HIGH RESOLUTION MULTI-BEAM SIDE LOOKING SONAR

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The conventional side–scan sonars does not ensure sufficient angular and range resolution to detect very small objects with small target strength. Decrease of beam width leads to the increase of angular resolution but requires the decrease of towing speed what means reduction of searched area. Other method of the angular resolution increased is designing multi–beam sonar or sonar with synthetic aperture.

The paper presents a design of effective multi–beam side looking sonars with a large angular and range resolution operates with 100 kHz, 200 kHz, 400 kHz and 600 kHz. The sonar, described in the paper, operates with 200 kHz frequency; LFM modulation – 20 kHz and 40 kHz band; array provides 32 elements with d/λ spacing what ensure a shaping of 5 or 9 beams with 0,40° width. The range of sonar is from 250 m to 300 m, the level of side lobes are smaller than -20 dB and level of grating lobes for 5 beams are smaller than -30 dB.

The principle of sonar performance and wideband effective processing are presented. Effectiveness of processing depends on beams number and decrease of beams number, together with the range increased, leads to increase of processing effectiveness.

INTRODUCTION

To detect a small underwater objects (i.e. mines lying on the sea bottom), the modern warships uses a various types of side looking (side-scan) sonars which are below shortly described – the basic advantage of the sonars has been presented.

1. Conventional Side Looking Sonar

Conventional side looking sonar uses a single beam (per each side) to generate an image of the sea floor. This type of sonar is characterized by degradation, with range, of the image resolution and for higher angular resolution requires a speed less to 4 knots. The sonar transmits a CW short pulse with resolution proportional to pulse length. The transmission of a short wide bandwidth pulse results in higher range resolution sonar images [3].

2. Side Looking Sonar (SLS) with LFM technology

The sonar transmits a linearly frequency modulated pulse with resolution proportional to transmit bandwidth, not to pulse length. Increase of the pulse bandwidth leads to higher range resolution of the sonar images and increase of pulse length means that more energy is projected into the water resulting in sonar range extension due to SNR increase. Range of the sonar with LFM pulse is up to 30 ÷ 50 % greater then conventional systems at the same frequency. The extended range and resolution provides for better sonar efficiency.

3. Side Looking Sonar with dynamically focused beam

Normalization of image resolution with range by dynamically focused beam (length of multi element linear transducer are dynamically changed with range).

4. Side Looking Sonar with dual-ping technology

Dual-ping technology means two mode of operation:

- conventional mode operation with long array and low speed for high resolution,
- dual pulse operation mode with split array (two separate arrays) and high speed for low resolution.

5. Side Looking Sonar with multi-ping technology

Multi-ping technology enables a breaking of conventional sonar range – ping period limitation of T= 2R/C because during one transmission a few (2 ÷ 4) type alternated coded pulses are emitted. The pulses are characterized by minimally different but separate frequency. As a result, at the same speed, the sonar can project – on a target – a number of pings 2 or 4 times greater than conventional sonar. This means 2 or 4 times greater survey speed. For mine hunting sonar angular resolution can be improved also.

6. Multi-beam Side Looking Sonar

Multi-beam Side Looking Sonar may be operated as:

- multi beam conventional sonar: multi elements cylindrical or linear array and conventional beamformer. Image resolution decreases with range but the sonar ensures a full bottom coverage – expensive realization;
- sonar with adjacent parallel beams: multi elements linear array, beam steering and focusing technique. Advanced beamformer are formed several simultaneous adjacent parallel beams – very expensive realization [1].

1. MULTI BEAM SIDE LOOKING SONAR FOR VARIOUS APPLICATIONS

The article presents the set of Multi Beam Side Looking Sonar (MBSLS) for military and civilian applications. The project takes into account a high quality of sonar performance with moderate cost of his realization. The basic elements of the sonar design and results of the computer simulation are described below.

1.1 PARAMETERS OF DESIGNING SONARS

The parameters established and calculated, of designed SLS "family" are shown below in Table 1 and Fig. 1, 2 and 3.

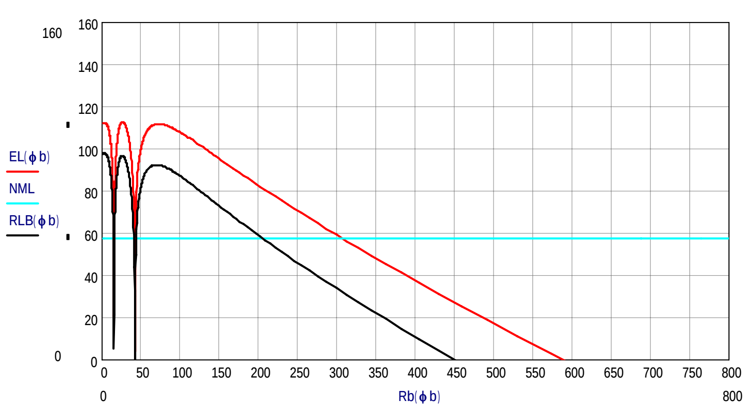

Fig.1 Range of SLS-200 sonar: vertical narrow beam, 7^{o} antenna tilt, Atlantic Ocean
NML – Noise Masking Level, EL(φb) – Echo Level
RLB(φb) – Bottom Reverberations Masking Level

Tab.1 Parameters of sonar's family

Parameter	**Unit of measure**	Type of sonar			
		SLS-100	**SLS-200**	**SLS-400**	SLS-600
f	kHz	100	200	400	**600**
d/λ $_{32\ elem.}$	–	2/1	4/2	8/4	**12/6**
$\mathbf{\Theta_{3\ dB}}$	deg	0,88	0,44	0,22	**0,15**
$\mathbf{\Theta_{HTx}}$	deg	12,7	12,7	6,2	**4,2**
B	kHz	10	20	40	**60**
τ	ms	25,6	25,6	25,6	**34,13**
SL	dB re 1µPa/1 m	205	205	200	**200**
$\mathbf{\Theta_{vTx}}$	deg	50 20*	50 20*	50 20*	**50** **20***
$\mathbf{\Theta_{vRx}}$	deg	50	50	50	**50**
R	m	620	370	170	**110**
$\mathbf{R_r}$	cm	15	7,5	3,75	**2,5**
$\mathbf{TV_{r=100\ m}}$	knots	> 20	12,0	6,0	**4**
$\mathbf{TV_{r=200\ m}}$	knots	8,0	4,5	2,5	**2,0**
$\mathbf{T_{r=100\ m}}$	cm	77	38	19	**14**
$T_{r=200\ m}$	**cm**	**154**	**77**	**38**	**28**

* vertical narrow beam

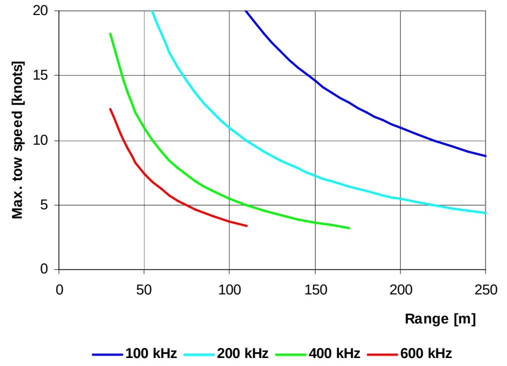

Fig.2 Maximum of the tow speed for different sonar frequency

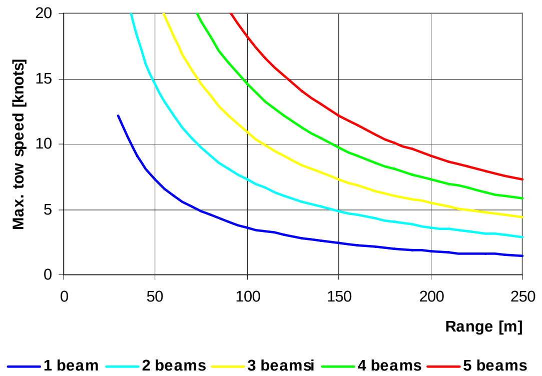

Fig.3 Maximum of the SLS-200 sonar tow speed for various number of beams

1.2 SONAR CONFIGURATION

SLS sonar, presented in the paper, consist in three basic units:

- placing on board console which contains control and processing sub-systems, power supply as well as data visualization unit;
- cable (power supply, data transmission, guidance commands);
- towfish contains 2 transducer arrays and the electronics (transmitters, receivers, switches and control sub-system) required for sonar data acquisition and towfish control.

Functional block diagram of SLS sonar are shown on Fig. 4.

From set of SLS sonars, it has been described, in details, SLS-200 sonar as characteristic (all-purpose) system.

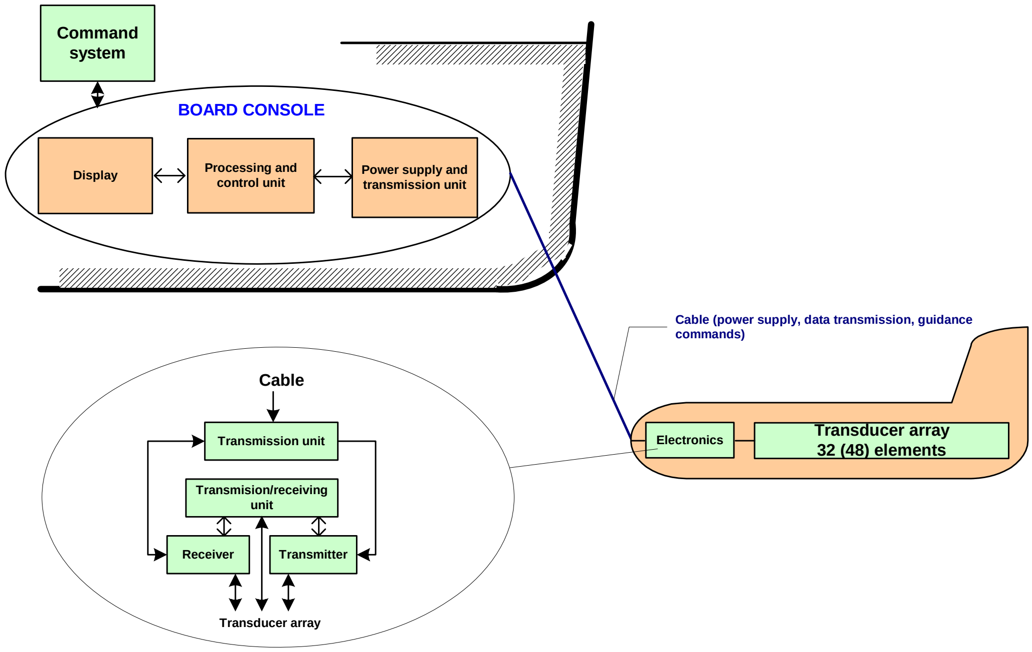

Fig.4 Block diagram of SLS sonar

1.3 SLS-200 SONAR

1. Parameters:

- frequency	f = 200 kHz,
- bandwidth	B = 20 kHz,
- number of array elements	N = 32 (48),
- number of receiving beams	9,
- beam width	0.40 deg,
- side looking sector	3.60 deg,
- range	350 m,
- sea depth	10 m ÷ 100 m,
- beams directions	0.00; +/- 0.40; +/- 0.80; +/- 1.20; +/- 1.60 deg,
- transmitting pulse parameters	T = 12.8 ms, LFM, BT = 256,
- frequency of complex sampling	20 kHz,
- segment length	25.6 ms with 50% overlay,
- number of segment samples	512.

2. Sonar array

The transducer is a 32 element uniformly spaced linear array. The array length is 96 cm for 200 kHz and remaining frequency but spacing changes from $d/\lambda=1$ to $d/\lambda=12$. To ensure no grating lobes over the sector covering ± 90°, typical linear array uses array elements spacing equal $\lambda/2$. For very small steering angels that utilized by multi beam side looking sonar, to minimize the number of array elements, spacing can be greater than wave length λ and spacing greater than $\lambda/2$ can be used without degradation of sonar performance. Only for short range – wider sector – beam steered on the sector edge has grating lobes that can degrade sonar performance. The array has a vertical beam width of about 50°.

In the case of projector array, several (3) elements fully covers a very narrow horizontal sector (12.7°) but side lobes in horizontal and vertical plane are well controlled. Fig. 5 and 6 shows beam patterns of a 32 elements uniformly spaced receiving linear array and 3 elements projecting array.

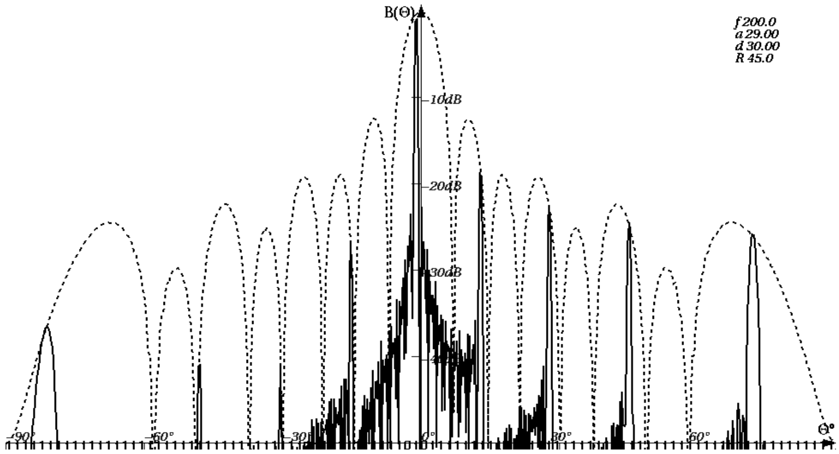

Fig.5 Beam patterns:
Tranmitting array – dot line,
Receiving array (edge sector beam) – solid line

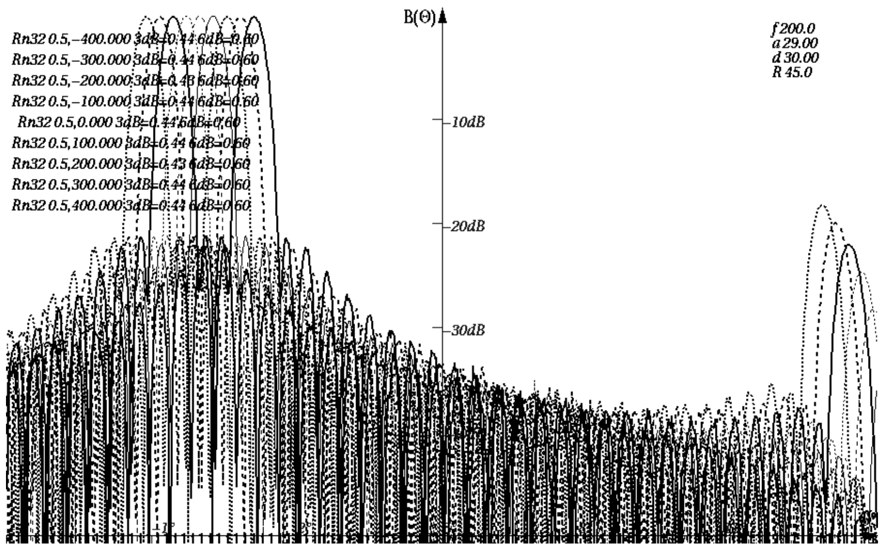

Fig.6 Beam patterns (after beamforming) of 32 elements receiving array,
Presented sector width ± 9° with shift – 5°, beam width $\Theta_{3\ dB} = 0{,}44^{o}$,
number of beams – 9, SL < -20 dB, GL < -18 dB

3. Electronics

Fig. 7 shows the block diagram of receiver (one channel). A low noise preamplifier is located as close as possible to the transducer element. The TVG, applies a variable gain, amplifiers a preampfilter output signal and mixer translates this signal to base band. A base band signal is filtered before sampling by analog to digital converter (ADC).

Real digital signal samples with f_s rate are used for computation complex signal values at $f_s/2$ rate. A complex samples are used by processor to produce the desired beams signals.

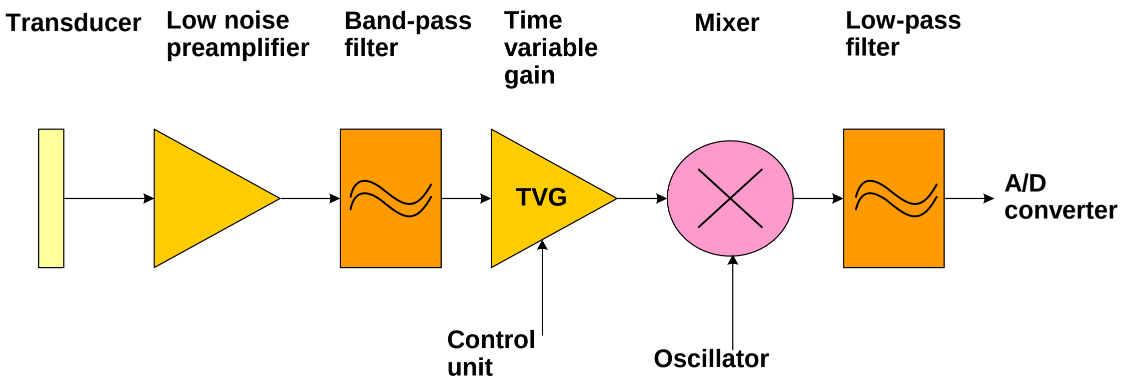

Fig.7 Block diagram of conditioning circuit

4. Processing

For each transmitting ping, on the electronics output appears a conditioned signals from 32 array elements. The following signal processing steps, shown in Fig. 8, are performed:

- creation of cylindrical snapshot by dynamically sampling (focusing),
- aperture weighting,
- complex samples creation,
- beamforming,
- matched filtration.

Due to relatively small of sounding range and simultaneously large of transducer aperture, a precisely beams focusing is required. The realization of the focusing for wideband LFM signals causes technical difficulties and moreover focusing in frequency domain is unprecisely because for the each data segment is assigned only one focus. It makes a large defocusing on the segment edges. Like that, focusing realization – by interpolation – in the time domain is also unprecisely and requires a great calculation power. In case of side looking sonar with several (5÷9) numbers of beams which covers a narrow sector, the focusing coefficients obtained for the central beams may be applied, without focusing degradation, for the all beams. The cylindrical snapshot can be also applied.

The 200 kHz ± 20 kHz LFM signal is sampled with 1MHz or 2MHz frequency and so controlled that cylindrical snapshot (Fig. 9) was obtained. The each cylindrical snapshot is matched to sonar range and dynamically changes together with range.

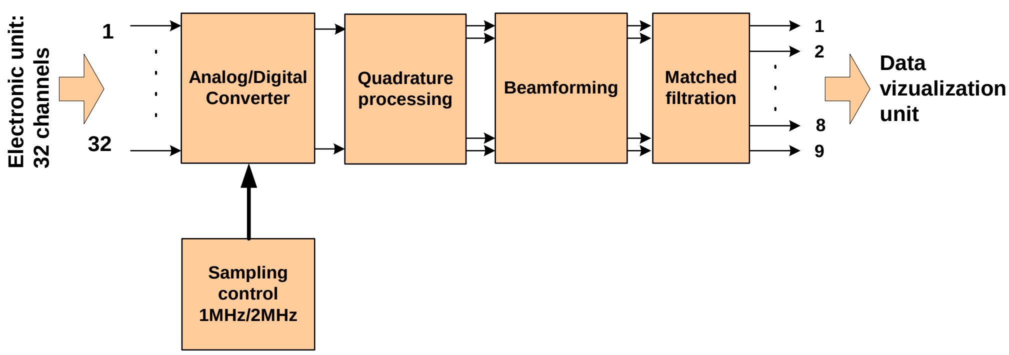

Fig.8 Signal processing block diagram

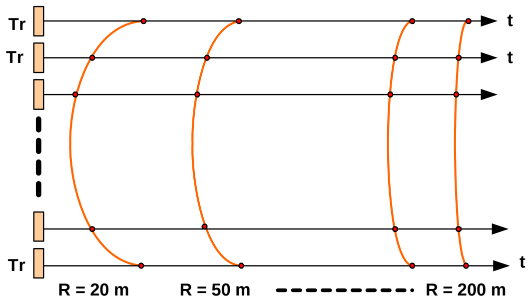

Fig.9 Cylindrical snapshots

To produce desired beam (standard beam pattern angle and SL < -20dB) array aperture weighting and dynamic focusing must be performed [2]. Fig. 10 shows desired and exactly focused beams after focusing and beamforming.

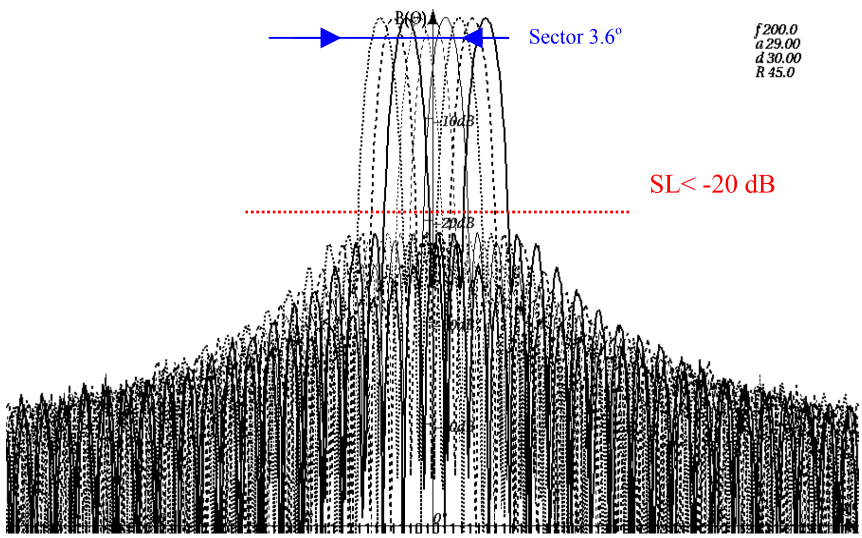

Fig.10 Beam patterns (after focusing and beamforming) of 32 elements receiving array
Presented sector width ± 9° (zoom), beam width $\Theta_{3\ dB}$ = 0,44°, number of beams – 9

It should be noted that, in practice, for greater range only one focusing term can be applied and width of the range cells may changed for 1 m to tens meters.

There are several efficient digital beamforming approaches for the linear array which utilized frequency domain processing (using Fourier transform). For limited number of array elements (32) and limited number of formed beams (5 or 9), this processing can implements true time-delay beamforming, where in the frequency domain a time delay corresponds to a phase shift. Matched filtration of the signals is very effective in the frequency domain owing to correlation receiving and processed signal with replica of the transmitted signal. IFFT execution creates the desired time series samples at each steering angle. Figs. 11 shows results of the focusing for the 20 m range and Fig. 12 shows results of the focusing with sampling accuracy of 1μs (f_s = 1 MHz) and 0.5 μs (f_s = 2 MHz).

For limited range resolution narrow band multi-beam SLS can be designed. For this sonar, a narrow band sampling and processing can be most efficient beamforming techniques.

For the limited band (≈ 2% of operating frequency f_o) in [4] is proposed focusing and beamforming by using signals delays calculated for f_o. It causes a small beams defocusing that appears as a limited signal level decrease, a side lobe level increase and a small broadening of beams patterns.

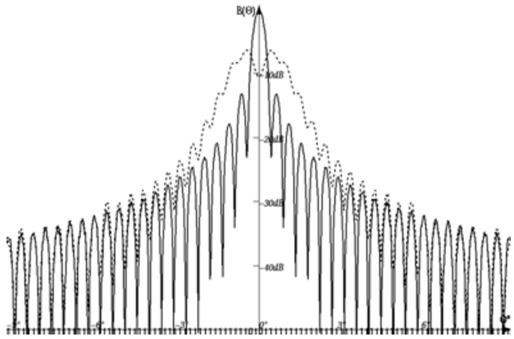

Fig.11 The comparison of focusing and nonfocusing (dot line) beams for 20 m range

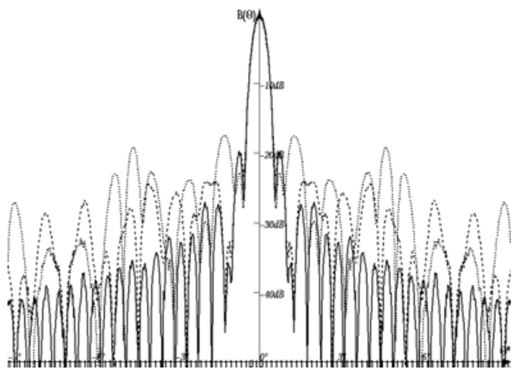

Fig.12 The comparison of exactly focusing beam and beams focused for sampling with 1 MHz (light dot line) and 2 MHz (dark dot line)

2. CONCLUSIONS

1. This paper describes the design and results of some sonar's parameters analysis for set of various frequencies applying to multi beam side looking sonars. Only set of sonar's various frequency can cover full application spectrum includes various detection range, various range resolution and towing speed.

2. Presented sonars demonstrated various multi beams along track resolution and adjusted tow speed ensure full coverage bottom surface at selected range.

3. The unique multi element array with switched d/λ is presented. It ensures a low grating lobes level for presented sonar. The grating lobes for 5 beams (basic quantity of beams) are suppressed by at last 30 dB.

4. Very effective focusing can be obtain by cylindrical snapshot sampling method with time quantization 10 times shorter than period of operating frequency.

5. The design of side looking sonar, presented in this paper, with relatively simply construction and advanced processing can make a base to development of moderate cost sonar for searching and detection a small underwater objects lying on the sea bottom.

REFRENCES

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[4] M. T. Shaw, Ch. D. Loggings, R. O. Nielsen, Performance Verification Testing of a High–Resolution– Side–Looking Sonar, www. sonatech.com.