

N.S.Karishnev, V.V.Semenov, M.M.Fuksov

**ONBOARD SONAR DETECTOR OPERATING IN INFRASONIC FREQUENCY BAND**

The Federal State Unitary Enterprise "Morphyspribor"  
 46 Chkalovsky Pr., St. Petersburg, 197376 Russia  
 Tel.: (812) 235 9287; Fax: (812) 320 8052  
 E-mail: mfp@mail.wplus.net

*The report considers a structure of infrasonic frequency detector featured by receiving antenna onboard the platform thus ensuring the circular search and estimation of motion parameters. Such feature of above detector as development of the signal signature attribute by spatial channel outputs depending on direction on the object was used as the principle of spatial filtration of noise sources*

**1. ACTUALITY**

The necessity of use of detectors operating in low sound and infrasonic frequency bands is defined by the rational concept of the all-range passive acoustics, according to which passive-listening sonars operating with receive antennas located on the platforms are characterized by frequency band extended to low frequencies. It should be also noted that low and infrasonic frequency bands owing to the large information capacity (residence of discrete components in a continuous part of a noise-emitting spectrum) has been attracting designers of sonar surveillance equipment for a long time.

The development of detectors operating in the above frequency band and featured by antennas located on the platforms thus ensuring the solution of a target-assignment task is of the great practical interest.

**2. DETECTOR'S ARRANGEMENT**

Let consider the detector's structure as is shown in Fig. 1. The detector has a receive antenna consisting of 4 nondirectional receivers located in a horizontal plane. Signals going from diagonal, orthogonally positioned pairs of receivers are subjected to the identical algorithmic processing, that ensures two independent outputs, whose normalized voltages caused by the acoustic field generated by plane-wave signal can be finally expressed by the following formulas:

- for output I: 
$$R(\theta, \alpha) = \frac{\int_{\omega_l}^{\omega_h} F_{PS}(\omega) \sin\left[\frac{\omega l}{c}(\cos \theta \cos \alpha)\right] d\omega}{\int_{\omega_l}^{\omega_h} F_{PS}(\omega) \sin\left(\frac{\omega l}{c}\right) d\omega} \tag{1}$$

- for output II: 
$$R(\theta, \alpha) = \frac{\int_{\omega_l}^{\omega_h} F_{PS}(\omega) \sin\left[\frac{\omega l}{c}(\sin \theta \cos \alpha)\right] d\omega}{\int_{\omega_l}^{\omega_h} F_{PS}(\omega) \sin\left(\frac{\omega l}{c}\right) d\omega} \tag{2}$$

where  $\theta, \alpha$  are the angles in the spherical coordinate system which describe orientation of the plane-wave signal (beam) of the antenna;

$F_{PS}(\omega)$  – energetic signal spectrum in the reception site;

$l$  – distance between receivers forming a diagonal pair.

Response of detector outputs I and II effected by the acoustic field of the plane sound wave at  $F_{PS}(\omega) = const$ ;  $\alpha = 0^0$ ;  $l = 0,2 \lambda_n$  is presented in Fig. 2a.

If a series of vertical lines is drawn in such way that they cross the curves  $R_I(\theta)$  and  $R_{II}(\theta)$ , then the corresponding pairs of coefficients  $K'_1$  and  $K''_1$ ,  $K'_2$  and  $K''_2$ , ... or the corresponding relations of voltage outputs taking into consideration their signs can unambiguously determine a direction to the object. Due to such structural feature of the detector it is possible to estimate current bearings and their

derivatives in accordance with the simultaneously measured voltages on two outputs of the above structure (Fig. 2b).

As the main advantages of the detector's structure the following ones can be revealed:

- wide band, which is defined by the stable azimuth directions (angle  $\theta$ ) to radiating sources (tone or noise), whereon the sign of the spatial transmission rate varies at any signal frequency at the chosen upper frequency limit, provided that  $l < \frac{\lambda_h}{2}$ . In case of above detector's structure, there are two such directions for each of algorithmically independent outputs and they are estimated by the angle  $\theta = \pm \frac{\pi}{2}$  with respect to the lines crossing the diagonal pairs of receivers;
- opportunity of the wide choice of the spacing parameter  $l$ , that is of the key concern in design of receive antennas of the class under discussion;
- lack of constant component caused by the sea noise (acoustic noise fields close to isotropic model or caused by a interfering ocean surface are considered);
- opportunity of functioning in passive listening and echo ranging modes;
- suppression of the noise, generated by the ocean surface by means of beam forming for each of two channels (Fig.3) featured by zero transmission rates in the direction orthogonal to the ocean surface;
- in the isotropic noise field, the noise immunity of the detector 2.5 times as many as the noise immunity of the detector that operates the antenna constructed as nondirectional receiver in condition of the equal working frequency ranges and history (accumulation) times.

### 3. ESTIMATION OF CURRENT BEARING TO THE OBJECT

According to expressions (1, 2) the coefficients of the spatial transmission rate of two detector's outputs depend on the form of the signal spectrum  $F_{pc}(\omega)$ , whose estimation at the sufficiently large s/n ratio can be performed by the output of any of band-pass filter (Fig. 1). In case of lack of the opportunity to carry out the estimation of the signal spectrum (because of the small s/n ratio), the hypothesis about the shape of noise spectrum of the object is assumed.

Then, according to expressions (1) and (2), the library of coefficients (LoC) is computed taking into consideration the available characteristics of the signal spectrum in the reception point and the antenna's parameters for two detector's outputs.

The LoC is assumed as a collection of computed numbers stating the unambiguous conformity between directions in a horizontal plane to the noise emitting object with respect to the array's orientation and also relation of the corresponding voltages on orthogonal detector's outputs, taking into consideration their signs at each of two outputs. The angle range  $\theta$ , wherein the LoC is formed (relevant number of pairs of coefficients  $K'_n$  and  $K''_n$  (Fig. 2a)) is equal to  $0-360^\circ$  with the step  $\Delta\theta$  as is determined by tactical tasks, i.e. by the system designated purpose.

After detection in passive listening mode and achieving the proper s/n value, the estimation of the bearing to the object is carried out according to the data going from two detector's outputs and LoC. Accordingly, the search is carried out for that pair of coefficients of the spatial transmission in LoC ( $K'_n$  and  $K''_n$ ) for the certain angle  $\theta_n$  (Fig. 2a), whose ratio taking into consideration their signs coincides most closely with the voltage ratio of two detector's outputs (Fig. 2b). The pair of coefficients of LoC, chosen in conformity with the above rule, unambiguously determinates the angle  $\theta_n$ , which can be considered as an estimation of the current bearing to the object at the moment  $t_n$ .

It should be noted, that the functioning of the proposed algorithm in passive listening generated by only one object. If more than one object is located in an observation area of the station, the proposed algorithm is able to solve the stated task, but only by discrete components of noise-emitting. In this

case the detector's structure is not changed essentially, nevertheless, after realization of a narrow-band frequency filtering, the estimation of frequencies whereon detection have been performed is carried out for each frequency component in multiplier's branches of integrators' outputs. Especially for these frequencies, LoC is collected having the information volume of  $2MK$  ( $M$  a number of discretizes at which the detection has been completed;  $K$  – number of coefficients defined by the angle step  $\Delta\theta$  in the azimuth angle range of  $0 \div 360^\circ$ ). The sign data analysis performed on detector's outputs for certain frequency components allows to reduce essentially the LoC volume and therefore the total time of the task solution.

#### 4. RESULTS OF MODELING

The modeling of the estimation algorithm for bearings to the noise-emitting object for the plane-wave signal arriving from horizontal directions (at  $\alpha = 0^\circ$ ) was carried out at the following detector's parameters:  $l = 0,2 \lambda_h$ ;  $f_l = 30$  Hz;  $f_h = 60$  Hz; the integrator's collection time is  $T=10$  s.

Results of modeling are presented for three s/n ratios on the integrator's output:  $Q=5, 10, 20$ .

With the purpose to study dependence of the accuracy of the estimation algorithm of the bearing to the object using the knowledge of the noise-emitting spectrum, the modeling of two options have been performed:

- the signal spectrum in the reception point is known precisely and has rolloff 6 dB/octave;
- the true signal spectrum in the reception point has rolloff 6 dB/octave, while for LoC collection, the hypothesis about a signal featured by constant spectral density is assumed, as caused by assumption that it is impossible to evaluate its spectrum.

According to modeling data, histograms based on 1000 measurements of directions to the object at input angles  $\theta = 45^\circ$  (Figs. 5a, b) and  $\theta = 90^\circ$  (Figs. 5c, d) are presented at the precisely known signal spectrum (Figs. 5a, c) and at the assumed hypothesis about it (Figs. 5b, d).

Results of modeling of the estimation of the bearing to the object according to proposed algorithm based on the hypothesis about the shape of a continuous part of the noise-emitting spectrum in reception point are practically invariant with respect to the spectrum shape in limits from uniform spectrum to the spectrum having rolloff 6 dB/octave. This peculiarity allows to use a hypothesis about signal spectrum shape instead of procedure of measuring of the signal spectrum, which can be ensured only at the sufficiently large s/n ratios. The analysis of histograms demonstrates the essential dependence of estimation accuracy of the bearing on the s/n ratio. Thus, with the growth of s/n ratios from  $Q=10$  up to  $Q=20$  (Figs. 5a, b), the root-mean-square error of the bearing estimation decreases from  $\sigma \approx 8^\circ$  to  $\sigma \approx 3^\circ$ .

The studies revealed that the modeling allows to estimate (depending on the tactical system designated purpose) the low limit (threshold) of the s/n ratio ( $Q \geq Q_{ires}$ ), since which it is expedient to use the proposed algorithm of estimation of the object motion parameters at the given upper limit of the error.

Analytical studies of electroacoustical sensitivity ( $\mu$ ) for the detector's spatial channel (at the integrator's output) with respect to the acoustic field of the noise (isotropic) shows the heavy dependence on the  $l/\lambda$  (Fig. 4). This dependence defines sufficiently high requirements to the low-noise capability of preliminary amplifiers.

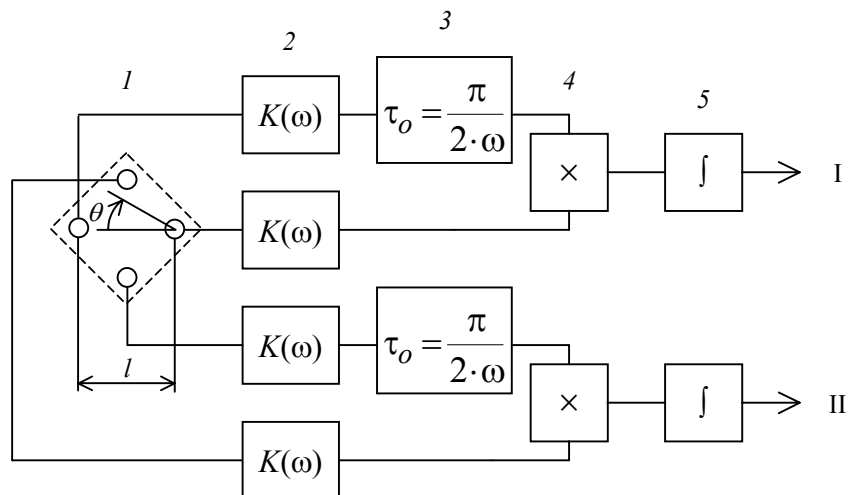


Fig. 1. Detector's structure: 1 - receive array; 2 – band-pass filter; 3 - phaser; 4 - multiplier; 5 - integrator

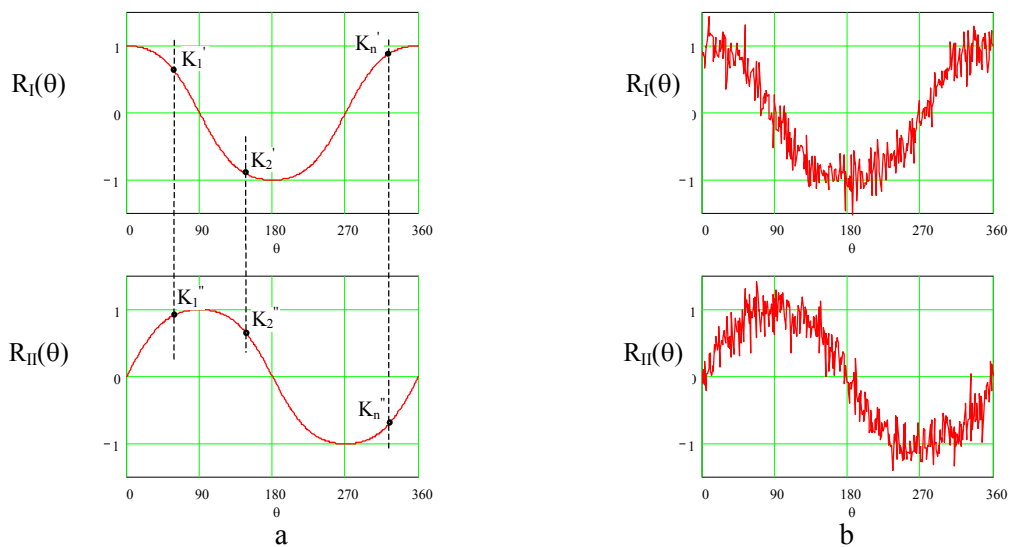
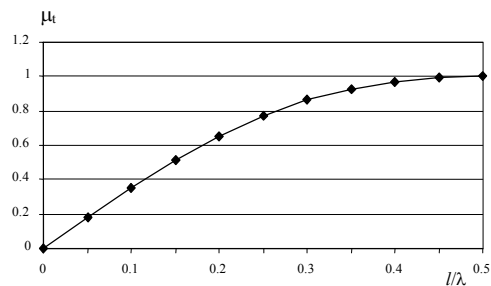


Fig. 2. Detector's voltage outputs versus direction (angle  $\theta$ ) to the object: a – no-noise condition; b - in the presence of the noise



Fig. 3. Beam pattern of the infrasonic frequency detector



g. Fig. 4. Normalized sensitivity of the spatial channel (integrator's output) in the isotropic noise field versus  $1/\lambda$

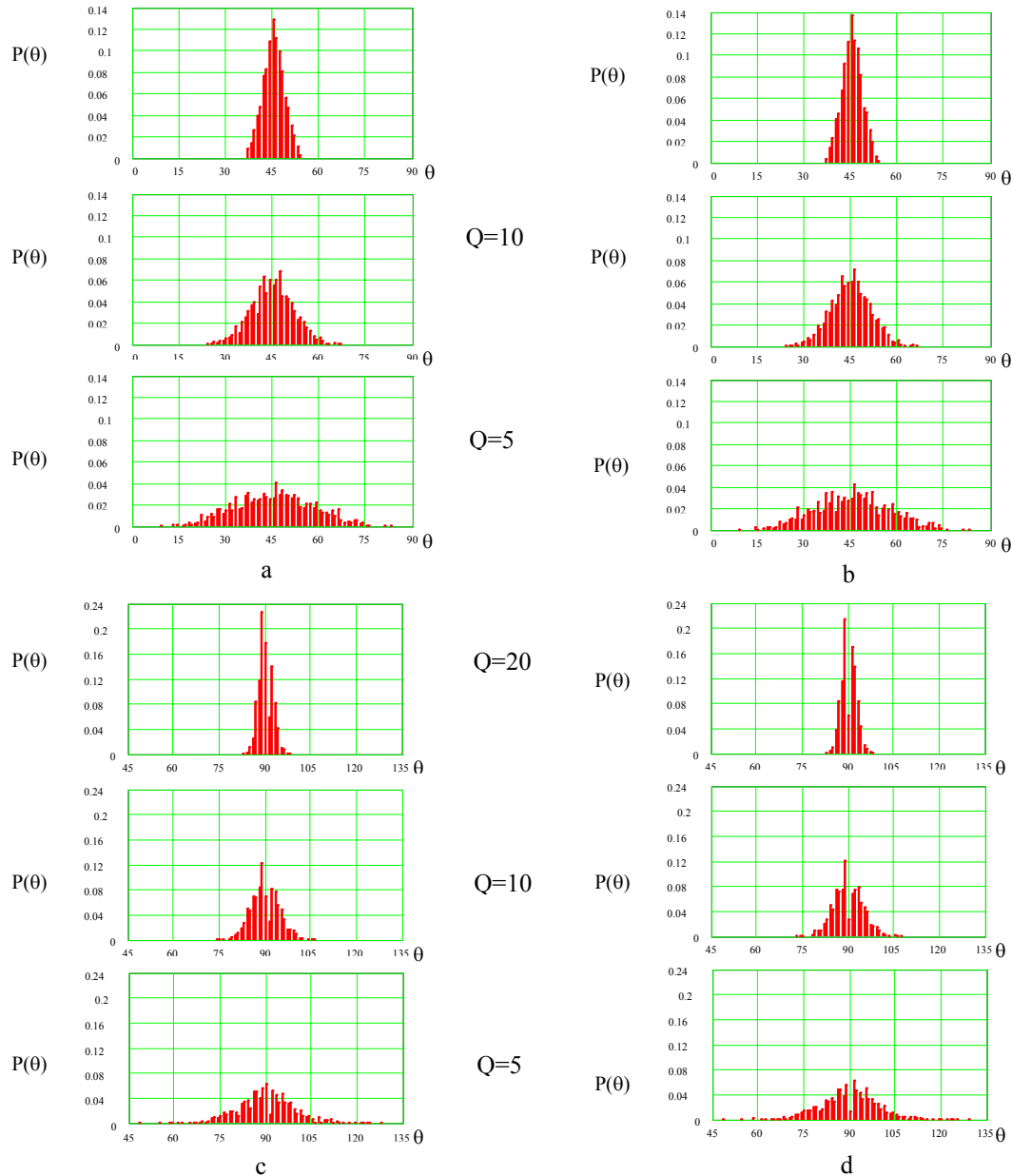


Fig. 5. Histograms of 1000 measurements of directions to the object for input angles of  $\theta = 45^\circ$  and  $\theta = 90^\circ$  at various signal-to-noise ratios

### 5. CONCLUSIONS

1. The proposed detector operating with the orthogonal antenna array whose receivers located as a diagonal pair have horizontal size equal to  $l < \frac{\lambda_h}{2}$ , ensures estimation of direction to the object with root-mean-square error  $\sigma \approx (3-5)^\circ$  in case of sufficient s/n ratio at the output of the spatial channel ( $Q = 10 \div 20$ );
2. Results of modeling of bearing estimation to the object in accordance with the proposed algorithm based on a hypothesis about the shape of continuous part of noise spectrum in reception site are actually invariant to its shape in the detector's frequency band in the limits from the uniform spectrum up to one having rolloff of 6 dB/oct;
3. The proposed detector is characterized by the absence of the constant output component of close to isotropic acoustic sea noise.