International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Research Article

Modelling and Design of Substrate Integrated Waveguide using Two Parallel Rows of Rectangular Conducting Slots

Yasser Arfat[A], Sharad P. Singh[A], Saleem Khan[B] and Sandeep Arya[B*]

[A]Department of Electronics & Communication Engineering, Arni University, Himachal Pardesh, India
[B]Department of Physics & Electronics, University of Jammu, Jammu, J&K, India

Accepted 25 December 2013, Available online 30 December 2013, **Vol.3, No.5 (December 2013)**

Abstract

In this work, substrate integrated waveguide (SIW) has been designed and analyzed using two parallel rows of rectangular conducting slots on dielectric substrate. Different operating parameters such as electric field, return losses and the transmission gain is evaluated taking air as dielectric material in-between the slots. The results are evaluated for frequency domain of 6 to 12 GHz. The design is studied theoretically followed by the finite-element method (FEM) based modelling for optimizing the geometrical dimensions of the SIW structure. The results obtained had shown that the transmission gain increases with the increase in frequency upto 9 GHz and the return loss is minimum for this frequency.

Keywords: *Substrate Integrated Waveguide, Finite Element Method, Return Loss, Transmission Gain, Electric Field.*

---

1. Introduction

Microwave and millimeter wave communication systems are developing in a rapid manner (*J. Hirokawa et al, 1998*). Due to increase in demand, emphasis is on high-performance applications of microwave communication systems with low cost, high selectivity, compact size, and low insertion losses (*Y. Cassivi et al, 2002*) (*D. Deslandes et al, 2001*). Waveguides possesses excellent performance but is expensive and difficult to synthesize due to high volume and bulkiness (*S. Germain et al, 2003*). Also, their integration with other planar circuits is complex (*W. Ke et al, 2003*). Substrate integrated waveguide (SIW) has been proposed as a new planar structure which is suitable to integrate with the planar structures (*A. Zeid et al, 2002*). SIW has been reported and implemented by several researchers for number of applications such as radiated RF/microwave components, transmission lines, filters, couplers, diplexers, oscillators, and leaky-wave antennas. These devices are substantially miniaturized with high performance characteristics (*D. Deslandes et al, 2002*) (*E. Miralles et al, 2011*). In a SIW structure, the electric field distribution fill the volume inside the waveguide and surface current propagate on a large cross-sectional area of the waveguide walls, resulting in lower conductor loss (*B. N. Das et al, 1986*). As the frequency of operation and circuit density continues to increase, closely spaced microstrip and strip line interconnects will no longer be viable options (*W. Grabherr et al, 1994*).

In this simulated work, SIW with rectangular via slots have been designed to evaluate their different operating parameters. FEM based software is used for simulation purpose after theoretical calculations.

2. Substrate Integrated Waveguide

Fig. 1 depicts a single SIW cavity resonator with appropriately labeled dimensions.

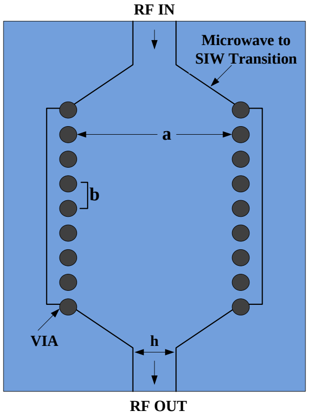

Figure 1 Layout of Substrate Integrated Waveguide

Substrate Integrated Waveguide (SIW) operates under the same basic principles as that of conventional air-cavity rectangular waveguides (*P. Mohammadi et al, 2011*) (*P. Mohammadi et al, 2012*). However, there are some differences in terms of the dielectrics of air versus a substrate material (*F. Mira et al, 2007*). SIW cavities are more sensitive than conventional waveguides for

---

*Corresponding author: **Sandeep Arya**

microwave applications. This is due to higher frequencies being more sensitive to substrate losses (*Y. Cassivi et al, 2002*) (*Z. Jian et al, 2007*). Additionally, compared to conventional 3-D rectangular waveguides, thinner substrate dielectrics prevent transverse magnetic (TM) modes to resonate. Therefore, only transverse electric (TE) modes can effectively propagate through SIW cavities (*M. Bozzi et al, 2008*). For design purposes, two primary design rules for SIW cavities are used to exploit for conventional waveguide modeling. These rules are as-

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

$$b \le 4d$$

where d is the diameter of the metal via posts and b is the via post spacing b (*T. Y. Huang et al*). By ignoring these expressions can create too much leakage loss for the via post in SIW cavity side walls. The following mathematical expressions provide the first resonant frequency mode for the SIW cavity (*T. Y. Huang et al*):

$$f_{101} = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{\pi}{w_{eff}}\right)^2 + \left(\frac{\pi}{w_{eff}}\right)^2}$$

$$l_{eff} = l - \frac{d^2}{0.95b},$$

$$w_{eff} = w - \frac{d^2}{0.95b}$$

where f_{101} is the first resonant mode of the cavity, w and l are the width and length of a single SIW cavity, d is the diameter of the vias, and b is the via spacing as shown in fig. 1. The guided wavelength in the SIW is given by following formula

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

where f is the resonant frequency, c is the speed of electromagnetic wave in free space and a is the width of the waveguide. SIW waveguides propagation characteristics are similar to classical rectangular waveguides (*J. E. Rayas-Sanchez et al, 2008*). Also, the field pattern and the dispersion characteristics are same.

3. Design and Analysis

Figure 2 shows the designed structure of an SIW that completely integrated on the same substrate without any mechanical assembly or tuning. The 50 Ω transmission line is connected to integrated waveguide. Mode matching is done by tapered section to transform the quasi-TEM mode of the microstrip line into the TE_{10} mode. Modelling and optimization in software over the desired frequency bandwidth is the most commonly used method, but this is typically very time consuming due to lots of metalized rectangular via holes. If analytical equation has been used, the design process would be speed up. FEM based software's used analytical equations. This designed structure of an SIW consisting of the top and bottom metal planes of a substrate with two parallel rectangular via fences in the substrate. The rectangular via are so composed that only patterns with vertical current distributed on the side wall can survive in SIWs.

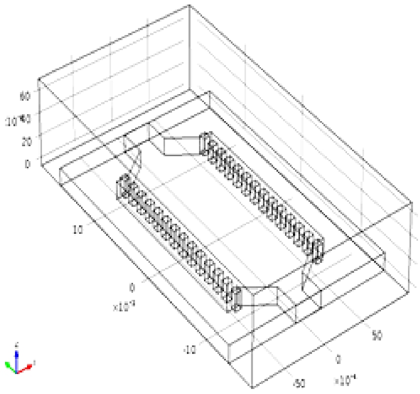

Figure 2 Structural design of SIW.

The current path will not be cut by via fences, therefore TE_{10} mode can be supported in an SIW. This holds for all TE_{m0} modes since their current distributions on the side walls are similar. On the other hand, horizontal components of the surface current exist on the sidewalls for all TM modes and TE_{mn} modes with nonzero n's. These current paths will be cut in SIW structures, which results in radiation. Therefore we can conclude that only TE_{m0} modes exist in SIW structures (*T. Y. Huang et al*). In our design, PCB has been taken as substrate with relative permittivity 3.38 and relative permeability 1. The model is designed using electromagnetic, frequency domain solver. Frequency of 6 to 12 GHz is applied through the lumped ports to analyze the results.

4. Results and Discussion

Fig. 3 shows the meshed design of the proposed model. Fine meshing is conducted on the SIW structure. The maximum element size selected is 0.00175. The design was simulated on the computational machine having 3.6 GHz processor speed. The virtual memory used while simulation was 2.99 GB. Extra-fine meshing is not selected to reduce the computational load.

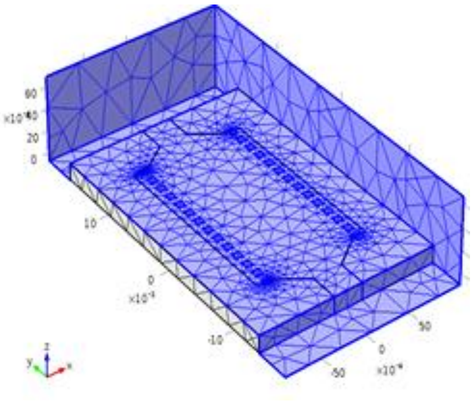

Figure 3 Meshed design of SIW.

The electric field generated while computing the results is shown in fig. 4. Fig. 4 shows the radiations due to electric field generated for PCB substrate.

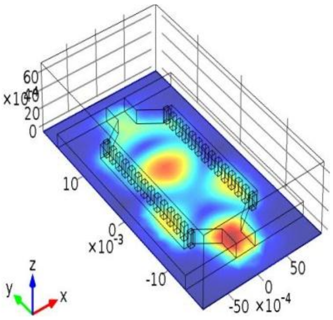

Figure 4 Electric field generated in SIW.

Similarly the plot shown in figure 5 indicates graph between S-parameters and the frequency. Return losses or input reflection coefficient (S11) and the forward transmission gain (S21) were plotted and show that the dip for return loss is observed at 9 GHz frequency and transmission gain increases upto 9 GHz and then saturates.

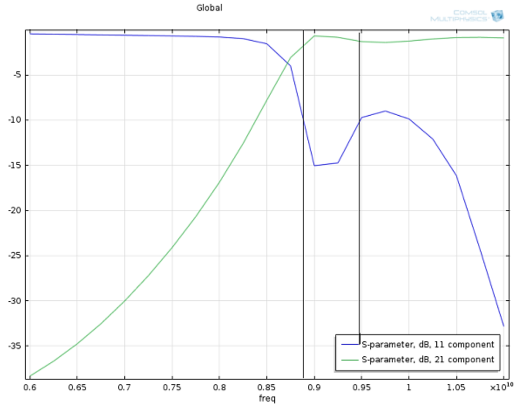

Figure 5 Plot between S-parameter vs frequency.

From the plot, it can be easily observed that the useful bandwidth for the design is in-between 8.88 to 9.45 GHz. Hence the operating bandwidth for this simulated design is 570 MHz.

Conclusions

Simulated experiment work is carried out to investigate the effect of cubical via on the electromagnetic wave propagation in SIW. S-parameters such as return loss and transmission gain were calculated for frequency ranging from 6 GHz to 12 GHz. It can be concluded that the SIW works efficiently in-between 8.88 to 9.45 GHz.

References

A. Zeid and H. Baudrand (2002), Electromagnetic scattering by metallic holes and its applications in microwave circuit design, *IEEE Transactions on Microwave Theory and Techniques*, vol. 50, pp. 1198-1206.

B. N. Das, K. V. S. V. R. Prasad, and K. V. S. Rao (1996), Excitation of Waveguide by Stripline and Microstrip-Line-Fed Slots, *IEEE Transactions on Microwave Theory and Techniques*, vol. 34, pp. 321-327.

C. Xiao-Ping and W. Ke (2008), Accurate and efficient design approach of substrate integrated waveguide filter using numerical TRL calibration technique, in Microwave Symposium Digest, 2008 *IEEE MTT-S International*, pp. 1231-1234.

D. Deslandes and K. Wu (2001), Integrated microstrip and rectangular waveguide in planar form, Microwave and Wireless Components Letters, *IEEE*, vol. 11, pp. 68-70.

D. Deslandes and K.Wu (2002), Design Consideration and Performance Analysis of Substrate Integrated Waveguide Components, in *Microwave Conference*, 32nd European, 2002, pp. 1-4.

D. Deslandes (2010), Design equations for tapered microstrip-to-Substrate Integrated Waveguide transitions, in Microwave Symposium Digest (MTT), 2010 *IEEE MTT-S International*, pp. 704-707.

E. Miralles, H. Esteban, C. Bachiller, A. Belenguer, and V. E. Boria (2011), Improvement for the design equations for tapered Microstrip-to-Substrate Integrated Waveguide transitions, in Electromagnetics in Advanced Applications (ICEAA), 2011 *International Conference on*, pp. 652-655.

F. Mira, A. A. San Blas, V. E. Boria and B. Gimeno (2007), Fast and Accurate Analysis and Design of Substrate Integrated Waveguide (SIW) Filters, in *Proc. 37th European Microwave Conference*, pp. 170-173.

J. E. Rayas-Sanchez and V. Gutierrez-Ayala (2008), A General EM-Based Design Procedure for Single-Layer Substrate Integrated Waveguide Interconnects with Microstrip Transitions, *IEEE MTT-S Int. Microwave Symp*. Dig., Atlanta, pp. 983-986.

J. Hirokawa and M. Ando (1998), Single-layer feed waveguide consisting of posts for plane TEM wave excitation in parallel plates, *IEEE Transactions on Antennas and Propagation*, vol. 46, pp. 625-630.

K. Wu, D. Deslandes, and Y. Cassivi (2003), The substrate integrated circuits - a new concept for high-frequency electronics and optoelectronics, in Telecommunications in Modern Satellite, Cable and Broadcasting Service, 2003. TELSIKS 2003. *6th International Conference on*, pp. P-III-P-X vol.1.

L. Yan, W. Hong, K. Wu, and T. J. Cui (2005), Investigations on the propagation characteristics of the substrate integrated waveguide based on the method of lines, Microwaves, Antennas and Propagation, *IEE Proceedings* -, vol. 152, pp. 35-42.

M. Bozzi, A. Georgiadis and K. Wu (2008), Review of substrate-integrated waveguide circuits and antennas, *IET Microw. Antennas Propag.*, vol. 5, no. 8, pp. 909–920.

P. Mohammadi and S. Demir (2012), Multi-layer substrate integrated waveguide e-plane power divider, *Progress In Electromagnetics Research C*, Vol. 30, 159-172.

P. Mohammadi, S. Demir (Aug 2011), Two layers substrate integrated waveguide power divider, *General Assembly and Scientific Symposium, 2011 XXXth URSI* , pp.1-4, 13-20

S. Germain, D. Deslandes, and K.Wu (2003), Development of substrate integrated waveguide power dividers, in Electrical and Computer Engineering, 2003. *IEEE CCECE 2003. Canadian Conference on*, pp. 1921-1924 vol.3.

T. Y. Huang, T. M. Shen and R. B. Wu. Design and Modeling of Microstrip Line to Substrate Integrated Waveguide Transitions, Passive Microwave Components and Antennas, Chapter 11, pp. 225-247, InTech, ISBN 978-953-307-083-4.

W. Grabherr, W. G. B. Huder, and W. Menzel (1994), Microstrip to waveguide transition compatible with MM-wave integrated circuits, *IEEE Transactions on Microwave Theory and Techniques*, vol. 42, pp. 1842-1843.

Y. Cassivi, L. Perregrini, K. Wu, G. Conciauro (Sept 2002), Low-cost and high-q millimeter-wave resonator using substrate integrated waveguide technique, *32nd European Microwave Conference*, Milan, Italy.

Y. Cassivi, L. Perregrini, P. Arcioni, M. Bressan, K.Wu, and G. Conciauro (2002), Dispersion characteristics of substrate integrated rectangular waveguide, *Microwave and Wireless Components Letters, IEEE*, vol. 12, pp. 333-335.

Z. Jian, Y. Yuanwei, Z. Yong, C. Chen, J. Shi Xing (Apr 2007), A high-q mems resonator, DTIP of MEMS and MOEMS.