

Wide-angle antenna systems with mechanoelectrical beam steering

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Abstract. This article presents an overview of scanning antenna systems' models, which were developed on basis of the laboratory "Antennas and microwave devices" of Siberian federal university. An antenna array with beam steering by mechanical dielectric lenses rotating and an antenna array with beam steering by mechanical subarrays rotating are introduced. Calculation and measurement results of the antennas are shown.

1. Introduction

Nowadays a continuous operation of satellite communications and data transmission systems for mobile consumers are increasingly important due to a widespread using of satellite communication' systems. In addition, promising satellite communication' systems with medium-orbit spacecraft are being developed, for which scanning antenna systems are also required for stationary consumers [1, 2]. The satellite communication is only way to broadband access to information services in some northern regions of the Russian Federation, therefore, it is so important to research and develop scanning methods to create mobile wide-angle antenna systems that could be used in remote northern regions. Existing scanning satellite antenna systems are inefficient in territories with a large geographical latitude (north regions), because geostationary communication satellites are visible at low elevation angles.

For satellite communication organization in motion traditionally two antenna types are used – mirror antennas with a mechanical beam steering and active phased antenna arrays with an electrical beam steering. These antennas have some significant disadvantages, which don't allow them to operate in regions with a large geographical latitude on mobile objects. The mirror antenna's disadvantages are large sizes and low response speed [3], the active antenna array's disadvantages are limited scanning sector and high cost due to a large number of active elements [4]. So the research antenna systems should form a maximum radiation pattern, that's oriented at small angles to the horizon. Existing scanning antenna systems have a limited sector of a scanning angles up to 40–60 degrees, and the sector increasing without disadvantage of the communication system characteristics and data transmission is impossible. The scanning antenna systems' development is actually not only for civilian consumers, but also for military and special applications.

2. Antenna array with beam steering by dielectric rotating lenses

2.1. Operating principle

An well-known way of beam direction' variation by antenna system (a position of the radiation pattern maximum changes) is a change in an inclination angle of wave' phase front with respect to

antenna aperture as it passes through a dielectric structure, that is provided a linear phase shift (Risley prism). Such the phase front change is ensured by a linear change in the dielectric layer' thickness along the structure (figure 1). More about this is written in a monograph [5], where zoning principle is also described (this principle is widely used in such systems for their thickness' reducing).

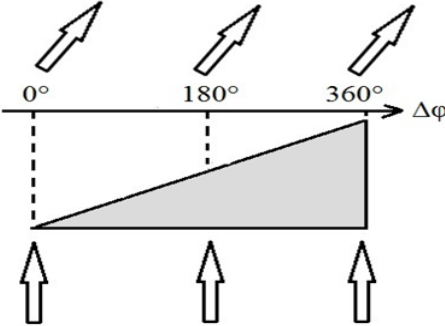


Figure 1. Principle of the beam inclination.

Other structures, that change the phase front, could be realize on basis Risley prism. Perforated dielectric structures were considered early [6] and also structures from dielectric wedges [7], in these structures changeable parameter isn't thickness, but is an effective dielectric constant ϵ , which influence on medium refractive index n .

In this chapter a structure composed of dielectrics with different dielectric constants will be considered. Structures are made in the two identical discs' form, and the beam steering principle, like in early considered structures, is based on the axial rotation of these discs relative to each other (figure 2).

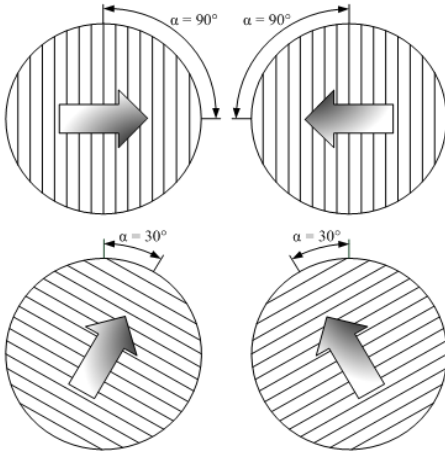


Figure 2. Variants of the inclination structures' mutual arrangement.

For the beam movement in the plane discs must be turned at a same angle in opposite directions.

2.2. Calculation and measurement results

A 3D model of the developed control system is presented in figure 3. The linear phase shift is ensured by the discrete changing the refractive index along the structure. This is achieved by using dielectrics with various ϵ . At table 1 are shown the ϵ and n used in a simulation, and also materials with appropriate properties for a model manufacturing. The thickness of the each dielectric is 6.5 mm. Considering zoning, 8 different discrete elements were used and the total thickness of one disc was 25.6 mm. As a diagram-forming scheme, a simplified model was used, that provides a necessary amplitude-phase distribution.

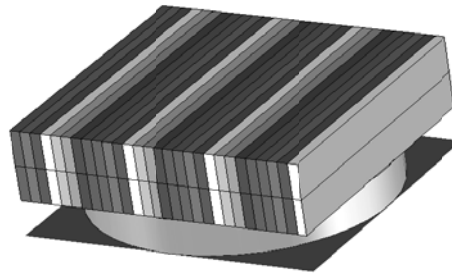


Figure3.Antenna system'3D model.

Table 1.Materials

n	1	1,14	1,27	1,4	1,6	1,7	1,8	2
ε	1	1,3	1,6	2,1	2,4	3	3,4	4
Material	Air	Perforated foamed PVC	Foamed PVC	Perforated polystyrene	Polystyrene	PET	UPPV C 1	UPPV C 2

Calculated radiation patterns for the research structure at the various angular displacement of the discs are shown in figure 4.

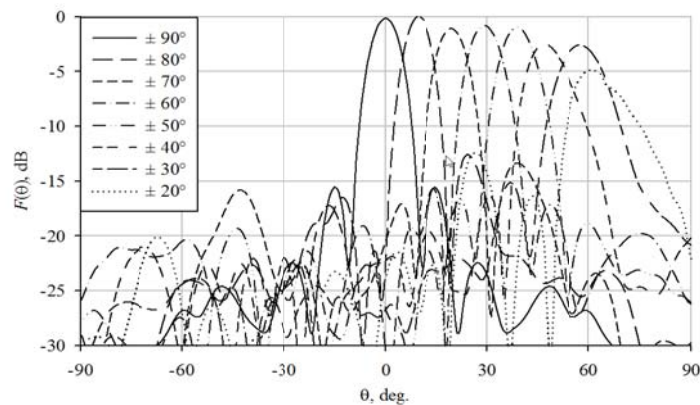


Figure4.Calculation radiation patterns for the various disc displacement at 11.7 GHz.

The maximum inclination' angle of the radiation pattern was 60° (scanning sector is 120°), and directivity' degradation relative the maximum value was no more than 5 dB. Sidelobe level didn't exceed -13 dB level. The scanning system model was manufactured on the calculated model' basis (figure 5).



Figure5.Antenna system' model.

The steering discs' materials were chosen correspond the table 1. A small number of inserts in an air layer between dielectrics with $\varepsilon_2 = 1.3$ and $\varepsilon_8 = 4$ were used to implement n close to one. A conical horn with dielectric lens, which forms the linear phase front, was used as a diagram-forming scheme. This horn in an aperture has a uniform phase distribution and tapered amplitudes. Supporting elements

of the antenna system are manufactured of plywood. The results graphs of measuring the model in an anechoic chamber are presented in figures 6 and 7.

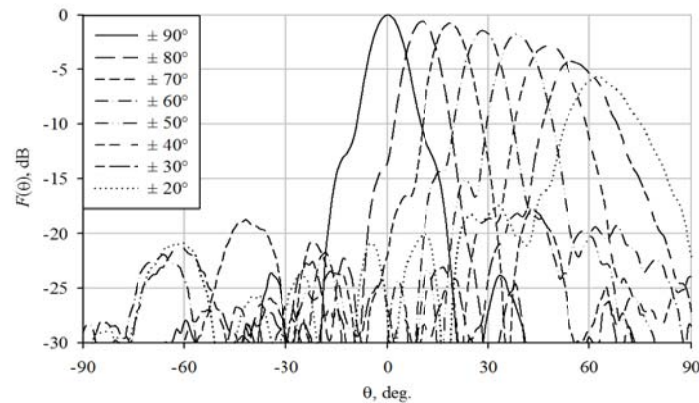


Figure6. Measuring radiation patterns of the antenna system at the 11,7 GHz (in E-plane).

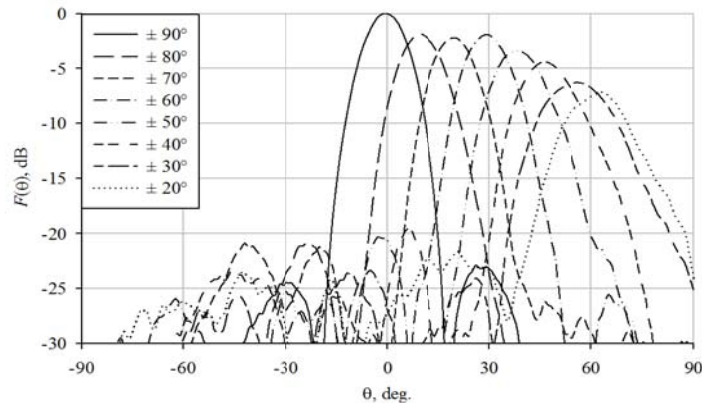


Figure6. Measuring radiation patterns of the antenna system at the 11,7 GHz (in H-plane).

The maximum inclination angle of the radiation pattern was 60°, while the directivity' degradation relative to the maximum value was no more than 6dB. However for the inclination angle was 55° or less, the directivity' degradation didn't exceed 3 dB. Thisidelobeleveldidn't exceedthe -15dBlevel.

3. Antenna array with beam steering by subarrays rotating

3.1. Operating principle

Proposed antenna array with beam steering by subarrays (figure 8) consists of several mechanically rotating subarrays, the signals from which are summed through controlled phase shifters. The developed subarray model for research antenna array consists of 20 elements at the azimuth plane and 1 – at the elevation plane. Subarray' sizes are 260x22mm. The subarray topology was realized by the photolithography method. The substrate was a foamed polystyrene with a dielectric constant close to the air permeability.

Beam steering in the vertical plane is achieved by changing the subarrays rotation angle and addition of a linear phase shift to subarrays. In the horizontal plane beam steering is achieved by rotation of the whole antenna array.

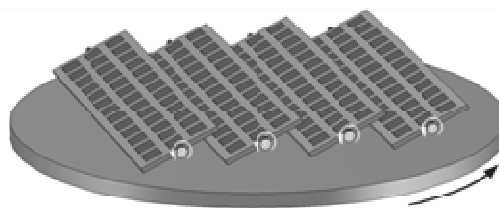


Figure8. Antenna system' 3D model.

3.2. Calculation and measurement results

Manufacturing model of antenna array with beam steering by subarrays rotating consists of eight subarrays. Its sizes are 285x230x5mm. Each subarray mechanically rotated around its axis in an elevation plane. The model' photo of produced antenna array with combined beam steering is presents in figure 9. A microstrip binary power divider provides the linear phase delay introduction along the subarrays with a linear phase shift corresponding to a certain radiation pattern maximum direction of the antenna array.

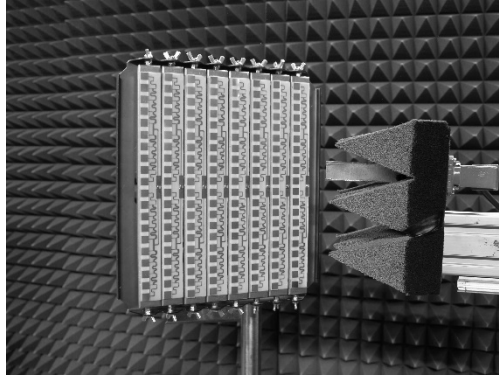


Figure9.Antenna system' model.

Figures 10-11 show measured radiation patterns of the antenna array with beam steering by rotating subarrays at 11 GHz and at 11,5 GHz.

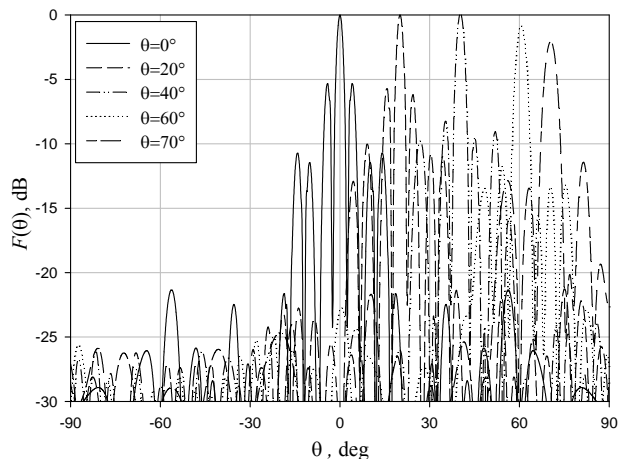


Figure6.Measuringradiationpatterns of the antenna system at the 11 GHz (in E-plane).

The directivity' degradation at the inclination angle at 60° was no more than 2,6 dB in the operating band. Radiation pattern' main lobe expanded at scanning angles more 45° due to antenna' effective aperture decreasing. The high diffraction lobe level at the inclination angle of radiation pattern from 0° to 30° could be explained step subarray more than one wavelength. Operating frequency band of the research antenna decreases because a diffraction lobe level increasing at the radiation pattern' inclination on more than 45° at high frequencies [8].

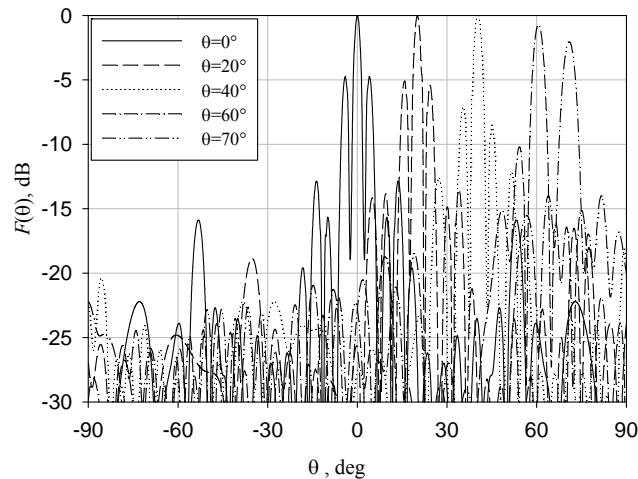


Figure 6. Measuring radiation patterns of the antenna system at the 11,5 GHz (in E-plane). Calculation and measurement results have a match [9], so using this mechano-electrical beam steering, a scanning angle sector is expanded, and also the weight and sizes of antenna system significantly reduce.

4. Conclusion

Research results are shown development' possibility of antenna systems with mechano-electrical beam steering for the satellite communication' organization in a motion in the whole hemisphere. The mechano-electrical scanning methods' research and antennas' realization processes, based on ones, would contribute to improve the connectivity of the Russian Federation territories, and also serve to create additional demand for telecommunication spacecraft. As a result all of this should lead to outer space exploration and using it.

5. References

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