

# Compact 2-step Septulum Polarization Converters for Radars and Satellite Systems

Stepan Piltyay<sup>1</sup>, Andrew Bulashenko<sup>1</sup>, Iryna Fesyuk<sup>1</sup>, and Oleksandr Bulashenko<sup>2</sup>

<sup>1</sup>Department of Radio Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine

<sup>2</sup>Electromechanical Department, Ivan Kozhedub Shostka Professional College of Sumy State University, Shostka, Ukraine

Corresponding author: Stepan Piltyay (e-mail: crosspolar@ukr.net).

**ABSTRACT** This article presents the results of analysis, numerical simulations and optimization of new narrowband guide septulum polarization converters. Orthomode duplexers and polarization converter designs based on septulums are widely used in modern microwave systems with orthogonal circularly polarized signals. Septulum guide polarizer is an effective compact device, which transforms right-hand circularly polarized (RHCP) and left-hand circularly polarized (LHCP) electromagnetic modes into linearly polarized ones. At the same time, it divides RHCP and LHCP modes and directs them to two different rectangular guides with high signal discrimination to each other. Thus, a septulum-based guide device integrates performance of a polarization transformer and of an orthomode duplexer. The main electromagnetic characteristics of the suggested polarization converter were simulated using the finite elements method. The proposed design of a compact narrowband guide polarization converter has a septulum with two steps. Several designs of septulum polarization converters were developed and compared for different relative bandwidths of 5%, 10%, and 15%. The comparative investigation of the obtained designs was carried out. Main electromagnetic characteristics of optimal septulum polarization converters were modeled and compared in considered fractional bandwidths. These include reflection coefficients, cross-polarization discrimination, ellipticity parameter, and ports discrimination. Developed compact septulum polarization converters can be applied in modern antenna systems for radars and satellite communication systems.

**INDEX TERMS** electromagnetic simulation; microwave engineering; waveguide components; antennas; electromagnetics; septulum polarizer; waveguide polarizer; microwave passive devices; satellite systems.

## I. INTRODUCTION

**P**OLARIZATION signal adaptation and processing ensure a variety of advantages and play one of the leading roles in modern radio engineering systems including radio location and information transmission systems [1]. It allows to advance the functionality of modern communication systems and to increase information capacity of applied wireless channels. Main passive guide components of antennas for dual-polarized systems are orthomode duplexers and guide polarization converters.

Waveguide orthomode duplexers or transducers [2] provide the discrimination of independent radio signals in transceiver modules that are transmitted or received in the same frequency range. Additional microwave filters [3] for various purposes also play one of the key roles in such engineering appliances. Microwave polarization processing devices transform the polarization type and are mainly designed based on square [4] or circular waveguide structures [5].

There are many methods of theoretical analysis of modern guide devices. Among them one can highlight the

mode matching technique [6], the integral equations technique [7], the field matching method [8], equivalent circuit technique [9] and wave matrix technique [10].

The main function of a polarization converter is to create a 90-degree phase difference between modes obtaining linear polarizations at the output of the device. This is achieved by using different kinds of reactive discontinuity elements, which are placed in a guide structure. Among these discontinuities we can mention posts [11], reactive elements in the form of coaxial ridged structures [12], and reactive loads in the form of conducting diaphragms [13]. Diaphragm-based polarization converters are widely used in satellite antenna systems [14]. In addition, there are new polarization converter structures, where posts and irises are combined together [15]. The designs of waveguide septulum polarization converters are broadly used in antennas of satellite, radio location systems [16] and 5G telecommunication systems of mm-wave range of operation [17].

The constructions of septulum polarization converters are developed for various engineering applications and frequency bands [18, 19]. Designed in [20] septulum

polarization converter consists of a square guide structure and a longitudinal conducting septulum with 4 steps. Peculiarity of the suggested structure is the triangular shape of a septulum, which provides the improvement of electromagnetic characteristics of a polarization converter design. The operating frequency band of the developed septulum-based polarization converter is 8.0–8.4 GHz. Corresponding relative operating bandwidth is 5%. Ellipticity parameter of the output circularly polarized mode is lower than 0.4 dB. Return losses are greater than 30 dB. The ports discrimination is better than 24 dB.

In paper [21] the authors analyze a new 4-step septulum polarization converter for satellite Ka-band (27.5–30 GHz). Improvement of the polarization converter's performance is achieved due to the geometrical modification of the septulum's longitudinal profile using Legendre polynomials. The resulting ellipticity parameter is lower than 0.1 dB. Return losses and ports discrimination of the polarization converter are greater than 30 dB.

Presented in [21] septulum polarization converter was based on a square guide structure. The design includes a transition from a square guide to a circular one and two guide twists with integrated transformers. Operating frequency range of the converter is 214–236 GHz (10%). Return losses are greater than 30 dB. The ports discrimination is better than 38 dB. Optimized ellipticity parameter is lower than 0.3 dB.

A septulum polarization converter for operating satellite X-band (8–9 GHz) is developed in [23]. The suggested polarization converter design was based on a square guide and its conducting septulum had 4 steps. The relative bandwidth of its operating frequency range was 12%. Measured by the authors Return losses at each port of the polarization converter were greater than 20 dB. The ports discrimination was better than 20 dB. Measured ellipticity parameter was lower than 0.7 dB in the most part of operating satellite X-band.

In [24, 25] the authors present a septulum polarization converter for modern wireless communication transceivers. The design was based on a conducting septulum with 3 steps. The polarization converter operated in satellite Ku-band 12.7–14.8 GHz with relative bandwidth of 15%. The ellipticity parameter was less than 0.6 dB. Return losses of the polarization converter were greater than 25 dB. The ports discrimination was better than 30 dB.

A compact septulum polarization converter with integrated square to circular guide transition was developed in [26]. A 4-step conducting septulum was placed in the transition region of the polarization converter. The operating frequency band of the developed polarization converter was 18.5–21.5 GHz. The corresponding bandwidth ratio of this band is 15%. The ellipticity parameter of the converter was lower than 0.5 dB. Return losses and ports discrimination of the polarization converter were greater than 25 dB.

Therefore, the development and optimization of new designs of compact septulum polarization converters and

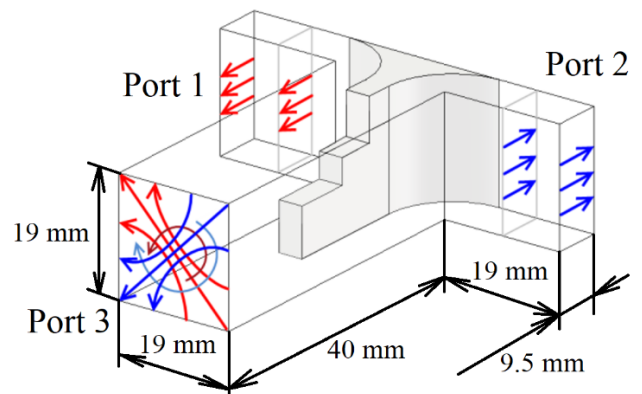
comparison of their operational characteristics, which are reached in different relative bandwidths, is an interesting and relevant engineering problem.

## II. STRUCTURE AND WORKING PRINCIPLE OF A SEPTULUM POLARIZATION CONVERTER

Input guide of a septulum polarization converter must support the propagation of electromagnetic waves with two orthogonal circular polarizations without any additional introduced shift of phases between them within an input port of an applied guide structure. Therefore, it should be a circular or a square-shaped guide. A square guide structure is a typical choice because it is more convenient for the fabrication by milling technology.

The main structural element of the polarization converter's design is a conducting septulum. It has several steps for the structure's matching improvement. On one side, the application of a septulum with greater number of steps provides the possibility to perform the variation of more geometrical parameters during the optimization process. Consequently, better polarization performance of the septulum polarization converter can be obtained, if the septulum structure has more number of steps. On the other side, the increase of number of steps results in the increase of optimization time and into complexity of the simulation process. Besides, some previous scientific works on waveguide polarizers with longitudinal conducting plates [27, 28] have demonstrated that their electromagnetic characteristics improve less with each additional step applied in the septulum design. This means that several steps of septulum are an optimal choice for the design with moderate characteristics and bandwidths. Therefore, in this research a compact 2-step conducting septulum structure was chosen for the analysis and comparison of a guide polarization converter's characteristics versus the relative bandwidth of its operational frequency range.

The inner structure of the investigated septulum polarization converter is presented in Fig. 1.



**FIGURE 1.** The structure of a compact 2-step septulum polarization converter and propagation of electromagnetic modes in it.

Polarizer consists of an input square guide, a 2-step septulum, 2 rounded E-plane twists and two output rectangular guides. The cross-section of a square guide is 19

× 19 mm<sup>2</sup>. The size of broad walls of output rectangular guides was also equal to 19 mm to provide good matching with standard rectangular guides WR75. All other dimensions of the polarization converter were varied in broad limits in order to optimize the electromagnetic characteristics in the operating band with central frequency of 10 GHz. The minimum value of the ellipticity parameter, reflection coefficients and the discrimination between rectangular guide ports were the goal functions of numerical optimization process.

Fig. 1 presents the structure of a septulum polarization converter and demonstrates its operation principle in the case of simultaneous propagation of two fundamental electromagnetic modes, which possess orthogonal circular polarizations.

The electric field components of the right hand circularly polarized (RHCP) fundamental electromagnetic mode in a septulum polarization converter are shown by the blue vectors, and ones of the left hand circularly polarized mode are shown by the red vectors.

Now let us separately consider the RHCP electromagnetic mode. The process of its propagation is presented in Fig. 2. Vectors of its electric and magnetic fields rotate clockwise in the transversal plane of an applied square guide. This RHCP mode can be equivalently represented as a sum of two orthogonal fundamental linearly polarized modes with electric field phasors  $\dot{E}_{\parallel}$  and  $\dot{E}_{\perp}$  parallel to the septulum plane and perpendicular to it, respectively (Fig. 2b). The component with horizontal linear polarization possesses an initial phase difference  $-90^{\circ}$  relative to the component with vertical linear polarization. The presence of a septulum in a structure results into the decrease of phase velocity for the vertically polarized electromagnetic component. Therefore, correctly designed septulum will compensate the initial phase difference at the input port by introducing required differential phase shift  $\Delta\varphi$  close to  $90^{\circ}$ . As a result, two excited modes will be antiphase at the left rectangular waveguide port and in-phase at the right port. Consequently, the left guide port is highly discriminated for this circularly polarized mode and input signal is transmitted to the right guide port. Mathematical formulation of described physical processes is as follows:

$$\dot{E}_1 = \frac{\dot{E}_{\perp}}{\sqrt{2}} + \frac{\dot{E}_{\parallel}}{\sqrt{2}} e^{i\Delta\varphi}, \quad \dot{E}_2 = \frac{\dot{E}_{\perp}}{\sqrt{2}} - \frac{\dot{E}_{\parallel}}{\sqrt{2}} e^{i\Delta\varphi}. \quad \text{Equivalently}$$

polarization conversion mechanism can be written in the matrix form:

$$\begin{bmatrix} \dot{E}_1 \\ \dot{E}_2 \end{bmatrix} = \frac{1}{\sqrt{2}} \cdot \begin{bmatrix} 1 & e^{i\Delta\varphi} \\ 1 & -e^{i\Delta\varphi} \end{bmatrix} \cdot \begin{bmatrix} \dot{E}_{\perp} \\ \dot{E}_{\parallel} \end{bmatrix}. \quad (1)$$

Now let us define the amplitude-phase ratio  $\dot{d}$  for the electromagnetic modes transmitted to rectangular waveguide ports:

$$\dot{d} = d e^{i\zeta} = \frac{\dot{E}_2}{\dot{E}_1}.$$

From (1) we obtain the following expression:

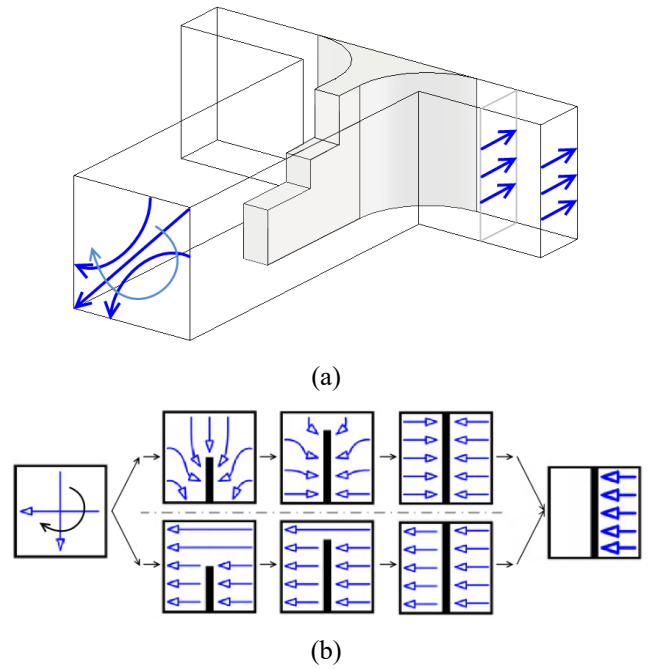
$$\dot{d} = \frac{1 - \dot{p} e^{i\Delta\varphi}}{1 + \dot{p} e^{i\Delta\varphi}}, \quad (2)$$

where  $\dot{p} = p e^{i\varphi} = \frac{\dot{E}_{\parallel}}{\dot{E}_{\perp}}$  designates the polarization parameter (phasor) in the linear basis for the electromagnetic wave at the input square waveguide port 3 (Fig. 1). Having performed mathematical transformations of (2), we obtain the ratio  $d$  of the amplitudes for the modes at two output rectangular waveguide ports:

$$d = \sqrt{\frac{1 + p^2 - 2p \cos(\varphi + \Delta\varphi)}{1 + p^2 + 2p \cos(\varphi + \Delta\varphi)}}. \quad (3)$$

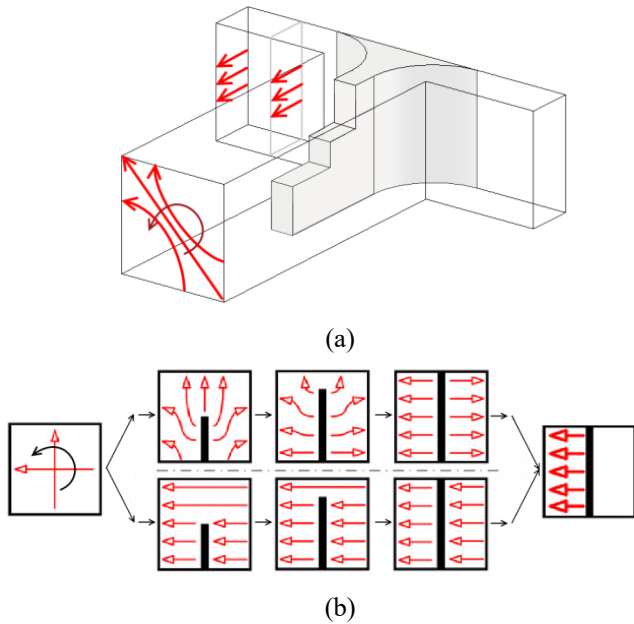
From (3) we obtain the dependence of cross-polarization discrimination (XPD) versus the differential phase shift  $\Delta\varphi$  introduced by the polarizer:

$$\text{XPD} = -20 \log_{10} \left| \text{tg} \left| \frac{\Delta\varphi - 90^{\circ}}{2} \right| \right|.$$



**FIGURE 2.** Propagation of RHCP mode in a septulum polarization converter: (a) propagation from port to port; (b) representation of the transmission as a superposition of orthogonal modes.

The propagation of left hand circularly polarized (LHCP) electromagnetic mode happens in a similar way. It is illustrated in detail in the Fig. 3. LHCP electromagnetic mode is transmitted through the septulum structure to the left waveguide port of a polarization converter. In this case the right rectangular waveguide port will be discriminated.

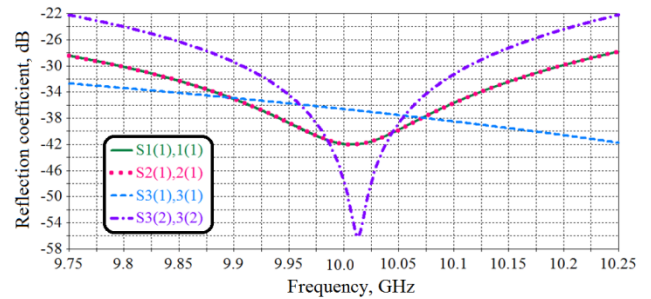


**FIGURE 3.** Propagation of LHCP mode in a septulum polarization converter: (a) propagation from port to port; (b) representation of the transmission as a superposition of orthogonal modes.

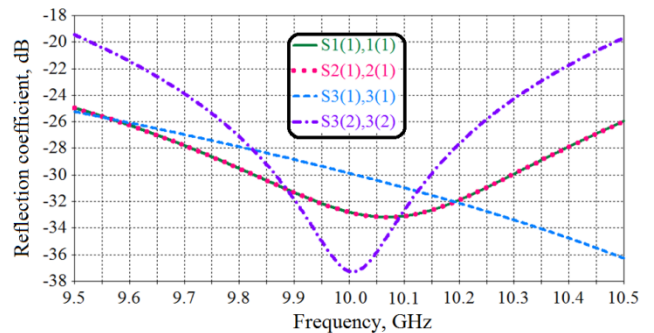
### III. RESULTS OF SEPTULUM POLARIZATION CONVERTER OPTIMIZATION FOR DIFFERENT BANDS

The modeling of electromagnetic performance of the proposed structures was carried out using CST Microwave Studio. The most efficient and universal state-of-the-art numerical schemes for electromagnetic simulation are realized in the mentioned software. They include finite difference time domain (FDTD) method and finite elements method (FEM). Recent scientific publications [29, 30] were dedicated to the comparative analysis of FDTD and FEM for the modelling of waveguide devices. They revealed advantages of FEM, which provides faster calculation and requires less memory for electromagnetic processes modeling. Besides, FEM divides inner volume of the structure into tetrahedral mesh elements using adaptive techniques. This leads to more accurate and faster modeling of field singularities near sharp edges of conducting surfaces, which are present in waveguide polarizers with septulum, diaphragms, posts etc. In [31] a trust region algorithm was effectively applied for the performance optimization of waveguide polarizers with discontinuities of various types. Therefore, in current investigation the numerical calculations and optimization of the waveguide polarizer with a conducting septulum were carried out using FEM and trust region algorithm, respectively. Goal functions of optimization process were obtaining of simultaneous possible minima of reflection coefficient and ellipticity parameter (or equivalent cross-polarization discrimination) in the determined operating frequency range. Geometrical configurations of a septulum polarization converter have been optimized numerically within a series of operating frequency ranges with center frequency of 10 GHz and relative bandwidths 5%, 10% and 15%. Typical dependences of reflection

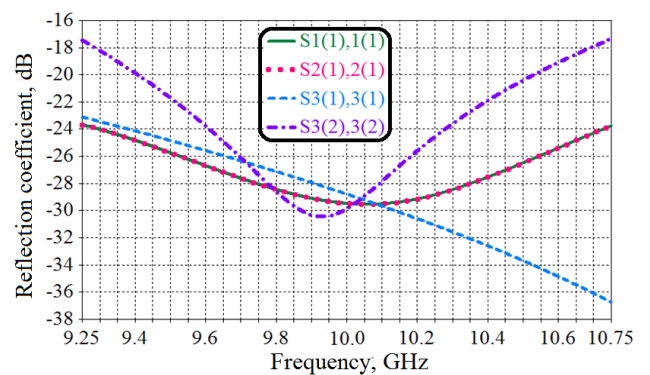
coefficients of all three guide ports versus frequency are demonstrated in Fig. 4. Port 1 corresponds to the left rectangular waveguide, port 2 corresponds to the right rectangular waveguide, port 3 is a square waveguide's port with horizontally polarized fundamental electromagnetic mode 3(1) and vertically polarized fundamental electromagnetic mode 3(2).



(a)



(b)

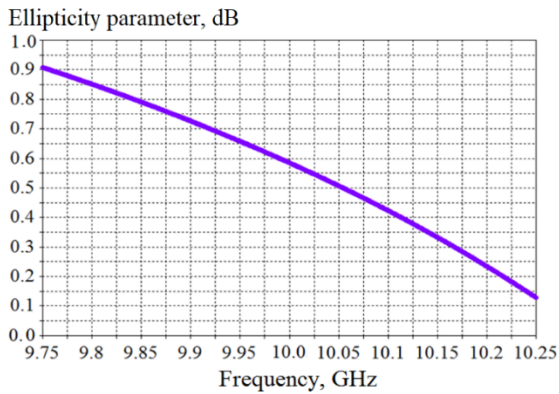


(c)

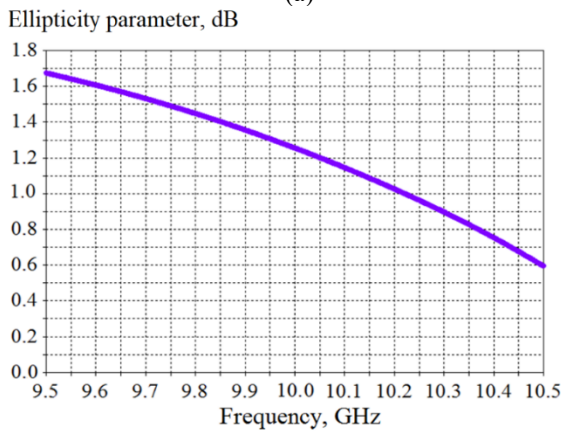
**FIGURE 4.** Dependences of the reflection coefficients of all 3 ports on frequency for different values of the fractional bandwidth: (a) 5% relative bandwidth; (b) 10% relative bandwidth; (c) 15% relative bandwidth.

Fig. 5 demonstrates the ellipticity parameters of an optimized structure of 2-step septulum polarization converters in the operating frequency bands with relative widths of 5%, 10% and 15%. Fig. 5a shows that the ellipticity parameter is lower than 0.9 dB in the 5% operating band with center frequency of 10 GHz. The

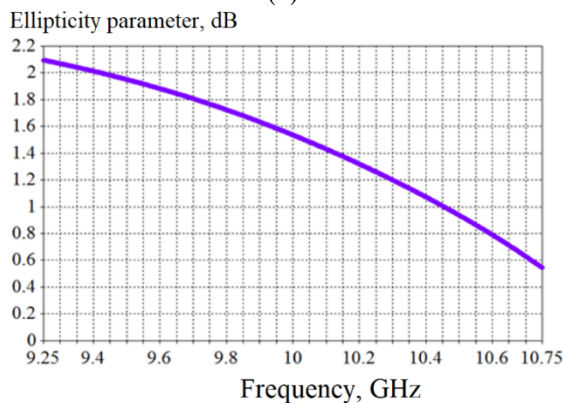
peak value of the parameter occurs at frequency of 9.75 GHz. In Fig. 5b we see that at 9.5 GHz the ellipticity parameter has its maximum value equal to 1.7 dB in the 10% operating band with center frequency of 10 GHz. It can be seen in Fig. 5c that the maximum value of ellipticity parameter in the 15% operating band is equal to 2.1 dB. It is observed at the lowest band frequency of 9.25 GHz. Therefore, all the highest values of ellipticity parameters for the considered optimized designs of compact 2-step septulum polarization converters are observed at the lowest frequency of the operating satellite band.



(a)



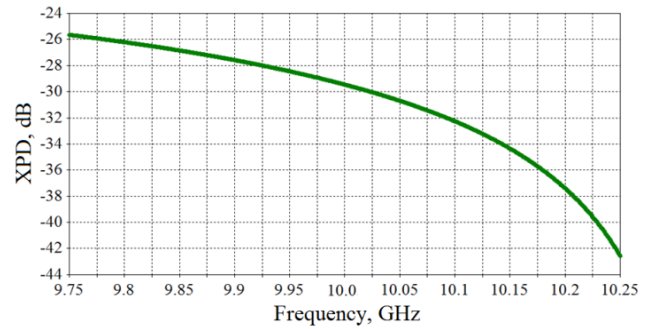
(b)



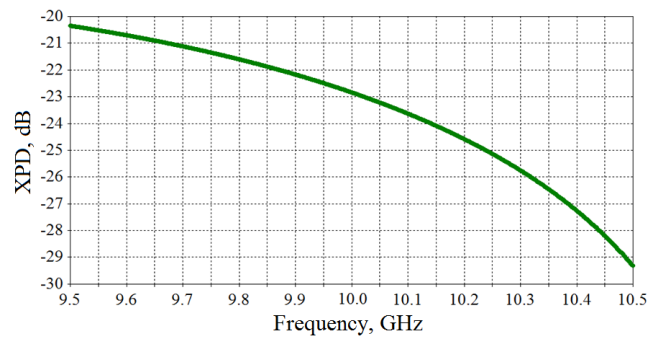
(c)

**FIGURE 5.** Dependences of ellipticity parameters of a septulum polarizer for different bandwidths: (a) 5% relative bandwidth; (b) 10% relative bandwidth; (c) 15% relative bandwidth.

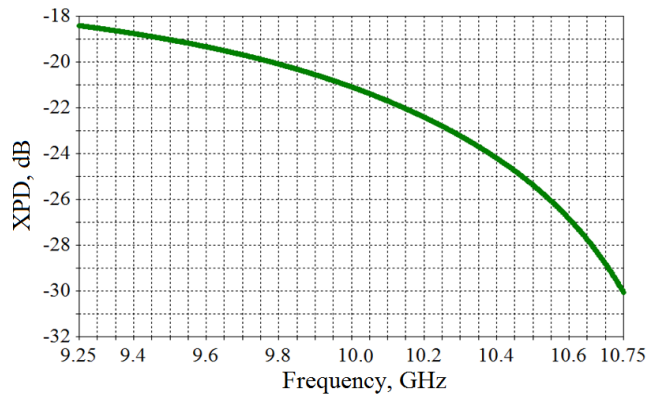
Fig. 6 presents the simulated cross-polarization discriminations of the optimized designs of 2-step septulum polarization converters in the operating frequency ranges.



(a)



(b)



(c)

**FIGURE 6.** Dependences of cross-polarization discriminations of a 2-step septulum polarizer on frequency for different relative bandwidths: (a) 5% relative bandwidth; (b) 10% relative bandwidth; (c) 15% relative bandwidth.

Fig. 6a shows that the cross-polarization discrimination is higher than 26 dB in the 5% operating band with center frequency of 10 GHz. The peak value occurs at the frequency of 9.75 GHz. Fig. 6b demonstrates that the cross-polarization discrimination is greater than 20.4 dB in the 10% operating frequency band with center frequency of 10 GHz. It can be seen in Fig. 6c that the extreme cross-polarization value of 18.5 dB is observed at the frequency of 9.25 GHz for the 15% operating band with center frequency of 10 GHz.

For all considered optimized designs of 2-step septulum polarization converters the worst cross-polarization discriminations are observed at the lowest frequencies of the operating bands. The summary on the obtained for 5–15% fractional bandwidths results for Reflection coefficients, discriminations between the rectangular ports and cross-polarization discriminations is presented in the Table I.

**TABLE I.** CHARACTERISTICS OF OPTIMIZED 2-STEP SEPTULUM POLARIZATION CONVERTERS FOR VARIOUS FREQUENCY BANDWIDTHS

Relative bandwidth, %	Reflection coefficient, dB	Isolation, dB	XPD, dB
5	-22.1	27.3	25.6
10	-19.4	24.0	20.3
15	-17.3	21.4	18.4

As can be seen in the Table I, obtained electromagnetic characteristics of a septulum polarization converter deteriorate when the relative bandwidth expands. The cross-polarization discrimination is worse than 25 dB for relative bandwidths broader than 5%. The corresponding differential phase shift of a converter lies in the range of  $90^\circ \pm 6^\circ$ . Therefore, the cross-polarization discrimination characteristic critically limits bandwidth performance of a septulum polarization converter.

Optimized designs of a narrowband 2-step septulum polarization converter provide moderate polarization and isolation performances. For relative bandwidths from 5 % to 15 % the return losses, ports discriminations and cross-polarization discrimination are greater than 17, 21 and 18 dB, respectively. In this case the simulated ports discriminations and cross-polarization discrimination decrease at approximately 3 dB per each 5% of relative bandwidth. For wider bandwidths this deterioration speed becomes lower, but the characteristics are already worse than approximately 20 dB, which is unacceptable for most modern radio engineering appliances.

Some recently published works [18–21] on polarizers with longitudinal septa have also demonstrated their efficient performance in narrow and moderate bandwidths. Suggested in this paper design of a polarizer differs from the most part of existent structures by the application in it of only 2 steps of a septulum. Consequently, obtained design is 20–30% more compact compared to the polarizers with 3 or 4 steps. In addition, numerical optimization was performed faster due to lower number of geometrical parameters. Another distinguish feature is the utilization of rounded waveguide bends in E-plane, that allowed to provide good total matching and possibility of subsequent connection with rectangular waveguides.

For most applications of polarization converters and orthomode duplexers the cross-polarization discrimination and ports discrimination, which are less than 25 dB, are unacceptable values. Therefore, if relative frequency bandwidth is wider than 5%, it is recommended to apply the

combination of a polarization converter (based on diaphragms, posts or combs) and a separate guide orthomode duplexer [32] instead of a single septulum polarization converter. On the other hand, a guide 2-step septulum polarization converter provides a more compact design, which is preferable for narrowband radar and telecommunication applications with relative bandwidths up to 5%.

#### IV. CONCLUSIONS

New compact designs of septulum polarization converters were developed and optimized for narrow bandwidth applications. It has been found that the rectangular ports isolation and cross-polarization discrimination characteristics critically limit bandwidth performance of a compact guide septulum polarization converter. Performed simulations showed that rectangular ports discrimination and cross-polarization discrimination decrease at approximately 3 dB per each 5% of relative bandwidth. In 5% relative bandwidth developed polarizer provides reflection coefficient less than -22 dB. In this fractional frequency range rectangular ports isolation and XPD are greater than 27 and 25 dB, respectively. The developed compact waveguide septulum polarization converters can be applied in modern narrowband radars and satellite communication systems.

#### REFERENCES

- [1] W. L. Stutzman, *Polarization in Electromagnetic Systems*. Norwood, MA, USA: Artech House, 2018.
- [2] F. F. Dubrovka, et al., "Novel high performance coherent dual-wideband orthomode transducer for coaxial horn feeds", *Proceedings of XI International Conference on Antenna Theory and Techniques (ICATT)*, Kyiv, Ukraine, May 2017, pp. 277–280. DOI: 10.1109/ICATT.2017.7972642.
- [3] M. Omelianenko and T. Romanenko, "E-plane stepped-impedance bandpass filter with wide stopband," *IEEE 40th Int. Conference on Electronics and Nano technology*, Kyiv, Ukraine, April 2020.
- [4] S.I. Pilyay, O.Yu. Sushko, A.V. Bulashenko, and I.V. Demchenko, "Compact Ku-band iris polarizers for satellite telecommunication systems", *Telecommunications and Radio Engineering*, vol. 79, no. 19, pp. 1673–1690, December 2020. DOI: 10.1615/TelecomRadEng.v79.i19.10.
- [5] A. A. Kirilenko, S. O. Steshenko, V. N. Derkach, and Y. M. Ostrizhnyi, "A tunable compact polarizer in a circular waveguide," *IEEE Trans. on Microwave Theory and Techniques*, vol. 67, no. 2, pp. 592–596, 2019. DOI: 10.1109/TMTT.2018.2881089.
- [6] J. Schorer and J. Bornemann, "A mode-matching technique for the analysis of waveguide-on-substrate components", *IEEE MTT-S International Conference on Numerical Electromagnetic and Physics Modeling and Optimization*, Ottawa, Canada, August 2015.
- [7] F. F. Dubrovka, et al., "Electrodynamics boundary problem solution for sectoral coaxial ridged waveguides by integral equation technique," *Radioelectronics and Communications Systems*, vol. 55, no. 5, pp. 191–203. May 2012. DOI: 10.3103/S0735272712050019.
- [8] F. F. Dubrovka, et al., "Eigenmodes analysis of sectoral coaxial ridged waveguides by transverse field-matching technique. Part 1. Theory," *Visnyk NTUU KPI Seriya – Radiotekhnika, Radioaparaturbuduvannia*, vol. 54, pp. 13–23. 2013. DOI: 10.20535/RADAP.2013.54.13-23.
- [9] A. V. Bulashenko and S. I. Pilyay, "Equivalent microwave circuit technique for waveguide iris polarizers development," *Visnyk NTUU KPI Seriya – Radiotekhnika, Radioaparaturbuduvannia*, vol.

- 83, pp. 17–28, December 2020. DOI: 10.20535/RADAP.2020.83.17-28.
- [10] A. V. Bulashenko, S. I. Pilyay, and I. V. Demchenko, “Wave matrix technique for waveguide iris polarizers simulation. Theory,” *Journal of Nano- and Electronic Physics*, vol. 12, no. 6, pp. 06026-1–06026-5, December 2020. DOI: 10.21272/jnep.12(6).06026.
- [11] A. Polishchuk et al., “Compact posts-based waveguide polarizer for satellite communications and radar systems,” *IEEE 3rd Ukraine Conference on Electrical and Computer Engineering (UKRCON)*, Lviv, Ukraine, August 2021, pp. 78–83. DOI: 10.1109/UKRCON53503.2021.9575462.
- [12] F. F. Dubrovka, et al., “Eigenmodes of coaxial quad-ridged waveguides. Numerical results,” *Radioelectronics and Communications Systems*, vol. 57, no. 2, pp. 59–69, February 2014. DOI: 10.3103/S0735272714020010.
- [13] S. I. Pilyay, A. V. Bulashenko, and I. V. Demchenko, “Waveguide iris polarizers for Ku-band satellite antenna feeds,” *Journal of Nano- and Electronic Physics*, vol. 12, no. 5, pp. 05024-1–05024-5, October 2020. DOI: 10.21272/jnep.12(5).05024.
- [14] S. Pilyay, A. Bulashenko, and I. Demchenko, “Compact polarizers for satellite information systems,” *IEEE International Conference on Problems of Infocommunications. Science and Technology (PIC S&T)*, Kharkiv, Ukraine, October 2020, pp. 557–562. DOI: 10.1109/PICST51311.2020.9467889.
- [15] S. Pilyay, A. Bulashenko, H. Kushnir, and O. Bulashenko, “New tunable iris-post square waveguide polarizers for satellite information systems,” *IEEE 2nd International Conference on Advanced Trends in Information Theory*, Kyiv, Ukraine, November 2020, pp. 342–348. DOI: 10.1109/ATIT50783.2020.9349357.
- [16] I. Fesyuk et al., “Waveguide polarizer for radar systems of 2 cm wavelength range,” *IEEE 3rd Ukraine Conference on Electrical and Computer Engineering (UKRCON)*, Lviv, Ukraine, August 2021, pp. 15–20. DOI: 10.1109/UKRCON53503.2021.9575278.
- [17] K. Al-Amoodi, et al., “A compact substrate integrated waveguide notched-septum polarizer for 5G mobile devices,” *IEEE Antennas and Wireless Propagation Letters*, Vol. 19, no. 12, pp. 2517–2521, 2020. DOI: 10.1109/LAWP.2020.3038404.
- [18] F. F. Dubrovka, et al., “Optimum septum polarizer design for various fractional bandwidths,” *Radioelectronics and Communications Systems*, vol. 63, no. 1, pp. 15–23, January 2020. DOI: 10.3103/S0735272720010021.
- [19] F. Dubrovka, et al., “Compact X-band stepped-thickness septum polarizer,” *IEEE Ukrainian Microwave Week (UkrMW)*, Kharkiv, Ukraine, September 2020, pp. 135–138. DOI: 10.1109/UkrMW49653.2020.9252583.
- [20] J. Kim, S. Yoon, E. Jung, J. W. Lee, T. K. Lee, and W. K. Lee, “Triangular-shaped stepped septum polarizer for satellite communication,” *IEEE International Symposium on Antennas and Propagation (APSURSI)*, Spokane, USA, August 2011, pp. 854–857. DOI: 10.1109/APS.2011.5996409.
- [21] J.-C. Angevain, and N. J. G. Fonseca, “Waveguide septum polarizer shaped with Legendre polynomials,” 11th European Conference on Antennas and Propagation (EUCAP), pp. 2286–2290, March 2017. DOI: 10.23919/EuCAP.2017.7928324.
- [22] C. A. Leal-Sevillano, K. B. Cooper, J. A. Ruiz-Cruz, J. R. Montejo-Garai, and J. M. Rebollar, “A 225 GHz circular polarization waveguide duplexer based on a septum orthomode transducer polarizer,” *IEEE Transactions on Terahertz Science and Technology*, vol. 3, no. 5, pp. 574–583, September 2013. DOI: 10.1109/TTHZ.2013.2264317.
- [23] W. Zhong, B. Li, Q. Fan, and Z. Shen, “X-band Compact Septum Polarizer Design,” *IEEE International Conference on Microwave Technology and Computational Electromagnetics (ICMTCE)*, Beijing, China, May 2011, pp. 167–170. DOI: 10.1109/ICMTCE.2011.5915191.
- [24] J. A. Ruiz-Cruz, M. M. Fahmi, M. Daneshmand, and R. R. Mansour, “Compact reconfigurable waveguide circular polarizers,” *Proceedings of IEEE Microwave Symposium Digest*, Baltimore, USA, June 2011, pp. 1–4. DOI: 10.1109/MWSYM.2011.5972872.
- [25] J. A. Ruiz-Cruz, M. M. Fahmi, S. A. Fouladi, and R. R. Mansour, “Waveguide antenna feeders with integrated reconfigurable dual circular polarization,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 59, no. 12, pp. 3365–3374, December 2011. DOI: 10.1109/TMTT.2011.2170581.
- [26] N. Nikolic, et al., “A septum polarizer with integrated square to circular tapered waveguide transition,” *Proceedings of IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, Boston, USA, July 2018. DOI: 10.1109/APUSNCURSINRSM.2018.8608909.
- [27] F. F. Dubrovka, et al., “Optimal designs of X-band waveguide stepped-thickness septum polarizer,” *Radioelectronics and Communications Systems*, vol. 64, no. 9, pp. 494–500, September 2021. DOI: 10.3103/S0735272721090041.
- [28] S. Pilyay, “Electromagnetic and bandwidth performance optimization of new waveguide polarizers with septum of a stepped-thickness type for satellite systems,” *Journal of Electromagnetic Waves and Applications*, vol. 36, 2022. DOI: 10.1080/09205071.2021.2016500.
- [29] S. Pilyay, A. Bulashenko, Y. Herhil, and O. Bulashenko, “FDTD and FEM simulation of microwave waveguide polarizers,” *IEEE 2nd International Conference on Advanced Trends in Information Theory (ATIT)*, Kyiv, Ukraine, November 2020, pp. 357–363. DOI: 10.1109/ATIT50783.2020.9349339.
- [30] S. I. Pilyay, A. V. Bulashenko, and Y. Y. Herhil, “Numerical performance of FEM and FDTD methods for the simulation of waveguide polarizers,” *Visnyk NTUU KPI Seriya – Radiotekhnika Radioaparaturbuduvannia*, vol. 84, pp. 11–21, March 2021. DOI: 10.20535/RADAP.2021.84.11-21.
- [31] S. Pilyay et al., “Analytical modeling and optimization of new Ku-band tunable square waveguide iris-post polarizer,” *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, vol. 34, no. 5, pp. 1–27, 2021. DOI: 10.1002/JNM.2890.
- [32] S. I. Pilyay, “High performance extended C-band 3.4–4.8 GHz dual circular polarization feed system,” *XI International Conference on Antenna Theory and Techniques (ICATT)*, Kyiv, Ukraine, May 2017, pp. 284–287. DOI: 10.1109/ICATT.2017.7972644.