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Methodology for Estimating the Time Characteristics of Sequences of Multifrequency Spatial - Temporal Signals

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ABSTRACT

The article presents theoretical studies that allow one to determine the boundary conditions for the operability of microprocessor technology, semiconductor radioelements when exposed to multifrequency space-time signals.

The temporal characteristics of a sequence of multifrequency spatio-temporal signals, at which irreversible changes in radioelements are possible, are determined.

Their amplitude-frequency spectrum is analyzed for radiation by a cylindrical phased antenna array for different elevation angles of a point. A method is proposed for calculating an additional linear phase distribution for scanning the directional pattern of a cylindrical phased antenna array in elevation.

Keywords: semiconductor, affection, probability, microprocessor technology, control system, space-time signal, mathematical model.

1. INTRODUCTION

The result of the effect of electromagnetic radiation on the semiconductor base is the irreversible destruction of radioelements of functional devices: low-noise antenna amplifiers, crystal mixers, transistor intermediate frequency amplifiers and detectors. In this case, certain requirements must be met for the time and energy parameters of the impacting electromagnetic radiation [1, 2, 26].

When evaluating the temporal parameters of electromagnetic radiation, it is necessary to take into account that in a number of cases, to protect the input circuits, special protection devices with a short response time can be used, blocking the receiving devices if there is not only a signal of their own transmitter at their input (with a combined receiving and transmitting antenna), but and high level of any other input signals. The response time of the best protection devices that have been implemented by industry is on the order of 10 ns [2-5]. Therefore, the duration of the destructive signal τp must correspond to the condition:

$$\tau_p \le \tau_к = 10\text{ns} , \qquad (1)$$

where $\tau_к$ – response time of protection devices when the specified maximum signal level in the input circuits is exceeded.

The purpose of the article is to evaluate the temporal characteristics of sequences of multifrequency spatio-temporal signals emitted by a cylindrical phased antenna array.

2. MAIN MATERIAL

From a literature review, two variants of the effect of electromagnetic radiation on microprocessor equipment and semiconductor radioelements are known: in-band and out-of-band. In-band exposure requires accurate data, for example, about the operating frequency and bandwidth of the receiver, the clock frequency of a computer or special calculator, the resonant frequency of the structures of fasteners of electronic elements on boards, etc.

The energy loss of the acting electromagnetic energy when passing through the input circuits of the receiving path in this case depends on the ratio between the bandwidth of the receiving path $\Delta f_п$ and the bandwidth of the influencing signal $\Delta f_p \approx 1/\tau_p$. In most cases, these losses do not exceed -10...-15 dB [2].

Out-of-band exposure does not require precise frequency range data. Impact can be made through the mounting holes at any frequencies outside their bandwidth.

The resulting losses in this case can reach the value -30...-40 dB [2, 18-25].

As for the effects of influence on microprocessor technology, then, in addition to thermal breakdown of microcircuits, one can conditionally also include a failure of the clock frequency and, as a consequence, the so-called "freeze" of the program being executed. The latter is provided at lower energy costs.

The energy threshold for achieving the degradation effect of various electronic devices should be determined taking into account the characteristic relaxation time of thermal processes, which for semiconductor devices and integrated circuits turns out to be quite large $\tau_T \geq 10...100$ ns [3, 13-17].

If the condition is met $\tau_p \leq \tau_к$ the condition $\tau_p \leq \tau_T$. In this case, the total effect can be estimated using the total time of the entire sequence of influencing signals minus the intervals between them, if the period of their repetition $T_p < \tau_T$.

The smallest radiated power flux density can be achieved by creating spatio-temporal periodic short signals leading to self-excitation of the input stages or receiving devices in general.

With a sequence of multifrequency spatio-temporal signals to maintain stable self-excitation of the receiving devices, the duration of the acting pulses should be selected from the above condition (1). Suppose the condition $\tau_p \leq 5$ ns.

In turn, the following period T_p of such influencing impulses should be chosen in such a way that self-excitation oscillations decay by no more than 50...70%:

$$T_p \leq (0{,}7...1{,}2)\tau_П \approx \frac{0{,}7...1{,}2}{\pi \Delta f_П} \approx \frac{0{,}22...0{,}38}{\Delta f_П}, \qquad (2)$$

where $\Delta f_П$ и $\tau_П$ – bandwidth and settling time constant of natural oscillations of the receiving device.

Since the overwhelming majority of the bandwidth for real receivers is $\Delta f_П \leq 10$ MHz [4-12, 26], then, taking into account (2), we obtain $T_p \leq 220...380$ ns and accordingly, the value of the duty cycle of such periodic sequences of acting pulses $\tau_p \leq 5$ ns will be $Q = T_p / \tau_p \leq 50...80$.

For further calculations, we choose the number of pulses N_i=100 at duty cycle Q<10.

To determine the structure of the field emitted by a cylindrical phased array antenna with horn radiators, we use the following expression:

$$\begin{aligned}\dot{E}(P,t) = \sum_{m=1}^{M_x}\sum_{n=1}^{N_y}\frac{\dot{F}_{mn}(\beta_\Phi,\alpha_\Phi)}{R_{mn}}\sqrt{60P_{mn}G_{max_{mn}}} \times \\ \times \exp\left\{j\left[2\pi f_{0\,mn}\left(t-\frac{R_{mn}}{c}\right)+\varphi_{0\,mn}\right]\right\},\end{aligned} \qquad (2)$$

where m and n – indices defining the number of the radiator;

M_x, N_y – the number of radiating elements along the guide and the generatrix of the cylinder, respectively;

$\dot{F}_{m,n}(\beta_\Phi,\alpha_\Phi)$ – the value of the complex radiation pattern of the emitter in the direction to the focal point;

β_Φ, α_Φ – angles defining the direction to the focus point;

R_{mn} – distance from emitter to focus point;

P_{mn} – power supplied to the mnth element of the phased array antenna;

G_{mn} – single emitter gain;

$f_{0\ mn}$, $\varphi_{0\ mn}$ – frequency and initial phase of the spectral component of multifrequency space-time signals supplied to the element of the phased array antenna;

t – observation time.

The law of frequency variation along the aperture of a cylindrical phased antenna array will have the form:

$$f_{0mn} = \begin{cases} f_0 + \nu[m/\nu]\Delta F_{n\,max}, \\ f_0 + \nu[n/\nu]\Delta F_{n\,max}, \end{cases} \qquad (3)$$

where f_{0mn} – frequency in mn emitter;

f_0 – middle frequency spectrum;

ΔF_x, ΔF_y – frequency sampling along the axes O_x and O_y;

$$[m/\nu]\Delta F_{n\,max} = \left[\frac{f_0 \dfrac{\rho_{mn}^2}{2\gamma d_x^2 - \rho_{mn}^2}}{\nu}\right];$$

$\gamma = 1 + f_0/\Delta F_{nmax}$; $\Delta F_{nmax} = \max(\Delta F_x, \Delta F_y)$;

$\rho_{mn}^2 = x_{mn}^2 + y_{mn}^2$;

ν – duty cycle reduction factor.

Analysis of the calculations shows that in the case of using a multistage V-shaped distribution law of carrier frequencies, with a decrease in the duty cycle of the formed sequence of signals, the pulse parameters do not change, only the structure of the side peaks changes.

For example, figure 1 shows the normalized value of the electric field strength with the duty cycle Q=8 for a range of 1 km and a signal spectrum width 2 GHz.

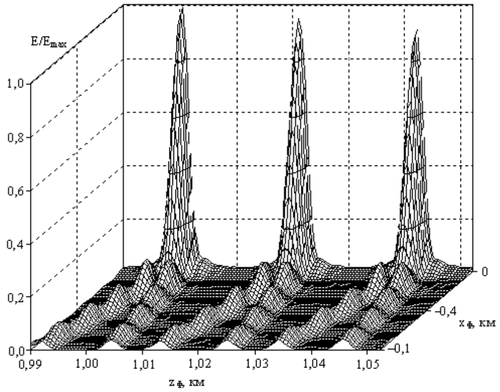

Figure 1: The normalized value of the electric field strength (Q=8)

Из figure 1 it follows that the spatial duration of the signal at the level of 0.5 is of the order of 1m, or τ_i=3 ns, the steepness of the leading edge is 1 ns, the level of the first side lobe is of the order of –10dB. Transverse size of the "spot" x_Φ=7 m.

In the vicinity of the lesion point (R = 1 km), the level of the first side lobe does not exceed $E_S < 0{,}3E_{max}$.

A decrease in the duty cycle leads to partial overlap of the far side lobes and a decrease in their level compared to the radiation field when using a single-stage V-shaped frequency distribution over the aperture.

Analysis of the calculation results also showed that the temporal structure of the multifrequency space-time signal emitted by a cylindrical phased antenna array in the azimuthal plane along the normal to the array does not depend on the azimuth of the target, since the space-frequency spectrum of the signal does not change.

At the same time, when the elevation angle of the observed object changes, the conditions for the formation of a multifrequency spatio-temporal signal change, which leads to a change in its amplitude spectrum.

Figure 2 shows the amplitude-frequency spectrum of the radiated signal along the normal to the phased antenna array for Q=8.

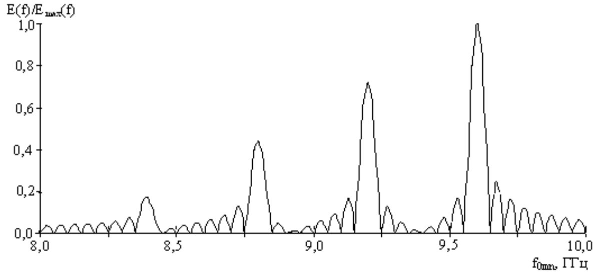

Figure 2: Amplitude-frequency multifrequency space-time signal along the normal to the phased antenna array (Q=8)

Figure 3 shows the amplitude-frequency spectrum of the emitted signal when the focusing direction is shifted along the generatrix by an amount equal to the transverse linear size of the signal d=x_Φ when forming it along the normal to the lattice for Q=8.

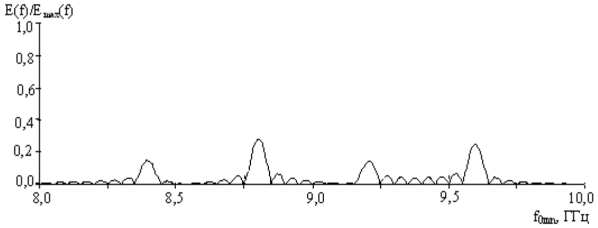

Figure 3: Amplitude-frequency multifrequency space-time signal for d=x_Φ (Q=8)

Figure 4 shows the amplitude-frequency spectrum of the emitted signal when the focusing direction is shifted along the generatrix by an amount equal to two transverse linear dimensions of the space-time signal d=2x_Φ when forming it along the normal to the lattice for Q=8.

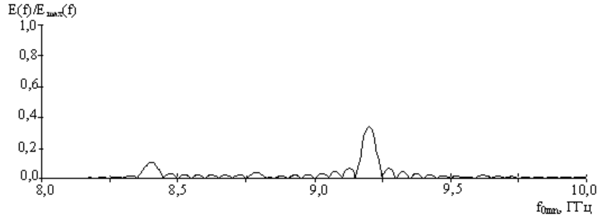

Figure 4. Amplitude-frequency multifrequency space-time signal for d=2x_Φ (Q=8)

Similar results were obtained for the duty cycle Q=4. Figure 5 shows the amplitude-frequency spectrum of the radiated signal along the normal to the phased array for Q=4.

Figure 6 shows the amplitude-frequency spectrum of the radiated signal when the focusing direction is shifted along the generatrix by an amount equal to the transverse linear size of the multifrequency space-time signal d=x_Φ when forming it along the normal to the lattice for Q=4.

Figure 7 shows the amplitude-frequency spectrum of the emitted signal when the focusing direction is shifted along the generatrix by an amount equal to two transverse linear dimensions of the multifrequency space-time signal $d=2x_Ф$ when forming it along the normal to the lattice for Q=4.

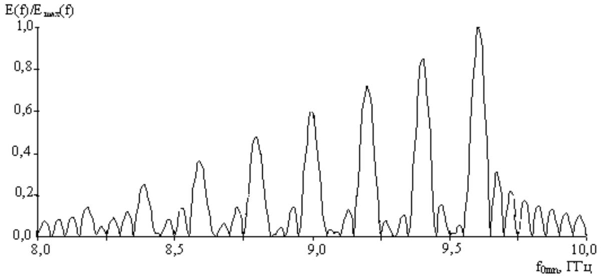

Figure 5: Amplitude-frequency multifrequency space-time signal of the signal along the normal to the phased array antenna (Q=4)

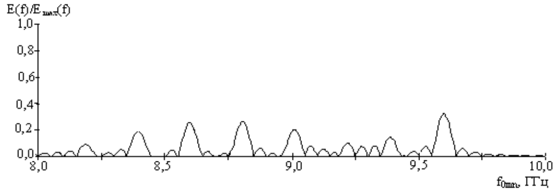

Figure 6: Amplitude-frequency multifrequency space-time signal for $d=x_Ф$ (Q=4)

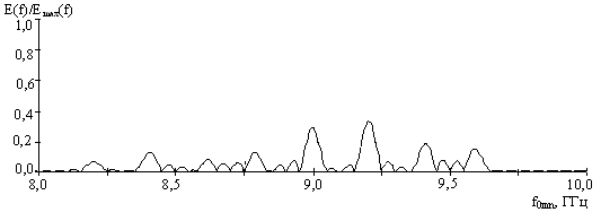

Figure 7: Amplitude-frequency multifrequency space-time signal for $d=2x_Ф$ (Q=4)

From the analysis of figure 2 - 7 it follows that when the focusing point moves away from the direction of the normal to the axis of the antenna array, the multifrequency spatio-temporal signal is "blurred", the electric field strength decreases significantly (up to 70%), the structure of the amplitude-frequency spectra becomes irregular and tends to the noise-like.

In order to make it possible to scan in directions other than the direction of the normal to the axis of the phased antenna array, it is necessary to provide an additional linear phase distribution, which allows scanning the radiation pattern.

To carry out scanning at a certain distance, it is advisable to provide for the possibility of creating a sequence of multifrequency spatio-temporal signals in directions other than the direction of the normal to the axis of the cylindrical phased antenna array. The coordinates of an object in the general case can be calculated if, at a given time, the coordinates of the trajectory of the tracked object are extrapolated on the basis of radar information obtained in previous time readings.

Based on the known rectangular coordinates of the focusing point at a given moment in time, their new values in a spherical coordinate system associated with a phased array antenna can be calculated as:

$$\begin{cases} R(t)=\sqrt{x_Ф(t)^2+y_Ф(t)^2+z_Ф(t)^2}, \\ \varepsilon(t)=\arccos\left[z_Ф(t)/R_n(t)\right], \\ \beta(t)=\mathrm{arctg}\left[z_Ф(t)/y_Ф(t)\right], \end{cases} \qquad (3)$$

where R, β, ε – spherical coordinates;
$x_Ф$, $y_Ф$, $z_Ф$ – cartesian coordinates.

Knowledge of the angular coordinate by the elevation angle allows you to specify an additional phase distribution in the form of a linear term to expression (2), which ensures the deviation of the radiation pattern from the direction of the normal to the phased antenna array in elevation.

The addition in the plane of the generatrix (azimuthal direction) is impractical to set due to the axisymmetric design of the cylindrical phased array antenna.

It is known [5] that for scanning it is necessary to set an additional linear phase distribution along the aperture of the phased array antenna. In the case under consideration, the addition in the elevation plane $\varphi_{0\varepsilon}$ has the form:

$$\varphi_{0\varepsilon}(x_n)=-a(t)x_n\ ,$$

where $a(t)=\frac{\pi L}{\lambda}\sin\varepsilon(t)\cos\beta(t)$ – phase slope in the elevation plane.

In the case of focusing on a moving point, the coefficients a (t) will depend on time in accordance with the given law of motion of the object, determined by (3).

In this case, the expression for the electric field strength (2) for focusing to the point of the trajectory will have the form:

$$\dot{E}(P,t)=\sum_{m=1}^{M_x}\sum_{n=1}^{N_y}\frac{\dot{F}_{mn}(\beta_Ф,\alpha_Ф)}{R_{mn}}\sqrt{60P_{mn}G_{maxmn}}\times \\ \times\exp\left\{j\left[2\pi f_{0\,mn}\left(t-\frac{R_{mn}}{c}\right)+f_{0\,mn}+a(t)x_n\right]\right\}, \qquad (4)$$

Expression (4) describes the electric field strength in a direction other than the normal to the cylindrical axis (4). It is obvious that the amplitude-frequency spectrum of the multifrequency space-time signal in this case does not change.

3. CONCLUSION

The calculation of the amplitude - frequency spectra of multifrequency space - time signals at different elevation angles has been carried out. When the lesion point is removed from the direction of the normal to the axis of the phased array, the multifrequency spatio-temporal signal is "blurred", the electric field strength significantly decreases (up to 70%), the structure of the amplitude-frequency spectra becomes irregular and tends to noise-like.

A method is proposed for calculating an additional linear phase distribution for scanning with a cylindrical radiation pattern (4) in elevation.

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