An Only Metal, Compact, and Circular Polarizer Designed with Helical Array Rods

Seyed Jalil Hosseini[1]

[1]Iran University of Science and Technology

August 18, 2022

Abstract

This paper presents a simple method to realize a circular polarizer by inserting rods arranged helically in the cylindrical waveguide. In the proposed polarizer, the rods are installed to excite the electric fields on the perpendicular axis to the input field. In addition, the rod locations create a 900 phase difference between two perpendicular axes to convert the polarization from linear to circular. In the proposed structure, the axial ratio is smaller than 0.4 dB and the phase difference is about 900 at 10 GHz frequency. In addition, the reflection coefficients are better than -14 dB for both E_x and E_y polarizations at the same frequency. Also, this structure is very compact compared to similar structures. Furthermore, this is made only of metal. Therefore, there is no dielectric loss and it has high endurance. The validation results have a good agreement with the simulation.

Introduction

Waveguide polarizers are frequently used to increase the system's attractiveness, and are mostly used in aperture antennas. The circular polarizer waveguides (CPWs) convert a field with linear polarization (LP) into a circular one. For the goal, the electric field should be excited in two axes that are perpendicular to each other [1].

The proposed CPW is compared to the previous ones as follows. C. Chang et al. present a rectangular bending waveguide that converts an LP field into a circular polarization (CP) field. Because the dominant mode is the TE_{10}, in the rectangular waveguides, the CPW can convert the LP-TE_{10} mode to the CP-TE_{10}. The major disadvantage of the structure is the misalignment of the inlet and outlet. Hence, the CPW is not suitable for many applications [2]. In Ref. [3], a K-band CPW is investigated. A pair of rectangular waveguides has been converted into a circular waveguide. Also, a stepped blade is used inside the polarizer. The first problem of the CPW is to be very long (about $5\lambda_0$). Therefore, a rectangular or circular waveguide cannot be used to convert a linear field into a circular one. Rather, a rectangle-to-circle waveguide converter should be used, which increases the complexity of the CPW. Ref. [4] proposes a CPW that can transduce an LP field to CP one by a dielectric septum. By using dielectric in the structure, the loss is increased, dramatically. Therefore, electrical breakdown increases due to the increase in the possibility of electrical creep. Hence, the structure is unsuitable for high-power microwave (HPM) applications. The CPW proposed in Ref. [5], is a mode converter. The mode converters installed to the outlet of the electromagnetics sources to convert a donut-shaped pattern to a directive one are the waveguides that transduce a TM_{01} or TEM mode to a TE_{11}mode and or to a TE_{10} mode, in the circular and rectangular waveguide, respectively [6-16]. The CPW introduced in Ref. [5], is a mode converter that converts an LP-TM_{01} mode to a CP-TE_{11} one. Due to the excitation of TM_{01} mode in the CPW input, its applications are limited. Ref. [17] introduces a pair of grooves on the wall of a waveguide installed on the length of the CPW. The use of grooves has caused complexity in the CPW structure. In addition, a simple circular waveguide cannot be used as a CPW. Also, due to the increase in the external volume of the system, its compactness has decreased, dramatically.

In this paper, we tried to resolve the limitations of the previous structures. In the compact CPW proposed, we have used only a metal structure to achieve a simple method to transduce an LP to a CP field in a simple circular waveguide. Using only metal increases efficiency and eliminates dielectric losses, completely. The only metal structure aim is the ease of implementation and reduction of complexity. Also, the proposed CPW is designed such that it does not occupy any volume outside the circular waveguide. Hence the proposed CPW compactness is increased, dramatically.

This paper is organized as follows. Sec. 2 presents the structure and design of the proposed CPW. Sec. 3 reports some numerical studies on the CPW features. Finally, in Sec. 4, the conclusion is presented.

Design Principle and Structure

The proposed polarizer consists of a circular metallic waveguide and a few metal rods. The input field is in the form of the LP-TE_{11} mode of a circular waveguide. In a circular waveguide, TE_{11} mode is the dominant or fundamental mode. Also, the output mode is CP-TE_{11} of a circular waveguide [18-22]. In the structure, inside the simple circular waveguide, several metal rods are placed. These rods are arranged with different lengths, helically. Because to generate a CP field, it must be equally excited in two perpendicular axes (for example, X and Y). This issue alone will not enough to generate a CP field, but the phase difference between the two excited fields in the X and Y direction must be 90° [23-26]. If the phase difference is zero degrees, the polarization will be slant. Furthermore, If the excited field in two perpendicular axes is not equal or the phase difference is not zero or 90°, the field polarization is elliptical. The lengths of the rods have been calculated and optimized to excite the equal electric fields in two perpendicular axes with a phase difference of 90°, in the circular waveguide outlet. In Fig. 1, the proposed CPW is shown.

Fig. 1. The proposed CPW structure, (a) top view, (b) side view

The proposed CPW is simulated and optimized with CST Microwave Studio. Also, the results are validated by Ansys HFSS software. In the structure, the operation frequency is selected at 10 GHz. To prevent the excitation of higher modes, the diameter of the circular waveguide is 20 mm. In Table 1, the dimensions of the CPW are presented.

Fig. 2. The dimensions of the proposed CPW

The dimensions indicated in Fig. 2 are listed in Table 1.

Table 1. The proposed CPW dimensions.

Dimension	**Value (mm)**	**Dimension**	**Value (mm)**
d_w	20.00	L_7	2.78
L_w	55.12	L_8	3.43
s	4.37	L_9	1.83
d	2.50	L_{10}	4.75
d_r	1.24	L_{11}	5.33
t	1.00	L_{12}	0.71
L_1	3.74	L_{13}	3.88
L_2	3.27	L_{14}	1.73
L_3	4.12	L_{15}	2.15
L_4	0.68	L_{16}	1.30
L_5	0.84	L_{17}	2.67
L_6	1.62	L_{18}	5.27

The dimensions of the circular waveguides are determined according to the operation frequency. But the dimensions and location of the rods have been achieved by the numerical methods of optimization. The number of rods is calculated according to the distance between the rods so that the helical array of the rods can rotate 360°. Hence, the overall size of the CPW in the length, and radius is 55.12 and 20 mm, respectively, which is equivalent to 1.84 λ_0 and 0.67 λ_0, respectively.

The principle of the CPW working is as the following. To study the proposed CPW working, changes in electric field intensity in the presence of a conductor rod inside a circular waveguide must be investigated. Fig. 3 indicates the electric vectors around a metal rod inside a circular waveguide.

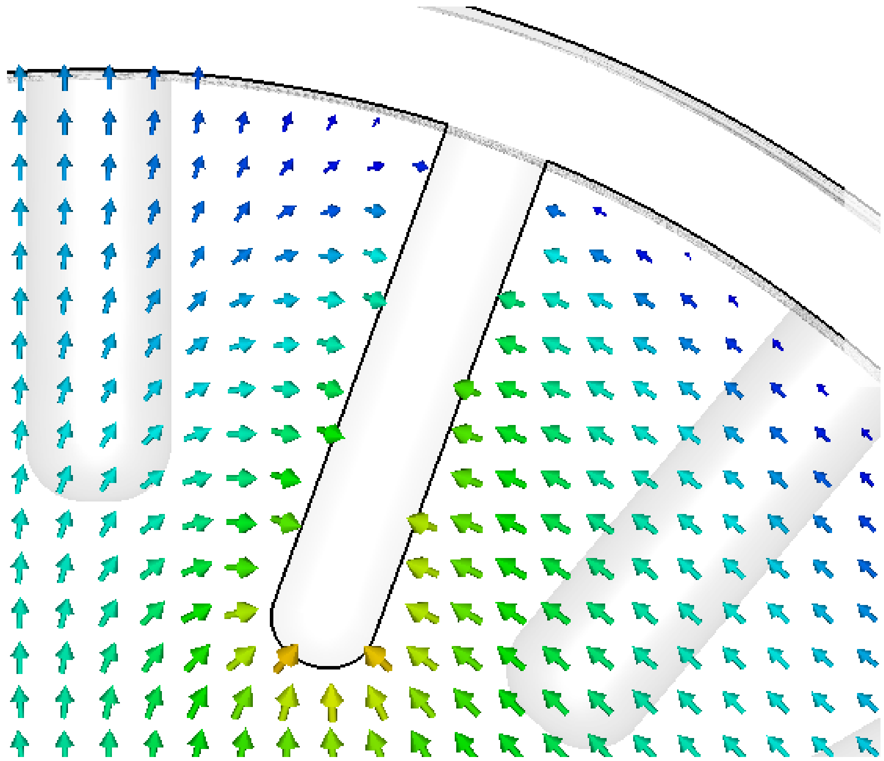

Fig. 3. The electric vectors around a metal rod inside a circular waveguide.

According to the boundary conditions of electric fields, as expected, and shown in Fig. 3, electric fields must always be perpendicular to a conductor surface, also, a conductor rod inside the circular waveguide change the direction of the electric field vectors. This brings us closer to our goal, which is to convert an LP into a CP field. Using a helical array along the length of the circular waveguide can generalize this issue to all waveguide aperture. Optimizing makes it possible to create an equal field intensity with a phase difference of 900 in two axes perpendicular to each other, on the CPW aperture.

Numerical results

Fig. 4 indicates the axial ratio, that is, the ratio of the vertical and horizontal TE_{11} modes, and the phase difference of these modes. Note, to achieve circular polarization, we create electric fields in two perpendicular directions with a phase difference of 900. In addition to proving the electric field purity at the output of the waveguide, the second and third components of the electric field are shown in Fig. 5.

Hosted file

`image4.emf` available at https://authorea.com/users/502151/articles/582308-an-only-metal-compact-and-circular-polarizer-designed-with-helical-array-rods

Fig. 4. The axial ratio (AR) and the phase difference (PD) simulated by CST Microwave Studio and validated by Ansys HFSS. The blue solid line indicates the ideal results of the axial ratio and phase difference.

Hosted file

`image5.emf` available at https://authorea.com/users/502151/articles/582308-an-only-metal-compact-and-circular-polarizer-designed-with-helical-array-rods

Fig. 5. The other components of the electric field on the CPW aperture simulated by CST Microwave Studio. The $TE_{21}{}^{1}$ and $TE_{21}{}^{2}$ are degenerate modes.

The other major result of the proposed CPW is the reflection coefficient. The reflection coefficient that is under the acceptable range (i.e., -10 dB) is shown in Fig. 6.

Hosted file

`image6.emf` available at https://authorea.com/users/502151/articles/582308-an-only-metal-compact-and-circular-polarizer-designed-with-helical-array-rods

Fig. 6. The reflection coefficient of the proposed CPW simulated by CST Microwave Studio and validated by Ansys HFSS.

Conclusion

In this paper, we present a compact CPW, only metal, and easy to manufacture, at the 10 GHz frequency. The overall size of the CPW in the length and radius is 55.12 and 20 mm, respectively, which is equivalent to 1.84 λ_0 and 0.67 λ_0, respectively. The axial ratio and phase difference of the polarizer are is smaller than 0.4 dB and about 900, respectively, at the operating frequency. The validation results validate the simulated ones, as well. Due to the compact size, the proposed polarizer can be used in a wide range of applications, including detectors and electromagnetic sources.

References

1. P. Naseri, J. R. Costa, S. A. Matos, C. A. Fernandes, and S. V. Hum, "Equivalent Circuit Modeling to Design a Dual-Band Dual Linear-to-Circular Polarizer Surface," *IEEE Transactions on Antennas and Propagation* , vol. 68, no. 7, pp. 5730–5735, Jul. 2020, Doi:*10.1109/TAP.2020.2963949.*
2. C. Chang, S. Church, S. Tantawi, P. Larkoski, M. Sieth, and and K. Devaraj, "Theory and Experiment of a Compact Waveguide Dual Circular Polarizer," *Progress In Electromagnetics Research* , vol. 131, pp. 211–225, 2012, Doi:*10.2528/PIER12072601.*
3. N. Nikolic, A. Weily, I. Kekic, S. L. Smith, and K. W. Smart, "A Septum Polarizer with Integrated Square to Circular Tapered Waveguide Transition," in *2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting* , Jul. 2018, pp. 725–726. Doi:*10.1109/APUSNCURSINRSM.2018.8608909.*
4. S.-W. Wang, C.-H. Chien, C.-L. Wang, and R.-B. Wu, "A circular polarizer designed with a dielectric septum loading," *IEEE Transactions on Microwave Theory and Techniques* , vol. 52, no. 7, pp. 1719–1723, Jul. 2004, Doi:*10.1109/TMTT.2004.830487.*
5. A. Chittora and S. V. Yadav, "A Compact Circular Waveguide Polarizer with Higher Order Mode Excitation," in *2020 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT)* , Jul. 2020, pp. 1–4. Doi:*10.1109/CONECCT50063.2020.9198499.*

6. S. J. Hosseini, M. Dahmardeh, and M. Yousefian, "A high power TEM to TE10 mode converter with 70% bandwidth," *Journal of Electromagnetic Waves and Applications* , vol. 35, no. 3, pp. 389–399, Feb. 2021, Doi:*10.1080/09205071.2020.1842255*.
7. S. J. Hosseini, R.-A. Sadeghzadeh, and H. Aliakbarian, "A TEM-TE11 mode-transducing sectoral antenna by using dual dielectric window," *International Journal of Electronics Letters* , vol. 6, no. 4, pp. 403–412, Oct. 2018, Doi:*10.1080/21681724.2017.1381997*.
8. S. J. Hosseini and M. Khalaj-Amirhosseini, "An Eight-Port Planar Antenna for 3-D Beam Steering," *IEEE Transactions on Antennas and Propagation* , pp. 1–1, 2022, DOI:*10.1109/TAP.2022.3184475*.
9. G. Addamo *et al.* , "3D Printing of a Monolithic K/Ka-Band Dual-Circular Polarization Antenna-Feeding Network," *IEEE Access* , vol. 9, pp. 88243–88255, 2021, Doi:*10.1109/ACCESS.2021.3089826*.
10. R. Liu *et al.* , "A Wideband Circular Polarization Implantable Antenna for Health Monitor Microsystem," *IEEE Antennas and Wireless Propagation Letters* , vol. 20, no. 5, pp. 848–852, May 2021, Doi:*10.1109/LAWP.2021.3065445*.
11. M. Yousefian, S. J. Hosseini, and M. Dahmardeh, "Compact broadband coaxial to rectangular waveguide transition," *Journal of Electromagnetic Waves and Applications* , vol. 33, no. 9, pp. 1239–1247, Jun. 2019, Doi:*10.1080/09205071.2019.1606737*.
12. S. J. Hosseini and M. Dahmardeh, "Compact smile-like mode converter antenna with high power capacity level," *Electromagnetics* , vol. 41, no. 3, pp. 222–238, Apr. 2021, Doi:*10.1080/02726343.2021.1903216*.
13. S. J. Hosseini, "Conversion Donut-Shaped Pattern to Directive Without Using Any Mode Converter," *American Journal of Electromagnetics and Applications* , vol. 9, no. 1, Art. no. 1, Mar. 2021, Doi:*10.11648/j.ajea.20210901.11*.
14. S. J. Hosseini and M. Dahmardeh, "Conversion of a donut-shaped pattern to a directive one using a wide frequency band hive-shaped pattern director antenna," *Electromagnetics* , vol. 41, no. 8, pp. 557–569, Nov. 2021, Doi:*10.1080/02726343.2022.2031156*.
15. S. J. Hosseini and H. Oraizi, "TEM-TE11 mode converter antenna like a pelican beak," *IET Microwaves, Antennas & Propagation* , vol. 14, no. 9, pp. 934–942, 2020, Doi:*10.1049/iet-map.2020.0017*.
16. S. J. Hosseini and H. Oraizi, "Wide-band conversion of donut-shaped pattern to directive one by square-shaped pattern director antenna," *International Journal of Microwave and Wireless Technologies* , pp. 1–8, Nov. 2021, Doi:*10.1017/S1759078721001422*.
17. C. Shu, S. Hu, Y. Yao, Y. Alfadhl, and X. Chen, "W-band grooved-wall circularly polarised horn antenna," *IET Microwaves, Antennas & Propagation* , vol. 14, no. 11, pp. 1171–1174, 2020, Doi:*10.1049/iet-map.2020.0100*.
18. S. J. Hosseini, "A circularly polarized TEM to TE11 mode converter antenna," *The Journal of Engineering* , vol. 2022, no. 2, pp. 216–222, 2022, Doi:*10.1049/tje2.12110*.
19. S.-W. Wang, C.-H. Chien, C.-L. Wang, and R.-B. Wu, "A circular polarizer designed with a dielectric septum loading," *IEEE Transactions on Microwave Theory and Techniques* , vol. 52, no. 7, pp. 1719–1723, Jul. 2004, Doi:*10.1109/TMTT.2004.830487*.
20. S. V. Yadav and A. Chittora, "Circularly polarized high-power antenna with higher-order mode excitation," *International Journal of Microwave and Wireless Technologies* , vol. 14, no. 4, pp. 477–481, May 2022, Doi:*10.1017/S1759078721000611*.
21. P. Naseri, J. R. Costa, S. A. Matos, C. A. Fernandes, and S. V. Hum, "Equivalent Circuit Modeling to Design a Dual-Band Dual Linear-to-Circular Polarizer Surface," *IEEE Transactions on Antennas and Propagation* , vol. 68, no. 7, pp. 5730–5735, Jul. 2020, Doi:*10.1109/TAP.2020.2963949*.
22. P. Das and K. Mandal, "Passive FSS based polarization converter integrated microstrip antenna," *International Journal of RF and Microwave Computer-Aided Engineering* , vol. 32, no. 2, p. e22982, 2022, Doi:*10.1002/mmce.22982*.
23. C. Chang, S. Church, S. Tantawi, P. Larkoski, M. Sieth, and and K. Devaraj, "Theory and Experiment of a Compact Waveguide Dual Circular Polarizer," *Progress In Electromagnetics Research* , vol. 131, pp. 211–225, 2012, Doi:*10.2528/PIER12072601*.
24. M. Rad, N. Nikkhah, B. Zakeri, and M. Yazdi, "Wideband Dielectric Resonator Antenna With Dual

Circular Polarization," *IEEE Transactions on Antennas and Propagation* , vol. 70, no. 1, pp. 714–719, Jan. 2022, Doi:*10.1109/TAP.2021.3098516*.

25. M. A. Sofi, K. Saurav, and S. K. Koul, "A linear to circular polarization reconfigurable converter based on frequency selective surface," *Microwave and Optical Technology Letters* , vol. 63, no. 5, pp. 1425–1433, 2021, Doi:*10.1002/mop.32779*.
26. S. J. Hosseini, "A Compact CP Mode Converter Antenna,"*Microwave Review* , vol. 28, no. 4, pp. 3–8, 2022.