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Three-Stepped Septum Waveguide Polarizer in the Operating Frequency Band 7.7-8.1 GHz

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In this article, we have proposed a new design for a waveguide polarizer with a metal plate. The plate has the shape of three steps. The septum polarizer has been designed to operate in the frequency band 7.7-8.1 GHz. Each step of the plate of such a device has its own height and thickness. It is necessary that the first step from the square port is the lowest and thinnest and the last one is the highest and thickest for better matching. The waveguide with a square cross section was chosen for simplicity of production. The basic electromagnetic characteristics of the developed waveguide polarization conversion device were optimized using commercial software. The well-known finite-domain electrodynamic method in the frequency domain was applied in the simulation program. The proposed development method also allows one to optimize the geometric dimensions of the entire waveguide polarizer based on a three-stepped metal plate. The obtained dimensions of the polarizer with the plates will provide the optimal phase characteristics, matching characteristics, polarization characteristics and isolation characteristics between the device ports. The method allows one to obtain the following dimensions: the height of the wall of a square waveguide, the height of three different steps of the plate, the distance between the steps of the plate. Accordingly, the waveguide septum polarizer is capable of cutting the following values of the electromagnetic characteristics in the operating frequency band 7.7-8.1 GHz. Differential phase shift can vary by 90º±0.86º. The maximum voltage standing wave ratio does is 1.044 for vertical and horizontal polarizations. The maximum value of the axial radio of the developed device is 0.13 dB. The maximum crosspolar discrimination of the polarization device is – 42 dB. The isolation between the first and second ports of a three-step polarizer with plates does not exceed – 39 dB. In this way the presented polarizer can be used in modern satellites and radar systems.

Keywords: Polarizer, Waveguide polarizer, Septum polarizer, Circular polarization, Differential phase shift, Axial ratio, Crosspolar discrimination, Satellite antenna systems.

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1. INTRODUCTION

Modern radar systems and satellite systems use polarization signal processing. It is carried out by polarization converting devices that convert the types of polarization [1]. Historically, the first to appear were polarizing devices with reactivities in the form of posts [2, 3]. Then polarized devices appeared based on a square waveguide with irises of different configurations [4-6]. In [4], a design of a polarizer based on a square waveguide with irises is presented. It operates in the C-band. The cross-polarization isolation does not exceed -35 dB. The reflection coefficient is – 40 dB. The design of a polarizer based on a circular waveguide with irises is described in [5]. The presented irises are elliptical. The differential phase shift of the designed device is 90º±1º. The return loss for both polarizations is better than 35 dB. In [6], the design of polarizers based on slot irises is proposed. These polarizers have a narrow bandwidth.

In addition, there are polarizing devices in the form of a combination of posts and irises. There are many techniques for the design and synthesis of such devices [7-9]. In [7], a method for analyzing waveguide polarizers with irises based on the technique of wave matrices is presented. The numerical results of the method are given in [8]. In [9], the method for the synthesis of waveguide polarizers with irises has been described.

There are also designs of polarization converters based on sections of rectangular waveguides with inner corner ridges and on the basis of sectorial coaxial ridged waveguides [10]. But for a narrow frequency range, polarization devices based on a square waveguide with a metal plate have better characteristics [11-17]. In [11], a method is described for the implementation of a polarizer with a dielectric plate in the frequency range 60-62.25 GHz. The axial ratio of the polarizer is less than 0.5 dB. The return loss is – 13 dB. In this design, it is possible to adjust the length of the dielectric plate. The two stepped septum polarizer is described in [12]. Design supports consistent power supply for increased bandwidth.

In [13], the development of a compact waveguide duplexer with high isolation is described. The device operates at 225 GHz. The design uses the reception and transmission of orthogonal circular polarizations. This

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is done using a septum polarizer. The developed system has an isolation of 30 dB in a relative frequency band of 10 %. The return loss of the proposed device is greater than 20 dB. A septum polarizer design for high power applications was proposed in [14]. A septum profiled with smooth edges is presented. The septum is represented by the sigmoid function. This function provides various configurations without any interruption. The profiles were optimized by the Particle Swarm Optimization technique in the HFSS software. In [15], a range illuminator design based on a stepped-septum polarizer is proposed. This polarizer can be used with dual-mode horns, pyramidal horns, and corrugated horns. The paper describes the procedure for determining the geometry of the partition in the form of two steps for subsequent optimization. Adaptive production technology has been proposed to minimize and integrate antenna systems [16]. It is used to fabricate waveguide components. In particular, it is used for the production of Ka-band septum polarizers. The developed prototypes have acceptable characteristics. In [17], the results of the development of a stepped wave-water septum polarizer in the 230 GHz range for radio astronomy are presented. This design allows for efficient elimination of processing errors. A new broadband septum polarizer is proposed in [18]. The relative bandwidth is 37.8 %. The wave-water design has the shape of an equilateral triangle. This provides the largest possible frequency range between the main and the next higher cutoff mode. As a result, two polarizer designs were designed for the frequency ranges 75-110 GHz and 18-26 GHz. The axial ratio of such polarizers is lower than 1.3 dB. In [19], a method is presented for describing the complete characteristics of the septum polarizer dielectric plate polarizer implementations in back-to-back configuration through standard amplitude/power measurements. The design of the hybrid tap is described in [20]. This design is based on the principle of operation of a septum polarizer. A prototype of the device was created in the frequency range 17.2-20.9 GHz. The axial ratio is less than 0.5 dB. The return loss of the device is 24 dB. In addition, a prototype of the device is created in the frequency band of 16.8-22.0 GHz. The axial ratio is less than 3.0 dB. The return loss of the device is 20 dB. Such devices can be used in power supply systems for complex antenna systems. The split-block manufacturing technique of the septum polarizer is described in [21]. A polarizer was developed based on the proposed technique. The device is designed in such a way that there is a minimum influence of welding and skewing effect on the characteristics of the polarizer.

Moreover, such polarizers are increasingly being used in modern telecommunication systems 5G [22-24]. In [22], a design of a septum polarizer with a toothed partition is proposed. The developed device was integrated into the substrate. The polarizer operates at 29 GHz for 5G applications in a 4.5 % relative bandwidth. The axial ratio is 3 dB. The transmission coefficient of the device does not exceed 1.6 dB. The results of the development of a broadband septum antenna for microwave applications are proposed in [23]. In such a dual circular polarized antenna, the polarizer has two overhangs. Due to this solution, it was possible to increase the antenna bandwidth. The proposed antenna has an axial ratio of less than 3 dB. Antenna reflectivity is less than – 14 dB. Antenna isolation is 22 dB. In [24], the design of a wideband antenna with double circular polarization for the W-frequency range is described. The antenna contains an optimized waveguide septum polarizer. This design allows both left-hand circular polarization and right-hand circular polarization to be transmitted and received simultaneously. The designed antenna has a bandwidth of 76.8-94.7 GHz. The axial ratio of such a system does not exceed 5.8 dB. Isolation between antenna channels is more than 20 dB. Reflectance parameter is less than – 15 dB.

Despite the large number of works devoted to various numerical methods for creating septum polarizers, there are many problems of optimizing the characteristics of such devices. Therefore, in this article, we have developed and optimized a new design of the X-band septum polarizer.

2. PRINCIPLE OF OPERATION OF A SEPTUM POLARIZER WITH PLATE

The septum polarizer is an essential passive component of receiver. It is a simple and compact device for converting linear polarization into circular polarization and vice versa.

The three-dimensional model a waveguide polarization conversion device with stepped plate is shown below (Fig. 1).

This design provides the basic polarization characteristics. The polarizing device is designed on the basis of a rectangular waveguide with a metal plate. The plate is designed in the form of three steps.

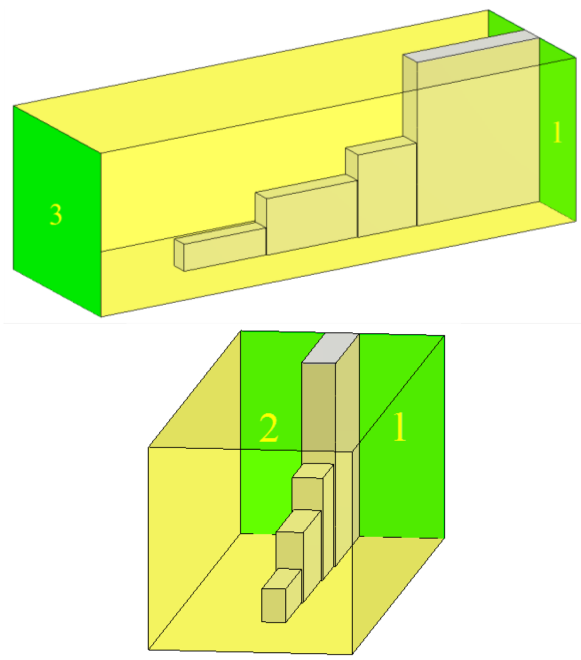

Fig. 1 – 3D model of a three-stepped waveguide polarizer

A signal applied to one of the inputs of a rectangular polarizer is converted in its square section into a circularly polarized signal. In this case, right circular polarizations or left circular polarizations are obtained depending on which of the inputs 1 or 2 of the polarizer is supplied with the input signal. On the contrary, a signal with circular polarization from a section with a square cross section, depending on the direction of rotation of the polarization vector, arrives at input 1 or 2.

The principle of operation of the waveguide polarizer is clear from Fig. 2.

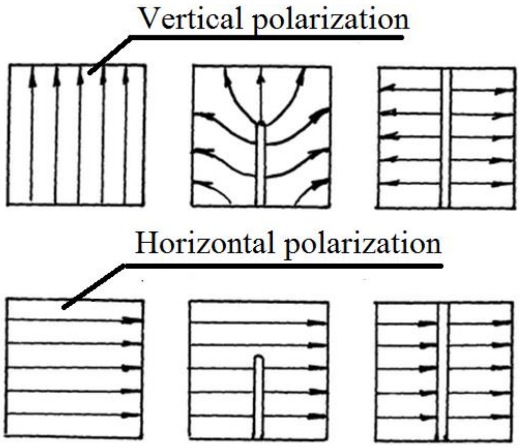

Fig. 2 – Horizontal and vertical polarizations

The component of the field, parallel to the partition, is transformed into two odd modes (counterphase components) in rectangular arms (inputs 1 and 2), and the perpendicular component is transformed into two even modes (in-phase components). If both components exist simultaneously, a mutual suppression of signals will occur in one of the rectangular arms. Suppose, for example, a signal with the first circular polarization propagates towards the partition from a square section, so that the vertical component is ahead of the horizontal one by 90°. The septum area can be viewed as a retarding structure for the vertical component. If the septum is made of such a length that the phase delay for the vertical component is 90°, both components will suppress each other in the input arm 1 and add up in phase in the input arm 2 of the polarizer.

Fig. 3 presents the designs and designations of dimensions of the polarizer with three stepped septum of constant and stepped thicknesses.

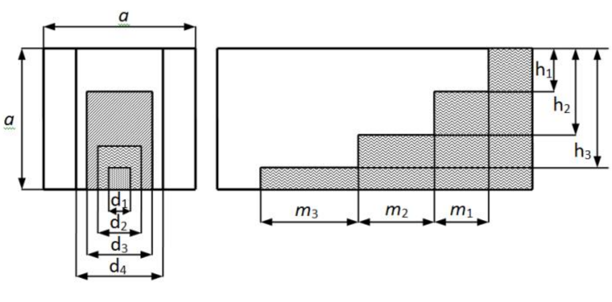

Fig. 3 – The design of a three-stepped waveguide polarizer

The optimization of the characteristics of a three-stepped waveguide septum polarizer were performed. The numerical results are summarized in Table 1.

Table 1 – Sizes of the optimized three-stepped septum polarizer

Parameter name	Numerical value, mm
Size of square waveguide walls	$a = 23.62$
Height of the highest plate	$h_1 = 11.72$
Height of the medium plate	$h_2 = 15.38$
Height of the lowest plate	$h_3 = 19.38$
Gap between the highest plate	$m_1 = 9.15$
Gap between the medium plate	$m_2 = 15.12$
Gap between the lowest plate	$m_3 = 13.45$
Thickness the highest plate	$d_1 = 11.72$
Thickness the medium plate	$d_2 = 15.38$
Thickness the lowest plate	$d_3 = 19.48$

3. NUMERICAL STUDY OF SEPTUM POLARIZER CHARACTERISTICS

Result of the performed research are presented hereinbelow. The frequency dependences of the electromagnetic characteristics of the developed device for the frequency range 7.7-8.1 GHz are presented. The results were obtained in a specialized program using computer simulation [25]. The main characteristics are differential phase shift, voltage standing wave ratio (VSWR), axial ratio and crosspolar discrimination (CPD), isolation.

Fig. 4 presents the frequency dependence of the VSWR of the developed polarizer for horizontal and vertical polarization. As can be seen, the maximum level of VSWR for both linear polarizations is 1.042. It is reached at a frequency of 7.7 GHz.

Fig. 5 shows the dependence of the differential phase shift of the polarizer in the frequency range 7.7-8.1 GHz. As can be seen, the differential phase shift is equal to 90° at a frequency of 7.95 GHz. In the operating frequency range, the differential phase shift of the polarizer varies from 90.86° to 89.9°. The minimum deviation from 90° is 89.9°. It is observed at 8.05 GHz.

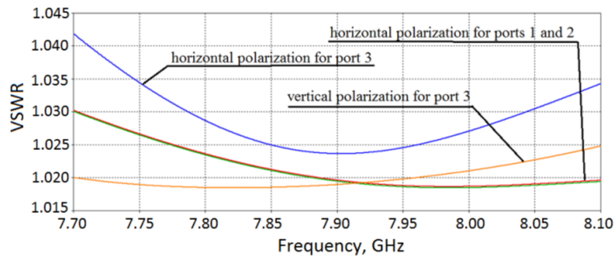

Fig. 4 – Dependence of VSWR on frequency for both polarizations

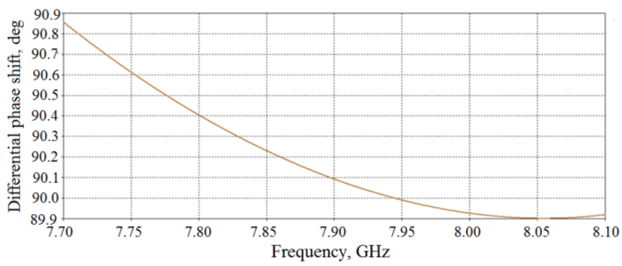

Fig. 5 – Dependence of differential phase shift on frequency

Fig. 6 demonstrates the dependence of the axial ratio of the polarizer in the frequency range 7.7-8.1 GHz. As can be seen, the axial ratio does not exceed 0.13 dB. The axial ratio at 7.94 GHz is 0.

Fig. 7 shows the dependence of the crosspolar discrimination of the development septum polarizer in the frequency range 7.7-8.1 GHz. As can be seen, the crosspolar discrimination does not exceed – 42 dB. The CPD at 7.94 GHz is – 105 dB.

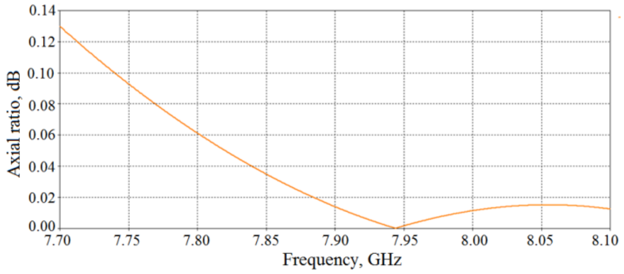

Fig. 6 – Dependence of axial ratio on frequency

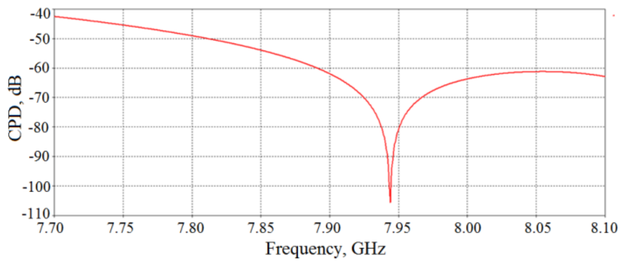

Fig. 7 – Dependence of crosspolar discrimination on frequency

Fig. 8 illustrates the isolation of the developed septum polarizer in the operating frequency bands 7.7-8.1 GHz. Fig. 8 presents that the isolation does not exceed – 39 dB at 8.1 GHz. At 7.856 GHz the maximum value of isolation between first and second ports is – 52 dB. Consequently, such values indicate a good isolation of the ports of the designed septum polarizer.

Therefore, the waveguide septum polarizer for satellite systems in the operating band 7.7-8.1 GHz was developed in the course of our research. The presented waveguide septum polarizer with a stepped plate has the following characteristics. The differential phase shift range is 90°±0.86°. The polarizer provides a VSWR of less than 1.044. Axial ratio is less than 0.13 dB. CPD is above 42 dB. The characteristics of the developed device perfectly meet the requirements of modern satellite and radioelectronics systems.

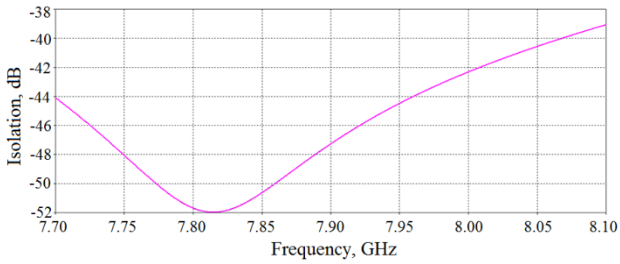

Fig. 8 – Dependences of isolation of a developed septum polarization transducer on frequency for 1 and 2 ports

4. CONCLUSIONS

A new three-stepped septum waveguide polarizer has been developed for the operating frequency band of 7.7-8.1 GHz. The differential phase shift of the developed device is 90°±0.86°. The isolation between the first and second ports is – 39 dB. VSWR has a maximum value is 1.044. In this case, the crosspolar discrimination is more than 42 dB.

In this way, the developed polarization device can be recommended for practical use in modern telecommunication systems. In future studies, we propose to investigate other step configurations for the design of waveguide septum polarizers.

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Триступінчастий хвилеводний поляризатор із перегородкою в діапазоні робочих частот 7.7-8.1 ГГц

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У цій статті ми запропонували нову конструкцію хвилеводного поляризатора з металевою пластиною. Ця пластина зроблена у формі трьох сходинок. Поляризатор із пластиною був спроектований для роботи в діапазоні частот 7.7-8.1 ГГц. Кожна сходинка пластини такого пристрою має свою висоту та товщину. Для кращого узгодження необхідно щоб перша сходинка від квадратного порту була найнижчою і найтоншою, а остання високою та товстою. Для простоти виготовлення було обрано хвилевід із квадратним перетином. Базові електромагнітні характеристики розробленого хвилеводного пристрою перетворення поляризації були оптимізовані за допомогою комерційного програмного забезпечення. У програмі моделювання був застосований добре відомий електродинамічний метод кінцевих областей у частотної області. Запропонований метод розробки також дозволяє оптимізувати геометричні розміри всього хвилеводного поляризатора на основі металевої пластини у вигляді трьох сходинок. Отримані розміри поляризатора з пластинами забезпечуватимуть оптимальні фазові характеристики, характеристики узгодження, характеристики поляризації, характеристику розв'язки між портами пристрою. Метод дозволяє отримати такі розміри: висоту стінки квадратного хвилеводу, висоту трьох різних сходинок пластини, відстань між сходинками пластини. Таким чином, хвилеводний поляризатор з пластиною здатний підтримувати в робочій смузі частот 7,7-8,1 ГГц такі значення електромагнітних характеристик. Диференціальний фазовий зсув може змінюватися в межах 90±0,86º. Максимальне значення коефіцієнта стійної хвилі за напругою становить 1.044 для вертикальної та горизонтальної поляризацій. Максимальне значення коефіцієнта еліптичності розробленого пристрою становить 0,13 дБ. Максимальне значення кросполяризаційної розв'язки пристрою обробки поляризації становить – 42 дБ. Розв'язка між першим і другим портами триступінчастого поляризатора з пластинами не перевищує – 39 дБ. Таким чином, представлений поляризатор може застосовуватися в сучасних супутникових і радіолокаційних системах.

Ключові слова: Поляризатор, Хвилевідний поляризатор, Поляризатор із перегородкою, Колова поляризація, Диференційний фазовий зсув, Коефіцієнт еліптичності, Кросполяризаційна розв'язка, Супутникові антенні системи.