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Construction Features of the Transceiver Antenna-Waveguide Device of K- and Ka-Bands Communication Systems

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Abstract. The paper presents the results of the development of an antenna and waveguide transmission line providing reception and transmission of signals in the extended K- and Ka-bands with an autotracking mode implemented on the excitation of higher types of waves. The indicators efficiency of the feed, parameters of the waveguide device for extracting error signals, frequency duplexer, phase shifting sections, and polarization conversion devices were determined.

Keywords: antenna and waveguide transmission line, radiation pattern, corrugated horn

Loaded lines of communication systems in the Ka-band with reception and transmission channels at 19 GHz and 30 GHz leads to the need to move to higher frequency values when creating promising communication systems, which will increase the amount of information transmitted through the channels of ground stations of satellite communication. To increase the transmission quality the signals of orthogonal circular polarizations are widely used. Application of polarization multiplexing in such systems assumes providing a multiband dish antenna (MDA) of a level of cross-polarization decoupling in working frequency bands not less than –30 dB [1]. To work in the millimeter frequency range an MDA should have high performance indicators to ensure the reception and transmission of signals in different weather conditions [2, 3]. In this case, the choice of the required values of performance indicators should be carried out taking into account the possibility of ensuring increased accuracy of pointing and holding the maximum of the radiation pattern, which with increasing frequency leads to a significant reduction in its width.

Obviously, the solution to the problem of creating a high-efficiency MDA is associated, first of all, with the development of the primary antenna-waveguide device (AWD). In accordance with this, the purpose of this article is to study the frequency characteristics of the components of the AWD for a dual-band satellite communication antenna of the K- and Ka-band.

The purpose of this article is to evaluate the possibility of developing an AWD of the K- and Ka-band with cross-polarization decoupling of at least minus –30 dB and the possibility of building an autotracking mode on a single horn-type radiator.

Tasks to be solved:

1. Analysis of the possibility of creating combined the K- and Ka-band receiving and transmitting AWDs with cross-polarization decoupling characteristics of at least minus –30 dB and the possibility of building an autotracking mode on a single horn-type radiator.
2. Selection of a variant of construction of the developed AWD, radiator efficiency indicators, parameters of a waveguide device for extracting error signals (WD EES), frequency duplexer, phase shifting sections, and polarization transformation devices providing the maximum efficiency of an MDA.
3. Study of the frequency characteristics of the developed receiving and transmitting antenna and waveguide transmission line.

To provide automatic tracking of spacecraft, as a rule, a monopulse method based on the simultaneous use of total and difference radiation patterns formed by the mirror antenna is used [4]. A single multimode corrugated conical horn is mainly used to obtain the sum-difference radiation patterns, in which the main wave type H11 is used to excite sum radiation patterns, and for difference radiation patterns the higher wave types E01, H01, and H21 are employed.

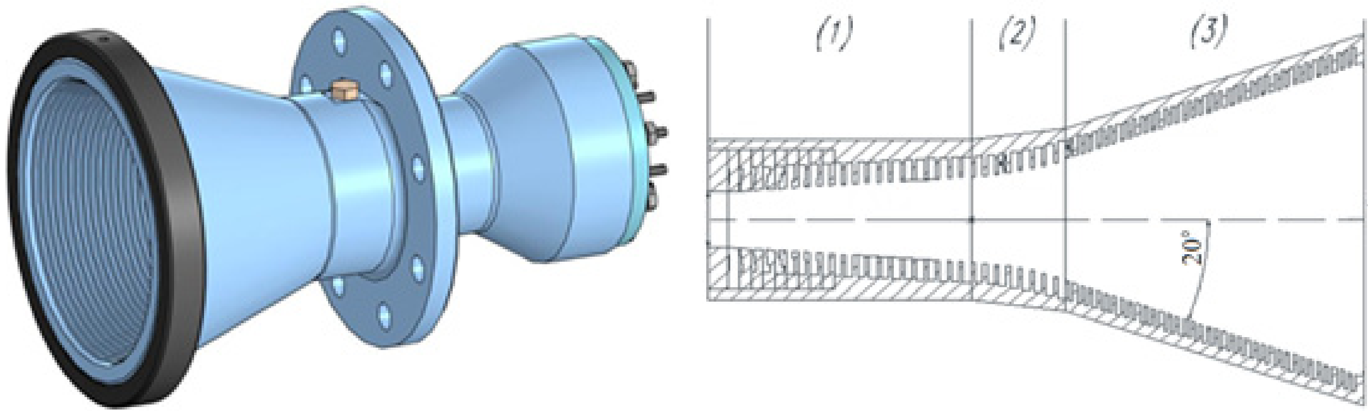
Mirror antennas should contain a combined antenna and waveguide transmission and reception line, which consists of a series-connected broadband corrugated horn, which forms a radiation pattern of sum and difference channels, waveguide device for extraction of the H21 higher type wave based on a mode coupler, and frequency selector of signals of receiving and transmitting channels (frequency duplexer) with circular polarization transformation devices [5, 6].

Known technical solutions do not provide a full range of requirements for mirror antennas of K- and Ka-bands of ground stations of satellite communication including autotracking on a single horn radiator.

To maintain communication with tracked satellites the stations must contain a combined antenna and waveguide transmission and reception line with autotracking mode. The presented AWD contains a series-connected receiving feed with a corrugated internal structure, waveguide device WD EES based on the H21 mode coupler and addition device, frequency splitter and summator, polarization transformation devices (polarizers, polarization selectors, and in the receiving (sum and difference) channels there are band pass filters to prevent the transmitted signals from getting into the receiving channel.

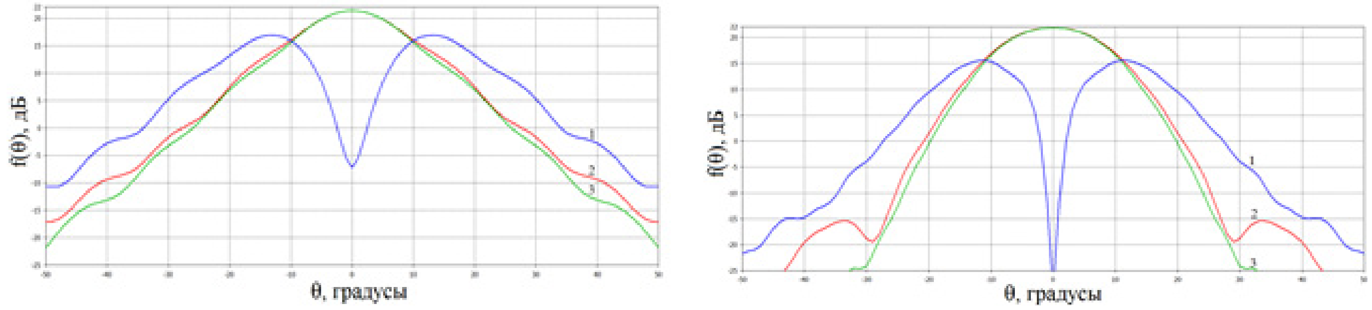
During the creation of the AWD, all included waveguide devices were designed. Optimization of geometric parameters of the internal structure of the devices was carried out based on ensuring high electrical characteristics of MDAs.

Excitation of the main and higher types of waves (H11 and H21), as well as the formation of the corresponding total and differential radiation patterns is achieved by the design of the feed with a waveguide output section diameter of 1.1K{λ0} and a corrugated internal structure of the horn part of the feed [7]. The general view of the feed is shown in Fig. 1a.



a) b)

Fig. 1. The feed a) general view, b) internal structure, where 1 is the mode transducer, 2 is the radial transition, and 3 is the cone section.



a) b)

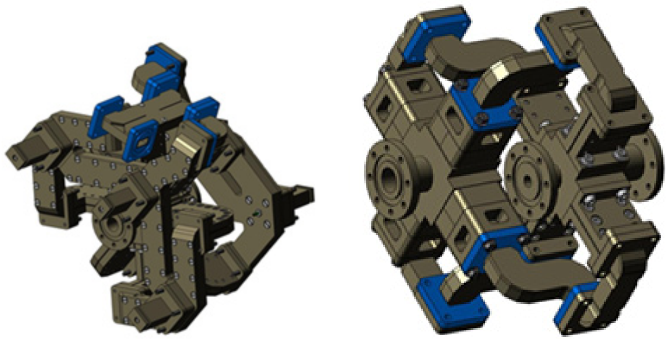
Fig. 2. The radiation pattern (RP) of the feed: a) receiving channel; b) transmitting channel, where 1 is the difference RP, 2 is the total RP in the E-plane, 3 is the total RP in the H-plane

The feed is a conic horn with a ribbed inner surface formed by a periodic structure of circular grooves and functionally consists of a mode transducer of the length 5K{λ0} 1, radial transition of the length 1.6K{λ0} 2, and conical section of the length 4K{λ0} 3 forming its opening and changes with increasing frequency in the range 4K{λ0}–6K{λ0}. The internal structure of the feed is shown in Fig. 4b.

The obtained radiation patterns of the feed at the central frequencies of the operating frequency bands are shown in Fig. 2.

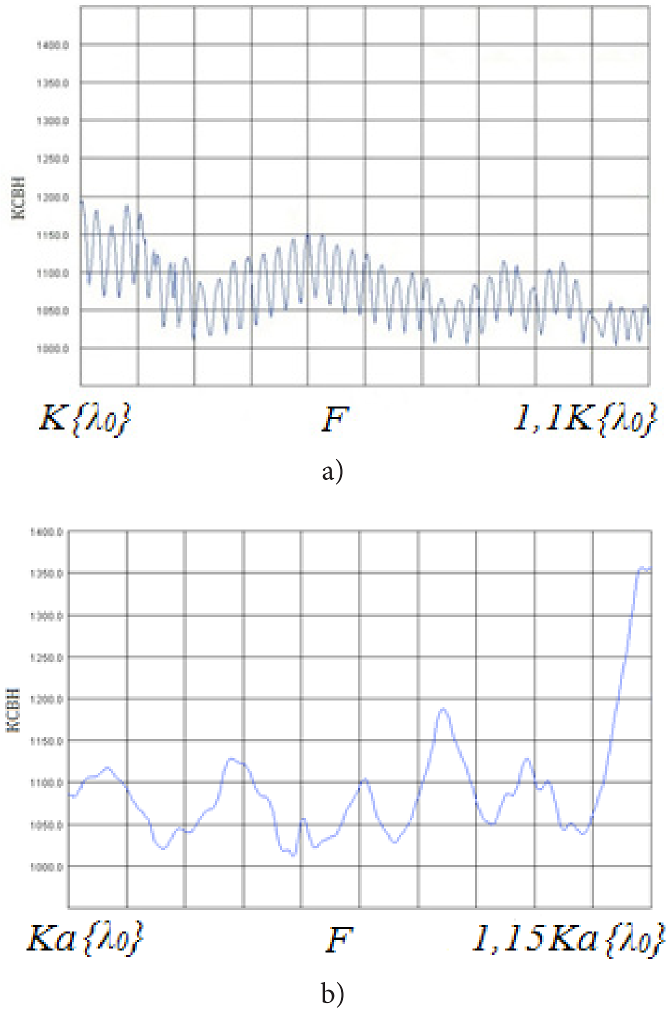
The obtained RPs of the feed provide optimal characteristics of the counterreflector radiation in the K- and Ka-bands with the radiation angle of 18° and in general will allow achieving high energy characteristics of the antenna system. The presence of the difference RP with a pronounced dip (a zero RP) in the direction of the maximum of the total RP will permit providing the automatic tracking mode of the AWD.

To extract the signals of an error and form the difference channel the WD EES is used based on the coupler of the higher mode H21. The coupler of the mode H21 has an increased cross section, which provides the propagation of higher types of waves in a circular waveguide and extraction of the signals of an error on its side outputs. It contains rectangular slots in each coupling line and does not introduce perturbations into the total channel. When receiving and transmitting signals in the circular waveguide of the WD EES the main wave H11, which provides the formation of the difference and the total RP is excited along with the wave of the higher type H21. The coupler of the mode is made based on a circular waveguide cross section of 1.1K{λ0} with eight diametrically arranged slits, which form the waveguide channels. The general view of the developed WD EES is shown in Fig. 3, a.



a) b)

Fig. 3. Общие виды: a) waveguide device to extract a signal of an error signal; b) frequency duplexer.



b)

Fig. 4. Standing wave ratio of the frequency duplexer: a) K-band, b) Ka-band SWR

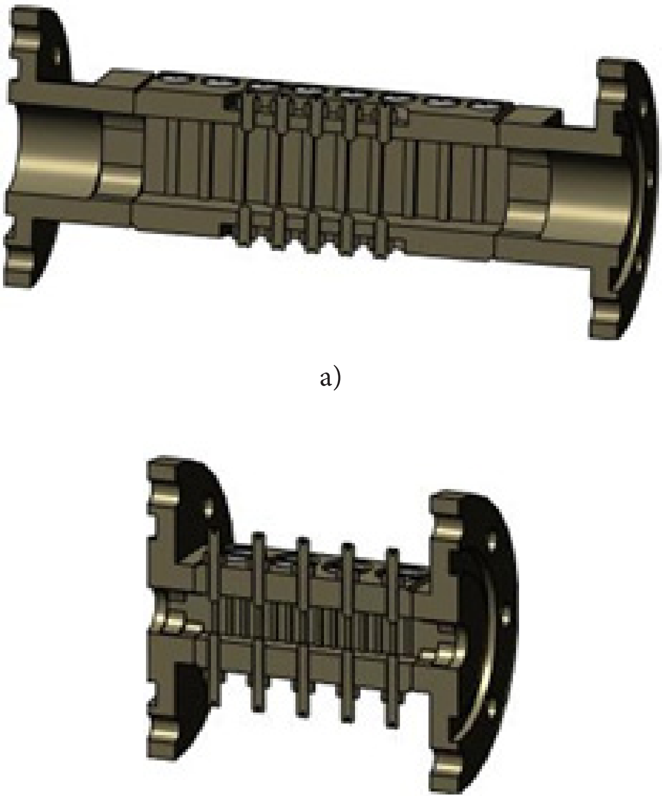
The coupler is made of the series-connected circular waveguide 0.86K{λ0}, conical smooth transition with diametrically located longitudinal slits, and circular waveguide 0.41K{λ0}. The low-pass filters are of a waffle type based on a rectangular waveguide with the cross section of 11 x 5.5 mm. The summator is a conical transition with diametrically arranged longitudinal slits to the circular waveguide 0.73K{λ0}.

The general view of the developed frequency duplexer is shown in Fig. 3, b.

The values of the standing wave ratio in the K- and Ka-band obtained after modeling the internal structure and running the fabricated sample are shown in Fig. 4.

The polarizers of the receiving and transmitting channels are made using 90°-phase-shifting sections consisting of a section of a square waveguide on two opposite walls of which periodic corrugated structures are made, as well as transitions to a cylindrical waveguide with the diameter of 0.73K{λ0} and 0.41K{λ0}, respectively.

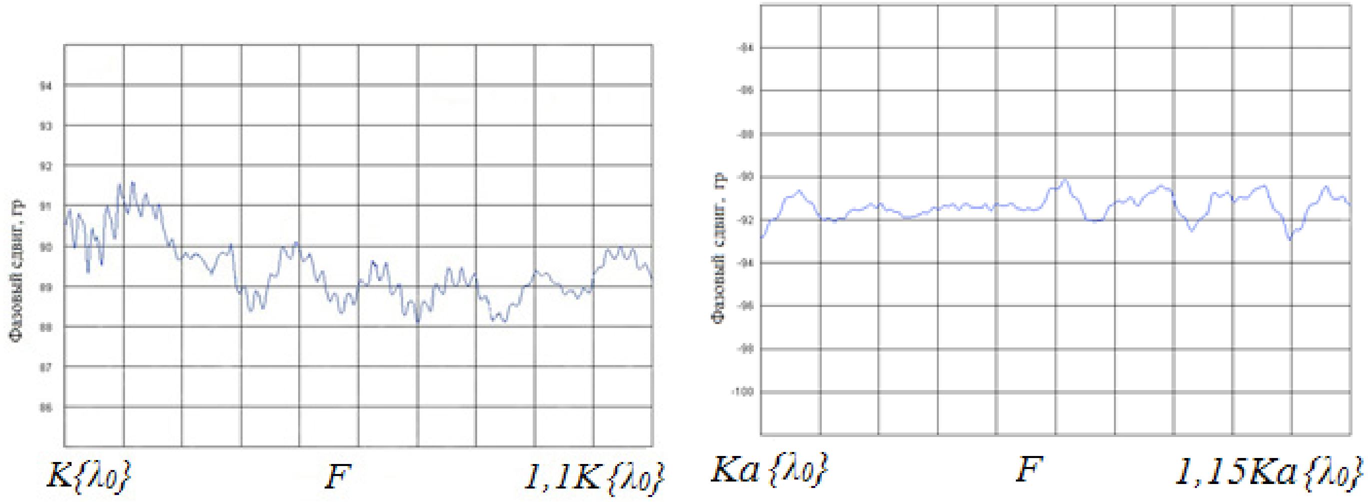
To perform polarization conversion of circular polarization signals, the polarizer sections are installed at 45° to the outputs of orthomode transducers. General types of polarizers are shown in Fig. 5.



б)

Fig. 5. The general view of the receiving (a) and transmitting (b) channel polarizers.

The obtained dependences of the differential phase shift on the frequency of the polarizers of the receiving and transmitting channels are shown in Fig. 6.

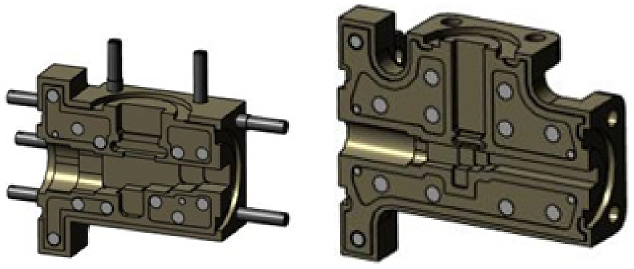


a) b)

Fig. 6. The dependence of differential phase shift of polarizers of receiving (a) and transmitting (b) channels on frequency. Phase shift °

Deviation of differential phase shift of polarizers of receiving and transmitting channels from 90° is not more than 1.8° and 2.9°, respectively. This makes it possible to achieve the required values of cross-polarization decoupling.

Polarization selectors of the receiving and transmitting channels are made in the form of tees consisting structurally of two parts. The inner structure is based on a square waveguide with a cross section of 11 x 11 mm in the receiving channel and 4.3 x 4.3 mm in the transmitting channel, contains a stepped transition to a rectangular waveguide with a standard cross section of 11 x 5.5 mm in the receiving channel and 6.2 x 3.1 mm in the transmitting channel, respectively. General views of the selectors are shown in Fig. 7.



a) b)

Fig. 7. The general view of the transmiting (a) and receiving selectors (b).

Upon completion of the topology and design of the incoming devices, a transmitting and receiving antenna waveguide transmission line was formed providing reception and transmission of signals in the K- and Ka- frequency bands with an autotracking mode for placement in the MDA. Fig. 8 shows a general view of the prototype of the AWD.

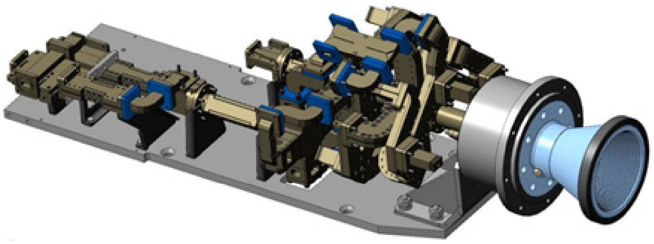


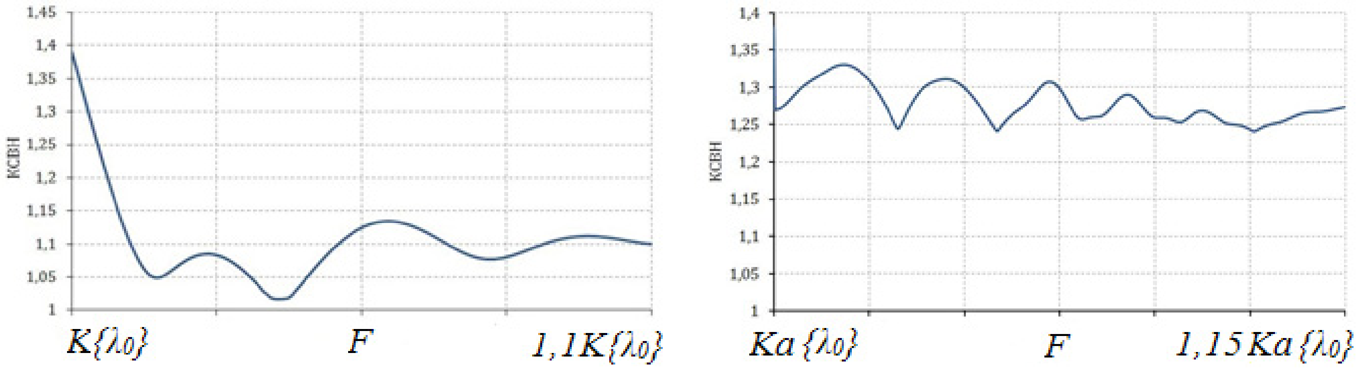
Fig. 8. The general view of the receiving and transmitting antenna waveguide transmission line.

High characteristics of all devices obtained during modeling, as well as technological design according to the results of manufacturing allowed achieving the required values of cross-polarization isolation and VSWR in the mode of reception and transmission of orthogonal signals of circular polarizations in the K- and Ka-band in the outputs of the antenna waveguide transmission line.

Fig. 9 shows the level of matching of the manufactured sample of the AWD on the receiving and transmitting channel. The VSWR does not exceed the value of 1.4.

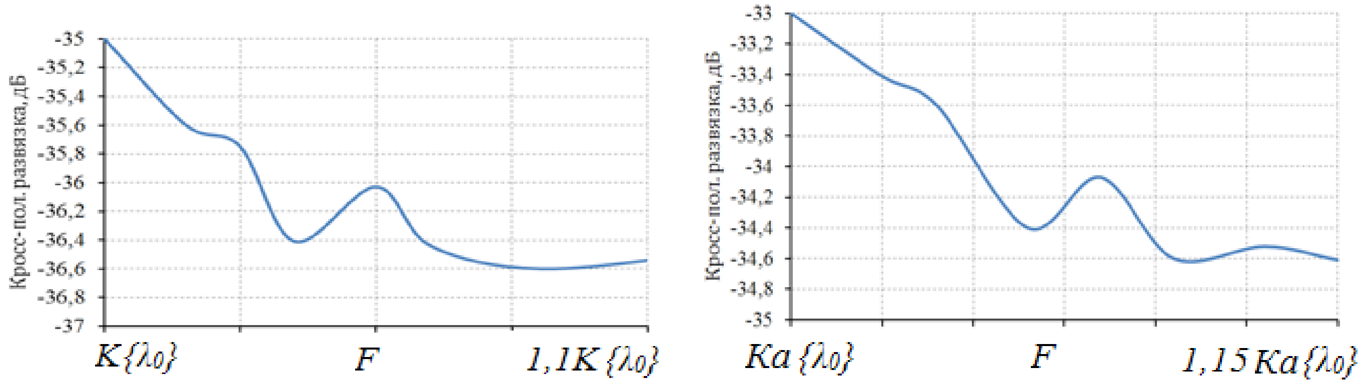
Figure 10 shows the graphs of the dependence of the measured cross-polarization decoupling of the AWD on the receiving and transmitting channels.

The graphs in Fig. 10 show that cross-polarization decoupling in the receiving channel does not exceed –35 dB, and in the transmitting channel: –33 dB.



a) b)

Fig. 9. SWR the antenna and waveguide transmission line: a) by the receiving channel; b) by the transmitting channel VSWR



a) b)

Fig. 10. Cross-polarization decoupling of the antenna and waveguide transmission line: a) on the receiving channel, b) on the transmitting channel cross-polarization decoupling, dB

Hence, the proposed configuration of the antenna and waveguide transmission line of the K- and Ka-bands with a single horn radiator provides reception and transmission of orthogonal circular polarization signals with the possibility of automatic tracking of spacecraft by a monopulse method when working in the receiving and transmitting MDA.

Conclusions

1. The analysis of the possibility of creating combined transmitting-receiving K- and Ka-band AWDs with cross-polarization decoupling characteristics not less than –30 dB and the possibility of building an autotracking mode on a single horn radiator showed the need to use a corrugated horn radiator on a higher section having a complex transducer of different wave types.

2. The choice of the construction option for the developed AWD and its various waveguide devices including the corrugated horn radiator should provide the optimal choice of parameters for a set of given requirements: bandwidth, cross-polarization decoupling, losses in the receiving and transmitting channels, possibility of forming sum-difference radiation patterns.

3. The study of frequency characteristics of the developed receiving and transmitting antenna and waveguide transmission line showed that the chosen variant of construction of the AWD provides reception and transmission of signals of the K- and Ka-bands, cross-polarization decoupling of 35 and 33 dB and provides formation of sum-difference radiation patterns.

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