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BISTATIC SYSTEMS

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This paper describes key features of a bistatic operation in the hydroacoustic systems, his performance model and constraints imposed by environment and propagation conditions in shallow water. The architecture and construction of bistatic systems, their features and requirements has been presented. The application of bistatic systems, especially in protection systems, has been presented as barriers protecting anchorage or harbour, barriers protecting straits or entries to the harbour. Attention was paid on possibility of cooperation among existing, commonly available sonars and bistatic acoustics devices.

Key words: bistatic, multistatic, sonar, protection.

1. Introduction – bistatic geometry

Bistatic configuration is characterized by a triangle of source, target and receiver positions – Fig. 1, and his performance may be expressed in the form of bistatic sonar equation (1) [4].

$$\mathrm{SE} = \mathrm{ESL} - \mathrm{TL}_1 - \mathrm{TL}_2 - [(\mathrm{NL} - \mathrm{AGN}) \oplus \mathrm{RL}] + \mathrm{TS} - \mathrm{DL} - \mathrm{L}, \qquad (1)$$

where SE – signal excess, ESL – energy source level, $\mathrm{ESL} = \mathrm{SL} + 10\log 10T$; T is the duration of the transmitted pulse, TL_1 – transmission loss from source to target, TL_2 – transmission loss from target to receiver, NL – noise spectral level, AGN – array gain against noise, TS – target strength, DL – threshold required for detection, L – loss term to account for time and system losses, RL – reverberation spectral level, $\oplus$ – "power summation" defined as $\oplus = 10\log\sum_{i=1}^{n} 10^{L_i/10}$ where L_i is the level of the i-th noise source [dB] and n the number of contributing noise sources.

In the BS segment presented in Fig. 1 – the R_x module received (after the time $t_0 = R/c$) direct blast and then echoes signals within the time from t_0 to $t_{\max}$, where $t_{\max} = 2R/c$ is the maximum delay of echoes from targets located at the detection range. The target location, in relation to R_x position, can be determined by R_2 and bearing β. The bearing is the angle between R_0 and R_2 lines and may be determined

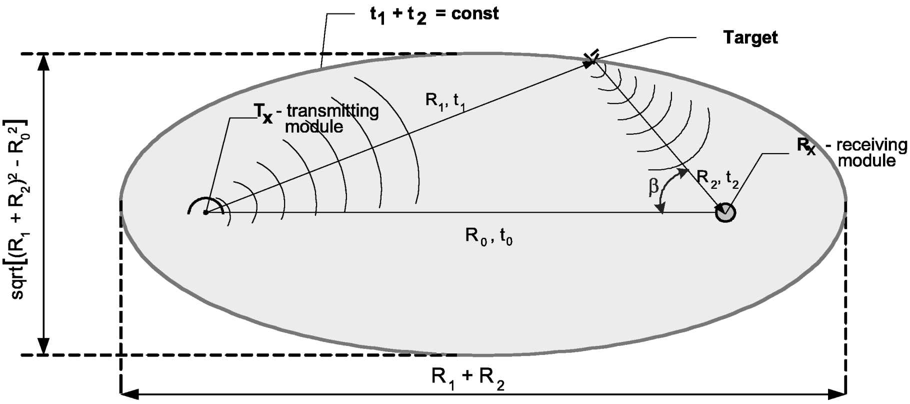

Fig. 1. Bistatic geometry.

by receiver's antenna position (i.e. from electronic compass) and beamformer data. The distance between the target and R_x module is given by following equation [1]:

$$R_2 = \frac{1}{2} t \cdot c \frac{t \cdot c + 2R_0}{t \cdot c + 2R_0(1 - \cos \beta)}, \tag{2}$$

where c – sound velocity, $t = t_1 + t_2 - t_0$ – difference of travel delays between the target echo and the direct signal from source (T_x).

Bistatic geometry causes a target location error, depends on target localization – see Fig. 2.

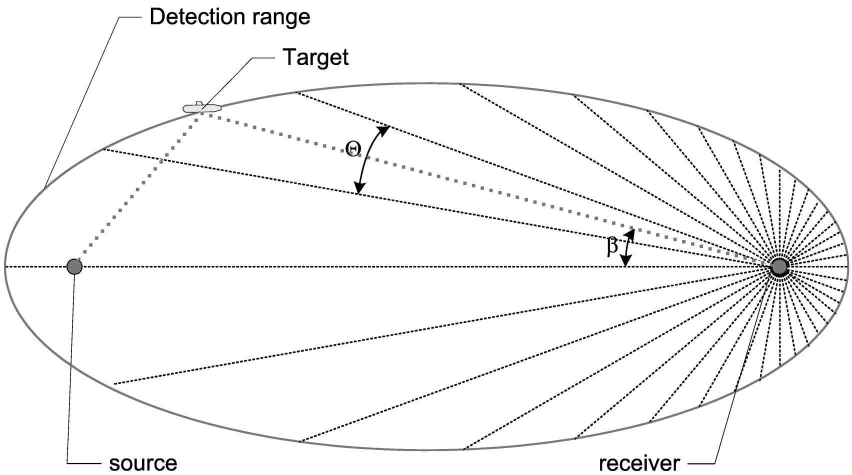

Fig. 2. The error of target position estimation for defined bearing and receiving beamwidth (Θ).

The calculated relative target location error (TLE) versus the beams number and distance R_0 between transmitter and receiver is presented in Fig. 3. The detection area (grey area in Fig. 1) depends on the T_x and R_x parameters, R_0 and pulse length as well as propagation conditions. The calculated of the detection area versus R_0 at various pulse lengths are shown in Fig. 4.

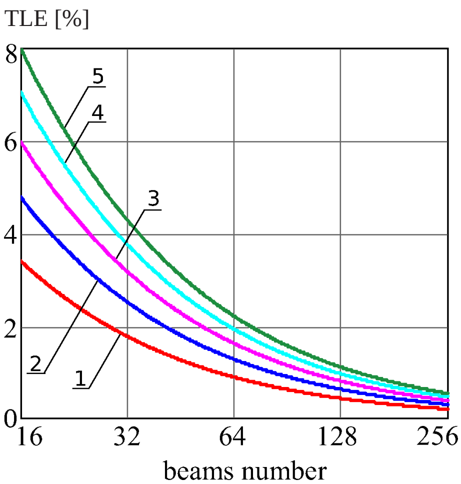

Fig. 3. Relative target location error (TLE) versus beams number of receiving module R_x for five different distances R_0 and $\beta = 60°$: 1 – $R_0 = 0.5 \cdot R$, 2 – $R_0 = 0.75 \cdot R$, 3 – $R_0 = 1.0 \cdot R$, 4 – $R_0 = 1.25 \cdot R$, 5 – $R_0 = 1.5 \cdot R$.

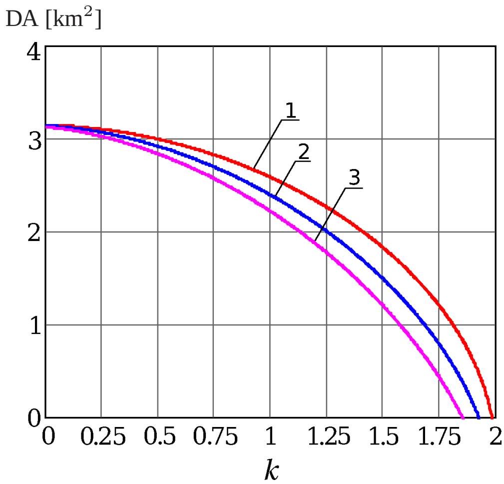

Fig. 4. Detection area (DA) versus distance $R_0 = k \cdot R$ ($R = 1$ km), for three pulse lengths: 1 – $\tau = 10$ ms, 2 – $\tau = 50$ ms and 3 – $\tau = 100$ ms.

It should be noted that set of bistatic/monostatic configuration in area covered by source range creates multistatic system where echo from the target may be recorded by a few receivers or receiver may be recorded the target echoes from different sources – see Fig. 5.

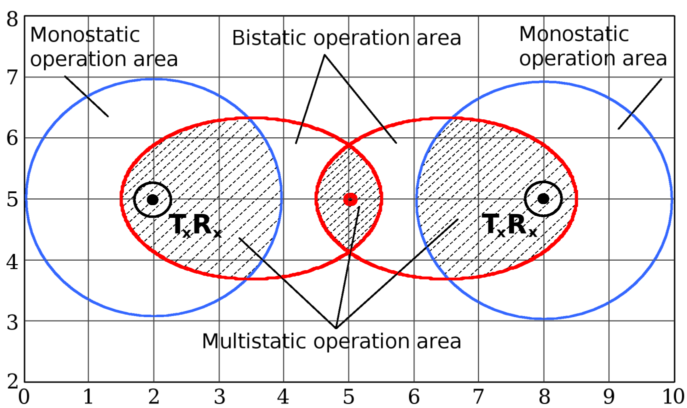

Fig. 5. Mono-, bi- and multistatic operation.

Multistatic system ensures an obtainment multiple viewpoints, extended coverage both spatially and temporally, reduces the ambiguity as well as an obtainment more precise estimation of object kinematics and characteristics than it is possible through the best individual sensor.

Acoustic propagation in shallow water (depth less than 200 m) is dominated by repeated interaction with boundaries channel – sea bottom and surface (see Fig. 6). The signals arriving to receiver along each propagation path contains target signal, if any, surface, bottom and volume reverberations, environment noises and moreover each paths has "own" transmission loss. It is noted that in bistatic and multistatic configuration, forward and out-of-plane scattering are important unlike monostatic configuration when reverberations is due to backscatter.

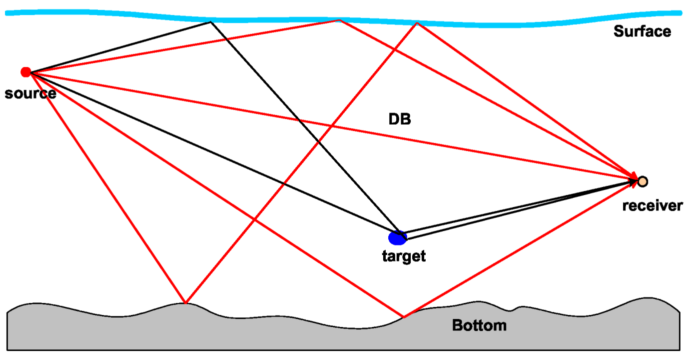

Fig. 6. Multiple paths (DB – direct blast).

2. Application of bistatic configuration

The essential applications of bistatic configuration are systems aimed for localization of underwater objects, their tracking and identification (military application mainly) as well as systems designed for protection high value assets, i.e. harbour, offshore construction, anchorage. In this paper we focused on civil applications of the bistatic configuration in the surveillance systems.

2.1. Underwater barriers

The barriers formed by bistatic segments (source and receiver placed in different localization), creates the chain of the transmitting and receiving modules distributed uniformly and alternately – Fig. 7.

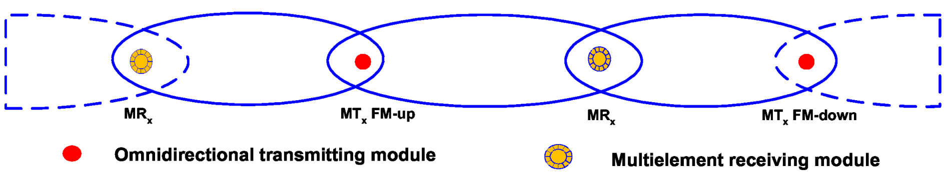

Fig. 7. Barrier formed by bistatic segments.

The barrier configuration depends on size and shape of protected area, modules parameters especially transmitting module source level (SL), processing gain of the receiving module and predicted propagation conditions. For protection of the berth/pier or other similar objects, barrier with modules which the observation sector is 180° may be applied.

Detection area of the barrier depends on propagation condition – worsening of the propagation conditions causes decrease of barrier width but without unprotected parts of barrier – see Fig. 8.

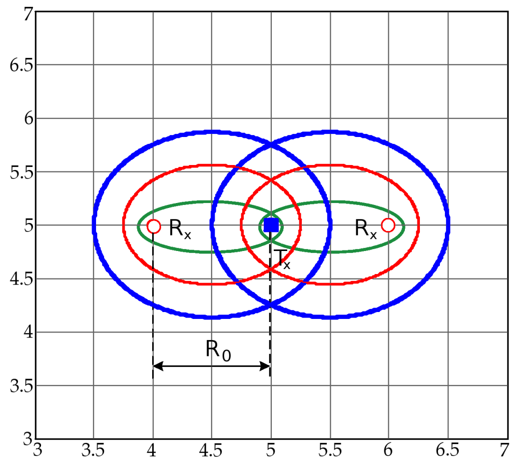

Fig. 8. Detection areas for three propagation conditions. Distance R_0 is constant.

2.2. *Sonar barrier*

The sonar barrier can be composed of a number of diver detection sonar (DDS) with 360° or 180° sector observation, operating independently with adjacent DDS. An example of the DDS barrier is shown in the Fig. 9.

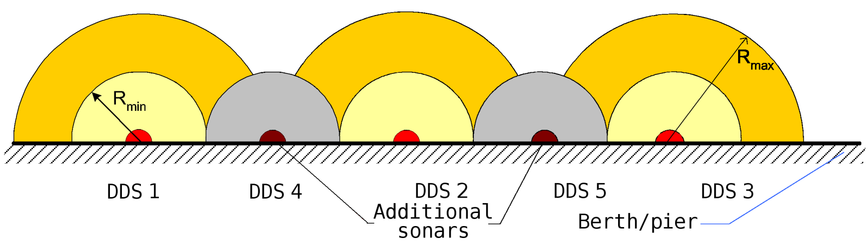

Fig. 9. Barrier composed from three basic sonars (DDS 1, DDS 2 and DDS 3) and two additional sonars (DDS 4 and DDS 5) which operates only in unfavourable propagation condition. $R_{\max}$ – range at favourable condition, $R_{\min}$ – range at unfavourable condition.

Water condition at the surface and propagation condition in the water column significantly affect the $R_{\max}$ sonar operating range, what means that in very unfavourable condition operating range can be reduced to $R_{\min}$, thus the unprotected areas may considerably increases. To cover the unprotected area/parts of barrier, the additional DDS should be installed in the centre of unprotected berth parts (between existing DDS) as presented in Fig. 9. The disadvantage of the DDS barrier is significantly rise of cost (5 sonars instead 3) and very high level of mutual interferences.

2.3. DDS sonar barrier with additional transmitting or receiving modules

Instead of additional sonars, in unprotected areas may be placed, significantly cheaper, transmitting T_x or receiving R_x modules. As results of this we can obtain the protection effectiveness similar with additional DDS. The size of area protected by additional T_x depends on the distance between DDS and T_x module, the SL of T_x module, processing gain of the DDS receivers and propagation conditions.

The protection quality at various propagation conditions of the barrier containing 2 DDS and the transmitting module is shown in Fig. 10.

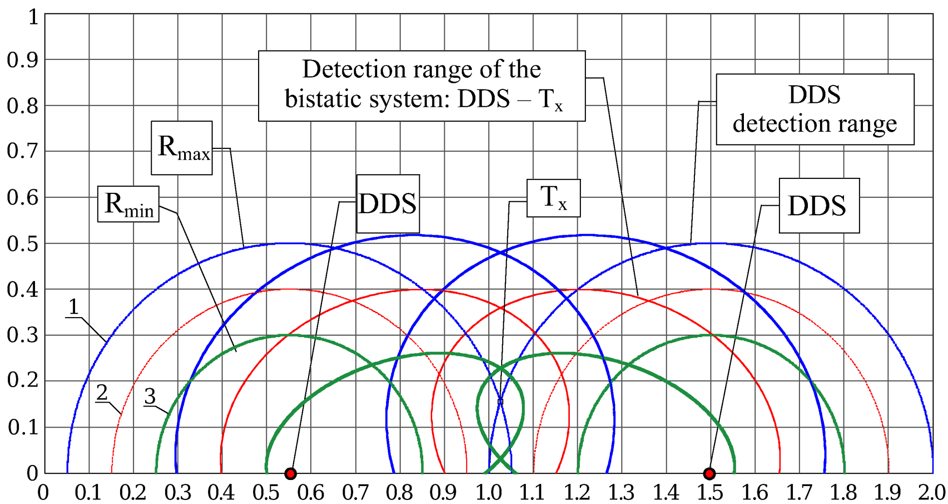

Fig. 10. The configuration of the barrier containing 2 DDS and T_x transmitting module ($T_{x,180}: R_{x,180}; T_{x,360}; T_{x,180}: R_{x,180}$) operating in three different propagation condition. DDS range: 1 – 500 m, 2 – 400 m, 3 – 300 m. Pulse length – 5 ms. Distance between DDS and T_x – 500 m.

3. Conclusions

1. The usage of bistatic technique enables designing and building an effective active acoustic systems i.e. barrier with extended, in comparison with monostatic systems, observation sector – in the connection DDS with additional BS modules, the coverage area can increased about 60%.

2. To obtain time synchronization, the bistatic system requires a reliable communication between transmitter and receiver (or at least transmitter and receiver must have

very accurate clocks). The essential role in utilization of bistatic system possibilities is fulfilled by the data fusion.

3. The bistatic systems with covered observation sectors are creating the multistatic system leading to a new extended detection capabilities, tracking and localization of targets. Both, bi– and multistatic systems are today widely researched and implemented in military and civil applications.

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