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ON THE BASIC CONCEPTS OF UWB RADAR SCAN

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In this paper, the terms in wide use, the Ultra Wideband (UWB) signal and the Ultra Shot Impulse (USI), are discussed. Their usage conditions are considered and the difference in meanings is determined. As main tool for describing the power requirements to UWB Radar, the generalized Radar Range Equation (RRE) valid to arbitrary width of the spectrum is employed. The assumptions as to the UWB Radar characteristics allowing to represent the RRE in similarity to the traditional form are considered. The use of the Impulse Active Antenna Array can be a way to the UWB power problem solution. The problems regarding the high peak power UWB signals are posed. It is possible, as demonstrated, to produce the complex UWB pulse signal with large time-bandwidth product.

1. Terminology

The application of Ultra Wideband signals is known since early 90-th. According to [1-3], the UWB signal has to be defined only in the frequency domain with the use of the spectral parameters:

$$\mu = \frac{\Delta f}{f_0} = 2\frac{f_h - f_l}{f_h + f_l} \approx 1; \quad \mu \geq 0,25. \qquad (1)$$

The boarding value $\mu \geq 0.25...1$ can be chosen in accordance with the practical task.

Another definition must be applied to radar signals as Ultra Short Impulses. This definition compares the space length of radar impulse t_p (radar range resolution) and the size of target L:

$$ct_p \ll L. \qquad (2)$$

For usual targets the expression (2) leads to impulses in the nano- and picosecond duration range. In this case the radar target can be represented as a sum of local scattered centers. Such model is the first order approximation to real target characteristics. But appellation “the nano- and picosecond pulses” is not equal to UWB and USI. In Fig. 1 the modulus of frequency response of conducting sphere is shown against the spectral density function of narrowband, USI and UWB signals [1].

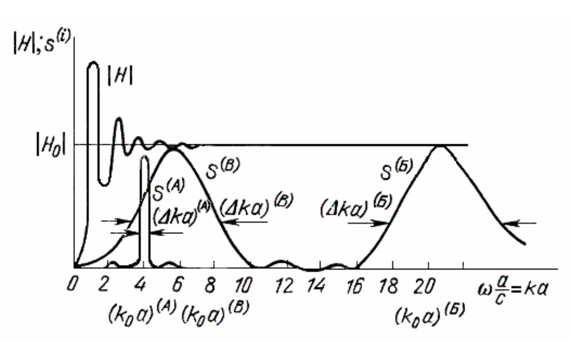

Fig. 1.

The signal with $S^{(A)}(k_0 a)$ spectral density function is a narrowband signal because $(\Delta ka)^{(A)}$ value is small. The signal with $S^{(Б)}(k_0 a)$ spectral density function is a USI signal because $(\Delta ka)^{(Б)}$ is large. Finally, signal $S^{(B)}(k_0 a)$ is a UWB signal in accordance with (1). Note there exist all signal features combinations: UWB and USI, UWB not USI, not UWB but USI and the last.

2. UWB Radar Range Equation

The conventional Radar Range Equation expresses the ratio of transmitted to received power in the dependence of transmitted antenna gain, receiving antenna area and the target reflection (local) cross section.

$$P_R = P_T \frac{G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \cdot A. \qquad (3)$$

Usually it expected a monochromatic signal and average power

$$s(t) = U_m \cos \omega_0 t; \quad \overline{P} = U_m^2 / 2.$$

In monochromatic approximation the parameters of (3) are

$$G(\omega_0) \quad \sigma(\omega_0) \quad A(\omega_0).$$

In fact, the radar signal detection is a result of the comparison of instantaneous signal voltage with a threshold have to be chosen in accordance with noise dispersion σ_n^2 and probability function of detection [2]. So (3) must be rewritten as

$$S_R(t) = S_T(t)\frac{1}{4\pi R^2}\sqrt{G(\omega_0)}\sqrt{\sigma(\omega_0)}\sqrt{A(\omega_0)}\,.$$

In the conventional threshold equation, the ratio signal energy to noise density is used

$$\sqrt{\frac{E_0}{N_0}} \ge q\,.$$

It apprehends the signal matched filtration. However such processing is not necessary and not successful for a single UWB impulse signal. Thus the comparison with threshold q must be made regarding the raw signal peak voltage

$$S_{R\max}(t) \ge q\sqrt{\sigma_n^2}\,.$$

Note that it is the same as a matched filtration result

$$\sqrt{\frac{E_0}{N_0}} = \frac{s_{R\max}(t)}{\sigma_n}.$$

3. Frequency and Impulse Responses of a Radar as a Linear System

In case of nonsinusoidal signals the Radar Range Equation becomes frequency dependent

$$S_R(\omega) = \frac{1}{4\pi R^2}\int_{-\infty}^{\infty} S_T(t)\sqrt{G(\omega)\sigma(\omega)A(\omega)}\,e^{-i\omega t}\,dt = \frac{1}{4\pi R^2}S_T(\omega)\sqrt{G(\omega)\sigma(\omega)A(\omega)}\,,$$

where $S_T(\omega)$ is the Fouirer transform of $S(t)$ signal.
The ratio

$$H(\omega) = \frac{S_R(\omega)}{S_T(\omega)}$$

is the radar Frequency response and

$$h(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} H(\omega)e^{i\omega t}d\omega = h_G(t)\otimes h_\sigma(t)\otimes h_A(t)$$

is the radar Impulse response. Note the parameters of target cross section and antenna area acquire the dimensions of the length

$$[\sigma] = [A] = [\text{meter}].$$

4. The Approximations of Radar Range Equation Parameters

Some approximations of RRE parameters in respect to practical use are possible.

4.1. Antenna Area

This parameter is almost frequency independent except the receiver frequency response. Thus

$$A(\omega) = A(\omega_0); \quad h_A = \sqrt{A(\omega_0)}\,\delta(t)\,,$$

where $\delta(t)$ is the Dirac function.

4.2. UWB Parameters of Target

The high range resolution of Ultra Short Signals makes possible to represent the radar cross section of the large target as a sum of local scattering centers reflections

$$h_\sigma(t) = \sum_{i=1}^{k} h_{\sigma i}(t - t_i)\,.$$

The first approximation of local reflection can be chosen as $\sigma_i(\omega) \approx \lambda_0^2$ on a target edges or as $2\pi R^2$ on a smooth target like a sphere. Then the target detection will be related to a single local center. The use for the target detection of all local centers reflections is possible; however, the necessary bank of the target images becomes very large.

4.3. UWB Antenna Features

The antenna gain $G(\omega)$ is the measure of a transmit antenna radiation directivity and is closed with antenna pattern angle $\theta^0 \approx 1/G$. But the concept of antenna pattern by use of UWB signals is not definite because the radiated signal shape is changed with the angle. In Fig. 2 the antenna patterns are defined as the angle dependence of signal peak voltage (3) or as

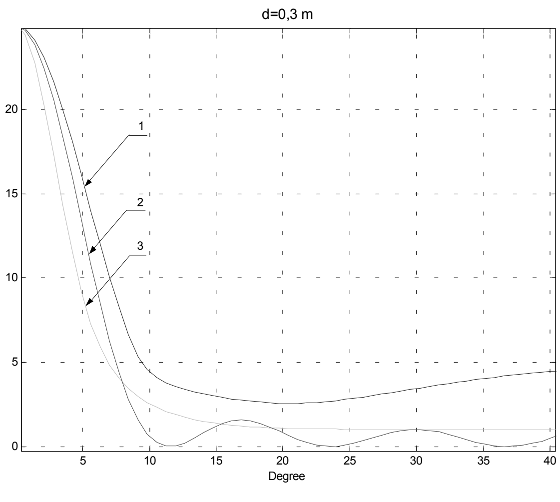

Fig. 2.

the impulse signal energy (1) and are compared with antenna pattern (2) of monochromatic signal of ω_0 frequency.

The θ_0 parameters of these diagrams are close enough and, thus, the $G(\omega_0)$ is the good first approximation of UWB antenna gain $G(\omega)$, despite the three times change of frequency inside UWB signal spectrum width.

5. The Impulse Active Antenna Array

The most used kind of UWB signal forming is the pulse excitation of antenna. Then the transmitted signal spectrum is as

$$S_T(\omega) = S_P(\omega) H_A(\omega),$$

where $S_P(\omega)$ is the exciting pulse spectrum and $H_A(\omega)$ is the antenna frequency response. The factor of excitation effectiveness is:

$$\eta = \frac{\int_{-\infty}^{\infty} \left[H_A(\omega) S_p(\omega)\right]^2 d\omega}{\int_{-\infty}^{\infty} \left[S_p(\omega)\right]^2 d\omega} \approx 0,3 .$$

For TEM horn antenna $\eta \approx 0.3$ [4]. The electrical field strength E at the distance R can be represented with effective transmitter potential [4]:

$$U_{Ei} = ER = U_P \sqrt{\frac{120\pi}{Z_0}} \sqrt{\eta},$$

where U_P is the peak voltage of exciting generator and Z_0 is the feeder line impedance. For *N*-elements antenna array the effective potential is

$$U_E = \sum_N U_{Ei} \approx 1.2 N U_P .$$

Thus with $N = 81$ and $U_P = 10$ kV the effective potential is $U_E = 1$ MV or $P_E = 10$ GW. In this case the field strength at 100 m distance achieves 10 kV/m which involves a number of environmental and EMC problems.

6. UWB Pulse Position Modulated Signals

The alternative way of signal energy accumulation is the use of signal with large time-bandwidth product. In the context of UWB signal it can be the batch of *N* pulses with their time position modulation so as the time side lobes of correlation function of signal to decrease. It is similar to well known chirp signal and its the time-bandwidth product *B* is equal to number of pulses *N*.

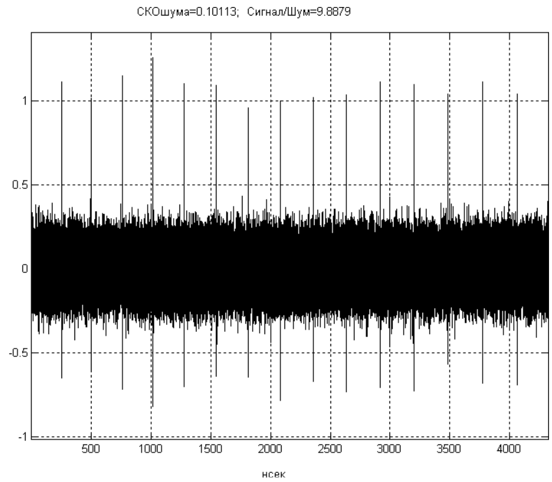

Fig. 3 (a).

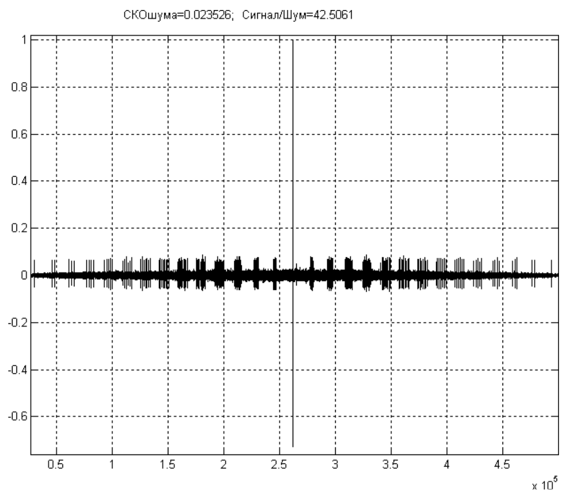

Fig. 3 (b).

In Fig. 3(a) the UWB signal with time position modulation by $N = 15$ pulses submerged in noise is depicted.

In Fig. 3(b) the result of matched signal-compression is shown. Note the time side lobes is of $1/N$ level due to the successful choice of a time position modulation rule.

In Fig. 3(b) the result of matched signal-compression is shown. Note the time side lobes is of $1/N$ level due to the successful choice of a time position modulation rule.

The use of UWB time position modulated signals is the good tool for UWB impulse high power problem decreasing

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ОСНОВНЫЕ АСПЕКТЫ ШИРОКОПОЛОСНОГО РАДАРНОГО СКАНИРОВАНИЯ

Л.Ю. Астанин, А.А. Костылев, А.А. Флёрова

Предметом обсуждения являются два общеизвестных термина: сверхширокополосные (СШП) сигналы и ультракороткие импульсы (УКИ). Рассматривается условия их употребления и различие в значении. Обобщенное основное уравнение локации (ОУЛ), верное для сигналов с произвольной шириной спектра, применяется как основное средство описания энергетических требований к СШП радарам. Рассмотрены допущения относительно характеристик СШП радаров, позволяющие представить ОУЛ в форме, похожей на традиционную. Использование импульсных активных антенных решеток может быть способом решения проблем энергетики СШП сигналов. Поставлены задачи, касающиеся высокой пиковой мощности СШП сигналов. Показано, что можно получать сложные СШП импульсные сигналы с большой базой сигнала.

ОСНОВНІ АСПЕКТИ ШИРОКОСМУГОВОГО РАДАРНОГО СКАНУВАННЯ

Л.Ю. Астанін, О.О. Костилев, А.О. Фльорова

Предметом обговорення є два загальновідомі терміни: надширокосмугові (НШС) сигнали та ультракороткі імпульси (УКІ). Розглянуто умови їх вживання та різниця у значенні. Узагальнене основне рівняння локації (ОРЛ), що є вірним для сигналів з довільною шириною спектру, застосовується як основний засіб опису енергетичних вимог до НШС радарів. Розглянуто припущення щодо характеристик НШС радарів, що дозволяють представити ОРЛ у формі схожій на традиційну. Застосування імпульсних активних антенних решіток може бути засобом вирішення проблем енергії НШС сигналів. Поставлено задачі щодо високої пікової потужності НШС сигналів. Показано, що виявилось можливим отримувати складні НШС імпульсні сигнали з великою базою сигналу.