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THE DEFINITION OF THE TIME-SPACE AND POWER PERFORMANCES OF THE ULTRAWIDEBAND ANTENNAS

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The definitions of the time-space, frequency–space and power characteristics of the ultrawideband antenna systems permitting to evaluate from unified positions the overall performance of different function videopulse radiotechnic systems are given.

The variety of the ultrawideband (UWB) signals possible ages require the development of antenna systems with different spatial and time characteristics. The classical definitions of a pattern, when using the UWB signals, become unsuitable as the pulse temporal (frequency) parameters and the antennas directional properties become mutually dependent.

Let's explain it as follows. If we present antenna as a linear link having some frequency variance, there will be different patterns for the different spectrum frequency components. Which change the radiator directional properties, which, in their turn, define the shape and magnitude of the radiated (received) signal. When receiving, it makes the signal duration structure change at the handling scheme input, whereupon there is a signal and filter misalignment, which results in some optimum reception conditions violation. The directional characteristic becomes time-dependent. Therefore the UWB antenna systems usage makes us reinterpret the definitions of the majority of characteristics and parameters circumscribing directional and temporal properties.

As a result, the radiotechnic system (RTS) power characteristics are changed as well, which complicates the solutions of the radiolocation, link, undistorted information transfer, etc. problems. Thereby it is necessary to determine the antenna time-space or spatial-frequency characteristics (TSC, SFC) in case we use UWB signals. Let's state that today there is no established terminology to define the TSC, SFC, informative and power characteristics of UWB antennas in literature. Therefore this paper is to determine the space, frequency, time, etc. characteristics necessary to estimate overall performance of UWB RTS.

If we present the transmitting antenna as a time-space modulator and the receiving one as a filter with appropriate SFC, then the field in the far-field region at ω frequency can be given as

$$\dot{E}(\omega,\Theta,\varphi) = \dot{V}(\omega,\Theta,\varphi)\dot{S}(\omega), \qquad (1)$$

where Θ, φ – the angular coordinates of a view point,

$\dot{V}(\omega,\Theta,\varphi) =$

$$\frac{1}{r\sqrt{\pi}}\sqrt{D_{\max}(\omega)}\dot{F}(\omega,\Theta,\varphi)\exp(-ikr)$$ –

the complex SFC of antenna,

r – the distance up to a view point,

$D_{\max}(\omega,\Theta=0,\varphi=0)$ – the directive gain at ω frequency in the direction of the principal maximum,

$\dot{F}(\omega,\Theta,\varphi)$ – the complex pattern on a field at ω frequency,

k – wave number,

$\dot{S}(\omega)$ – the spectral concentration of a current pulse exciting the antenna.

Expression (1) represents SFC of the antenna. We shall take it as the relationship between the radiated field magnitude and the frequency and angular coordinates with a view point (in free space) placed at infinity.

Then the SFC $|\dot{E}(\omega,\Theta,\varphi)|$ module represents the amplitude SFC of the antenna, the argument – the phase SFC. The function $|\dot{E}(\omega,\Theta,\varphi)|$ cross-section by a plane $\omega = \text{const}$ represents the pattern on a field at ω frequency; $|\dot{E}(\omega,\Theta,0)|$ and $|\dot{E}(\omega,0,\varphi)|$ – the pattern in E- and H-planes accordingly. If we fix $\Theta = \Theta_0 = \text{const}$ and $\varphi = \varphi_0 = \text{const}$, the function $|\dot{E}(\omega,\Theta_0,\varphi_0)|$ will describe the signal spectrum in this direction.

The Fourier transform of expression (1) gives SFC of the antenna

$$\dot{E}(t,\Theta,\varphi) = \frac{1}{2\pi r}\int_{-\infty}^{\infty} \dot{E}(\omega,\Theta,\varphi)\exp(-j\omega t')\,d\omega \;,(2)$$

where $t' = t - \frac{R}{c}$ – the time delay.

Thus, as the SFC of the antenna we take the relationship between the radiated field magnitude and the time and angular data with a view point (in free space) placed at infinity. Considering cross-sections of SFC by different planes ($\Theta = \Theta_0$, $\varphi = \varphi_0$), it is possible to give a series of visual and practically useful definitions of different patterns, which could be used (separately or combined with other) when estimating the UWB antenna systems spatial properties.

To determine the criteria of the far-field region if we use UWB signals, we use the definition of a far-field region for the aperture in case of a narrow-band signal: $r > \frac{2L^2}{\lambda_0}$. This ratio is obtained from the nonexceeding the medium frequency ω_0 phase error maximal value criteria on the edge of the aperture equal to $\pi/8$ [1], which matches the temporal delay $\Delta t_{\max} < T_0/16$ (T_0 – the period of oscillations). By analogy, if we use UWB signals as the far-field region criteria, it is possible to take the maximum admissible temporal delay on the edge of the aperture. It matches the value $\Delta t_{\max} < T_h/8 = \tau_i/8$ (T_h – the period of the upper oscillation frequency). Then as the criterion of the far-field region it is possible to use the ratio

$$r > \frac{2L^2}{c\tau_u}, \qquad (3)$$

where L – the maximum linear size of the antenna,
c – the light speed, τ_i – pulse duration,
$c\tau_i$ – the spatial pulse duration.

In some instances, however, the ratio (3) can be diluted and finally depends on the required exactitude of evaluations and measurements.

All further definitions will be given at the fixed distance to the view point in a far-field region and the constant conditions of the antenna excitation.

Let's define the instant pattern $E(t_0,\Theta,\varphi)$ as a function of signal at fixed time $t = t_0$ on the angular coordinates.

The change of the radiated UWB signal shape depends on the spatial coordinates. Thus not only the pulse amplitude depends on direction, but also its shape and duration do [2]. Each of the stated signal parameters should be described by its spatial characteristic. Or a certain integral characteristic circumscribing radiator time-space properties of the UWB signals should be defined.

In the literature on UWB antennas, different definitions of the radiators directional characteristics are applied. Most frequently the peak patterns on amplitude and patterns on power [3, 4] are used.

As the peak pattern on amplitude we shall take the relation of the maximum SFC value to the angular coordinates (estimation is made when we cross the SFC by planes $\Theta = \Theta_0$, $\varphi = \varphi_0$, whence the t_0 value, matching the $E_{\max}(t_0,\Theta,\varphi))$ value is determined.

As the peak pattern on power we shall take the relationship between the signal fluency strength maximum value $|\vec{E}\times\vec{H}|_{\max}(t,\Theta,\varphi)$ and the angular coordinates.

Such characteristics are obvious for the one-peak radiated signal. However, as a rule, in a radiated signal repeated oscillations are present, the magnitude of which varies with the change of a view point angular position. Thus a temporal position of the peaks varies as well. Therefore the peak pattern becomes physically visual only if we use a series of idealizing assumptions.

For example, the power pattern and pattern on the mean power [3] may appear more preferable for the RTS of detection. The power pattern is the relationship between the energy flow transmitted through a single site, perpendicular to the signal propagation direction during the field existence in a view point and the direction:

$$F_E(\Theta,\varphi) = \int_{t_1}^{t_2} \Pi(r_0,\Theta,\varphi,t)\,dt \,,$$

where $\Pi(r_0,\Theta,\varphi,t) = \frac{1}{Z_0}|E(r_0,\Theta,\varphi,t)|^2$ – the magnitude of the Poynting vector,
Z_0 – the free space wave resistance,
r_0,Θ,φ – the view point coordinates,
t_1, t_2 – the instants defining the pulse duration in a view point.

The pattern on the mean power may be defined as:

$$P_m(\Theta,\varphi) = \frac{F_E(\Theta,\varphi)}{t_2 - t_1}.$$

The given characteristics have a larger physical obviousness than the previous ones as they are irrelevant to the radiated signal shape.

A temporal structure, mainly the shape and duration of a received signal may be used for RTS, solving the recognition problem. As a pattern on duration we take the relationship between UWB signal duration and the angular coordinates.

The shape of a received signal is informative as to the target tags. Therefore it is preferably to give a preliminary integral estimation of the distortions of the radiated signal shape, which can further be used at the handling. Moreover, such estimation allows to roughly estimate the antennas informative properties as separate link of the information transmission channel and to estimate the contribution to common temporal structure of a UWB signal electromagnetic field of the distortions originating at the radiation.

Such estimation may be made on the basis of the temporal moment calculation [3].

Considering the real models of UWB signals with the integrated energy (as elements of the space $\mathcal{L}^2$), the degree of the UWB antenna systems SFC change may be determined as the affinity (distance) between the SFC value $E(t,\Theta=0,\varphi=0)$ in the direction of the principal maximum and the value $E(t,\Theta,\varphi)$ in some other direction. Thus, reducing its determination to the evaluation of their correlation function in the metric of this space.

It allows to give the definition to the correlation pattern, which we take as a function relation $E(t,\Theta=0,\varphi=0)\cdot E(t,\Theta,\varphi)$ at $t=t_0=\text{const}$ on the angular coordinates. In this case, however, there is a problem with its normalization.

The correlation pattern allows to analyze the radiated signal time-space modulation parameters and may be used at the handling accordingly.

The quantitative estimation of the STC and SFC change by the UWB antenna system can also be given, using the moments values:

– temporal (crossing the STC by planes $\Theta=\Theta_0=\text{const}$ and $\varphi=\varphi_0=\text{const}$):

$$\overline{t_\kappa(\Theta,\varphi)}=\frac{\int\limits_{-\infty}^{\infty} t^k E^2(t,\Theta,\varphi)\,dt}{\int\limits_{-\infty}^{\infty} E^2(t,\Theta,\varphi)\,dt}, \quad (4)$$

– frequency (at $\Theta=\Theta_0=\text{const}$ and $\varphi=\varphi_0=\text{const}$):

$$\overline{\omega_\kappa(\Theta,\varphi)}=\frac{\int\limits_{-\infty}^{\infty} \omega^k E^2(\omega,\Theta,\varphi)\,d\omega}{\int\limits_{-\infty}^{\infty} E^2(\omega,\Theta,\varphi)\,d\omega}, \quad (5)$$

– angular moments (at $t=t_0=\text{const}$):

$$\overline{\Lambda_\kappa(t)}=\frac{\int\limits_0^{2\pi}\int\limits_0^{\pi} \Theta^k\varphi^k E^2(t,\Theta,\varphi)\,d\Theta\,d\varphi}{\int\limits_0^{2\pi}\int\limits_0^{\pi} E^2(t,\Theta,\varphi)\,d\Theta\,d\varphi}. \quad (6)$$

The first of the moments (4–6) have obvious physical interpretation. So, $\overline{t(\Theta,\varphi)}$, $\overline{\omega(\Theta,\varphi)}$, $\overline{\Lambda(t)}$ describe the change of the impulse "centre of gravity" in space, of spectrum and the instant power pattern accordingly. The magnitudes $\delta t(\Theta,\varphi)=\sqrt{\overline{t^2(\Theta,\varphi)}-\overline{t(\Theta,\varphi)}^2}$, $\delta\omega(\Theta,\varphi)$, $\delta\Lambda(t)$ represent the "mean square" width (effective duration) of the pulse, the spectrum observed in the defined point of space, and the "diameter" of the instant power pattern accordingly.

The STC calculated in such a way allow to make the estimation of UWB RTS power characteristics. To determine the capabilities of the received signal handling we assume that we use as the signal $\dot{S}(\omega)$ handling device at the antenna system exit a compression filter with a frequency characteristic as

$$\dot{V}(\omega,\Theta=0,\varphi=0)=\dot{S}^*(\omega)\exp(-j\omega t_0),$$

where t_0 – a fixed delay in the filter.

To analyze and tentatively estimate the UWB RTS power characteristics we have compared the considered antenna and an antenna (similar to the given) having no frequency variance. Then assuming the compared antenna apertures and the noise spectral concentration stipulated by the active losses in the antenna channels are identical, we have obtained

$$\Delta Q(\Theta,\varphi)=\frac{\left|\int_{-\infty}^{\infty}\dot{V}(\omega,\Theta,\varphi)S^2(\omega)\,d\omega\right|^2}{\left|\int_{-\infty}^{\infty}S^2(\omega)\,d\omega\right|^2}. \quad (7)$$

As we see in (7), the magnitude ΔQ depends on the width of UWB signal spectrum, its shape and peak pattern. The expression (7) can serve as a basic calculated one when we determine UWB RTS power characteristics.

Except for previously given definitions of patterns, an important characteristic, circumscribing radiator directional properties, is the directivity factor. In the classical theory the directivity factor is determined only for the harmonic waves sources. In paper [5] for the antennas, radiating UWB signals the maximum directivity factor is determined as the ratio of the power flow transmitted through a single site perpendicular to the direction in which the pattern has the global maximum during the time equal to a signal duration in a view point, to the power flow, transmitted through a single site by a source radiating the same energy uniformly in all directions. If we present the field distribution on the aperture as a factorized functions of coordinates and time

$$\vec{E}_0 = \vec{x}^0 E_0(x,y) f(t),$$

where $E_0(x,y)$ – the distribution function on the aperture of the electric field strength amplitude,
$f(t)$ – the function of the field variation on aperture in time,
$\vec{x}^0$ – basis vector of the Cartesian frame,
then for the directivity factor we obtain the expression at $\Theta = 0$, $\varphi = 0$:

$$D_{\max}(\Theta,\varphi) = \frac{\varepsilon\mu}{\pi} \frac{\left[\int_S E_0(x,y)\,dS\right]^2}{\int_S E_0^2(x,y)\,dS} \frac{\int_{t_1}^{t_2} \left[\frac{df(\tau)}{d\tau}\right]^2 d\tau}{\int_{t_1}^{t_2} f^2(\tau)\,d\tau}, \quad (8)$$

where S – the aperture area.

Applying the Parseval equality, we obtain

$$D_{\max}(\Theta,\varphi) = \frac{\varepsilon\mu}{\pi} \frac{\left[\int_S E_0(x,y)\,dS\right]^2}{\int_S E_0^2(x,y)\,dS} \frac{\int_{-\infty}^{\infty} \omega^2 |S(\omega)|^2 d\omega}{\int_{-\infty}^{\infty} |S(\omega)|^2 d\omega}. \quad (9)$$

As we see in (8), (9) the UWB antenna directivity factor depends on the field distribution in the aperture, on the content frequency character or on the signal waveform and duration, which in general case makes it inconvenient to use the directivity factor if we use the UWB radiators.

In the case of non-factorizing field distributions on the aperture and in time the directivity factor maximum value should be determined for the instant (spectral component) matching the pulse (spectrum) center of the gravity position defined above through instants:

$$D_{\max}(\omega_{gp},\Theta = 0,\varphi = 0) = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} F_E(\omega_{gp},\Theta,\varphi)\sin\Theta\,d\Theta\,d\varphi}, \quad (10)$$

where ω_{gp} – the frequency matching the UWB signal spectrum center of gravity.

Expression (10) may be used to make a qualitative analysis of the radiolocation distance equation.

Thus, the definitions given in the paper allow to evaluate the spatial and time structure of the UWB signal field, spatial characteristics of UWB antennas, and, also to make integral estimation of the distortions originating in the information transmission channel from unified theoretical positions.

References

1. Ya.N. Feld, L.S. Benenson. Antennas centimetric and decimeter waves. A part 1.– Leningrad, 1955.– 207 pp.
2. A.M. Stadnik, G.V. Yermakov. Distortions of a ultrawideband electromagnetics impulses in atmosphere of the Earth. Radiotecnics and Electronics.– 1995.– V.40.– №.7.– pp. 1009-1016.
3. M.G.M. Hussain. A Self-Sterring Array For Nonsinusoidal Waver. IEEE Tr. On Electromagn. Compat.– 1986.– **EMC-28**.– №2.– pp. 96-104.
4. D.I. Voskresensky, E.V. Ovchinnikova. Performances of scanning antennas with the ultrashort pulses grounded on a spectrum analysis. Antennas.– 2000.– №.3 (46).– pp. 17-26.
5. M.V. Zernov, G.V. Merkulov. Power performances of the aperture antennas, emanatings nonharmonic waves. Radio engineering.– 1991.– №1.– pp. 68-71.

ОПРЕДЕЛЕНИЕ ПРОСТРАНСТВЕННО-ВРЕМЕННОЙ И ЭНЕРГЕТИЧЕСКОЙ ЭФФЕКТИВНОСТИ СВЕРХШИРОКОПОЛОСНЫХ АНТЕНН

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Даны определения пространственно-временным, пространственно-частотным и энергетическим характеристикам сверхширокополосных антенных систем, позволяющие оценивать с общей позиции общую эффективность видеоимпульсных радиотехнических систем различного назначения.

ВИЗНАЧЕННЯ ПРОСТОРОВО-ЧАСОВОЇ ТА ЕНЕРГЕТИЧНОЇ ЕФЕКТИВНОСТІ НАДШИРОКОСМУГОВИХ АНТЕН

В.І. Замятин, Г.В. Єрмаков

Дано визначення просторово-часовим, просторово-частотним та енергетичним характеристикам надширокосмугових антенних систем, що дозволяють оцінювати з загальної позиції загальну ефективність відеоімпульсних радіотехнічних систем різного призначення.