SOUNDING SIGNALS FOR THE ACTIVE LOCATION OF HIGH SPATIAL RESOLUTION

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Abstract. **Task of active location is detection of located object-target, determining the distance to it, the angular coordinates of the target, its direction and its speed. The problem is solved by using signals, which sounding, exploring the target of a non-contact method (remotely) - its irradiating, receiving reflected from the target (scattered from the target) signal and its processing. In active location of high spatial resolution are used short tonal signals (rectangular pulses with sinusoidal filling) and long-term wideband chaotic signals (limited on band of frequencies and duration of implementation). Short pulses are used when the distance to the target is not more than tens of meters. By increasing the distance to the target is required to increase the capacity to hundreds of megawatts per pulse. This is possible by using special devices, but burdened with a large set of problems. Processing outgoing and reflected short pulse produced oscillographic. Long-wideband chaotic signals formed by noise generators, using excitation in system of multiple modes of vibration and nonlinearity generator elements. Radiation, reception and processing of these signals provide the active location of high spatial resolution. Processing of chaotic signals is to construct a function of cross-correlation between the sent and received signal by a method of double spectral processing. In paper is compared the use of wideband chaotic signals in the radio- and hydrolocation.**

Keywords: **active location, sounding signals, tonal pulses, wideband chaotic signals, noise generator, dual spectral processing**

UDC 621.396.96, 623.519

Bibliography – 2 references *Received 14.05.2016*

RENSIT, 2016, 8(1):3-8 **DOI: 10.17725/rensit.2016.08.003**

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1. INTRODUCTION

Currently ongoing research and development in the field of improving the means of active location as a radio and acoustic. The most interesting is the choice of the sounding signals because of the frequency characteristics and the structure of these signals depends on the basic parameters of locators. To those features include the resolution of the range and angular coordinates, the possibility of allocating the signals reflected from the targets at the background ambient noises over long distances to the targets, the possibility of assessing the direction of movement and speed targets, and others. This is an extensive literature. For example it is our article, published in this journal [1]. The real work is devoted to a concrete selection of signals for the active location.

2. SPECIFICITY OF ACTIVE LOCATION OF HIGH SPATIAL RESOLUTION

Task of the active location is detecting of objects which scatter the radiation, and the determination of the distance to them, as well as the angular coordinates of this objects (targets). The additional task is estimates of motion direction and targets speed. According to the theory of wave processes, the power flux density with distance from the source (transmitting antenna) decreases in proportion to the square of the distance. Similarly, decreases flow power density of the signal reflected from located object (the target). As a result, the power of the sounding signal in the propagation to the target and back suffer substantial losses, the greater the greater the distance to the target. In the acoustic devices operating in an aqueous medium, the matter is compounded by significant dissipative losses, the greater, the higher the frequency of the sounding signal. Since reception of the reflected signal from the target is carried out against the background of the intrinsic noise of the receiving device and the ambient noise, important is the signal/noise ratio at the input of the receiving device locator

$$q^2 = \frac{2\int_{\tau} P_{in} dt}{N},$$

defined as ratio of integral of the received power in time (signal power) to the power spectral density of interference noises. With regard to surveillance radars for reliable target detection the value of this ratio must be greater than the number of 25.

Assuming that emitted and, accordingly, taken power of the sounding signal during the time send T is constant, and the noise is realized in the band Δf of frequencies occupied by the signal, then the above formula (S/N) can be written as follows:

$$q^2 = \frac{P_{in}}{P_N} \Delta f T.$$

The dimensionless expression ΔfT called signal base. Note that the process gain in the form of a rectangular pulse with a sine waveform (tone), previously widely used in radio and in sonar, is equal to **unity**.

These ratios indicate the need for a sharp increase in energy probing signal to assure confident detection of signal with an increase in the target range. So by increasing the range action of radar on the one order, the energy of the emitted signal must be increased by four orders of magnitude. And in sonar devices even more. Note that we are talking about the energy of signal. It can be increase not only due to the power, but also by increasing the base signal. An exception is the tone signal for which the base is equal unity. In this case it is necessary to increase the power only.

There are two basic ways in the processing of sounding signals in active location. The first method – a direct measurement of the time interval between the moments of emission and the return signal reflected from the target. Typically this is implemented by displaying the detected signals on the oscilloscope screen, the scanning speed is so selected that the two pulse fit on the screen. And by the visual distance between them could easily have calculated the distance to the target. To improve the measurement accuracy, the outgoing pulse is not displayed. Starting the scan is performed with a delay, and the second beam oscilloscope is supplied with timestamps. This method is applicable for the sounding signal in the form of very short pulses. It is necessary that the emitted and returned pulses do not overlap in time.

The second way is to calculating the cross-correlation function between sent and returning signals. The advantage of this method is the possibility to work with long sounding signals. In this case, the detection of distant targets can not be realized by increasing the power level of emitted signal, and by increasing the duration of the parcels. In terms of location of high spatial resolution this is very important.

The main requirement for sounding signal is the unimodality of its autocorrelation function – the presence of a single bright pronounced peak. These statistical physics say that such properties are possessed by the so-called "white noise" – the chaotic signal, an unlimited on spectrum and time. The maximum of the autocorrelation function of this signal is a delta function. In fact, you can work and by chaotic signals, that are limited band frequencies and the duration of implementation. **Fig. 1** shows plots of the autocorrelation function of the chaotic signal by narrowing of its spectrum.

These graphs show that the long-chaotic signal with a spectrum of finite width has the autocorrelation function with a single bright pronounced maximum. Its width determined by the upper boundary of the frequency spectrum. When cutting of spectrum up to the upper octave, function is left with a single maximum. Further cutting of the spectrum leads to the appearance of additional peaks, that are in the analysis can be seen as a mark of false targets.

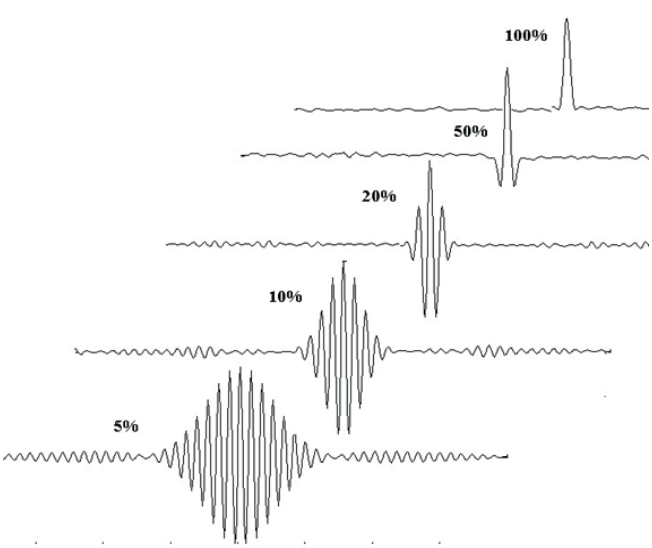

Fig. 1. *Evolution of the autocorrelation function of the chaotic signal by narrowing the bandwidth.*

From these data it is evident, that expedient use in locators of high spatial resolution, the prolonged broadband chaotic signals. An additional advantage of such signals is the possibility of a substantial increase in the resolution on the angular coordinates. When dealing with short parcels tone, to provide good resolution on the angle necessary to have an antenna system with a large aperture. For example, the radar 10 cm-range for resolution on the angle of about 1^0 must have the diameter of mirror antenna five meters. By working with a broadband chaotic signal, you can do small-sized antennas, spaced in space, using the interferometer principle, that widely used in the radio astronomical systems.

3. WORK FEATURES WITH TONAL SIGNALS AND SHORT PULSES

In high-precision radar systems the range resolution is determined by the pulse duration of the sounding signal. If the velocity of propagation of electromagnetic waves in an atmosphere of $C \sim 3 \cdot 10^8$ m/s and pulse duration is T then size L of the wave packet $C \times T$. This means that the 3rd meters (typical radar resolution) corresponds to the pulse duration of 10^{-8} seconds (10 nsec). Accordingly, for 30 cm – 1 nsec. In sonar systems, wave propagation speed in water at 20 000 times smaller. Accordingly, the pulse duration is increased for providing range resolution. It allows you to work with a more low-frequence signal.

Since increasing of resolution is connected to a decrease in the duration of the sounding signal, then for conservation of signal energy is required increasing its power. With an increase in the target range is required an additional increase in power due to reduced pulse repetition frequency – the processing of fewer pulses in a given time. Really we are talking about the power of tens-hundreds of megawatts per pulse. Such power in principle be achieved using so-called relativistic electron generators. It is extremely expensive to manufacture and operation of electrovacuum devices, which working with high-precision electron beams accelerated to a speed close to the speed of light. When dealing with such devices have problems related to protecting highly sensitive equipment at the time of the reception signal light, as well as the so-called "clutters", low-angle radar land clutter – signals reflected from local objects and received on the side lobes of the antenna pattern. The breakdown of the atmosphere is unlikely because the pulse is short. With regard to the sonar devices, increasing of power tonal signal leads to cavitation. Acceptable use of simple high-power pulses without tonal filling. In the geolocation widely are used sources of sounding signals explosive type. With regard to a hydrolocation, should consider the features of the propagation of such signals in the aquatic environment. We are talking about the rapid attenuation of high frequency components of the spectrum. As a result, a short pulse transforms as it propagates into a long-term low-frequency package. In the atmosphere this is very clearly visible. Lightning in the immediate vicinity of the observer sounds like a short, sharp click, which is turns into on the distance in long dull hum. Familiar military engineer, who was at the Semipalatinsk test site at the time of the test of the atomic bomb, told us that in fifty kilometers from the center of the explosion sound of it resembled the sound made by an intercontinental ballistic missile on takeoff.

It should also be noted that working with short pulses makes it impossible to determine the speeds of targets by using the Doppler effect. An exception is possible only when working with long sequences of tonal signals, as if cut from a highly stable sine wave. From the above it can be concluded about the possibilities of using the short pulse and tonal signals only at very small distances to targets. In radiolocation this units - tens of meters. In hydrolocation is even less.

4. WORK WITH A LONG WIDEBAND CHAOTIC SIGNALS

As already mentioned, processing of results of active locations by using broadband chaotic signals is possible by calculating the cross-correlation function emitted and scattered from target (s) signaling implementations.

Sequence of work with these signals consists of several procedures. Firstly, is necessary to form signals of predetermined duration, spectrum and autocorrelation characteristics. It can do by the analog and digital techniques. Secondly, it is necessary carry out the emission of signals in a predetermined direction, and then to take the signals reflected from targets. Finally, need to obtain by joint correlative processing of the emitted and received signals, the data about range to targets, the angular coordinates targets and, in the ideal case, the direction of movement and speed targets. Consider these procedures in detail.

The issues of formation of analog wideband chaotic signals have been studied in the Institute of Radio Engineering and

Electronics, Russian Academy of Sciences. In 1962 was discovered the effect of generation of noise fluctuations in the plasma system - an electron beam in a magnetic field. The development of this work led to the creation shumotronov - noise generators on traveling-wave tubes (TWT). It turned out that contributing to the chaoticness of generated oscillations such factors as the possibility of excitation in system the several modes of oscillations as well as a specific non-linearity of generator elements.

Further research and development led to the creation of different types of generators of wideband noise in the microwave-range on solid-state element base [incl. 2]. Details about the generators of wideband chaotic oscillations in [3]. Digital methods of implementing such fluctuations have been implemented on the basis of mathematical modeling of analog generators [4]. These studies revealed that the construction of such models allows the use of transformation and nonlinearities [5], unrealizable in the analog generators.

Digital methods allows also simulate a distribution as both of electromagnetic, and well as acoustic waves in various media. Particularly interesting is the variation of the autocorrelation function of the signal propagating in conditions of a strong dependence of the damping on the frequency, characteristic in acoustic and electromagnetic waves in the millimeter and submillimeter ranges. It is also possible modeling changes the structure of the wave packet in the reflection from a moving object with a predetermined speed, which provides an estimate of the velocity of the target relative to the radar.

The greatest difficulties are related to the joint processing of the emitted and received wideband chaotic sounding signals. The classic computer digital processing is currently only available for a relatively low-frequency signals. In reality maximum frequency should not exceed hundreds of MHz. This means that the used in radiolocation of high spatial resolution, wideband microwave signals can not be processed using digital techniques. Another thing - the hydrolocation, which working with signals in the tens - first few hundreds of kHz. Obviously in this case not exist the alternative for wideband chaotic signals.

For wideband chaotic microwave - signals there is a way of building cross-correlation function of the emitted and received signals. This so-called the double spectral processing. It is based on the famous theorem Wiener-Khinchin. According to this theorem, the cross-correlation function of two chaotic signals can be obtained by analyzing the spectrum of the sum of these signals [6]. The spectrum of the sum of the two signals is usually obtained by sequential analysis, using narrowband tunable filter, with followed by detection. Secondary spectrum is computed already digitally way. Specificity of this method is to increase the duration of processing with increasing distance to the target. We have to reduce the bandwidth of the tunable filter and the speed of its changeover. As a result, satisfactory results when working with signals in the centimeter range are obtained when range to the target in meters - tens of meters. Note also the possibility of estimating the distance between two targets located close to each other. To do this, the return signal from the targets is subject to double spectral processing. Good to use double spectral processing for realization of the interferometer. In this case, it is necessary to processing the sum of the

signals arriving at two spaced apart receiving antennas.

5. CONCLUSION

Summarizing the above, it can be argued that the use in active location of high spatial resolution the short pulsed and tonal signals is only possible at very small distances to targets. In this case, attract the simplicity of the signal processing for determining the distance to the target. But even in this case, the use of wideband chaotic sounding signals provides an additional benefit is the ability to substantially clarify the angular coordinates of targets and velocities of their movement. At large distances the use of noise signals allows to determine the distance between targets, the arranged close to each other, or "shiny" points of large-size target.

With regard to the possibilities for the implementation of high-resolution radar range for remote purposes, the most promising are long signals with frequency modulation on a discrete frequency grid. With regard to the possibilities for the implementation of high-resolution on range for radiolocation of remote targets, the most promising are long signals with frequency modulation on a discrete frequency grid.

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