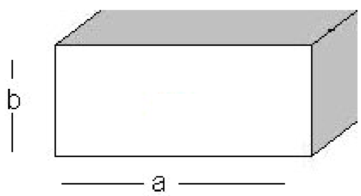

Fig. 2: Design parameters

the cut off frequency is expressed as [2,3]

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

where c is speed of light and is given as $3x10^8$ m/sec , m and n are modes, a and b are the dimensions of the waveguide. For TE10 mode the cutoff frequency is [4]

$$fc = \frac{c}{\lambda c} = \frac{c}{2a\sqrt{\mathcal{E}r}} \quad (2)$$

λc is can be found as

$$\lambda c = 2 \text{ x ad} \sqrt{\mathcal{E}r} \quad (3)$$

where ad is the width of rectangular waveguide.

The Design equation for SIW is given by

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

C. Dielectric losses

The dielectric loss α_d in a waveguide is given by

$$\alpha_d = \frac{k^2 \tan\delta}{2\beta} \quad (5)$$

Where tan δ is dielectric loss

D. Conductor losses

Conductor losses are given by

$$\alpha_c = R_s \frac{(2h\pi^2 + l^3 k^2)}{l^3 h\beta k\eta} \quad (6)$$

β represents phase constant

k-free space wave number, η is medium's intrinsic impedance and is given by

$$\eta = \sqrt{\frac{\mu_0}{\varepsilon_0 \varepsilon_r}} \quad (7)$$

σ is conductivity of material, R_s is surface resistivity of the conductors

$$R_s = \sqrt{\frac{\omega\mu_0}{2\sigma}} \quad (8)$$

$$\alpha_{wav} = \alpha_d + \alpha_c \quad (9)$$

E. Waveguide losses

Leakage losses α_l also affects losses, including this loss the dielectric losses can be rewritten as

$$\alpha_d = \frac{k^2 \tan\delta}{2k_z} \quad (10)$$

and conductor losses can be rewritten as

$$\alpha_c = \frac{R_s}{a_e\eta\sqrt{1-\frac{k_c^2}{k^2}}}\left[\frac{a_e}{w} + \frac{2k_c^2}{k^2}\right] \quad (11)$$

where$a_e$is equivalent width of SIW[9]

$$k_c^2 = k^2 - k_z^2 \quad (12)$$

$$k_2(f) = \sqrt{\left\{k^2 - \left[\frac{2}{a_e} cot^{-1}\left(\frac{f_c}{f} r_s(1-j)\right)\right]^2\right\}} \quad (13)$$

where$r_s$is real part of wave impedance of surface[10],f is operating frequency and f_c is cutoff frequency.

F. Radiation losses

These losses are due to gaps between metal vias. these are mostly negligible however if gap is large between the vias, the losses can be more.[11] it is given by

$$\alpha_R = \frac{\frac{1}{w}\left(\frac{d}{w}\right)^{2.84}\left(\frac{s}{d}-1\right)^{6.28}}{4.85\sqrt{\left(\frac{2w}{\lambda}\right)^2 - 1}} \quad (14)$$

these losses are measured in dB/m

G. Quality Factor

The unloaded quality factor of the waveguide which includes three types of losses is given by equation [6]

$$Q_u = \frac{Q_c.Q_d.Q_r}{Q_c.Q_d + Q_d.Q_r + Q_r.Q_c} \quad (15)$$

Where Q_c is the conductor losses by upper and lower ground plane, $Q_d$is the dielectric loss conveyed by dielectric substrate and Q_r is the radiation losses between the adjacent vias.

Conversely as discussed, the radiation losses can be controlled by spacing the via distance *p* smaller than half guided wavelength of highest operation frequency.

III. MODELING OF SUBSTRATE INTEGRATED WAVEGUIDE

The design of substrate integrated waveguide is coupled with microstrip line using taper. The microstrip line is designed as perfect electric conductor 0.1524 m thick substrate of dielectric. Width of line is 3.2 mm, length of line is 30 mm. Width of taper is 12.5 mm and length of taper is 20 mm. radius of via is taken as 0.5 mm. Width of microstrip line is matched to 50 Ω line. Except the ground plane, model domain is surrounded by scattering boundaries that signify an open space. With a is designed as 9.5 mm, the calculated cut of frequency is 8.5 GHz. The design of model is shown in figure 3. PCB is taken as substrate which has relative permittivity as 3.38 and relative permeability as 1. The applied frequency range is 6 GHz to 11 GHz is given to lumped port.

Table 1. Model design parameters

Description	Value
Substrate thickness	0.1524 cm
Width of feed line	3.2 mm
Length of feed line	30 mm
Width of taper	12.5 mm
Length of taper	20 mm
Radius of via	0.5 mm
Minimum frequency	6 GHz
Maximum frequency	11 GHz

Wave equation used using solving for electric field is given as

$$\nabla \times \mu_r^{-1}(\nabla \times E) - k_0^2\left(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0}\right)E = 0 \qquad (16)$$

Equation used for scattering boundary is

$$\mathrm{n} \times \left(\nabla \times (E)\right) - jkn \times (E \times n) = 0 \qquad (17)$$

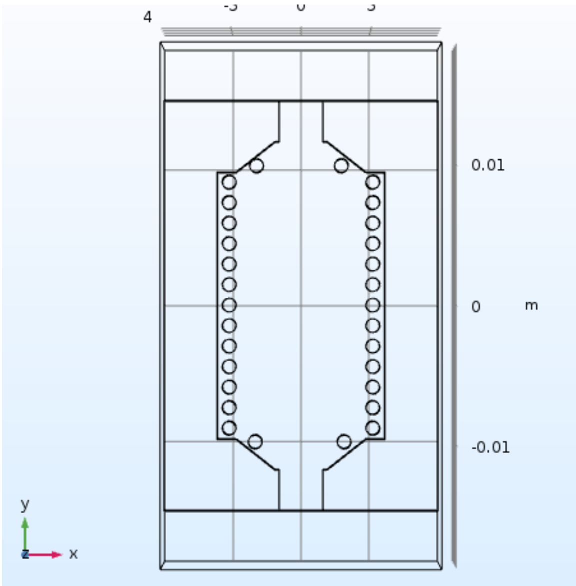

Figure 3. Designed model of substrate integrated waveguide

Figure 4 shows meshing of design. Normal meshing is conducted on SIW structure than extra fine meshing so to reduce computational load. The meshing is done by tetrahedral mesh with five elements per wavelength. In meshing 59822 tetrahedron values, 4860 prisms, 8796 triangles 500 quad, 676 edge elements and 36 vertex elements are used. Inside design of patch maximum element size of 23.060 is taken with curvature factor of 0.6.

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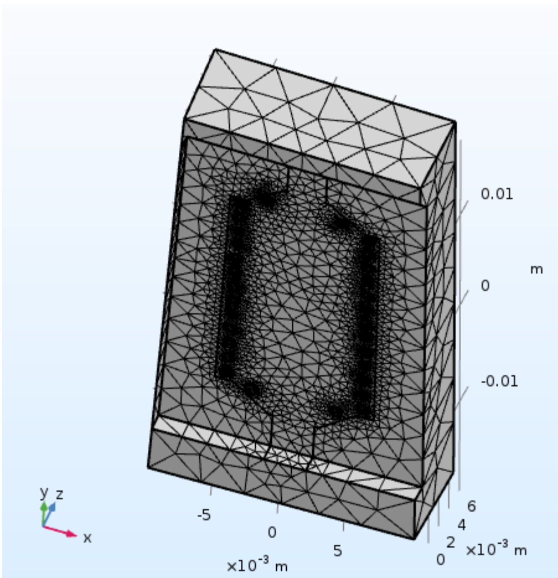

Figure 4. Meshing of design

IV. RESULTS AND DISSCUSSIONS

The design of the SIW structure was modeled and simulated on computational machine having 2.60 GHz. 3.2 GB was the virtual memory used while computation. The vias are composed like this so that only patterns with vertical current distributed on the side wall can survive in structure. TE_{10} can be supported in SIW as current path is not cut by via fences. Current paths will cut in SIW which results in radiation. As a result the Figure 5 shows electric field generated for the range of frequency from 6 GHz to 11 GHz.

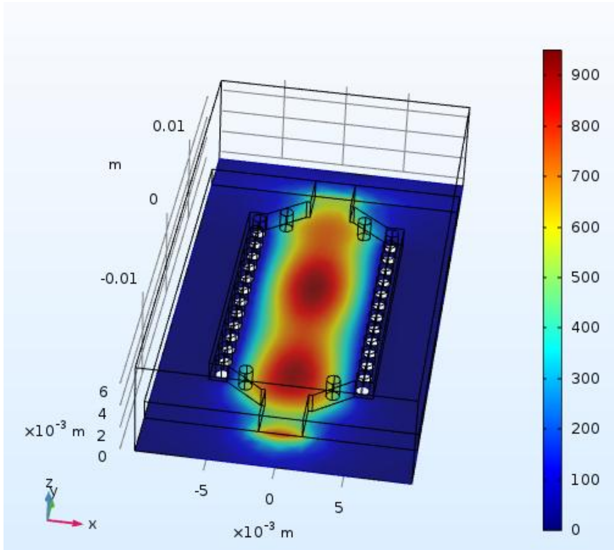

Fig. 5: Electric field generated in SIW

The s-parameter plot shown in Fig. 6, indicates return losses and transmission gains.

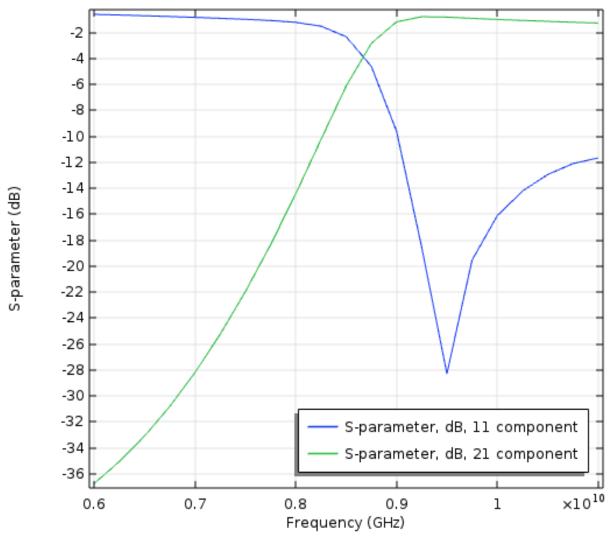

Fig. 6: s-parameter plot of design

The plotted s-parameter shows the transmission gain increases to 9 GHz and saturates. The frequency response behaves as high pass filter. The cutoff is observed near the calculated expected frequency. S_{11} falls after 8.3 GHz to 9.5 GHz then it rises. The gain -20 dB band between 9.2 GHz to 9.4 GHz hence it is useful bandwidth.

V. CONCLUSIONS

Numerous pros over the micro-strip and DFW, SIW is low loss waveguide for the transmission of higher frequency ranges. However the leakage loss can be substantial. Simulated experiment is carried out using designed substrate integrated waveguide to analyze electromagnetic wave propagation over structure. Electric field generated and s-parameter was calculated analyzed. The design acts as high pass filter with usable frequency band from 9.2 GHz to 9.4 GHz. The proposed design can be used in applications includes communication over 5G, Ultra-Wide band Antenna.

REFERENCES

1. TarekDjerafi and K. We," Super-compact Substrate IntegratedWaveguide Cruciform Directional coupler", IEEE Microwave and Wireless Components Letters, Vol.17, No11, pp: 757 - 759, 2007.
2. AsaneeSuntives, and Ramesh Abhari, "Transition Structures for 3-D Integration of Substrate Integrated Waveguide Interconnects,", IEEE Microwave And Wireless ComponentsLetters, Vol. 17, pp. 697-699, October 2007
3. H. Chu, J. X. Chen, S. Luo, and Y. X. Guo, "A millimeter-wave filteringmonopulse antenna array based on substrate integrated waveguide technology," IEEE Transactions on Antennas and Propagation. vol. 64, no. 1 pp. 316–321, Jan. 2016.
4. FarzanehTaringou and Jens Bornemann, Return-Loss Investigation of Equivalength width of Substrate IntegrtedWaveguideCircuits, IEEE MTT-S International Microwave Workshop Series on millimeter Wave Integraton Technologies, 2011.
5. M. J. Hill and R. W. Ziolkowski, J. Papapolymerou, "Simulated and measuredresults from a Duroid-based planar MBG cavity resonator filter," IEEE Microw. Wireless Compon. Lett., vol. 10, no. 12, pp. 528–530, Dec. 2010.I.S. Jacobs and C.P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G.T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350.
6. R. E. Collin, Foundations for Microwave Engineering. New York: McGraw-Hill,1992.
7. D. M. Pozar, Microwave Engineering, 2 ed. New York: Wiley, 1998.
8. J. E. Rayas-Sanchez and V. Gutierrez-Ayala, "A General EM-Based Design Procedure for Single-Layer Substrate Integrated Waveguide Interconnects with Microstrip Transitions", *IEEE MTT-S Int. Microwave Symp. Dig.*, Atlanta, GA, Jun. 2008, pp. 983-986.
9. SheeluKumari and ShwetaSrivastava. Notched Folded Substrate Integrated Waveguide (NFSIW) for Frequency Selective Applications
10. IRE Journal of Communications Antenna and Propagation (IRECAP), August 2012 Vol. 2 N. 4,pp. 259-263
11. D.Deslandes,K.Wu. Accurate modeling, wave mechanism & design considerations of substrate integrated waveguide.
12. M. Pasian, M. Bozzi, L. Perregrini, "Radiation Losses in Substrate Integrated Waveguides: a Semi-Analytical Approach for a Quantitative Determination," *2013 IEEE MTT-S International Microwave Symposium* (IMS2013),Seattle, WA, USA, June 2–7, 2013.
13. Manvinder Sharma, Harjinder Singh (2018). A Review on SubstarteIntergrated Waveguide for mmW. Circulation in Computer Science, ICIC 2018, (June 2018), 137-138.

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