Research of antenna arrays with non-equidistant emitters

Eduard Zhdanov[1*], *Andrey* Slavyansky[2], *Olga* Kharina[1], and *Alexander* Shpak[3]

[1]Moscow Financial and Industrial University "Synergy", Moscow, Russia
[2]Central Scientific Research Institute named after Academician A. I. Berg, Moscow, Russia
[3]MIREA - Russian Technological University, Moscow, Russia

Abstract. The results of studies of antenna arrays with non-equidistant emitters are presented. The characteristics of the formation of radiation patterns, the appearance of side diffraction maxima and the functionality of the antenna system as a whole were studied from the point of view of non-equidistant arrays. A statistical analysis of phase characteristics was carried out when the load resistance changed in accordance with the obtained distribution laws.

1 Introduction

Currently, the close attention of the world's largest concerns is aimed at developing the direction of creating multi-band antenna systems, including navigation and telemetry systems. One of the key issues in the development of antenna arrays is the study of the formation characteristics of radiation patterns, including for antenna arrays with non-equidistant emitters [1]. In this case, an important aspect is the choice of not only technological solutions, but also current approaches to modeling and obtaining the necessary radio characteristics of antenna arrays.

The purpose of the paper is to identify the basic principles of the functioning of antenna arrays for creating high-speed radio communication channels and providing an inertia-free overview of space as a dynamic space-time filter for aircraft.

The subject of the study is an antenna array containing a web of emitters, a set of transmitting modules, a power distribution device, a control device, made in the form of a complete sealed unit.

2 Methods and results

The design of an antenna array begins with the development of an antenna element that meets the requirements of a low-profile design, implemented using printed emitters [2]. Resonant emitters used to obtain circular polarization form a radiating aperture, which is a flat printed circuit board (Fig. 1).

* Corresponding author: zhdanov@ufanet.ru

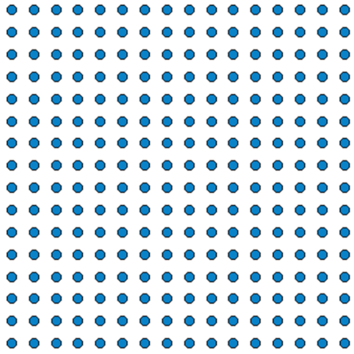


Fig. 1. Antenna array model (16×16).

Each emitter provides transmission of signals of one of the types of circular polarization. It is characterized by such parameters as the width of the radiation pattern, scanning sector, insertion loss [3]. The configuration of the emitters presented makes it possible to obtain a radiation pattern (Fig. 2-3) and a gain map (Fig. 4).

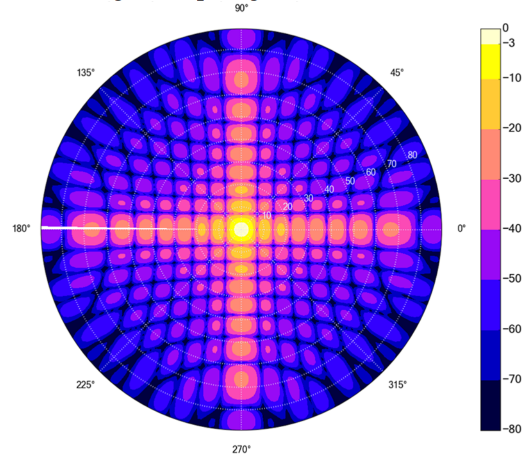


Fig. 2. Directional pattern for the antenna array (16×16).

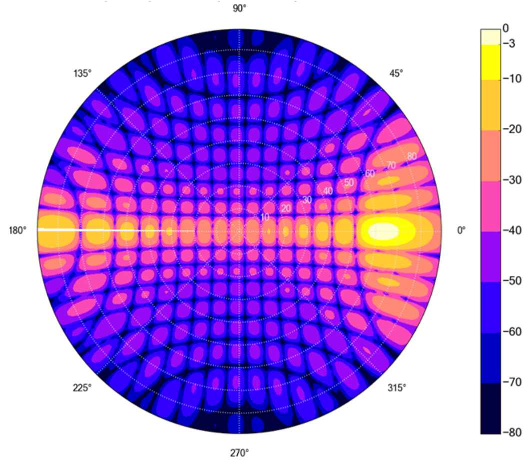


Fig. 3. Directional pattern for an antenna array (16×16) with a beam deflection of 50°.

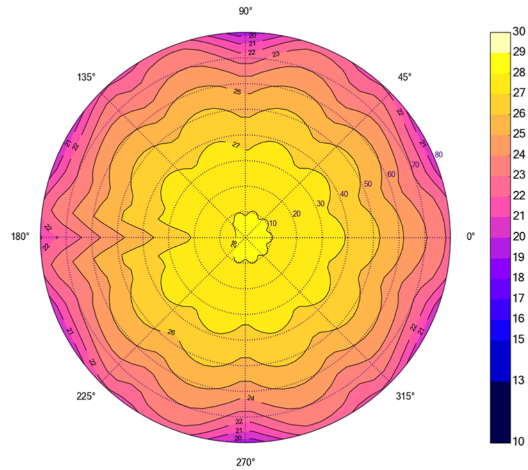


Fig. 4. Antenna array gain map (16×16).

The results obtained confirm the absence of diffraction maxima in the grating when the beam deviates from the normal to values of 50 degrees.

Let us consider the formation of the radiation pattern, the appearance of side diffraction maxima and the functionality of the antenna system as a whole from the point of view of non-equidistant arrays. Irregular placement of weakly directional emitters in the nodes of a flat opening of a rectangular grid is carried out using a random procedure. *M* emitters are placed at random into the lattice opening, which has *NxN* nodes, and the emitter hitting each node has an equal probability $M/N^2 < 1$.

When $N^2 \gg M$, the average background level of additional lateral radiation is approximately $1/M$ and does not depend on the size of the aperture. Side maxima do not arise, since in any scanning plane the equivalent linear radiating system is a non-equidistant antenna array containing all *M* emitters. A detailed probabilistic analysis [4] shows that in an ensemble of flat irregular random arrays with the same number of elements *M*, the vast majority of implementations of radiation patterns are close to average - antennas with very bad or very good radiation patterns are very rare. When choosing the permissible number of *M* elements, the requirement of the absence of side lobes exceeding the level of -13 dB came to the fore.

The surface utilization factor of a flat irregular array is determined by the ratio of its directional coefficient to the one of a flat in-phase aperture of the same area with a uniform amplitude distribution, which is determined by the equation:

$$D_0 = \frac{4\pi S}{\lambda^2} = \frac{4\pi N^2 (0{,}5\lambda^2)}{\lambda^2} = \pi N^2$$

The directional action coefficient of a sparse array is equal to the product of the directional action coefficient of one emitter and the number of elements, considering the assumption that the interconnection of elements with a rare arrangement has practically no effect on the radiated power:

$$D = M D_{el}$$

The coefficient of use of the surface of a sparse grating provided that the coefficient of directional action of a weakly directional printed emitter $D_{el} \approx 3$ is determined by the equation:

$$\mathrm{K}_{IP} \approx \frac{M}{N^2}$$

When $M \ll N^2$ regular arrays have a low surface use coefficient, despite the fact that the shape of the main lobe of the radiation pattern exactly matches the shape of the main lobe of the continuous aperture. The reduction in surface use factor is confirmed by power dissipation into an almost uniform background of lateral radiation. Thus, arrays with high rarefaction form the main lobe of the radiation pattern with a high level of side lobes (SLL) and are of little use for the assigned tasks [5].

The configuration of the emitters with a decrease in the number of emitters by 20% (Fig. 5) makes it possible to obtain a radiation pattern (Fig. 6-7) and a gain map for non-equidistant arrays (Fig. 8).

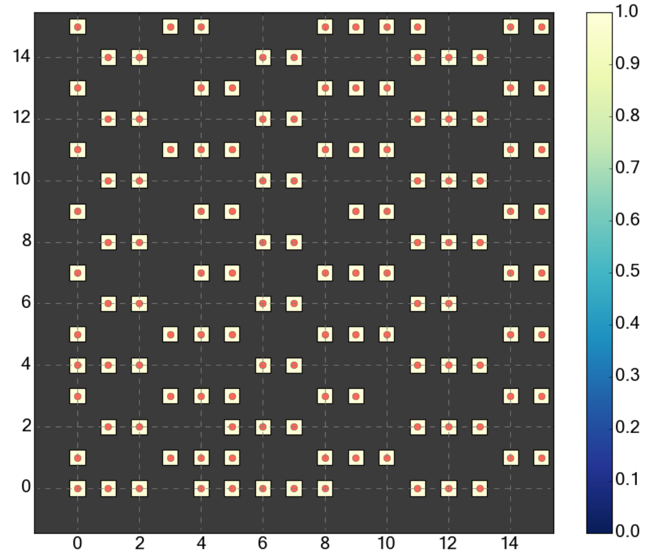


Fig. 5. Location of emitters in the aperture.

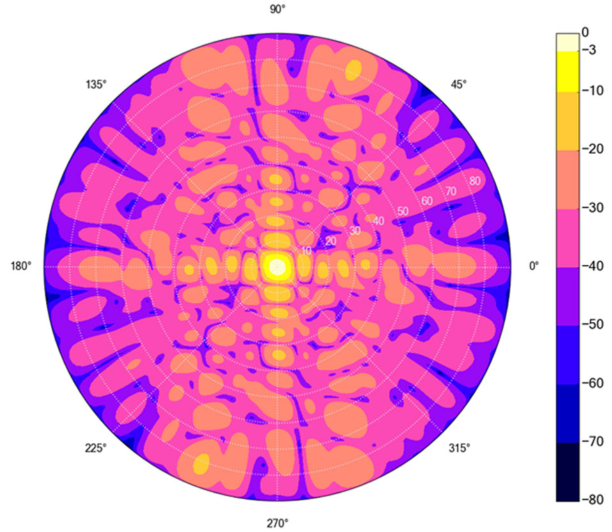


Fig. 6. Radiation pattern for an antenna array with a non-equidistant grid.

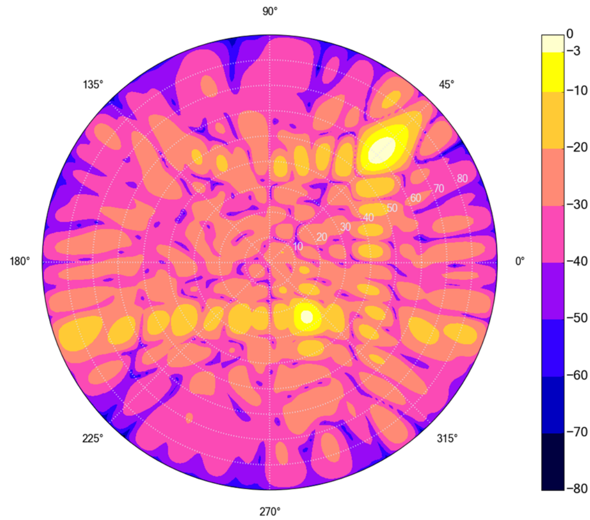


Fig. 7. Radiation pattern for an antenna array with a non-equidistant grid when the beam is deflected.

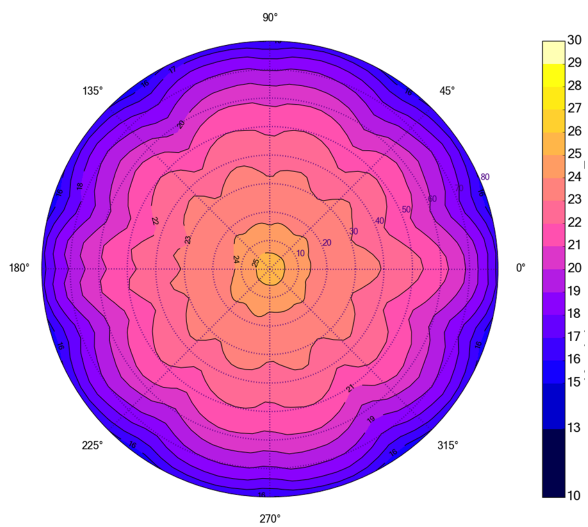


Fig. 8. Gain map of an antenna array with a non-equidistant grid.

An equidistant grid of transmitting channels does not lead to a significant expansion of the main lobe of the radiation pattern and an increase in the level of side lobes. In this case, the limits of beam swing are maintained without the appearance of higher-order diffraction maxima.

The configuration of the emitters with a reduction in the number of emitters by 60% (Fig. 9) makes it possible to obtain a radiation pattern (Fig. 10-11) and a gain map for non-equidistant arrays (Fig. 12).

The resulting radiation pattern at small beam deflection angles has diffraction maxima, that is, an antenna with a small number of emitters is unsuitable for use in the system under study.

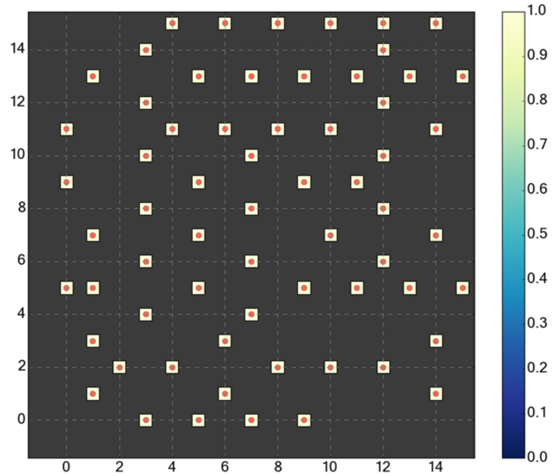


Fig. 9. Location of emitters in the aperture.

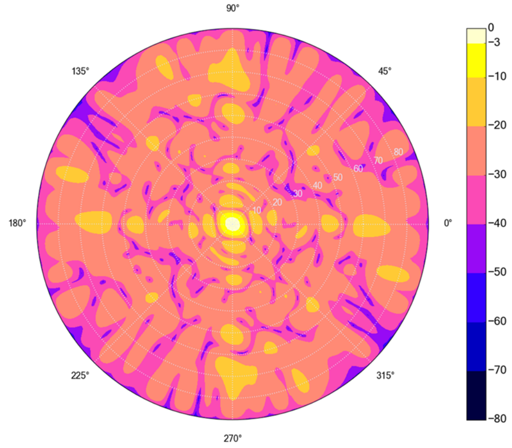


Fig. 10. Radiation pattern for an antenna array with a non-equidistant grid.

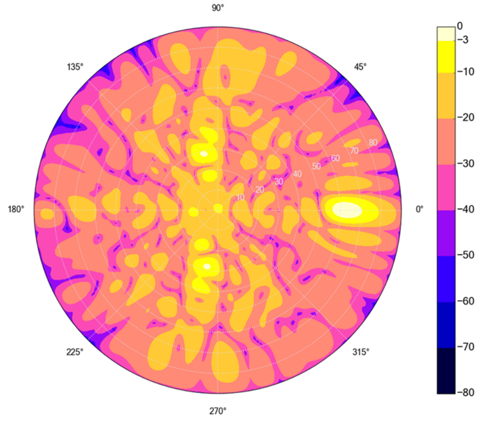


Fig. 11. Radiation pattern for an antenna array with a non-equidistant grid when the beam is deflected.

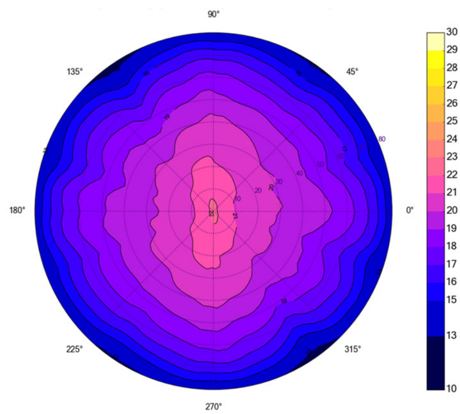
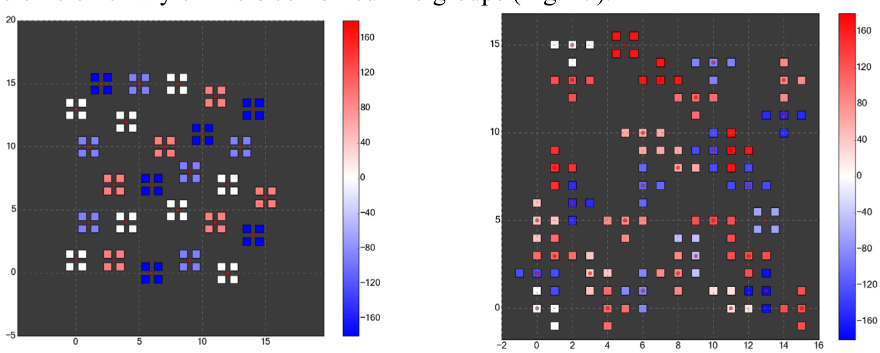


Fig. 12. Gain map of an antenna array with a non-equidistant grid.

Let us consider the possibility of creating an antenna array consisting of large-aperture emitters - elementary emitters combined into groups (Fig. 13).



a) b)

Fig. 13. Location of emitters in the aperture.

This configuration of large-aperture emitters makes it possible to obtain radiation patterns (Fig. 14-15).

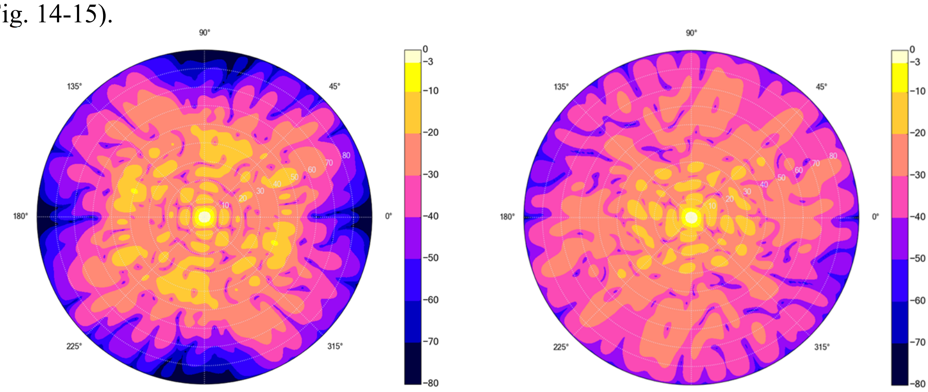


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Fig. 14. Radiation pattern for an antenna array with a non-equidistant grid.

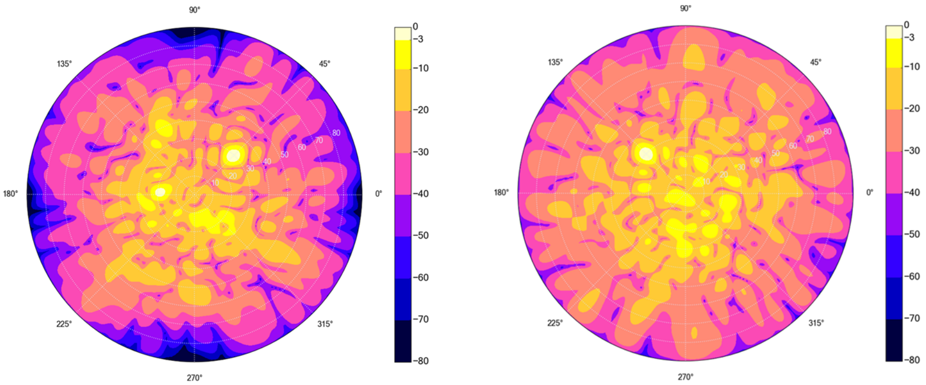

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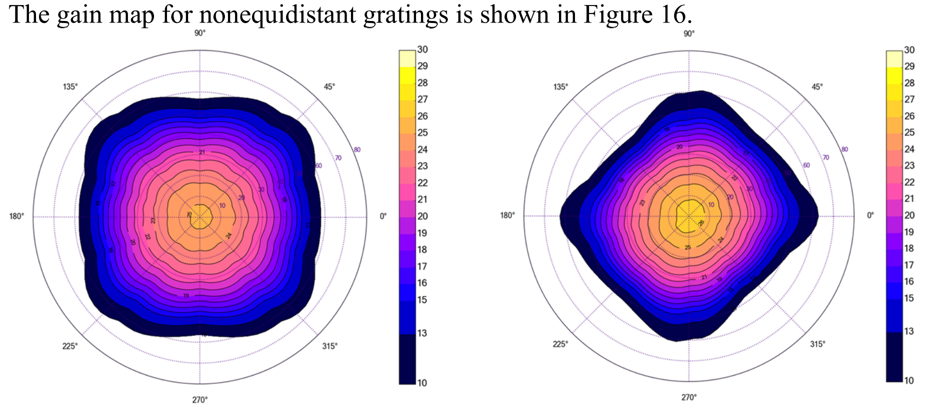
Fig. 15. Radiation pattern for an antenna array with a non-equidistant grid when the beam is deflected.

The gain map for nonequidistant gratings is shown in Figure 16.



a) b)

Fig. 16. Gain map of an antenna array with a non-equidistant grid.

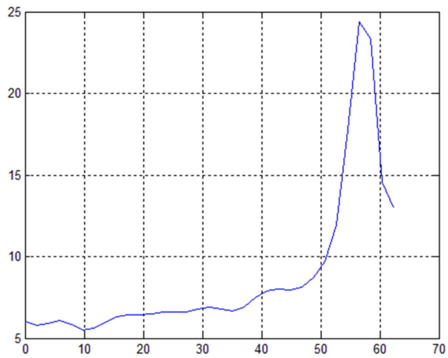
Thus, the creation of an antenna array consisting of large-aperture emitters - elementary emitters combined into groups shows that with a non-equidistant arrangement of elements, the periodicity of the array multiplier (relative to the generalized angular coordinate) is eliminated, due to which the main diffraction maxima of higher orders are reduced in magnitude.

3 Discussion

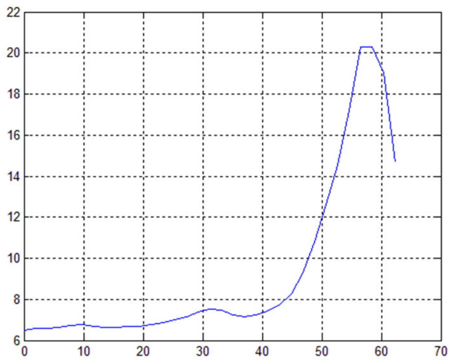
Any electrical oscillation obtained using methods known to modern science contains components of phase (or frequency) modulation of a random nature. Noise occurs in various elements of devices - resistors, capacitors, diodes and transistors. In different operating modes of the elements, the corresponding noise levels may change.

Shot effect noise has a Gaussian amplitude distribution because it is caused by a very large number of independent components. The result of the appearance of alternating voltage on the conductors, caused by the random thermal movement of free electrons in the volume of the conductor, is thermal noise. Low-frequency (1/f) noise is the third commonly encountered type with a Gaussian amplitude distribution, also known as excess or flicker noise [6]. Noise of this type is associated with contact and surface inhomogeneities in semiconductors and is caused by fluctuations in the conductivity of the medium through which current flows.

Assessing the effect of scanning on the phase error made it possible to determine the dispersion of the real and imaginary parts of the input resistance of the emitters at different scanning angles (Fig. 17).



a)



b)

Fig. 17. Dependences of a) real and b) imaginary components of the input resistance of emitters depending on the scanning angle.

Phase errors in the opening of antenna arrays are caused by the influence of transmitting modules. There is a constant component of the phase error caused by the non-identity of the phase characteristics of the microcircuits in the transmitting path. Their correction can be carried out by setting correction coefficients on the phase shifters.

The dispersion of the phase error of the transmitting channel depends on factors such as changes in the active and reactive components of the load resistance of the amplifiers, the temperature and amplitude dependence of the phase characteristics.

4 Conclusion

The paper presents studies of antenna arrays with different distributions of emitters. It is shown that within the framework of a random distribution of emitters on the array plane, as well as taking into account possible destabilizing environmental factors, the shape of radiation patterns, the level of side lobes and other parameters of the antenna array obey a random distribution law and are determined by errors in the influence of transmitting modules, including the terminal parts of paths and do not exceed 10-11º. The effect of such phase errors on the radiation patterns of a 16x16 array is determined mainly only on the far side lobes.

References

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