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90° Phase Shifter Based on Substrate Integrated Waveguide Technology for Ku-band Applications

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Abstract

Wireless systems are in a growing need for compact size phased antenna arrays, hence, compact phase shifters, as well. In addition, there are other numerous applications like isolators, filters, and couplers that deploy the phase shifter as an essential component. To implement the phase shifter in a compact size, the Substrate Integrated Waveguide (SIW) structure is selected. SIW technology has almost all the properties of rectangular waveguides. However, it keeps the advantage of the compactness and integration capability. The mode supported by SIW structures is the TE_{10}. This work introduces ferrite phase shifter with compact size compared to the traditional ferrite phase shifters that are bulky. The proposed non-reciprocal 90° phase shifter is based on SIW technology with less than $\pm 15°$ of phase variations over the Ku-band.

1 Introduction

Phased antenna arrays have a large variety of applications in wireless microwave communication systems. Recently, the need for compact and lightweight phased antenna arrays is growing rapidly to serve the communication networks that require smart antennas with controlled radiation pattern [1] and [2]. The key component in such antenna arrays is the phase shifter, where it is responsible for the function of steering the antenna array beam in the desired direction. Single-phased antenna array needs a huge number of phase shifters; this number can be in the order of hundreds or in some cases thousands [3]. With the intention to decrease the phased antenna arrays size and cost, the phase shifter is desired to have a compact size and light weight.

Rectangular waveguides are well-known structures that can handle high power with low losses compared to microstrip lines. Many phase shifters based on rectangular waveguides were introduced in the literature [4], [5], and [6]. The main advantage of such components is the high-power handling capability and the low losses. Non-reciprocal phase shifters are widely used in commercial high power four-port differential phase applications. The phase shifters in each waveguide are oppositely magnetized to produce the required differential phase shift between the two channels. A typical rectangular waveguide phase shifter consists of a rectangular waveguide with two or four ferrite tiles on its top and bottom broad walls magnetized perpendicular to the direction of propagation. It relies for its operation on the existence of natural planes of counter-rotating circularly polarized alternating magnetic fields on either side of its symmetry plane.

Recently, substrate integrated waveguide (SIW) technology became very popular as an integrated form of a rectangular waveguide. SIW technology has the advantages of the rectangular waveguide such as low losses and high-quality factor. Also, it is compatible with planar microwave circuits, and its fabrication cost is low [7]. Due to these advantages, the SIW technology is used in many microwave applications such as filters, couplers, and power dividers [8], [9]. This technology has also been deployed in antenna applications and its feeding structures [10]. Moreover, the phase shifters have been implemented based on SIW technology through various configurations. One of the common configurations builds on the periodic loading of the guiding structure to achieve the required phase shift [11], [12], and [13].

This work introduces a compact phase shifter based on SIW technology. The phase shift of the presented work is 90° with an ultra-flat response. The phase shift has a variation of less than $\pm 15°$ over the Ku-band. The paper is organized as follows. Section II introduces the proposed methodology to design non-reciprocal ferrite phase shifters. In section III, an example in the Ku-band is presented using the described methodology, and then the configuration of the proposed example is modeled and simulated through two commercial packages to validate the proposed design algorithm. Finally, conclusions and future work are addressed in section IV.

2 SIW Phase Shifter Configuration

The configuration of the proposed SIW phase shifter consists of two parallel waveguides (channels) with a common wall. Each channel has two ports, one for the input signal and another for the output. One ferrite tile with suitable magnetization in each channel, it is mounted on the top wall

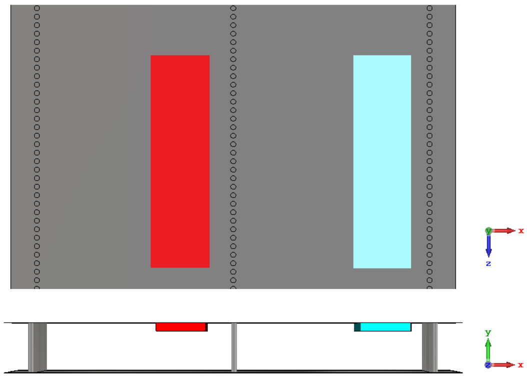

Figure 1. SIW phase shifter geometry.

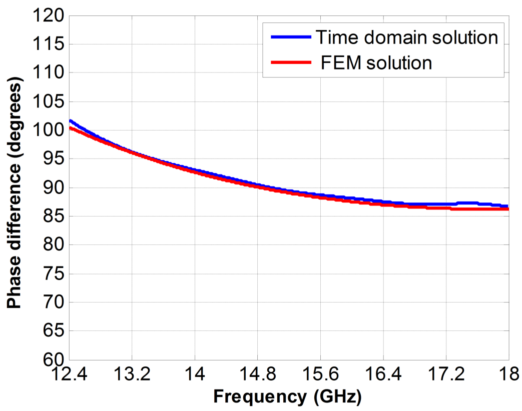

Figure 2. Differential phase between the two channels outputs.

of the SIW channel. The phase shifters in each waveguide are oppositely magnetized to produce a differential phase of 90° between the two channels. The differential phase between the two channels depends mainly on the width, length, height, and position of the ferrite tiles inside the waveguide.

3 Ku-Band Phase Shifter Example

This section presents a case of non-reciprocal ferrite phase shifter for Ku-band applications. The proposed structure is designed based on SIW technology to be used as a phase shifter in the previous section. The proposed configuration is simulated using two commercial tools to validate the proposed structure results. In Figure 1, the proposed phase shifter geometry is shown. The phase shifter is printed on Rogers RT 6002 with an epsilon of 2.94 and a thickness of 3.048 mm. The radius of the vias used in the SIW walls is 0.2 mm, the width of the SIW line is selected to be 9.3 mm. The ferrite tile has a width, height, and length of 2.4 mm, 0.75 mm and 83.5 mm, respectively. The ferrite tile in each channel is placed at the middle distance between the SIW side wall and its center. Also, the ferrite plate is attached to the top wall of each channel from inside. In Figure 2, the differential phase between the output signals of the two channels is shown, and in Figure 3 the matching

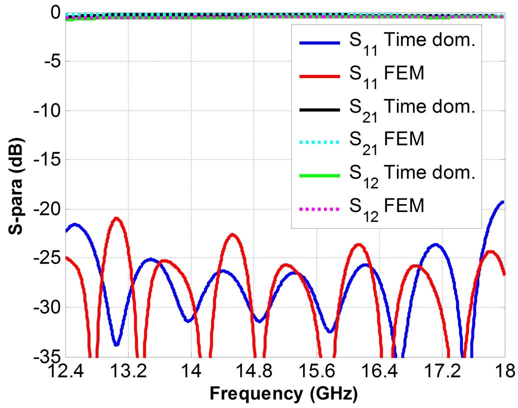

Figure 3. Matching and transmission coefficients of the proposed phase shifter.

and transmission coefficients are shown. The phase shift, matching, and transmission are extracted through two different numerical solvers in the time domain and in the frequency domain. Both results agree with each other, which validates the phase shift between the two channels.

4 Conclusion and Future Work

An SIW phase shifter design is presented in this paper with the ultra-flat response and compact size. The presented design dimensions in mm are $9.3 \times 3.048 \times 83.5$, which is less than 50% of the corresponding rectangular waveguide configuration. The introduced configuration has been tested by designing phase shifter for Ku-band applications. Moreover, the results have been validated by using two different numerical techniques, where both solvers have an excellent agreement. The extracted differential phase between the output phases is centered at 90° with phase shift variation less than $\pm 15°$ over the entire operating bandwidth. This work can be extended by deploying the presented structure in various applications such as isolators, duplexers, and feeding structures for circularly polarized antennas. One more important point that should be addressed is the excitation mechanism of this type of phase shifter to support the full operating bandwidth with a proper matching level.

References

[1] T. Lambard, O. Lafond, M. Himdi, H. Jeuland, S. Bolioli and L. Le Coq, "Ka-Band Phased Array Antenna for High-Data-Rate SATCOM," *IEEE Antennas and Wireless Propagation Letters*, **11**, 1, pp. 256-259, 2012.

[2] F. Tiezzi, D. Llorens, C. Dominguez and M. Fajardo, "A compact Ku-band transmit/receive low-profile antenna for broadband mobile satellite communications," *Proceedings of the Fourth European Conference on Antennas and Propagation*, Barcelona, Spain, pp. 1-4, 2010.

[3] C. Boyd, "Ferrite phased array antennas: Toward a more affordable design approach," *Antennas and Propagation Society International Symposium*, Blacksburg, VA, USA, pp. 1168-1171, 1987.

[4] D. M. Pozar, "Microwave Engineering," *New York: Wiley*, chapter 9, 2005.

[5] C. E. Fay, "Ferrite- tuned resonant cavities," *Proceedings of the IRE*, **44**, 10, pp. 1446-1449, 1956.

[6] A. Clavin, "Reciprocal Ferrite Phase Shifters in Rectangular Waveguide (Correspondence)," *IRE Transactions on Microwave Theory and Techniques*, **6**, 3, pp. 334-334, July 1958.

[7] K. W. P. A. M. Bozzi and L. Perregrini, "Current and future research trends in substrate integrated waveguide technology," *Radioengineering*, **18**, 2, pp. 201-209, 2009.

[8] O. Glubokov and D. Budimir, "Substrate integrated folded-waveguide cross-coupled filter with negative coupling structure," *IEEE Antennas and Propagation Society International Symposium, Charleston, SC*, pp. 1-4, 2009.

[9] Z. C. Hao, W. Hong, J. X. Chen, H. X. Zhou and K. Wu, "Single-layer substrate integrated waveguide directional couplers," *IEE Proceedings - Microwaves, Antennas and Propagation*, **153**, 5, pp. 426-431, Oct. 2006.

[10] Y. J. Cheng, W. Hong and K. Wu, "Design of a Monopulse Antenna Using a Dual V-Type Linearly Tapered Slot Antenna (DVLTSA)," *IEEE Transactions on Antennas and Propagation*, **56**, 9, pp. 2903-2909, Sept. 2008.

[11] A. Suntives, K. Payandehjoo and R. Abhari, "Design and characterization of periodically-loaded substrate integrated waveguide phase shifters," *IEEE MTT-S International Microwave Symposium*, Anaheim, CA, pp. 1584-1587, 2010.

[12] H. Peng, X. Xia and T. Yang, "Slotted substrate integrated waveguide phase shifter," *IEEE Information Technology, Networking, Electronic and Automation Control Conference*, Chongqing, pp. 1036-1039, 2016.

[13] A. Benleulmi, N. Y. Sama, P. Ferrari and F. Domingue, "Substrate Integrated Waveguide Phase Shifter for Hydrogen Sensing," *IEEE Microwave and Wireless Components Letters*, **26**, 9, pp. 744-746, Sept. 2016.