TRANSNAV http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 10 Number 1 March 2016
DOI: 10.12716/1001.10.01.14

The Selection of Signals for Continuous Wave Radar which Reduce the Sensitivity to Doppler Shift of Frequencies

V.M. Koshevyy, I.V. Koshevyy & D.O. Dolzhenko
Odessa National Maritime Academy, Odessa, Ukraine

ABSTRACT: The signals with ideal correlation properties are of interest for continuous wave radar. At the same time it's important to provide low sensitivity to Doppler shifts of frequencies. There were considered signals with special structure due to amplitude modulation which provide capability of radar work with Search and Rescue Transponder (SART). Because the amplitude modulation has a drawback – not efficient use of signal energy, in a class of proposed signals there were considered signals with uniform amplitude. The mismatched filtering may be used by means special weighting functions for obtaining the necessary correlation properties.

Due to the fact that the sensitivity to the Doppler frequency shifts is an important indicator for selecting signals for marine radars it is of interest to consider continuous signals with low sensitivity to the Doppler frequency shifts. Continuous signals reduce significantly the peak power of radiation and improve environmental ecology and electromagnetic compatibility with other radio electronic devices on a vessel.

One of the possible approaches to the choice of such signals has been considered in [1]. Since the search and rescue transponder (SART) has no compression filter, for its work in the class of continuous signals it is required amplitude modulation and peak factor other than one, in particular, a class of binary signals has been presented in [2] and has the form:

$$\vec{s} = \left[s_0 s_1 s_2 \ \ldots s_{N-1}\right] = \left[a \ \ b \ \ b \ \ldots \ \ b\right]$$

On the basis of this structure it was built a class of signals, which ensures to co-operate CW radar and SART.

For the work of marine radar the signals with ideal correlation properties are of interest. This helps improve immunity of signals against interference such as clutter.

Therefore, within the continuous discrete signals with non-uniform structure there were considered signals with zero side lobe level of periodic autocorrelation function (PAF) which are defined as follows [2]:

$$a = |a| \cdot e^{i\varphi_a} = \frac{N-2}{2}, \text{ where } N \geq 2 \qquad (1)$$
$$b = |b| \cdot e^{i\varphi_b} = 1$$

Such signals have a peak factor:

$$H = \frac{S_{n\max}^2}{\sum_{n=0}^{N-1} \frac{S_n^2}{N}} = \frac{N \cdot (N-2)^2}{(N-2)^2 + 4 \cdot (N-1)} \qquad (2)$$

In order to reduce the peak factor there was proposed a method in [3, 4] based on the known property of element-wise multiplication of signals with mutually prime periods [5]. This increases the coherence of the resulting signal. In particular, an example was presented, where the resultant signal is obtained due to the product of two signals (1) and $N = N_1 \cdot N_2 = 21 \cdot 4 = 84$; the peak factor has a value $H = 17$ (according to the left part of (2)).

Expression for the calculation of Periodic cross-ambiguity function has the form

$$\chi(k,l) = \sum_{n=0}^{N-1} w_n^* s_{(n+k)} e^{i\frac{2\pi nl}{4N}}, \qquad (3)$$

where k is the discrete interval of time, and l is discrete of frequency with step $\Delta f = \frac{1}{4NT_0}$; T_0 is elementary pulse duration; w_n is the filter coefficient.

Below in Fig. 1 plots of three sections of the periodic ambiguity function (AF) of the signal with $N = N_1 \cdot N_2 = 21 \cdot 4 = 84$ are shown.

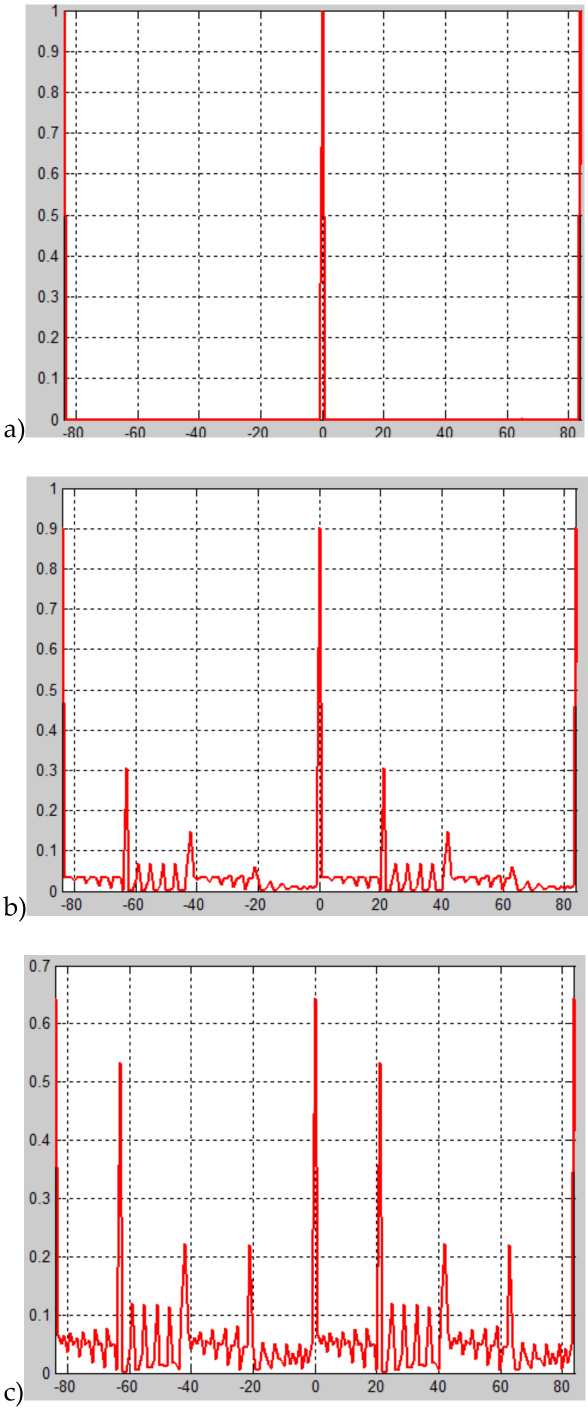

Figure 1. Sections of AF of signal $N = N_1 \cdot N_2 = 21 \cdot 4 = 84$: a) l=0; b) l=1; c) l=2.

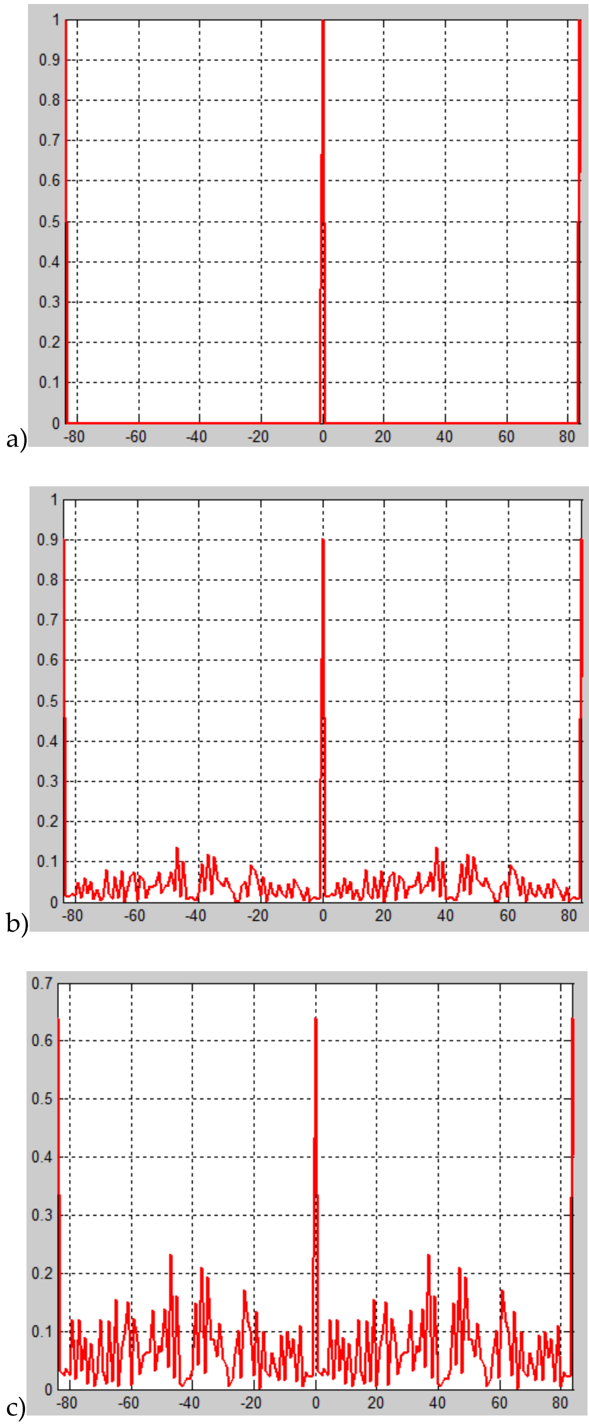

Figure 2. Sections of AF of signal $N = N_1 \cdot N_2 \cdot N_3 = 3 \cdot 4 \cdot 7 = 84$: a) l=0; b) l=1; c) l=2.

As it can be seen from the figure, a periodic autocorrelation function has ideal correlation properties. But the product of two signals has a drawback – not enough decreasing the value of peak factor $H = 9.5$ which leads to a noticeable sensitivity to Doppler frequency shift, which is undesirable. Therefore we consider the option, in which we can further reduce the peak factor. To do this, we can choose the smaller parts for product $N = N_1 \cdot N_2 \cdot N_3 = 3 \cdot 4 \cdot 7 = 84$. This will decrease the peak factor (according to (2)) of the signal to a value $H = 4.7$. At the same time, it is expected to reduce the side lobes of the cross sections of AF with a Doppler frequency shift.

a) b) c)

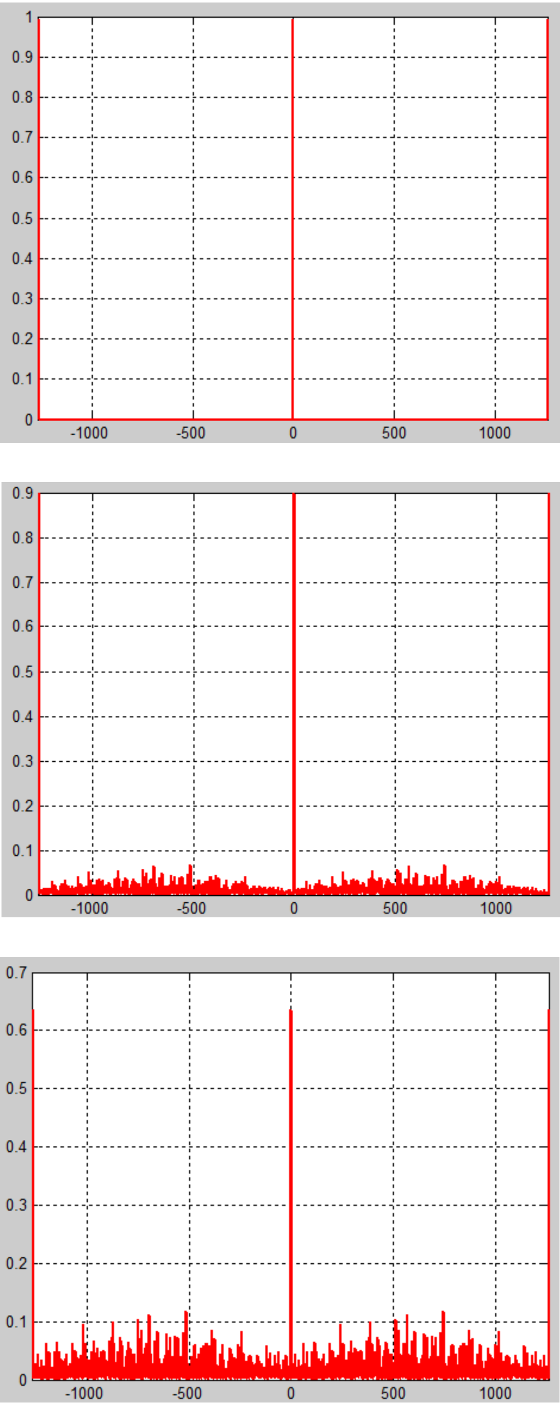

Figure 3. Sections of AF of signal $N = N_1 \cdot N_2 \cdot N_3 \cdot N_4 = 4 \cdot 5 \cdot 7 \cdot 9 = 1260$: a) *l*=0; b) *l*=1; c) *l*=2.

As it's expected and seen in Fig. 2 above, sensitivity to the Doppler frequency shift was reduced.

The presented approach is effective and can be used for obtaining signals with long periods. Consider, for example, a signal in the form of a product of four signals: $N = N_1 \cdot N_2 \cdot N_3 \cdot N_4 = 4 \cdot 5 \cdot 7 \cdot 9 = 1260$ (AF is on Figure 3) and peak factor is equal to $H = 5$.

It was confirmed that we have received periodic signal of long duration with a small peak factor and low sensitivity to the Doppler frequency shifts.

Thus, we can widely modify the peak factor of signals (1), obtaining an ideal correlation properties in the AF zero section, and with an increase in the coherent part of the signal we can reduce the side lobes of AF.

Further increasing of segments of resulting signal will lead to an increase in the peak factor. For the individual modes of radar let's consider the case when the peak factor is one: $H = 1$. In this case, the form of the signal is determined according to:

$$[a\,bb\ldots b], \text{ where } a = -1, \quad b = 1 \quad . \tag{4}$$

Thus to provide ideal properties of periodic autocorrelation function it can be used mismatched processing that is development of an approach described in [4]. The filter coefficients can be calculated according to the expression found:

$$w_0 = \frac{a(a + N - 1) - 2a - (N - 2)}{1 - a}; \quad w_n = 1$$

(n=1 $\div N - 1$). (5)

Arising some losses in signal-to-noise ratio can be found from the following expression:

$$\rho = \frac{\left[a\left[a\left(a+(N-1)\right)-2a-(N-2)\right]+(N-1)(1-a)\right]^2}{\left[\left[a\left(a+(N-1)\right)-2a-(N-2)\right]^2+(N-1)(1-a)^2\right]\cdot\left(a^2+(N-1)\right)} \tag{6}$$

If $a = -\frac{N-2}{2}$, then there has no losses in signal-to-noise ratio $\rho = 1$.

If $a = -1$; then the losses in signal-to-noise ratio can be calculated from the relation:

$$\rho = \frac{4 \cdot (N-2)^2}{\left[(N-3)^2 + (N-1)\right] \cdot N} \tag{7}$$

As an example there is a signal (4) when *N*=9, and on the Figure 4 there is cross- ambiguity function (CAF) of it.

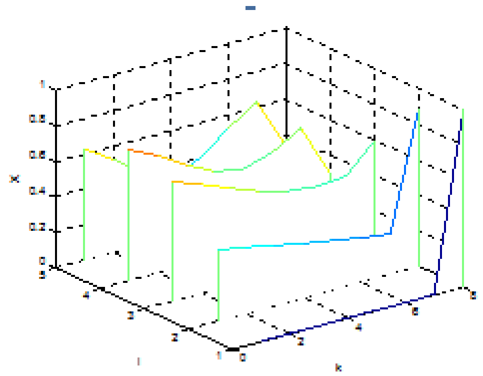

Figure 4. CAF of signal (2) N=9

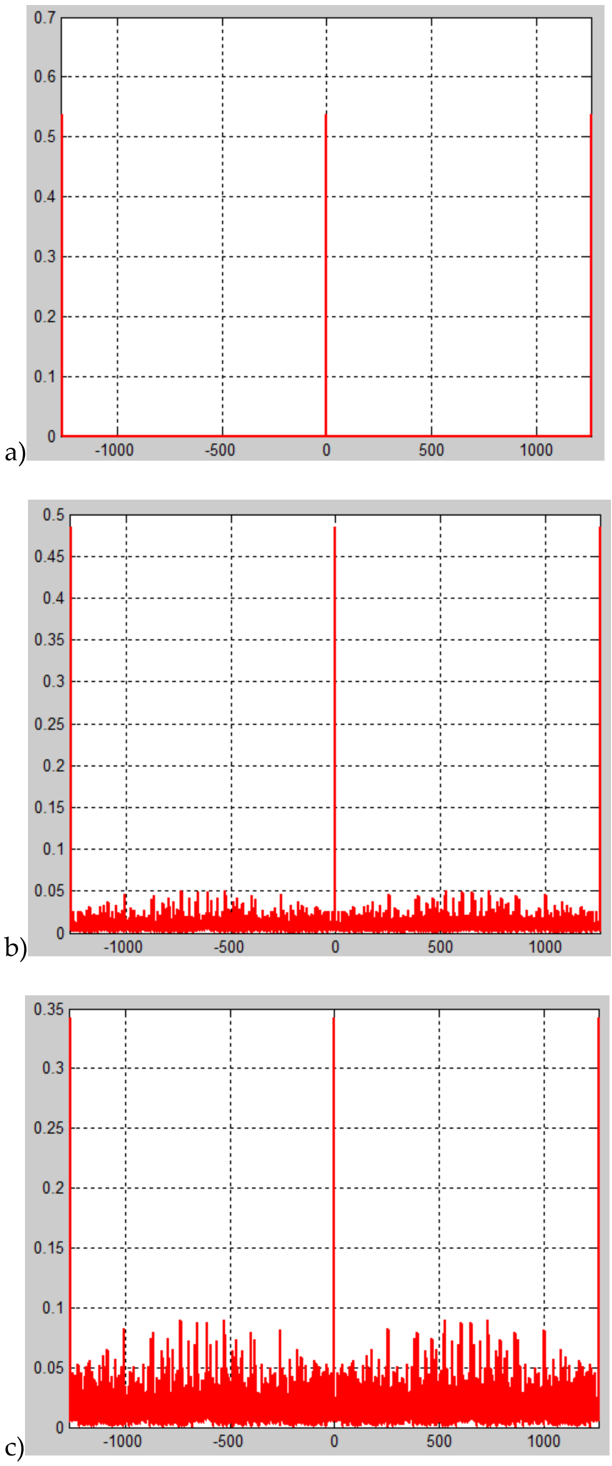

Figure 5. Sections of AF of signal $N = N_1 \cdot N_2 \cdot N_3 \cdot N_4 = 4 \cdot 5 \cdot 7 \cdot 9$: a) *l*=0; b) *l*=1; c) *l*=2

Here is an example where the resulting product signal is composed of signals (4) with relatively prime periods $N = N_1 \cdot N_2 \cdot N_3 \cdot N_4 = 4 \cdot 5 \cdot 7 \cdot 9 = 1260$.

The value of the loss in signal-to-noise ratio for the resulting signal will be a product of the values ρ of its component signals [6]: $\rho = \rho_1 \cdot \rho_2 \cdot \rho_3 \cdot \rho_4 = 1 \cdot 0.9 \cdot 0.65 \cdot 0.5 = 0.29$.

A cross- ambiguity function of product of the four signals $N = 4 \cdot 5 \cdot 7 \cdot 9$ in the case when the signals have the form $[a11\ldots1]\, a = -1$ is illustrated below in Figure 5.

On Fig.6 there is CAF of product of signals (4) when *N*=45.

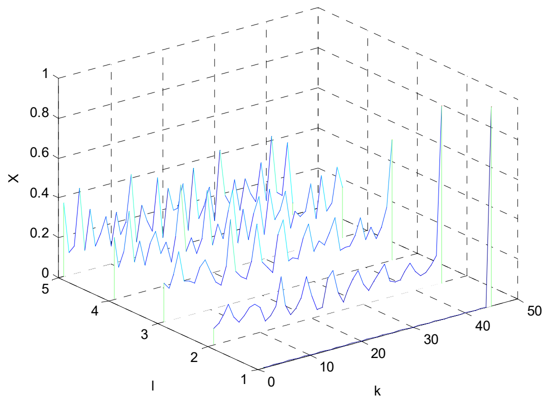

Figure 6. The CAF of product of signals (4), *N*=45

However, increasing N increases the losses in signal-to-noise ratio. Thus, when N> 11, the effectiveness of such signals will fall, because of significant losses in the signal-to-noise ratio. As possible solutions is using the additional classes of signals, including Barker codes. For example, consider a signal $N = N_1 \cdot N_2 \cdot N_3 \cdot N_4 = 4 \cdot 5 \cdot 7 \cdot 13$ which includes a Barker code $N_4 = 13$.

The presence of positive side lobes of the correlation function at the Barker code gives low losses in signal to noise ratio $\rho = 0.96$ [7]. Resulting ρ = 0,57.

Below in Fig. 7 CAF of such signal is presented.

However, the continuous mode has some difficulty in the practical implementation, since it requires the availability of two antennas on the vessel.

As a solution, we can use a quasi-continuous mode [8], when the entire signal is superimposed another signal with intervals of zeros. A disadvantage of such signals is that they are not suitable for all ranges of elements.

Another way is to use periodic signals of a certain duration [1], but they have a disadvantage which is a significant side-lobe level of AF equal $\frac{1}{N}$.

a)

b)

c)

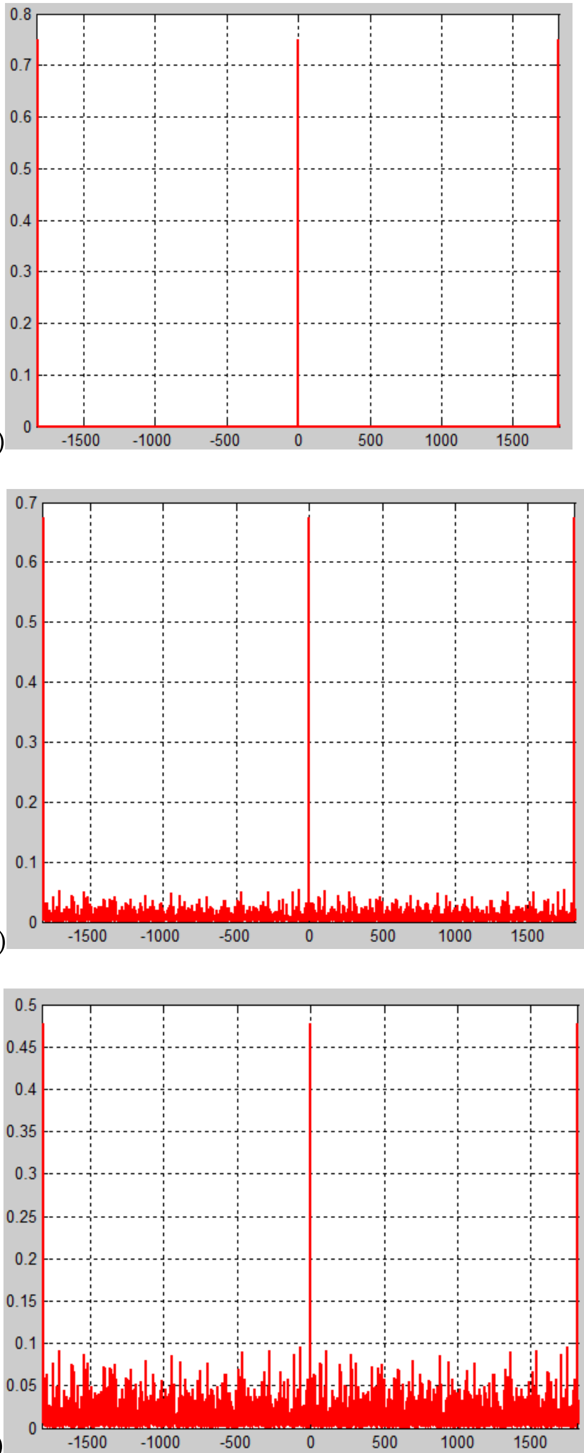

Figure 7. Sections of MAF of signal $N = N_1 \cdot N_2 \cdot N_3 \cdot N_4 = 4 \cdot 5 \cdot 7 \cdot 13$ with Barker code: a) l=0; б) l=1; в) l=2.

The third approach is the following: to radiate a certain signal in each period and due to complementarity zero side lobes of resulting aperiodic cross-correlation function will be provided.

Thus, based on the considered signals there are constructed composite signals of arbitrary length with suitable correlation properties and different peak factors, and in particular equal to unity. These signals provide low sensitivity to the Doppler shift of frequencies.

REFERENCES

[1] V. M. Koshevyy, D. O. Dolzhenko. The Selection of Signals which Enable Continuous Wave Radar in Conjunction with Existing SART [in Russian], Navigation (Судовождение), Odessa: ONMA, №21, 2012, pp124-129.

[2] V. M. Koshevyy, D. O. Dolzhenko. The Synthesis of Periodic Sequences with Given Correlation Properties // Proc. of IEEE East–West Design & Test Symposium (EWDTS'11), Sevastopol, Ukraine, September 9–12, 2011. – P. 341 – 344.

[3] V. M. Koshevyy, D. O. Dolzhenko. Selection of Signals for Continuous Wave Radar [in Russian], Automation of ship technical aids, Odessa: ONMA, №18, 2012, pp. 63-73.

[4] V. M. Koshevyy, D. O. Dolzhenko, The Signals of Marine Continuous Radar for Operation with SART, 10th International Navigational Symposium on "Marine Navigation and Safety of Sea Transportation" TRANS-NAV 2013, Gdynia.

[5] R. C. Titsworth, Correlation properties of cyclic sequences, Ph. D. Thesis, Calif. Inst. Tech., 1962.

[6] V. P. Ipatov, Periodic Discrete Signals with Optimal Correlation Properties, Radio I Svyaz, Moscow,1992.

[7] V. M. Koshevyy, A. O. Shapovalova,Optimization of filters for Periodic Cross-Ambiguity function side lobes suppression under additional constraints [in Russian], Navigation (Судовождение), Odessa: ONMA, №20, 2011, pp. 99-108.

[8] Pat. USA № 3727222.