Space-Phase-Frequency Control of Signals in Means of Generating Electromagnetic Radiation

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Abstract
The influence of these instabilities on the peak power level, duration and repetition period of a multifrequency spatio-temporal signal is considered, and we estimate the maximum values of the errors of the parameters of the laws of spatial-phase-frequency control of signals. The requirements for the accuracy of the location of the phase centers of the emitters in a cylindrical phased antenna array with pyramidal horns have been substantiated; it is advisable to calculate the radiation field using single-stage and multi-stage V-shaped frequency distribution laws in the presence of the indicated errors. The analysis of the location of the phase centers of individual radiation sources of a cylindrical phased antenna array has been carried out; they practically do not affect the duration and repetition period of a multifrequency spatio-temporal signal.
Keywords:
radio electronic means, electromagnetic radiation, ultrashort pulse duration, space-phase-frequency.

1. Introduction

Today, to ensure the operation of the means of generating electromagnetic radiation, it is necessary to use multi-element phased antenna arrays. Fluctuations in the parameters of signals and antennas arising from various random factors limit the potential of the means for generating electromagnetic radiation and can lead to significant changes in the generated multifrequency spatio-temporal signal, a decrease in their peak power [1-6]. Therefore, the purpose of the article is to analyze the influence of various random and deterministic changes in the electrical and design parameters of a cylindrical phased antenna array, control systems for emitted signals and the laws of spatial-phase-frequency control of the formation of an electromagnetic pulse.

2. Theoretical Consideration

Basic assumptions when carrying out a statistical analysis of the characteristics of a multifrequency spatio-temporal signal emitted by a cylindrical phased antenna array of a means for generating electromagnetic radiation. The parameters of the spatial-phase-frequency control law should be stable for a time equal to the average duration of pulses at the output of the emitters when a single multifrequency spatio-temporal signal is formed, and during the formation of a sequence - during the duration of this burst of a spatio-temporal signal, i.e. during $\tau_{p\Sigma}$. This imposes certain requirements on the accuracy and stability of the parameters of the law of spatial-phase-frequency control of signals. Therefore, it becomes necessary to study the influence of various kinds of deviations from the given values of the parameters of the law of space-phase-frequency control of the emitted signals in the channels of a cylindrical phased antenna array when forming sequences of multifrequency space-time signals. In addition, it is also necessary to investigate the influence of errors in setting a given discreteness of the initial phase and frequency on the characteristics of the generated signals.

The influence of typical errors arising during the operation of traditional antennas and elements of the antenna-feeder path on the characteristics of the radiation field has been well studied and considered in the known literature and can be taken into account when creating a means for generating electromagnetic radiation. Therefore, the paper considers only the features of the requirements for the accuracy of the location of the phase centers of the emitters and the requirements for the discreteness and accuracy of setting the initial phases and carrier frequencies along the aperture of a cylindrical phased antenna array, which are specific for

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spatial-phase-frequency focusing based on the proposed equally discrete V-shaped frequency distributions.
Statistical parameters of the laws of spatial-phase-frequency control of the formation of a multifrequency spatio-temporal signal (the form of the law of distribution of errors, dispersion and error correlation radii) are the initial values when studying the statistics of the radiation field. However, due to the large number of elements in the transmitting channels, types and sources of instabilities, it is rather difficult to determine the form of the distribution law of the signal parameters errors in each channel of the phased antenna array.

Taking into account the constructive independence of the transmitting channels and neglecting their mutual influence, we will further assume that the errors in setting the signal parameters in the channels of the cylindrical phased antenna array are uncorrelated and equally probable. It can be shown that in this case the error in the choice of the law will not exceed ±20% values of the total error (if the considered error is dominant).

In the future, we will consider the influence of these instabilities on the peak power level, duration and repetition period of a multifrequency spatio-temporal signal and estimate the maximum values of the errors of the parameters of the laws of spatial-phase-frequency control of signals, at which the specified characteristics of a focused multifrequency spatio-temporal signal change by no more than 10% [13-17].

3. Estimation of the error in the location of the phase centers of the emitters in the cylindrical phased antenna array

The quality of the formation of a multifrequency spatio-temporal signal depends on the degree of provision of the specified coordinates of the phase centers of the radiation sources. However, when creating specific samples, errors in ensuring the selected coordinates are possible and the laws of change in instantaneous phases will not correspond to the given requirement of signal formation at a given point in space. $P_\phi(x_\phi, y_\phi, z_\phi)$.
To substantiate the requirements for the accuracy of the location of the phase centers of emitters in a cylindrical phased antenna array with pyramidal horns, it is advisable to calculate the radiation field using single-stage and multi-stage V-shaped frequency distribution laws in the presence of the indicated errors[7-12]

The influence of errors in the location of the phase centers of individual radiation sources with an equiprobable law of their distribution on the mathematical expectation of the normalized electric field strength of a cylindrical phased array antenna can be obtained as:

$$\langle E(P_\phi,t)\rangle = \Bigg\langle \frac{1}{E_{max}} \sum_{m=-\frac{M_x-1}{2}}^{\frac{M_x-1}{2}} \sum_{n=-\frac{N_y-1}{2}}^{\frac{N_y-1}{2}} \frac{A_{mn}F_{mn}\left(n_\phi,\Theta_\phi\right)}{R_{mn}} \sqrt{60P_{mn}G_{max\ mn}} ? . \times \exp\left(-j\left[2\pi f_{0mn}\left[t-\frac{R_{mn}^{ош}}{c}\right]+n_{0mn}\right]\right)\Bigg\rangle, \quad (1)$$

where E_{max} – the maximum value of the electric field strength emitted by the cylindrical phased antenna array.
The distance to the observation point from each radiating element, taking into account the errors in the location of the phase centers, is:

$$R_{mn}^{ош} = \sqrt{(x_\phi - x_{mn}^{ош})^2 + (y_\phi - y_{mn}^{ош})^2 + (z_\phi - z_{mn}^{ош})^2}\ , \quad (2)$$

where $x_{mn}^{ош} = x_{mn} + \frac{\Delta\rho}{\sqrt{2}}\Psi_1$, $y_{mn}^{ош} = y_{mn} + \frac{\Delta\rho}{\sqrt{2}}\Psi_2$, $z_{mn}^{ош} = \Delta h \Psi_3$ – values of coordinates of phase centers of radiation sources of a cylindrical phased antenna array, taking into account errors;
$\Delta\rho$ and Δh – maximum values of errors in the location of phase centers of radiation sources;
Ψ_1, Ψ_2, Ψ_3 - random numbers uniformly distributed in the interval [-1,1].

The calculation of the electric field strength, taking into account errors, will be carried out for the case: the number of "working" elements $N = M_X \times N_Y = 88 \times 20 = 1760$; maximum aperture size L =1 м; cylinder radius 1.25 m; lattice spacing along the guide $d_x = 1{,}0\lambda$, along the generatrix $d_z = 0{,}8\lambda$; uniform amplitude distribution A(x,y) = 1.
Taking into account the selected wavelength range, the frequency discreteness between adjacent radiators is chosen $\Delta F_y = 2\,GHz/10 = 200MHz$, $\Delta F_x = 2\,Ghz/44 = 45\,MHz$ and, accordingly, the maximum carrier frequency spacing over the phased array aperture is $F_{xmax} = F_{ymax} = 2\,GHz$. This makes it possible to form a sequence of a multifrequency spatio-temporal signal with a duration $\tau_s = 3$ ns with a repetition period $T_p = 250$ ns.

Figure 1 shows the dependences of the mathematical expectation of the normalized value of the electric field strength cylindrical phased array antenna from errors $\Delta\rho$ and Δh, calculated in accordance with (1) using a single-stage V-shaped frequency distribution over the aperture for R = 5 km.

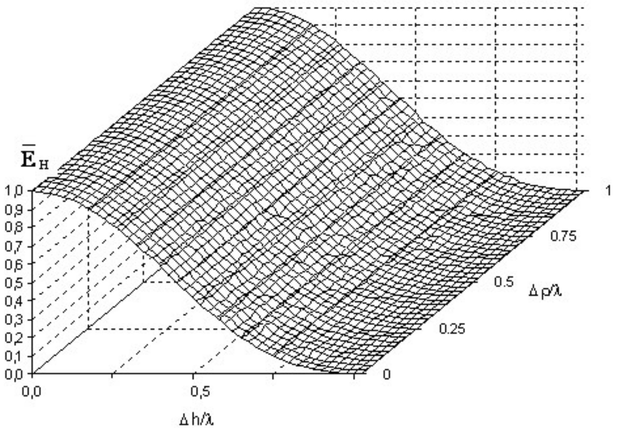

Figure 1: Dependence of the mathematical expectation of the normalized electric field strength on errors Δρ and Δh

Figure 2 shows similar dependencies $\overline{E}_н$ cylindrical phased antenna array along the normal to the generatrix depending on the distance without taking into account the errors in the location of the radiators ($\Delta\rho=0$; $\Delta h=0$),and also taking into account the maximum values of errors both in the plane of the generator at $\Delta\rho=\lambda$, and in the plane of the guide at $\Delta h=\lambda/6$ for R=5 km.

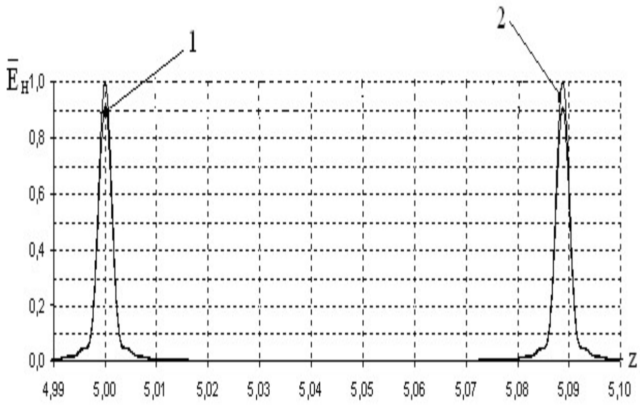

Figure 2: Impact of errors Δρ and Δh on the distribution of the electric field of the phased array antenna by range (1 – Δρ=0; Δh =λ/6)

As can be seen from Figures 1 and 2, the effect of errors in the location of the emitters in the plane of the generatrix in the far zone becomes insignificant. The influence of errors in the location of the phase centers of the emitters in the plane of the guide does not depend on the distance to the focusing point. The calculation results also showed that the influence of errors in the location of the emitters in the plane of the generatrix on the level of the electric field of the multifrequency spatio-temporal signal affects only in the Fresnel zone. Range of valid values Δh , in which decreasing the value E_H does not exceed 10%, is determined from the condition:

$$\Delta h \le \lambda/6 . \quad (3)$$

Figure 3 shows the dependencies $\overline{E}_н = \langle E(x,y,z,t)/E_{max} \rangle$ in the direction of the normal to the aperture of the cylindrical phased antenna array without taking into account errors in the location of the radiators ($\Delta\rho=0$; $\Delta h=0$),and also taking into account the maximum values of errors in the plane of the generator, equal to $\Delta\rho=\lambda$, and in the plane of the guide equal to , when using a multistage V-shaped law of frequency distribution over the aperture with the parameter ν = 4 (Q = 12) for z = 5 km.

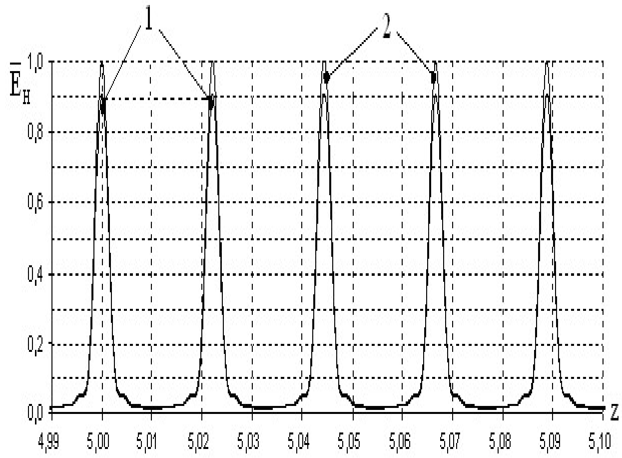

Figure 3: Impact of errors Δρ and Δh on the distribution of the electric field strength of a cylindrical phased antenna array along the range at ν = 4 (Q = 12)

As can be seen from Figure 3, the influence of errors in the location of the phase centers of the emitters is of the same nature as in the previous case. Range of valid values , in which decreasing the value $\overline{E}_н$ is no more 10%.

The performed mathematical modeling shows that the errors in the location of the phase centers of individual radiation sources of a cylindrical phased antenna array, equal to $\Delta\rho \le \lambda$ and $\Delta h \le \lambda/6$, have practically no effect on the duration and repetition period of a multifrequency space-time signal.

4. Conclusions

The influence of errors in the location of emitters along the aperture of a cylindrical phased antenna array in the far zone is not as significant as in the Fresnel zone. The influence of errors in the location of the phase centers of the emitters along the direction of radiation does not depend on the distance to the focusing point. Range of valid values $\Delta\rho$ and Δh, in which the decrease in the mean value of the electric field strength does not exceed 10%, is determined from the following conditions $\Delta\rho \le \lambda$ and $\Delta h \le \lambda/6$.

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