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SPATIAL PROCESSING BASED ON THE SHIP'S ANTENNA ARRAY WITH MINIMUM QUANTITY OF CONTROLLING ELEMENTS

ПРОСТРАНСТВЕННАЯ ОБРАБОТКА СИГНАЛОВ В СУДОВОЙ АНТЕННОЙ РЕШЕТКЕ МИНИМАЛЬНЫМ ЧИСЛОМ УПРАВЛЯЕМЫХ ЭЛЕМЕНТОВ

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ABSTRACT

The algorithm of radiation pattern linear antennas array formation for vessel's radar is suggested. Only two controlling elements of array are needed for obtaining practically full rejection of side lobe level of pattern linear antenna array at any azimuth angle outside the main lobe area. This gives the possibility separation of signals from vessels with big and small Target Cross Sections, equals range and close azimuth angels. The results of Radiation Pattern calculations for different situations are given. The possibility of twinning of rejection points is shown.

Key words: spatial filter, filter's weight coefficients, reception diagram, antenna directivity, resolution.

Formulation of the problem in general terms and it's connection with important scientific practical tasks

The modern radars are high-powered technical means of navigation and take important part to ensure maritime safety. But they have high ship's antenna reception diagram side lobes level. It's lay to impossibility of separate signal observation from the big vessel (which has big effective reflecting surface (ERS)) and from small vessel, which has small ERS, and which are situated on the same distance and have azimuth angle's close value. The solution of this problem can be received in ship radar antenna pattern formation with using linear antenna array with controlled elements. The solution of this problem can be received in ship radar antenna pattern formation with using linear antenna array with low side lobes level.

The last achievements and publications analysis, in which the solution of this problem is began and selection of the unsolved aspects of the problem

Questions regarding the construction of processing systems with a limited number of tunable weight coefficients were considered in [1].

However, management issues directly side-lobe rejection of a linear array are discussed in [2].

Optimal methods of radiation pattern linear array with controllable elements are known and involve the adjustment of all elements on the rather complicated algorithms and discussed in [5].

Therefore, the issues of formation of zero levels of side-lobe linear array with a minimum number of control elements are relevant, and this determines the choice of this publication.

The article purposes formulation

The purpose of this paper is to improve the resolution of the linear antenna array by varying of the linear antenna pattern increase by varying of receiver signal processing control, based on the change in functional connections be spatial filter and by varying of spatial filter's weight coefficients value.

Presentation of basic research material substantiating scientific results

To solve the problem the method of constructing a processing system was suggested. In this case all of the receiving antenna array of spatial filter's weights coefficients W_i of the processing, except two (first and last: W_1, W_N), are fixed (selected under the condition of providing the required antenna pattern side lobe's level) ($W_2; W_3; ...; W_{N-1}$). Value of the two tunable weights coefficients are selected for carried out the condition of providing zero values in two points (θ_1, θ_2) of the reception pattern. The expressions, which are describing the reception pattern of linear array antenna $G(\theta)$ for this case, may be written in the following form:

$$\begin{aligned} G(\theta) &= G_{N-2}(\theta) - \gamma_1(\theta) \cdot G_{N-2}(\theta_1) - \\ &- \gamma_2(\theta) \cdot G_{N-2}(\theta_2) = \sum_{i=1}^{N} W_i \cdot e^{-j2\pi(N-1)\frac{d}{\lambda}\sin\theta}, \end{aligned} \tag{1}$$

where $G_{N-2}(\theta)$ – partial reception diagram,

$$G_{N-2}(\theta) = \sum_{i=2}^{N-1} W_i \cdot e^{-j2\pi(N-1)\frac{d}{\lambda}\sin\theta} \tag{2}$$

$$\gamma_1(\theta) = \frac{e^{j2\pi(N-1)\frac{d}{\lambda}\sin\theta_2} - e^{-j2\pi(N-1)\frac{d}{\lambda}\sin\theta}}{e^{j2\pi(N-1)\frac{d}{\lambda}\sin\theta_2} - e^{j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1}}; \quad \gamma_2(\theta) = \frac{e^{-j2\pi(N-1)\frac{d}{\lambda}\sin\theta} - e^{-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1}}{e^{j2\pi(N-1)\frac{d}{\lambda}\sin\theta_2} - e^{j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1}} \tag{3}$$

$\varphi = 2\pi\frac{d sin\theta}{\lambda}$ – signal phase; λ – wave's length; d – distance between antenna's array elements; θ – angle between the normal to the axis of the array antenna and direction of coming signal.

(N-2) fixed weight coefficients may selected under condition of additional suppression average level of reception diagram's side lobes (2) with possible widening the main lobe of antenna array (1).

So, the full number of the coefficients, which creates reception array diagram, is equal .

The expression for fixed weight coefficients has the next form [4]:

$$W_f = D^{-1} \cdot 1 \tag{4}$$

where D^{-1} – inverse matrix; 1 – identity column-vector, which consists of all unit numbers.

Matrix D is formed as follows:

$$D = \sum_{L_1}^{L_2} 1 \cdot Q_l \cdot 1^t \cdot Q_l^*, \tag{5}$$

where Q_l – diagonal matrix:

$$Q_l = \begin{bmatrix} e^{j2l2\pi\frac{d}{\lambda}\sin\Delta\theta} & 0 & 0..... & 0 \\ 0 & e^{j3l2\pi\frac{d}{\lambda}\sin\Delta\theta} & 0 & ..... \quad 0 \\ 0 & 0 & 0 \quad ...... & e^{j(N-1)l2\pi\frac{d}{\lambda}\sin\Delta\theta} \end{bmatrix}$$

$\Delta\theta_f$ – an interval, between suppressing points of the spatial diagram $G_{N-2}(\theta)$; 1^t – transposed matrix; L_1, L_2 – upper and lower bounds for suppressed points.

Choosing in Q_l (5) step $\Delta\theta_f$, and also values L_1 and L_2 we can provide different values of average level of side lobes $G_{N-2}(\theta)$, but with varying degrees of its main lobe widening.

Thus, if $\Delta\theta_f = arcsin\,\frac{1}{2(d/\lambda)(N-2)}$ (ratio $d/\lambda = 0{,}5$ was set everywhere), $L_1 = 0$ and $L_2 = N-2$ from (4), (5) we are getting the case where all $W_1 = 1$ ($i \in (2, N\text{-}2)$).

That is the case of fully coherent to reception diagramm $G_{N-2}(\theta)$ (equable correction), which corresponds the condition with absence of main lobe widening (Fig.1, a). Such approach was considered in [1] and [2].

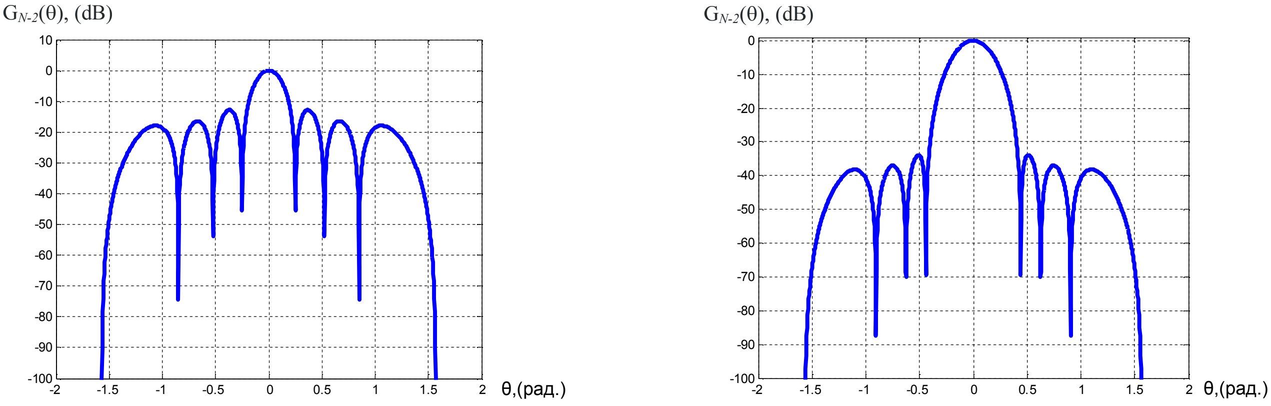
If $\Delta\theta_f = arcsin\,\frac{1}{4(d/\lambda)(N-2)}$, and $L_1 = 3$, $L_2 = 2N - 3$, the unequal values of weight coefficients can be obtained (uneven correction), which provides compromise between average value of side lobes suppression (more than – 30 dB) and relatively small main peak's extension (about 10%) (Fig.1, b).

This diagrams are showing, that average level of suppression with different W_i less, than in case, when $W_2 = W_3 = ... = W_{N-2}$.

The expression for tunable weight coefficients has the following form:

$$W_1 = \frac{G_{N\text{-}2}(\theta_2)\ e^{j2\pi 2\pi\text{-}1)\frac{d}{\lambda}sin\theta_1} - G_{N\text{-}2}(\theta_1)\ e^{j2\pi 2\pi\text{-}1)\frac{d}{\lambda}sin\theta_2}}{e^{j2\pi 2\pi\text{-}1)\frac{d}{\lambda}sin\theta_2} - e^{j2\pi 2\pi\text{-}1)\frac{d}{\lambda}sin\theta_1}}; \tag{6}$$

$$W_N = \frac{G_{N-2}(\theta_1) - G_{N-2}(\theta_2)}{e^{j2\pi(N-1)\frac{d}{\lambda}\sin\theta_2} - e^{j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1}} . \quad (7)$$



a) *b)*

Figure 1. Partial reception diagram: a – with equal weight coefficients values; b - with unequal weight coefficients values

Fig.2,*a-c* shows the calculation by expressions (1), (2), (3) for case of common-mode processing in partial antenna (all values $W_2 = W_3 = ... = W_{N-2} = 1$). In this case:

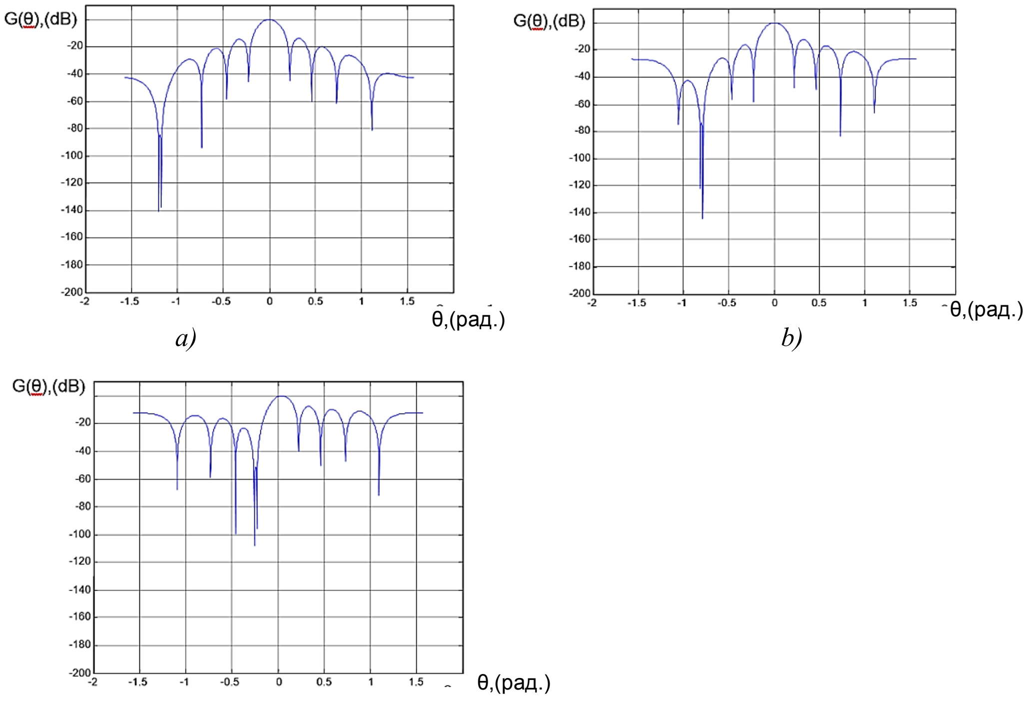
$$\Delta\theta_f = arcsin \frac{1}{2(d/\lambda)(N-2)} , \; L_1 = 0 \text{ и } L_2 = (N-2).$$

Losses in antenna's directivity to fully common-mode reception diagram:

$$\rho = \frac{|G(0)|^2}{N \sum_{n=1}^{N} |W_n|^2} . \quad (8)$$

The similar type of expressions, as (6), (7) were obtained for the signal time processing in the case of frequency selection [1], [6] and the time-frequency task selection signal [7].

As we can see, the suppression of this points is high enough, and the side lobes level between the suppressed points not high (about – 80 dB). Losses in antenna's directivity (8) are increase with drawing closer to main lobe, and in considered case isn't more than -1,4 dB.



a) *b)*

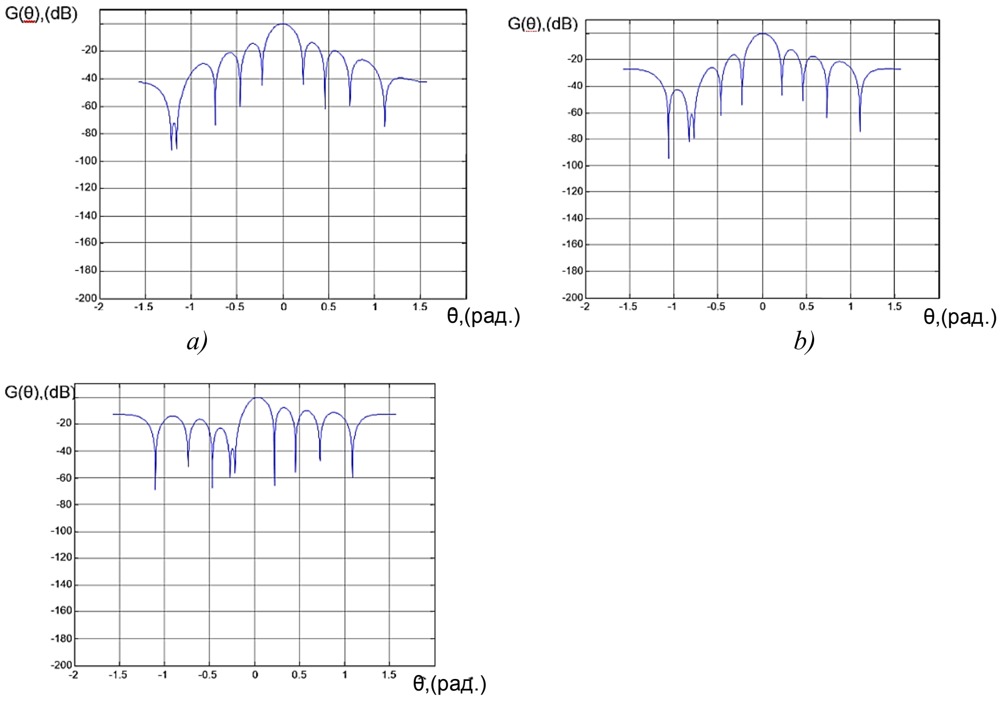
c)

Figure 2. Reception diagram (partial diagram equable correction):

a - $\theta_1 = -1.2001, \theta_2 = -1.1718, \rho = -0.2238, \text{dB}$; *b*- $\theta_1 = -0.8137, \theta_2 = -0.7854, \rho = -0.2784, \text{dB}$;

c - $\theta_1 = -0.2576, \theta_2 = -0.2293, \rho = -1.4107, \text{dB}$

For comparison, on fig.3, *a-c* was considered the case, when the distance between suppressed points was increasing in twice. The side lobes level between suppressed points is increase, but wasn't more than -40 – -60 dB.



a) *b)*

c)

Рисунок 3. Диаграмма направленности при равномерной коррекции (парциальной диаграммы) с удвоенным расстоянием между подавляемыми точками:

a – $\theta_1 = -1.2143, \theta_2 = -1.1577, \rho = -0.2228, \text{dB}$; *b* – $\theta_1 = -0.8278, \theta_2 = -0.7712, \rho = -0.2749, \text{dB}$;

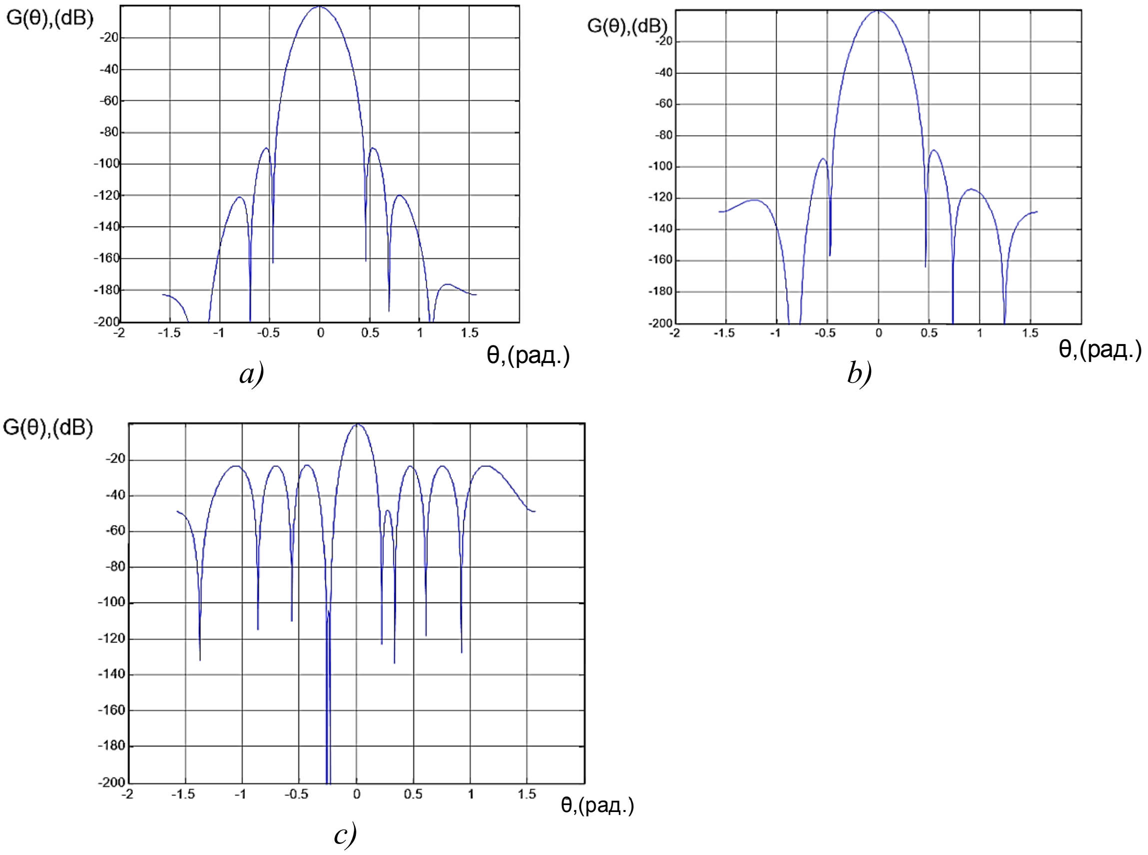
c – $\theta_1 = -0.2717, \theta_2 = -0.2152, \rho = -1.3647, \text{dB}$

For comparison, on fig.3, *a-c* was considered the case, when the distance between suppressed points was increasing in twice. The side lobes level between suppressed points is increase, but wasn't more than -40 – -60 dB.

Now let's consider the case, when:

$$\Delta\theta_f = \arcsin \frac{1}{4(d/\lambda)(N-2)}\ ,\ L_1 = 3 \text{ and } L_2 = (2N-3).$$

That is the case, when we get unequal values of weight coefficients, which are obtained by (4), (5), which provide the compromise between level of side lobes suppression (about 30 dB) and not high main lobe widening (about 10%) (fig.4, *a-c*).



a) *b)* *c)*

Figure 4. Reception diagram with equable correction (of partial diagram):

a – $\theta_1 = -1.2001, \theta_2 = -1.1718, \rho = -0.4202$, dB; *b* – $\theta_1 = -0.8137, \theta_2 = -0.7854, \rho = -0.4620$, dB;

c – $\theta_1 = -0.2576, \theta_2 = -0.2293, \rho = -2.7293$, dB

With the same suppressed points θ_1 и θ_2 we received less average side lobes level within the given area at the expense of some main lobe widening.

It interesting to note, than if instead of reception diagram, which described by (1), we use the expression for symmetrical form with real coefficients (11), (12) in following form:

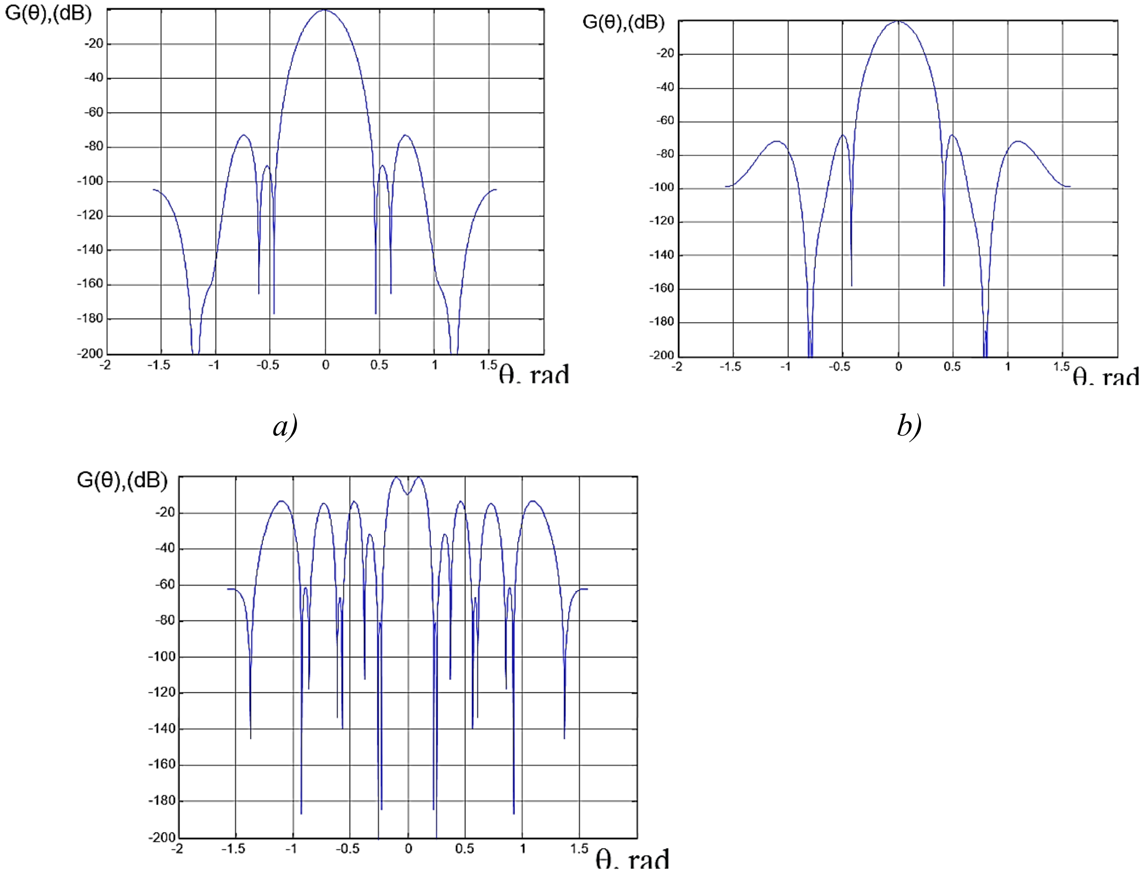
$$G^{(1)}(\theta) = G^{(1)}{}_{N-2}(\theta) - \gamma_1{}^{(1)}(\theta) \cdot G^{(1)}{}_{N-2}(\theta_1) - \\ - \gamma_2{}^{(1)}(\theta) \cdot G_{N-2}{}^{(1)}(\theta_2)$$

$$\text{где}\quad G_{N-2}^{(1)}(\theta) = G_{N-2}(\theta)\cdot e^{j\pi(N-1)\frac{d}{\lambda}\sin\theta}, \tag{10}$$

$$\gamma_1^{(1)}(\theta) = \frac{\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1\right]}{\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_2\right]-\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1\right]} - \frac{\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta\right]}{\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_2\right]-\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1\right]} \tag{11}$$

$$\gamma_2^{(1)}(\theta) = \frac{\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta\right]}{\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_2\right]-\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1\right]} - \frac{\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1\right]}{\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_2\right]-\cos\left[-j2\pi(N-1)\frac{d}{\lambda}\sin\theta_1\right]} \tag{12}$$

We can get reception diagram with suppressing in four points with symmetrical positioning relative to main lobe. As an example, on figure 5, a-c are showed the next diagrams:



a) *b)*

c)

Figure 5. Reception diagram with real coefficients (symmetrical):

a – $\theta_1 = -1.2001, \theta_2 = -1.1718, \rho = -1.0848$, dB*;* *b* $\theta_1 = -0.8137, \theta_2 = -0.7854, \rho = -1.5527$, dB*;*

c – $\theta_1 = -0.2576, \theta_2 = -0.2293, \rho = -2.4359$, dB

Conclusions and perspectives for further work in this area

Such away, the algorithm of radiation pattern linear antennas array formation for vessel's radar is suggested, which provide high enough side lobes level suppression of reception diagram with only two controlling elements, this gives the possibility separation of signals from vessels with big and small Target Cross Sections, equals range and close azimuth angels. It's impossible to reach by using standart vessel's antennas. As in the case of equal (N-2)- weight coefficients, which forms the partial diagram, as in the case of uneven correction, it's provided zero level of side lobes within the given area with reduced average side lobe's level in case of equable correction. Where in, the algorithm of tunable weight coefficients formation (6) and (7) are easy for practical implementation. The possibility of twinning of rejection points is shown. The further research will be directed to decrease the losses in antenna directivity.

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