Design of a Novel Structure SIW 90° Coupler

Abdelkhalek Nasri, Hassen Zairi and Ali Gharsallah

Department of Physics, Electronics Laboratory, Faculty of Science, Tunis El Manar 2092, Tunisia

Abstract: This paper focuses on the analysis of passive devices using a recent emerging technology named Substrate Integrated Waveguide (SIW). This technology has been used in the conception of planar compact components for the microwave and millimeter wave’s applications. Through using Ansoft HFSS and CST code a substrate integrated waveguide coupler has conceived and optimized in this study. The SIW 90° coupler design simulations show good performances with low return loss, high isolation better than -20 and -40 dB, respectively and broad operational bandwidth.

Keywords: Substrate Integrated Waveguide, HFSS, CST, 90° Coupler

Introduction

The extensive use of the rectangular waveguide components in millimeter-wave and microwave communication systems, radar and other equipments are due to their significant features such as their high Quality factor (Q-factor), high power capability and low insertion loss (Labay and Rao, 2011; Labay and Bornemann, 2008; Ahmad et al., 2013). However, they are difficult to be integrated in modern microwave and millimeter-wave integrated circuits because of their big size, nonplanar structure and strict requirement of manufacturing precision (Hao et al., 2006).

A new novel planar circuit named Substrate Integrated Waveguide (SIW) is facing recently a growing interest as it has common advantages with printed circuits such as low cost, small size (Labay and Rao, 2011; Ahmad et al., 2013) and which is known as the most popular and developed technology until now. Moreover, the SIW components are characterized with low insertion loss, low radiation loss and insensitive to outside interference since its components are covered by metal surfaces on both sides of the substrate (Hao et al., 2006; Abdel-Wahab et al., 2011; Rahali et al., 2014; Xinyu et al., 2005; Zhigang et al., 2011).

In this present paper, the design platform of the new SIW 90° coupler is presented and discussed. Besides, this letter presents 90° coupler prototypes which are optimized and simulated, in addition to the results which are presented and compared with two electromagnetic (3D) software.

Design of SIW 90° Coupler

SIW technology defines as a type of rectangular dielectric-filled waveguide which includes a planar substrate with arrays of metallic vias to realize bilateral edge walls and on the same substrate its transitions with planar structures for instance microstrip and Coplanar Waveguide (CPW) are designed and integrated (Murai et al., 2011; Patrovsky et al., 2008; Rahali and Fahem, 2013). Within the same planar platform the planar and nonplanar structures can be integrated, which leads in this case to the design and development of low-cost millimeter-wave Integrated Circuits (ICs) and systems (Ali et al., 2008; 2009; Rahali and Fahem, 2014).

A 90° coupler with low cost and low loss Substrate Integrated Waveguide (SIW) has been designed for low profile and compact mm-wave applications.

Design of SIW

The SIW consists of two linear metallic connected via dielectric substrate with a height of b. The electromagnetic fields within the SIW are confined by these metallic via arrays (Ali et al., 2008). The width of the SIW is a, the diameter of the metallic vias is D while the space between the adjacent vias is s. The geometric parameters are primarily determined by the relationship between the conventional rectangular waveguide and the SIW (Guo et al., 2008; Djerafi and Wu, 2007, 2012; Djerafi et al., 2010, 2011).

In Fig. 1, port 1 is the input port, port 2 is considered as the through port, while port 3 stands for the coupling port and finally port 4 is used as an isolation port.

In order to achieve a wide-band performance the coupler parameters are finely tuned using three-Dimensional (3D) Electromagnetic (EM) simulation with HFSS and CST software.

Figure 2 presents the design parameters for the microstrip-to-SIW coupler. The designs use SIW parameters of low loss dielectric material, Rogers RO 4003 with εr = 2.2 and loss tangent of 0.009, substrate height b = 0.5 mm and the vias holes are D = 0.4 mm and their distances s = 0.7 mm.
For the microstrip line which has the same substrate and metallization thickness as the SIW is selected and which leads to a 50 Ω line width of $w_1 = 1.3 \text{ mm}$. These parameters are identical for all microstrip-to-SIW couplers highlighted in this study and the remaining design-specific dimensions are presented in Table 1.

**Parameter Studies for SIW 90° Coupler**

As an example, SIW 90° coupler is designed and the extra metallic via $D_{via}$ is optimized with different diameters. This variation shows a good improvement in the return loss and isolation. The design of the SIW coupler with different parameters $D_{via}$ is optimized to improve the return loss and isolation of -17 to -23 dB and, -27 to -44 dB, respectively. These results are shown in Fig. 3 and 4.

**Simulation Results**

The electric field distribution of the $TE_{10}$ mode (Abdel-Wahab et al., 2012), the reflection coefficients $S_{11}$, the transmission coefficients $S_{21}$, the coupling coefficient $S_{31}$ as well as the isolation coefficient $S_{41}$ are presented in Fig. 5 and 6, respectively. It is noticeable through the results of this analysis that the 90° coupler character in the band is [9.5-12.5] GHz, in which the levels of reflection and isolation are below -15dB in more than 24% of the bandwidth and the insertion loss $S_{21}$ and coupling $S_{31}$ are between -3 and -6 dB.

The simulation phase difference between two outputs ports is shown in Fig. 7. It is obvious that the phase difference is distributed in the range 89~93° in which the frequency band fluctuates between 9.5 and 12.5 GHz.

So, it is clear that these simulation results demonstrate the good performance of this integrated structure.

---

**Table 1. Dimension of the structure**

| Parameter | Value 1 | Value 2 | Value 3 | Value 4 |
|-----------|---------|---------|---------|---------|
| $a$       | 12.25 mm| 2.2 mm  | 20.5 mm | 7.2 mm  |
| $w_2$     | 3.7 mm  |         |         |         |
| $t_1$     |         |         |         |         |
| $t_2$     |         |         |         |         |
Conclusion

This paper focuses on the analysis of 90° coupler using a recent emerging technology named Substrate Integrated Waveguide (SIW). Prototypes of these 90° couplers with different via diameters are designed and simulated by the HFSS and CST code. Therefore, the paper presents results of this modeling which are discussed and allow as well integrating these devices in planar circuits.
Acknowledgement

We would like to acknowledge Faculty of Science, University Tunis El Manar for supporting our work.

Funding Information

The authors have no support or funding to report.

Author’s Contributions

Abdelkhaled Nasri: Author makes considerable contributions to conception and design, Analysis and interpretation of data.

Hassen Zairi: Author contributes in reviewing the article it critically for significant intellectual content.

Ali Gharsallah: Author give final approval of the version to be submitted.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of other authors have read and approved the manuscript and no ethical issues involved.

References

Abdel-Wahab, W.M. and S.N. Safieddin, 2011. Low loss double-layer substrate integrated waveguide-hybrid branch line coupler for mm-wave antenna arrays. Proceedings of the IEEE International Symposium on Antennas and Propagation, Jul. 3-8, IEEE Xplore Press, pp: 2074-2076. DOI: 10.1109/APS.2011.5996917

Abdel-Wahab, W.M. and S. Safavi-Naeini, 2012. Low loss H-shape SIW hybrid coupler for millimeter-wave phased arrays antenna systems. Proceedings of the IEEE Antennas and Propagation Society International Symposium, Jul. 8-14, IEEE Xplore Press, Chicago, IL, pp: 1-2. DOI: 10.1109/APS.2012.6348904

Ahmad, B.H., S.S. Sabri and A.R. Othman, 2013. Design of a compact x-band substrate integrated waveguide directional coupler. Int. J. Eng. Technol., 5: 1905-1911.

Ali, A., F. Coccetti, H. Aubert and N.J.G. Fonseca, 2008. Novel multi-layer SIW broadband coupler for Nolen matrix design in Ku band. Proceedings of the IEEE Antennas and Propagation Society International Symposium, Jul. 5-11, IEEE Xplore Press, San Diego, CA, pp: 1-4. DOI: 10.1109/APS.2008.4619915

Ali, A., H. Aubert, N. Fonseca and F. Coccetti, 2009. Wideband two-layer SIW coupler: Design and experiment. Electron. Lett., 45: 687-689. DOI: 10.1049/el.2009.0464

Djerafari, T. and K. Wu, 2007. Super-compact substrate integrated waveguide cruciform directional coupler. IEEE Microwave Wireless Compon. Lett., 17: 757-759. DOI: 10.1109/LMWC.2007.908040

Djerafari, T. and K. Wu, 2012. A low-cost wideband 77-GHz planar butler matrix in SIW technology. IEEE Trans. Antennas Propagat., 60: 4949-4954. DOI: 10.1109/TAP.2012.2207309

Djerafari, T., J. Gauthier and K. Wu, 2010. Quasi-optical cruciform Substrate Integrated Waveguide (SIW) coupler for millimeter-wave systems. Proceedings of the IEEE MTT-S International Microwave Symposium Digest, May 23-28, IEEE Xplore Press, Anaheim, CA, pp: 716-719. DOI: 10.1109/MWSYM.2010.5515889

Djerafari, T., N.J.G. Fonseca and K. Wu, 2011. Broadband substrate integrated waveguide 4 *4 Nolen matrix based on coupler delay compensation. IEEE Trans. Microwave Theory Techniques, 59: 1740-1745. DOI: 10.1109/TMTT.2011.2142320

Guo, H.Z., H. Wei, K. Wu, J.X. Chen and C. Peng et al., 2008. Folded half mode substrate integrated waveguide 3 dB coupler. IEEE Microwave Wireless Compon. Lett., 18: 512-514. DOI: 10.1109/LMWC.2008.2001006

Hao, Z.C., W. Hong, J.X. Chen, H.X. Zhou and K. Wu, 2006. Single-layer substrate integrated waveguide directional couplers. IEE Proc. Microw. Antennas Propag., 153: 426-431. DOI: 10.1049/ip-map:20050171

Labay, V.A. and T.R. Rao, 2011. Microstrip-to-substrate integrated waveguide aperture couplers. Proceedings of the 2nd International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace and Electronics Systems Technology, Feb. 28-Mar. 3, IEEE Xplore Press, Chennai, pp: 1-4. DOI: 10.1109/WIRELESSVITAE.2011.5940866

Labay, V.A. and J. Bornemann, 2008. E-plane directional couplers in substrate-integrated waveguide technology. Proceedings of the Asia-Pacific Microwave Conference, Dec. 16-20, IEEE Xplore Press, Macau, pp: 1-3. DOI: 10.1109/APMC.2008.4957920

Murai, K., H. Ikeuchi, T. Kawai, M. Kishihara and I. Ohta, 2011. Broadband design method of SIW directional couplers. Proceedings of the China-Japan Joint Microwave Conference Proceedings, Apr. 20-22, IEEE Xplore Press, Hangzhou, pp: 1-4.

Patrovsky, A., M. Daigle and K. Wu, 2008. Coupling mechanism in hybrid SIW-CPW forward couplers for millimeter-wave substrate integrated circuits. IEEE Trans. Microwave Theory Techniques, 56: 2594-2601. DOI: 10.1109/TMTT.2008.2005919
Rahali, B. and M. Feham, 2013. Design of v-band substrate integrated waveguide power divider, circulator and coupler. Comput. Sci. Inform. Technol., 3: 35-44. DOI: 10.5121/csit.2013.3804
Rahali, B. and M. Feham, 2014. Design of k-band substrate integrated waveguide coupler, circulator and power divider. Int. J. Inform. Electron. Eng., 4: 47-53. DOI: 10.7763/IJIEE.2014.V4.406
Rahali, B., M. Feham and J. Tao, 2014. Analysis of S band substrate integrated waveguide power divider, circulator and coupler. Int. J. Comput. Sci. Eng. Applic., 4: 1-12. DOI: 10.5121/ijcsea.2014.4201
Xinyu, X., R.G. Bosisio and K. Wu, 2005. A new six-port junction based on substrate integrated waveguide technology. IEEE Trans. Microwave Theory Techniques, 53: 2267-2273. DOI: 10.1109/TMTT.2005.850455
Zhigang, Z., F. Yong, Y. Cheng and Y. Zhang, 2011. A novel E-plane Half-Mode Substrate Integrated Waveguide (HMSIW) coupler. Proceedings of the China-Japan Joint Microwave Conference Proceedings, Apr. 20-22, IEEE Xplore Press, Hangzhou, pp: 1-3.