ELABORATION OF THE POLARIZER'S CONSTRUCTION FOR WORK IN Ka-BAND

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Abstract: The problems of the polarizer`s construction over the basis of the circular waveguide for work in Ka-band are highlighted in the article. The purpose of the article is to establish the possibility of using the proposed design for the construction of high-tech Ka-band polarizers and to prove the correctness of analytical expressions for determining the structural dimensions by experimentally obtained characteristics. The analysis of the current decisions from the point of view of construction and technology is held. On the conclusion had been drawn more technological polarizer`s construction with the calculation of the main constructive sizes is proposed.

Theoretical principles of construction and calculation of structural dimensions of the C and Ku ranges polarizers' phase-shifting sections are covered in detail in the works of modern researchers and tested on real devices. However, while constructing AFT elements designed to operate in higher frequency operating bands, such as the Ka-band (20/30 GHz), there are certain difficulties, the solution of which continues.

In order to check the proposed decision, an experimental model of the polarizer was made and an investigation of the main characteristics corroborating the right theoretical assumption was held. For a practical study of the proposed design, a mock-up of a polarizer based on a round waveguide with an inner diameter of 11 millimeters was made. In the prototype, the rod structure was implemented in the form of five pairs of adjusting screws with a diameter of one millimeter. The final length of the polarizing plate, taking into account the smooth transitions designed to align the plate with the waveguide, was defined as the sum of the lengths of its regular part and one smooth transition multiplied by 0.9.

The experimentally obtained characteristics confirm the possibility of using the proposed design for the construction of high-tech Ka-band polarizers, and the correctness of analytical expressions for determining the structural dimensions. Further development of the proposed solution may be the analysis and finding the necessary analytical relationships between the structural dimensions of the rod and dielectric structures in order to expand the operating range of the polarizer.

Keywords: Polarizer, frequency, metal-rod type, Ka-band (20/30 GHz), design.

Problem Statement.

Increasing requirements for the information resource of modern satellite communication channels determines the need to create radiant systems of mirror antennas operating at higher frequencies and in wider frequency bands for both reception and transmission. To increase the bandwidth of communication channels on modern satellites, there is also a requirement to use signals with orthogonal polarization for both reception and transmission. In addition to the fact that modern irradiation systems must operate in a wide frequency band with signals of different polarization, it is also necessary that the irradiator has a small mass and size.

Analysis of recent research and publications.

Modern irradiation systems consist of three main components, namely: irradiator, polarizer, and orthomode selector. The components of frequency polarization signal processing include a polarizer and an orthomode selector. A polarizer is a device that provides primary polarization processing of received signals. In the case of circular polarization signals, the latter are converted into signals with linear polarization, and in the case of signals with linear polarization, it is possible to change the orientation of their dimensions.

An orthomode selector is a device that provides further frequency and polarization selection of signals into individual channels [1]. In fact, the orthomode selector is a passive waveguide splitter [2; 3], the function of which is the frequency and polarization selection of signals received by the antenna. [4; 5]. Given the tendency to polarize the communication channels, the task of achieving high values of the cross-polarization decoupling is a significant problem. Successful examples of technical solutions of such problems are in the C- and Ku- frequency bands, and in solving similar problems in the Ka-band there are some difficulties in achieving the required values of the cross-polarization decoupling.

Highlighting previously unsolved parts of the overall problem.

Theoretical principles of construction and calculation of structural dimensions of phase-shifting sections of polarizers of the C- and Ku- ranges are covered in detail in the works of modern researchers [1-4] and tested on real devices that have found application. However, when designing AFT elements designed to operate in higher frequency operating bands, such as the Ka-band (20/30 GHz), when designing such devices, there are certain difficulties, the finding the solution of which continues.

The purpose of the article.

To establish the possibility of using the proposed design for the construction of high-tech Ka-band polarizers, and the correctness of analytical expressions for determining the structural dimensions by experimentally obtained characteristics.

Presenting main material.

In antenna-feeder paths of antenna systems (AS), for polarization signal processing, polarizers based on circular waveguides are widely used. As is known, such devices are structurally a segment of a circular waveguide where there are certain longitudinal inhomogeneities at the angle of 45 degrees to the polarization dimension of the incident wave, which create a phase shift between the components of the electric field, respectively parallel and perpendicular to the inhomogeneity plane. In the general, the value of the phase shift in the polarizers is determined as follows

$$\Theta = (\beta_1 - \beta_2) l \quad (1),$$

where $\beta_{1,2}$ - phase constants of the vector E components;

l - the length of the phase shift section.

Depending on the AS type and purpose, the phase shift between the components should be 90 degrees (circular polarization) or 180 degrees (linear polarization). The main task posed in the development of such devices is to compensate for the variance of the phase shift in a given band of operating frequencies, resulting from the specified values of the ellipticity factor, or cross-polarization solution of the AS.

At the moment, in the antenna-feeder paths (AFP), the most widely used designs of polarizers, e.g. metal-rod, dielectric and metal-dielectric types, schematic images of which are shown in Fig.1 (a,b,c)

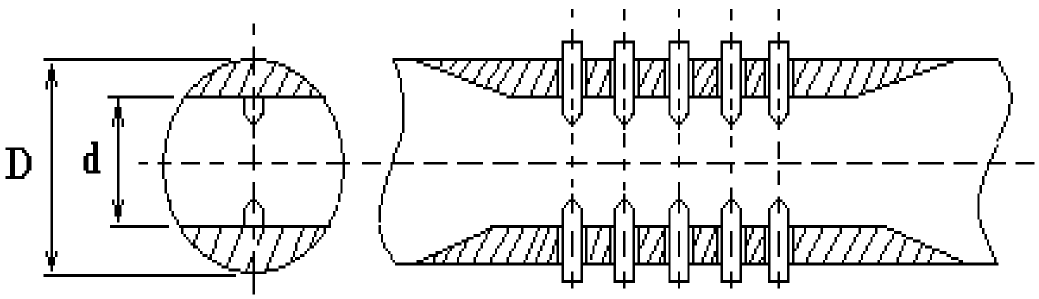

Fig.1a. Polarizer metal-rod type

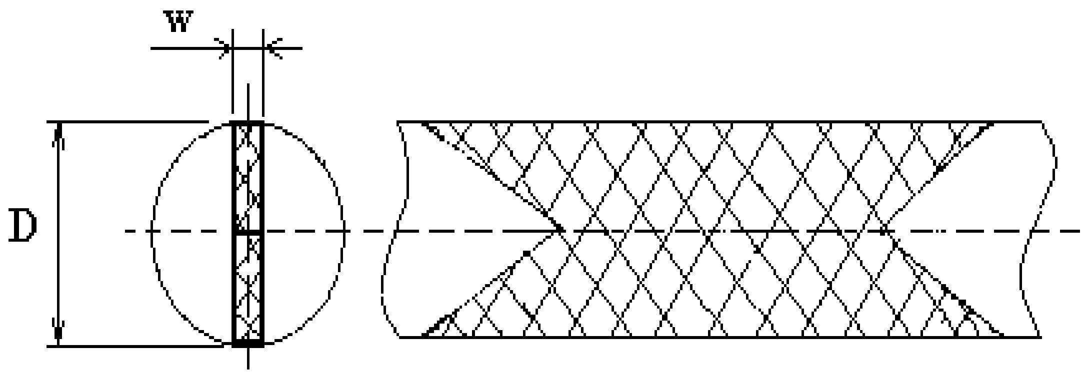

Fig.1b. Polarizer dielectric type.

The principles of construction and calculation of the design dimensions of phase-shifting sections of these types of polarizers, elaborated in sufficient detail theoretically [1, 2, 3, 4], and tested on real devices that are used in different operating ranges at frequencies from 4 to 14 GHz. However, the development of AFP elements designed to operate in higher frequency operating bands, such as Ka-band (20/30 GHz), faces some difficulties associated with the following factors: significant increase in the requirements for the required accuracy of manufacturing elements; decrease in the geometric dimensions of the elements themselves; grow of the influence of heterogeneity of physical and geometrical characteristics of materials on radio technical characteristics of devices.

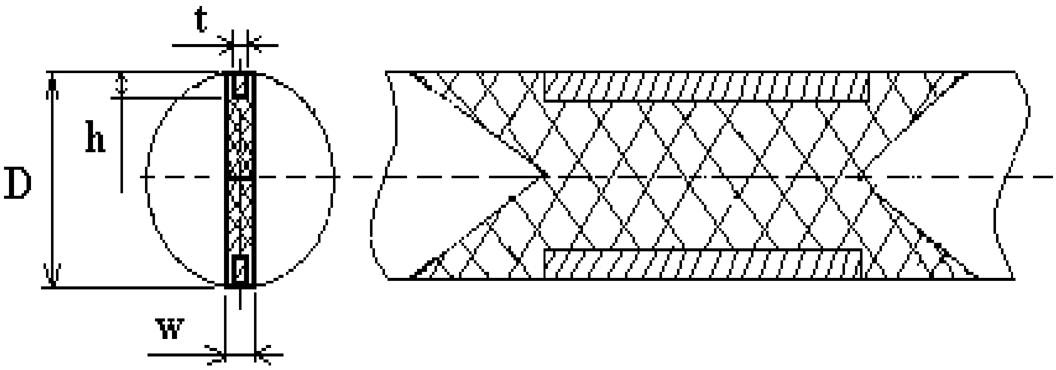

Fig.1c. Polarizer metal-dielectric type.

Taking into account these factors, we will analyze the features of structural-technological implementation of the designs of polarizers shown in Fig. 1 in the frequency band of 20/30 GHz. Preliminary calculation of the main structural dimensions of phase-shifting sections gives the following results:

- based on the operating conditions on the main type of wave for a round waveguide, the inner diameter of the waveguides 11 mm is chosen;
- the optimal ratio between the phase shift created by the narrowed part of the waveguide Fig.1a and the rod structure is defined as

$$(\frac{D-d}{2})/R \times 0{,}095 \qquad (2),$$

where R is the radius of the waveguide, determines the size d equal to approximately 8 mm. Accordingly, the thickness of the narrowing plate should not exceed one millimeter;

- the thickness of the dielectric plate of Fig.1b, is chosen under the condition of performing a ratio $w = \ 2R$ that determines the approach to zero of the coefficients of interconnection between the closest to the main types of waves H_{mn}, E_{mn}. According to the selected waveguide diameter, the thickness of the dielectric plate should not exceed two millimeters;
- the conditions for determining the thickness of the dielectric plate are correct for the design of the polarizer shown in Fig.1c. it is obvious that when $w \leq 2ì\ ì$ the thickness of the metal plate should not exceed one millimeter.

The analysis of the obtained results shows that the application of the designs of polarizers of metal-rod and metal-dielectric types, in a given frequency range, is quite problematic. The latter is due to the fact that technologically, longitudinal metal inhomogeneities must be soldered into the main waveguide, and given the obtained design dimensions, compliance with the required values of tolerances for dimension parallelism, coaxiality, etc., is if impossible, then quite complex technological task.

In this context, the design of a dielectric polarizer looks the most suitable for the application. The main technological problem in the implementation of such a structure is the mechanical fixation of the plate inside the waveguide. In order to minimize active losses, the dielectric plate is made of fluoroplastic. However, the determined thickness of the plate and the physical properties of the material itself do not allow to ensure a reliable mechanical fit of the plate in the waveguide, which determines the need for the technological process of gluing the plate. To ensure the latter, it is necessary to carry out a complex physical and chemical treatment of the fluoroplastic plate, which, given the harmfulness of technological processes, is possible only at a few enterprises in Ukraine. From a radio technical perspective, the disadvantages of the design of dielectric type polarizers include the relative narrowband of the latter, as a consequence of the absence in the design of the polarizer of additional elements to compensate for phase shift dispersion created by the dielectric plate in the operating frequency range.

In order to solve the above technological difficulties and improve the radio technical characteristics, we propose to modify the dielectric polarizer. Conventionally, the proposed design can be classified as a polarizer of dielectric-rod type. A schematic view of the proposed design is shown in Fig.2.

Obviously, from a technological point of view, the proposed design allows for reliable mechanical fixation of the plate in the waveguide and does not require significant technological training in the manufacture. From a radio engineering point of view, the principle of construction of the phase-shifting section in the proposed structure is to combine the phase shift generated by the dielectric plate and a series of rods in the form of adjusting screws.

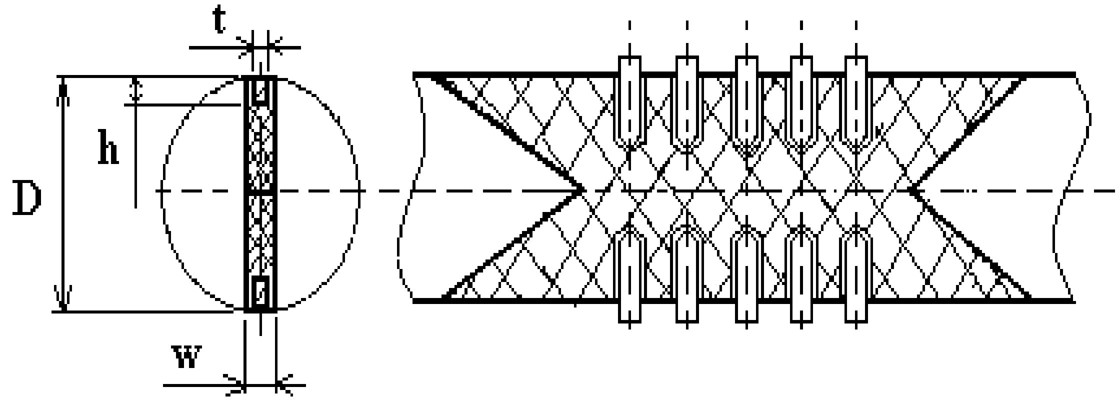

Fig.2. Polarizer dielectric - rod type.

Despite the need for adjustment work and the corresponding increase in complexity, the design solution allows for rapid adjustment of the characteristics of the ellipticity coefficient over the range, as well as to compensate for possible differences in physical and geometric properties of fluoroplastic plates from different batches. Given the presence of adjusting screws, the calculation of the linear size of the dielectric plate, determined by expression (1), must be performed for the value of the phase shift slightly less than that required for this type of polarizer. For example, for a 90-degree polarizer, the value of the phase shift generated by the dielectric plate should be around 80 degrees.

In this case, in the case of partial filling of the waveguide with a dielectric, the phase constants of the respective components of the electric field vector E can be determined as follows.

In this respect, in the case of partial filling of the waveguide with a dielectric, the phase constants of vector E of the electric field can be determined as follows:

$$\beta_0 = \sqrt{(k_{1,2}^2 - \chi^2)} \quad (3)$$

where $\kappa_{1,2} = \frac{2\pi\sqrt{\varepsilon_{1,2}^{ефект.}}}{\lambda_0}$ - wave numbers of the vector E components

$\chi = \frac{2\pi}{\lambda_{хвил.}}$ - critical wave number of the main type wave H_{11}

$\varepsilon_{1,2}^{ефект.}$ - effective equivalent relative dielectric constants parallel and perpendicular to the plane of the plate of the vector E components

λ_0 - working wavelength

The values of relative dielectric constants are based on the method of wave equations [5]. In this case, the system of wave equations for several types of waves $\acute{I}_{m,n}, E_{m,n}$ in the waveguide is solved, taking into account the mutual connection between them, which is a consequence of the presence of a dielectric plate. For relatively thin plates, the system of equations can be solved in the diagonal or zero approximation. Since this condition is met when choosing the thickness of the polarizer plate, the values of the effective dielectric constants of the respective components of the vector E can be determined by the following expressions [3]:

$$\varepsilon_{1,2}^{ефект.} = 1 + (\varepsilon_m - 1)S_\varepsilon / S + [(\varepsilon_m - 1)/\pi] \sin(\pi S_\varepsilon / S) \quad (4)$$

$$\varepsilon_1^{ефект.} = 1 + (\varepsilon_m - 1)S_\varepsilon / S \quad (5),$$

where ε_m - the value of the dielectric constant of the plate material (for fluoroplastic ε_m=2,25)

S_ε / S - the cross-sectional plane of the dielectric plate and the waveguide, respectively

Using the above analytical expressions, the length of the fluoroplastic plate with a thickness of two millimeters, required to obtain a phase shift between the orthogonal components of the vector E, which would be equal to 80 degrees at a frequency of 20 GHz, was determined. Given that the adjusting screws of the rod structure are located in a waveguide structure partially filled with dielectric, the distance between the latter was determined $\lambda_p / 4$

where λ_0 the wavelength for the vector E_{01} components.

The results of experimental studies.

Based on the obtained results, for the practical study of the proposed design, a mock-up of a polarizer based on a round waveguide with an inner diameter of 11 millimeters was made (Fig. 3).

Fig.3. Polarizer prototype.

In the prototype, the rod structure was implemented in the form of five pairs of adjusting screws with a diameter of one millimeter. The final length of the polarizing plate, taking into account the smooth transitions designed to align the plate with the waveguide, was defined as the sum of the lengths of its regular part and one smooth transition multiplied by 0.9. Figure 4a shows the results of measuring the ellipticity coefficient, and Figure 4b shows the results of standing wave ratio measurement, performed by a prototype of the polarizer.

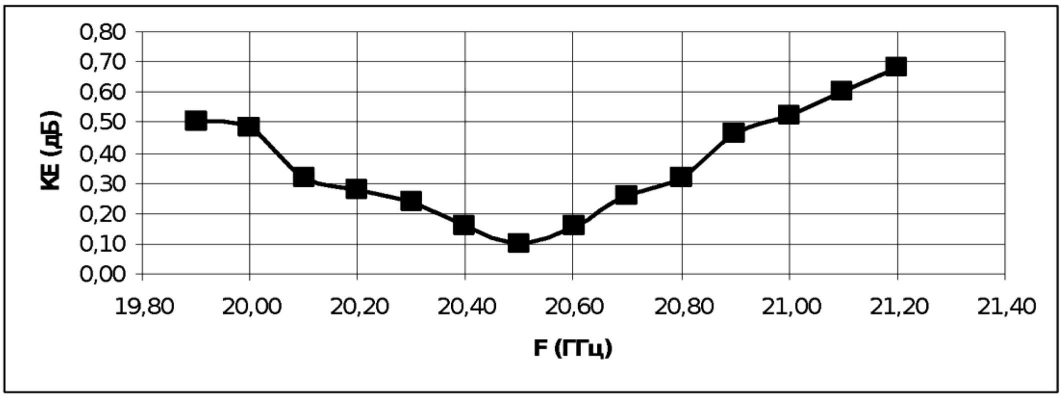

Fig.4a Results the ellipticity of the polarizer measurement

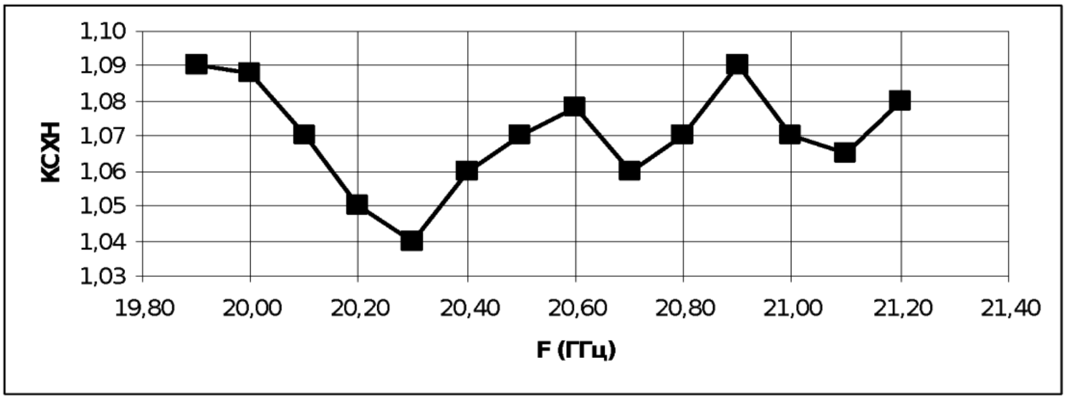

Fig.4b Results of the polarizer standing wave ratio measurement

Conclusions.

The experimentally obtained characteristics confirm the possibility of using the proposed design for the construction of high-tech Ka-band polarizers, and the correctness of analytical expressions to determine the structural dimensions.

Further development of the proposed solution may be the analysis and finding the necessary analytical relationships between the structural dimensions of the rod and dielectric structures in order to expand the operating range of the polarizer.

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