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Dual-polarization arrays of wide-band printed radiating patches for operation in X and Ku-bands

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Abstract: **Based on the developed dual-polarization module in the form of a four-element array of printed patches, solutions for two antenna systems of X and Ku bands are implemented. The parabolic reflector antenna for Ku-band satellite communication systems with the feeder in the form of the four-element array of printed patches with switchable linear polarization is investigated. The feeder forms axisymmetric radiation with high-quality linear polarization in the wide frequency band. The reflector antenna with the aperture diameter of 1.2 m in the Ku range is characterized by a gain of 39-41 dBi. The antenna array for the X-band radar made on the basis of modules of printed patches four-element arrays with switchable linear polarization is investigated. The antenna array is characterized by scanning sectors of 70° and 65° in orthogonal planes. The presented parabolic antenna and antenna array are intended for use as part of radio-electronic complexes installed on moving objects.**

Keywords: **printed antenna, reflector antenna, phased-array antenna, satellite communication, radar antenna**

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Contents

1. INTRODUCTION

Evolution of antenna complexes for X and Ku-band satellite communication systems and radars is attributed to application of different printed radiating patches featuring multi-polarization mode of operation, wide-band matching, small dimensions, etc. Design and analysis of the wide-band printed patches is covered in many publications [1-6]. Small sizes, ease of manufacturing and ability to effectively control performance of the patches make it possible to use them as a basis for highly capable antenna systems that can fulfill constantly increasing modern requirements. Besides achieving quality power and radiating features, production of antenna systems that utilize printed patches enables to implement additional requirements to aerodynamics, mechanical integrity of the antenna system framework, etc. Therefore, this field is still up-to-date and is of practical importance. We have also presented designs of dual-polarization four-element modules of wide-band printed patches as well as antenna arrays built using them [7-9]. Printed patches are fed through probes. Distinct features of the printed patch modules presented in [8,9] are the shape of the squared patch corners and use of passive metal superstructures of the same complex shape. Also presented below are the following feeding arrangements for the patches: differential feeding of pairs of patches to ensure two linear polarizations and two-phase feeding of patches to produce two circular polarizations [8,9]. Suggested design of the patch module makes it possible to ensure quality polarization within a wide band while maintaining axially symmetrical radiation with relatively steady gain.

Obtained results made it possible to use the developed module for solving a vast number of practical problems. This paper outlines antenna system designs that utilize the module of patches and its modifications that we have developed. Performance calculations have been performed using a dedicated electrodynamic CAD system with built-in Method of Moments and Physical Optics Method.

Section 2 of this paper describes a parabolic reflector antenna for Ku-band satellite communication which uses a four-element array of radiating patches with dual linear polarization as its feeding antenna.

Section 3 presents dual-polarization antenna array of radiating patches for X-band radars for sector scanning in both elevation and azimuth planes.

2. KU-BAND PARABOLIC REFLECTOR ANTENNA

VSAT systems are widely used on land-based and marine moving objects for communication, television broadcasting, etc. Onboard VSAT system complexes often include parabolic reflector antennas. Improvements in this type of antennas are mostly dependent on the development of the feeding system which can enhance certain parameters of the reflector antenna [10-12]. Printed antenna and their arrays featuring small overall and transverse dimensions are considered among others to be used as feeding antennas [13].

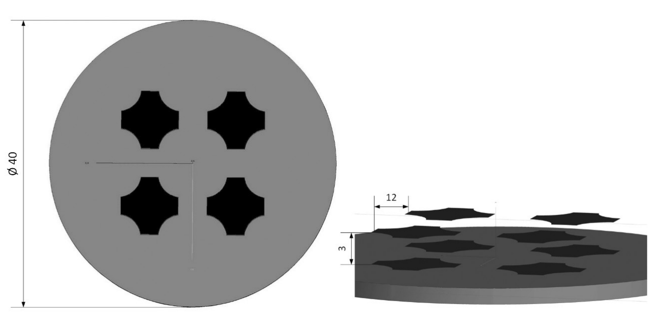
First, we will look at a small-sized squared four-element array of the printed patches [8] as a feeding antenna for VSAT parabolic reflector antenna.

Fig. 1 shows a model of the printed patch array.

Parameters of the substrate dielectric: dielectric constant is 2.4, dielectric dissipation is 0.001, substrate thickness is 1.5 mm.

Each of the patches includes two feeding points, i.e. two ports (**Fig. 2**) which make it possible to produce two linear orthogonal polarizations in the four-element module.

We will then analyze feeding layouts producing different field polarizations of the array as shown in Fig. 2. Linear polarizations



a *b*

Fig. 1. *Model of the feeding antenna: (a) top view and (b) side view.*

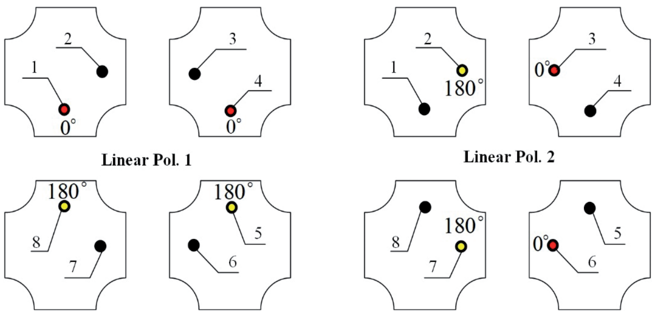


Fig. 2. *Layouts for producing two linear polarizations.*

are produced for port groups with antiphase feeding as follows:

— group 1: ports 1 and 4

— group 2: ports 5 and 8

— group 3: ports 2 and 7

— group 4: ports 3 and 6

Red color in Fig. 2 denotes ports of groups with 0º initial current phase, yellow color — ports of groups with 180º initial current phase.

Such patch feeding layout ensures high symmetry of the radiation pattern and cross-polar radiation of no more than – 48 dB across the entire antenna bandwidth.

To improve matching within a wide frequency band, the feeding antenna has been modified to include passive superstructures placed above the patches at a height of 3 mm (Fig. 1*b*).

Inactive ports of the patches are connected to the matched load.

Therefore, the feeding antenna can be produced in two options: (1) simplified option including one type of linear polarization and (2) options with two switching linear polarizations.

Next we will analyze performance of the printed patch array. **Fig. 3** shows a 3D normalized radiation pattern (RP) of the array at 10.7 GHz frequency for the main radiation polarization.

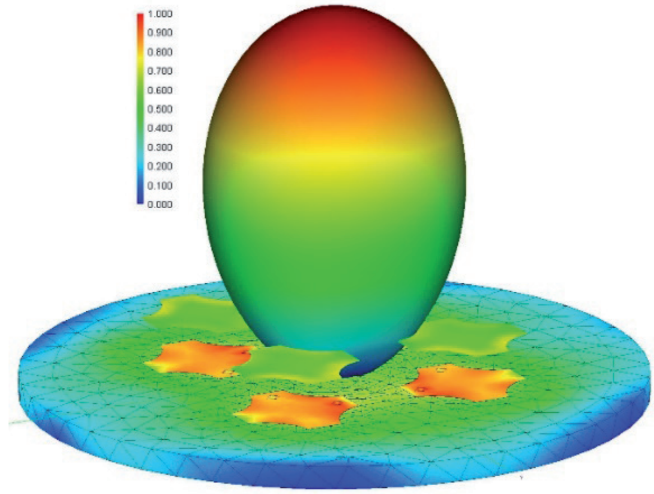


Fig. 3. *3D normalized radiation pattern of the array at 10.7 GHz and main radiation polarization.*

Within 10.7 to 12.7 GHz band, RP of the patch array in E-plane and H-plane features main lobe beamwidth varying from 52° to 60°. Side-lobe radiation level does not exceed –27 dB. Cross-polar radiation is below –48 dB. The gain is within 10.5 to 11.5 dBi. SWR at active ports ranges from 1.2 to 1.45.

Within 13.7 to 14.5 GHz band, RP of the patch array in E-plane and H-plane features main lobe beamwidth of about 44°. Side-lobe radiation level does not exceed –12 dB. Cross-polar radiation is below –48 dB. The gain is around 12 dBi. SWR at active ports ranges from 1.05 to 1.25.

Now we will analyze a model of axially symmetrical parabolic reflector antenna that utilizes a developed printed patch array as a feeding antenna.

Parameters of the parabolic reflector are as follows: 1.2 m diameter and 0.6 m focal distance.

Given pattern characteristics of the feeding antenna, in the reflector aperture there will be produced an amplitude distribution that will decrease from the center towards the edges of the aperture and form a pedestal at the reflector edge

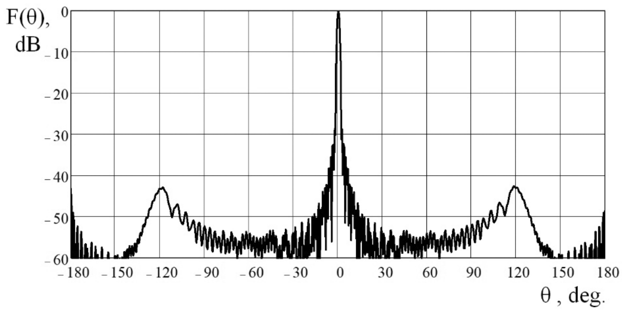


Fig. 4. *RP of the reflector antenna in E-plane at 10.7 GHz frequency.*

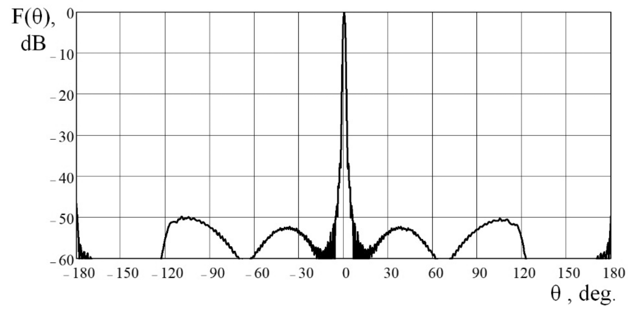


Fig. 5. *RP of the reflector antenna in E-plane at 14.5 GHz frequency.*

of 0.1 to 0.2 of the maximum value in the axial direction (along the focal axis of the reflector).

Now we will analyze performance of the reflector antenna that utilizes the developed four-element array of the printed patches as a feeding antenna in 10.7 to 12.7 GHz band.

Fig. 4 shows a RP of the reflector antenna in E-plane at 10.7 GHz frequency. Since RP of the printed patch array has almost the same width in E and H-planes, thus the RPs of the reflector antenna in the main planes are nearly identical. Within the bandwidth, the beamwidth of the main lobe varies from 1.5° (10.7 GHz) to 1.3° (12.7 GHz). Side-lobe radiation does not exceed –29 dB (10.7 GHz) and –33 dB (12.7 GHz). On-axis ellipticity is –56 dB (10.7 GHz) and –57 dB (12.7 GHz). The gain is about 40 to 41 dBi.

Now we will analyze performance of the reflector antenna in 13.7 to 14.5 GHz band. **Fig. 5** shows RP of the reflector antenna in E-plane at 14.5 GHz frequency.

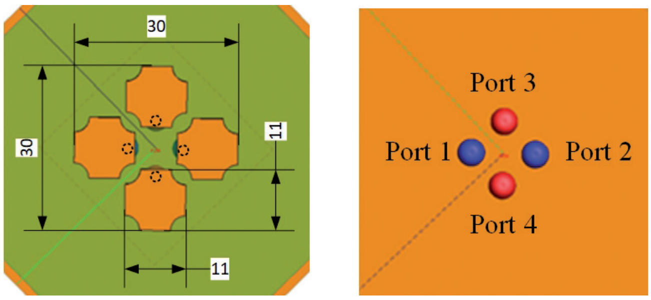
RPs of the reflector antenna in the main planes are nearly identical. Within the bandwidth, the beamwidth of the main lobe varies from 1.3° (13.7 GHz) to 1.2° (14.5 GHz). Side-lobe radiation does not exceed –36 dB (13.7 GHz) and –37 dB (14.5 GHz). On-axis ellipticity is –44 dB (13.7 GHz) and –41.5 dB (14.5 GHz). The gain is 40.5 dBi (13.7 GHz) and 39 dBi (14.5 GHz). Decrease in the gain at 13.7 to 14.5 GHz band is attributed to the decreased ellipticity ratio due to the slight increase in the cross-polar radiation.

3. PHASED-ARRAY ANTENNA FOR X-BAND RADAR

Some civil and military vehicles are equipped with mobile radar systems for scanning the surroundings, parking assistance [14], monitoring, movement detection, object tracking, navigation, etc. Among the variety of mobile radar systems, we will focus on long-range systems [15]. These installations can be divided into two groups: for all-round or sector scanning. In some cases, all-round scanning is achieved by using multi-segment antenna systems, with each of the segments being an antenna subsystem covering a certain sector of a surrounding area [16,17]. Number of such segments can be 3, 4 and more [18].

Long-range radars operate in 8.5 to 10 GHz band (X-band).

Summarized below are the results of development of an X-band phased-array antenna with switching linear polarization and sector scanning in elevation and azimuth planes. Based on the above considerations, we are proposing a model of the printed patch module as shown in **Fig. 6.**



a *b*

Fig. 6. *Model of radiating patch module: top view (a) and detailed view from the bottom.*

There is one feeding port for each patch. For each of the orthogonal linear polarizations in question there is a dedicated pair of patches in the module that are feed through the ports as follows:

— ports 1 and 2 are fed in antiphase — linear polarization 1

— ports 3 and 4 are fed in antiphase — linear polarization 2 being orthogonal to linear polarization 1

Below are the parameters of the substrate dielectric:

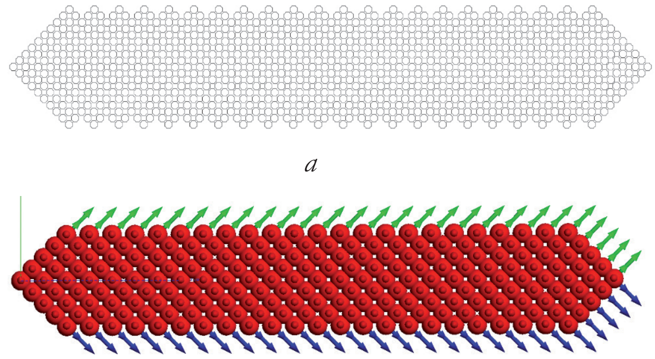
— dielectric constant: 3.3

— dielectric dissipation: 0.0001

— substrate thickness: 1.5 mm

Dimensions of patches (in mm) are shown in Fig. 6*a*.

Selected bandwidth is from 8.5 to 10 GHz. With that, the gain of the module is from 7.5 to 8.5 dBi. Module's radiation exhibits insignificantly changing directional properties, with RP being narrower in E-plane compared to H-plane. Polarization of the radiation field is linear with relative level of the cross-polar radiation not exceeding –30 dB. Impedance of the module at active ports is close to 50 Ohm and matching quality within the bandwidth demonstrates SWR of no greater than 1.35.



a

b

Fig. 7. *Printed patch array (a) and its model in CAD system (b).*

Model of the phased-array antenna (PAA) developed by us is shown in **Fig. 7**. Overall dimensions of the patch array are 970 by 180 mm. Number of modules in the array is 223.

Performance of the PAA in axial radiation mode is analyzed below.

Main lobe beamwidth varies as follows:

— in E-plane (vertical): from 10.4° (10 GHz) to 12.3° (8.5 GHz);

— in H-plane (horizontal): from 1.7° (10 GHz) to 2° (8.5 GHz).

Side-lobe levels vary as follows:

— in E-plane: from –16.3 dB (10 GHz) to –17 dB (8.5 GHz);

— in H-plane: –13.4 dB (8.5 to 10 GHz).

The gain is from 32 to 32.5 dBi. On-axis ellipticity does not exceed –36 dB.

RP of PAA at 9 GHz frequency is shown in **Fig. 8**.

The following results have been obtained from the analysis of PAA's RP at a scanning angle of 35° in the horizontal plane.

Beamwidth of the main lobe in the H-plane varies from 2.5° (8.5 GHz) to 2.1° (10 GHz). Side-lobe radiation in H-plane is from –12.9 dB (8.5 GHz) to –13.4 dB (10 GHz). The gain is about 32 dBi throughout the bandwidth. The gain is about 32 dBi throughout the

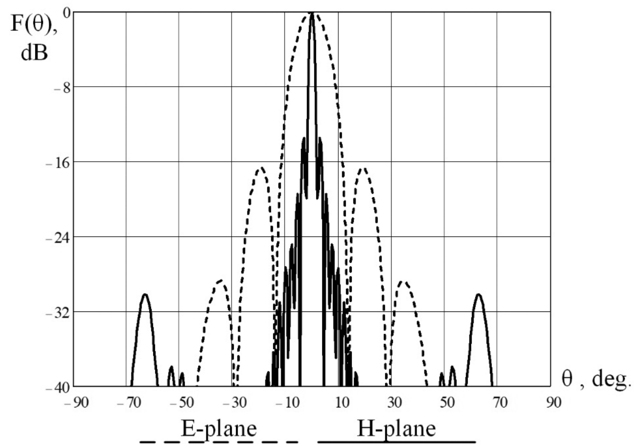


Fig. 8. *Axial RP of PAA at 9 GHz frequency.*

bandwidth. Grating lobe at 10 GHz does not exceed –24 dB. Polarization performance has not degraded.

The following results have been obtained from the analysis of PAA's RP at a scanning angle of 32.5° in the vertical plane.

Beamwidth of the main lobe in the E-plane varies from 13.5° (8.5 GHz) to 15.5° (10 GHz). The gain is about 32 dBi throughout the bandwidth. Side-lobe radiation is from –12 dB to –10 dB. Ellipticity ratio is below –35 dB.

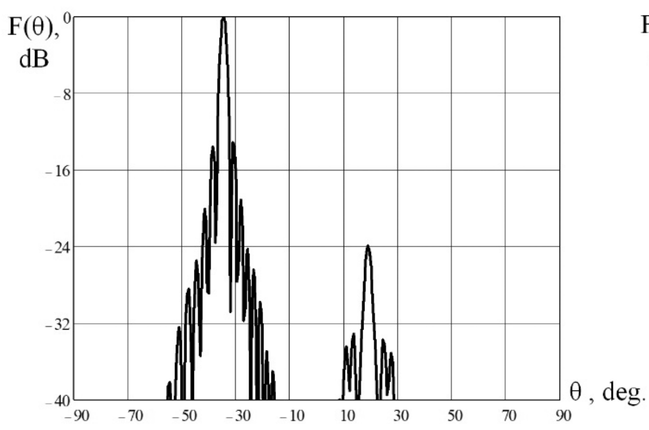
Fig. 9 shows RP of the PAA at 9 GHz at a scanning angle of 35° in the horizontal H-plane and 32.5° in the vertical E-plane.

4. CONCLUSION

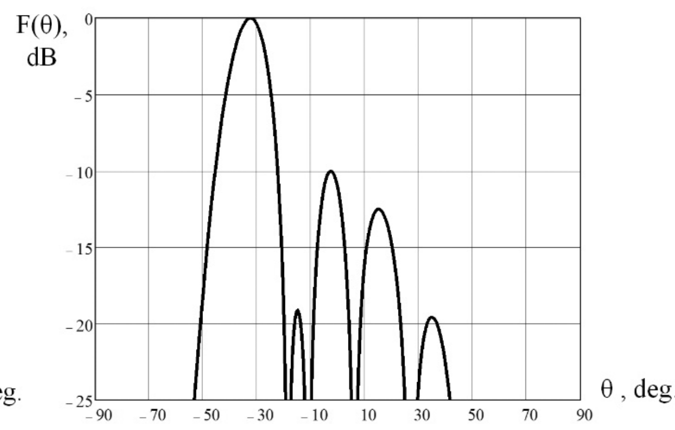
Several options for the design of Ku-band VSAT parabolic reflector antenna and patch panel for the X-band radar's phased-array antenna have been elaborated based on the dual-polarization wideband module of the printed patches [8, 9] as proposed by the authors.

It has been suggested to use a four-element array of the printed patches demonstrating quality input and polarization characteristics in 10.7 to 14.5 bandwidth as a feeding antenna for the parabolic reflector antenna. Small transverse dimensions of such feeding antenna offer little obscuring of the aperture with axially symmetric positioning of the feeding antenna. With that, the parabolic antenna demonstrates relatively high aperture efficiency. Such antenna system can effectively employed in mobile satellite communication systems.

The developed small-sized dual-polarization phased-array antenna comprising of the printed patches ensures scanning within 70° sectors along the major axis of the patch array and 65° along the minor axis of the patch array. Using this PAA it is possible to make a multi-beam antenna system that would ensure multi-beam



a



b

Fig. 9. *RP of the PAA at 9 GHz at a scanning angle of 35° in the horizontal H-plane (a) and 32.5° in the vertical E-plane (b).*

coverage within the required sector in the azimuth plane (e.g. azimuth sector of 180° is fully covered by the three PAA). Such multi-beam antenna system can be used as part of radar systems onboard land-based or marine moving objects.

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