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INVESTIGATION OF DIRECTIONAL PROPERTIES OF CURVED ANTENNA ARRAYS

Annotation. Research results of potential directional properties of a curved antenna array are given in the paper. The antenna elements are arranged along a circle arc and an ellipse arc. The expressions for the equivalent aperture of the antenna array are obtained. The analysis of radiation characteristics for different types and orientations of the antenna elements are carried out. Parameters of antenna patterns at different angles scanning are given. The values of the amplitude to excite the antenna elements on the basis of the genetic algorithm are obtained. Obtained results can be used to implement the MIMO technology.

Keywords: curved antenna array, circle arc, ellipse arc, equivalent aperture, parameters of antenna patternsgenetic algorithm, MIMO technology.

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ИССЛЕДОВАНИЕ НАПРАВЛЕННЫХ СВОЙСТВ КРИВОЛИНЕЙНЫХ АНТЕННЫХ РЕШЕТОК

Аннотация. В статье приведены результаты исследования потенциальных направленных свойств криволинейной антенной решетки. Антенные элементы расположены вдоль дуги окружности и дуги эллипса. Получены выражения для эквивалентной апертуры антенной решетки. Выполнен анализ характеристик излучения для различных типов и ориентации антенных элементов. Приведены параметры диаграмм направленности при различных углах сканирования. Значения амплитуд возбуждения антенных элементов получены на основе генетического алгоритма. Полученные результаты могут быть использованы при реализации MIMO технологии.

Ключевые слова: криволинейная антенная решетка, дуга окружности, дуга эллипса, эквивалентная апертура, параметры диаграмм направленности, генетический алгоритм, MIMO технология.

I. Introduction

The development of mobile telecommunications is determined primarily by needs of market for new services. Modern mobile networks must allow traffic in the projected volumes and better meet the growing consumer demand for high-speed data. However, such services require the high performance of the mobile systems. Effective technology choice plays an important role in achieving this goal. Provide high performance at the current level of science development and technology must approved standards LTE (Long Term Evolution) [1] and LTE Advanced [2]. These standards are fourth generation standards of mobile communication. LTE and LTE Advanced represent the technology on basic OFDM-modulation for supporting of the scalable bandwidth and improved transmission from multiple antennas providing beamforming and spatial multiplexing. One of the main radio technologies used in the LTE and LTE Advanced, is the technology of MIMO (Multiple Input Multiple Output) and its extended version of Multi-user MIMO or MU-MIMO [1,2]. This technology involves the use of multiple antennas or antenna arrays as at the receiving side and at the transmission side, and a diverse set of processing algorithms radiosignals [1,3,4].

The main advantages of MIMO technology are the following factors.

- Reducing fading at a receiver input due to the implementation of different kinds of a diversity;
- Increase of capacity due to spatial separation and combining the channels (space multiplexing);
- Increase the signal-noise ratio at a receiver input due to the signals coherent summation at transmit and/or receive sides of a radio link (beamforming).

All of these advantages of MIMO technology are realized through signal processing algorithms and due to the potential properties of used antenna devices. Today theory and technique of the antenna devices including an antenna arrays are sufficiently developed [5,6]. However, for the antenna devices and their properties by the MIMO technology implementation are given little attention. Probably therefore [7] the optimistic estimates of performance MIMO and mobile system standards LTE и LTE Advanced are obtained.

Potential properties of an antenna arrays defined the spatial arrangement of the antenna elements and their number, the type of the antenna element, and their orientation, the amplitude and phase excitation of the antenna elements. The purpose of this work was to analyze the potential properties of the antenna arrays when antenna elements are arranged on a curved surface and randomly oriented in space.

II. Research of directed properties of curvilinear antenna arrays

A. Geometric description of the curvilinear antenna array and analysis of its equivalent aperture

The curvilinear surfaces along which the antenna elements can be located are chosen the arc of circumference and arc of ellipse [8,9]. The geometrical configuration of the arc antenna array is defined by the following parameters: the curve geometrical parameters along which the antenna elements are located, namely the arch of a circle relative radius R/λ and relative length of a chord D/λ, where λ is the electromagnetic radiation wavelength; quantity of antenna elements N and its relative positioning. The basic geometrical parameters of elliptic antenna array are relative length of a chord or proper axis of the ellipse D_a/λ, D_b/λ, where λ is the electromagnetic radiation wavelength, and eccentricity of the ellipse ex.

The properties of linear antenna array in the case of $D/R \to 0$ and semicircle antenna array in the case of $D/R = 2{,}0$ can be researched on a base of basic approach, changing the relation of circle arc geometric parameters D/R, along which antenna elements are situated [8]. All intermediate values in the case of $0 < D/R < 2{,}0$ would define arc antenna array (Fig. 1).

The new generalized configurations of elliptic antenna array with elements arranged along an arch of ellipse, is based on major and minor axes of ellipse are offered. Such a geometrical configuration of arc antenna array allows to unite also on the basis of the general approaches linear and semicircle antenna arrays, arc antenna arrays with arbitrary values of an eccentricity of an ellipse $0 \le ex < 1$ (Fig. 2).

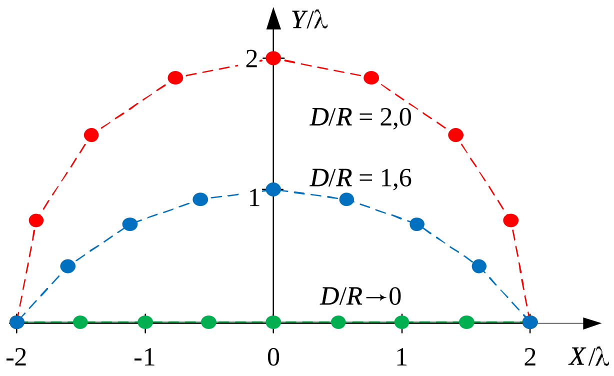

Fig. 1. Geometry of the arc antenna array

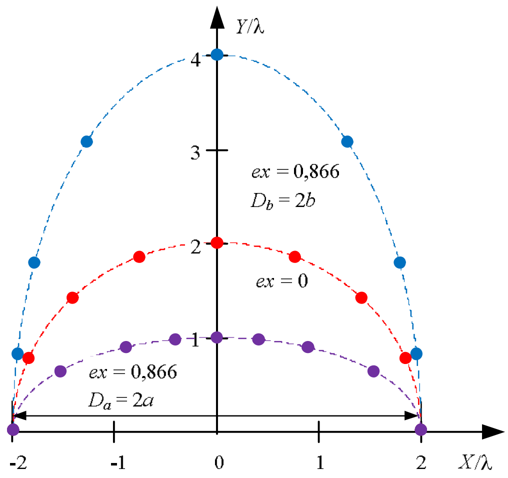

Fig. 2. Geometry of the elliptic antenna array

Mathematical models of arc antenna array equivalent aperture $D_{eq}(\theta)$ at an arrangement of the antenna elements both along a circle arch and an ellipse arch are obtained [9]. These models allow to analyze angular changes of arc antenna array equivalent aperture in the given sector of scanning angles. The dependences $D_{eq}(\theta)$ for cases of arc antenna arrays with arrangement of antenna elements along an arch, based on the major D_a and the minor D_b axes of an ellipse in the case of $ex = 0{,}866$, $ex = 0$ and also for arc antenna arrays with antenna elements arrangement along a circle arch with a ratio of geometrical parameters $D/R = 1{,}6$ at identical overall dimensions are shown in Fig. 3.

According to the dependencies an increase in the equivalent aperture of the curvilinear antenna array compared to the equivalent aperture of the linear antenna array is clearly seen. Based on the criterion of the maximum equivalent aperture in the scanning angles sector θ from 0 to 90 degree possible to allocate the curved antenna array with the antenna elements located along the ellipse arc that is based on the minor axis of the ellipse $D_b = 2b$ (Fig. 3, curve 1). In this case, the eccentricity of the ellipse is chosen to be $ex = 0{,}866$ that corresponds to equality of the transverse $D_b = 2b$ and longitudinal a dimensions of the antenna array. This is accompanied by exceeding of the equivalent aperture D_{eq} above cross overall dimension $D_b = 2b$ of 15,5% in the direction of $\theta = 55$ degrees. Quantitative estimates of D_{eq} show an increase compared with $D_b = 2b$ more than 5% in the scanning angles sector $\theta = 20\ldots84$ degree, more than 10% in the scanning angles sector $\theta = 31\ldots76$ degree, and more than 15% in the scanning angle sector $\theta = 48\ldots61$ degrees.

B. Radiation field of the curvilinear antenna array and analysis of its antenna patterns

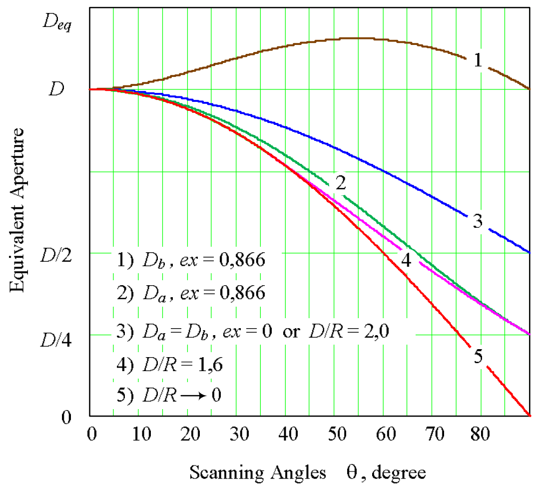

Fig. 3. **Equivalent aperture of the antenna array**

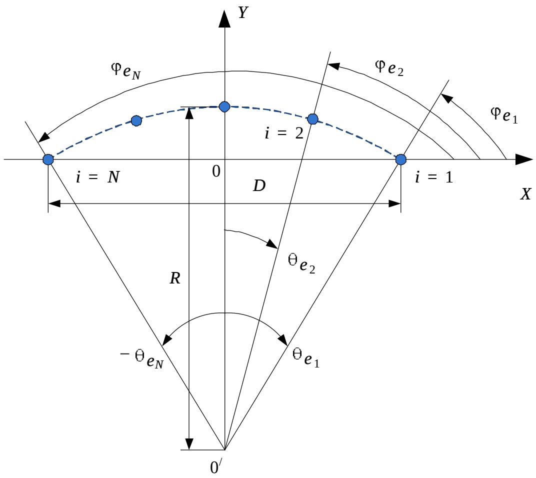

Fig. 4. **Geometry of the curved antenna array**

The mathematical model of the antenna array radiation field, when the antenna elements are situated on a curvilinear surface is obtained [8,9]

$$F(\theta)=\frac{1}{N}\left|\sum_{i=1}^{N}\dot{I}_i\,\dot{f}_{e_i}(\theta)\exp\left(-\mathrm{j}k\,\Delta r_i(\theta)\right)\right|,$$

where $k = 2\pi/\lambda$ is the wave number of the free space;

$$\Delta r_i(\theta)=d_i\sin(\theta-\gamma_i);$$

$$d_i=2R\sin\left[0{,}5\left(\varphi_{e_i}-\varphi_{e_1}\right)\right];$$

$$\gamma_i=\operatorname{asin}\left(\frac{\sin\varphi_{e_i}-\sin\varphi_{e_1}}{2\sin\left[0{,}5\left(\varphi_{e_i}-\varphi_{e_1}\right)\right]}\right);$$

φ_{e_i}, φ_{e_1} are angle coordinates of the antenna elements;

N is the number of the antenna elements;

R, D are the radius of the curved and its overall size, respectively.

The antenna elements have an arbitrary excitement and arbitrary oriented complex antenna pattern f_{ei} (θ). The most characteristic orientations of the antenna elements are collinear and radial. The mutual location of the antenna elements in the space is defined by a geometrical difference of a beam path $\Delta r_i(\theta)$. The amplitude-phase excitement is defined by complex amplitude of corresponding currents $\dot{I}_i$.

In Fig.4 the location of the curved antenna elements is shown by dots. The elements are arranged evenly along the arc. Coordinates of the elements are determined by the formulas:

$$x_i=R\cos\varphi_i;\; y_i=R\left(\sin\varphi_i-\sin\varphi_1\right).$$

Formation of the directional radiation from the antenna array is determined the in-phase excitation of the equivalent aperture. For this phase shift due to the difference in the geometric path of the rays $\Delta r_i(\theta)$ from each antenna element to be compensated.

The radiation characteristics of the curvilinear antenna array were calculated using the obtained mathematical model. Radiation pattern of the curved antenna array in plane: at θ_{max}= 0° ; at θ_{max}= ±30° ; at θ_{max}= ±60° (N = 9, D = 0,16R) and collinear and radial orientations of the antenna elements , will look as it is shown in Fig.5.

The dependences of the radiation pattern parameters on the scanning angle for different orientations of the antenna elements were obtained. The most typical results of the change the beamwidth on the scanning angle are shown in Fig.6. The most typical results of the change the level of side lobes on the scanning angle are shown in Fig.7.

The analysis of the radiation characteristics of the curvilinear antenna array revealed a high level of side lobes. To minimize this level it is necessary to choose corresponding amplitude excitation of the antenna elements. The choise was done on the basis of the genetic algorithm.

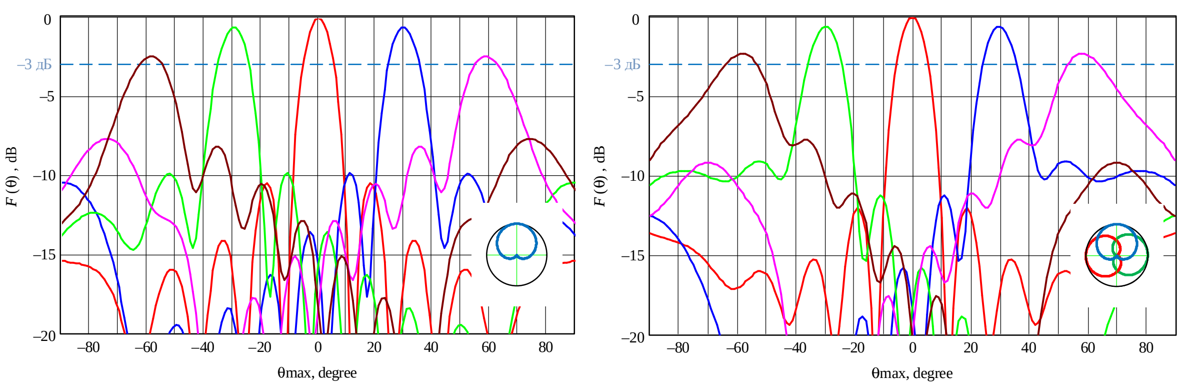

Fig. 5. **Radiation pattern of the curvilinear antenna array**

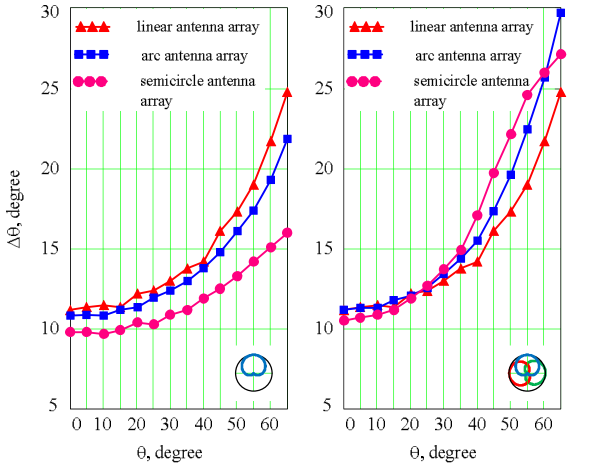

Fig. 6. Dependences of changing the beamwidth on the scanning angle

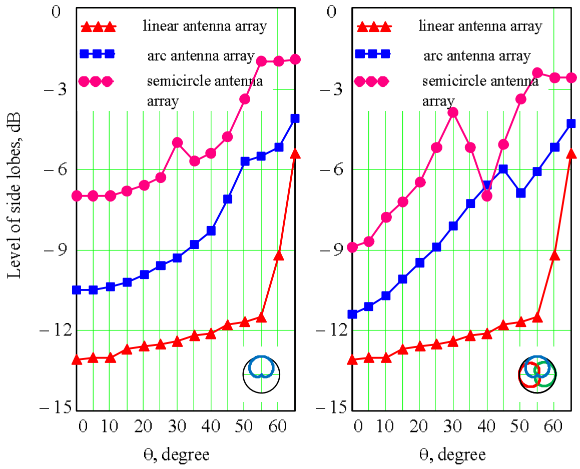

Fig. 7. Dependences of changing the level of side lobes on the scanning angle

III. Conclusion

Thus, on basis of the researches can state the following.

- New generalized configurations of the antenna arrays with the location of the antenna elements along the circular arc were investigated. This geometric configuration of the curvilinear antenna array based on common approaches allows to analyze the linear and semicircle antenna arrays, the arc antenna arrays with arbitrary geometrical parameters of the circular arc.
- New generalized configurations of the curvilinear antenna array with the location of the antenna elements along the ellipse arc that is based on the major and minor axis of the ellipse were investigated. This geometric configuration of the curvilinear antenna array also based on common approaches allows to analyze the linear and semicircle arrays, elliptical antenna arrays with arbitrary values of the ellipse eccentricity $0 \le ex < 1$.
- The new mathematical models of the equivalent aperture of the curvilinear antenna array with the location of the antenna elements as along the circle arc and along the ellipse arc were obtained. These models allow us to analyze the equivalent aperture in the scanning angles sector θ.
- The qualitative and quantitative analysis of the angular variation of the equivalent aperture of the curvilinear antenna array were made. The efficiency of the antenna array with the location of the antenna elements along the ellipse arc with positions more the equivalent aperture in the scanning angles sector θ from 0 to 90 degree.
- Analysis of antenna patterns based on the generalized mathematical model of the radiation field of the curvilinear antenna array was carried out. The angular dependences of the antenna patterns parameters were obtained.
- The basic advantages and disadvantages of the curvilinear antenna array were revealed. It is shown that the side-lobe level increases while maintaining the shape of antenna patterns in the scanning angle sector. Reduce the side-lobe level is possible due to the orientation of the antenna elements. Also reduce the side-lobe level is possible due to the optimal amplitude excitation of the antenna elements.
- The method of the optimum amplitude excitation of the antenna elements based on genetic algorithm was developed.
- The results can be used to estimate throughput for MIMO technology implementing.

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