CW AND CHIRP SIGNALS BOTTOM BACKSCATTERING IN THE PEZ OF THE BALTIC SEA

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High-frequency bottom backscattering experiments were carried out in the Polish Economy Zone of the Southern Baltic Sea. CW and chirp signals were used to determine scattering reverberation as a function of the incident wave grazing angle and at vertical sounding. The chirp signals covered the frequency range from 40 to 80 kHz whilst the CW signals were selected at 40, 60 and 80 kHz. Acoustic data concerning the angular dependence of the backscattering were taken at the points where appropriate investigations of sediment properties had been earlier made by the Polish Geology Institute. The sediment types include not only acoustically hard fine and coarse sand bottom covered with gravel but also a flat muddy bottom. The results present the backscattering as a function of frequency, signal type and sediments properties. Times of reverberation and other statistical properties of returned signal are also discussed. When possible, due to more complete information on the sediments properties the measured backscattering strength was compared to the models developed by Jackson et al.

INTRODUCTION

Many hydroacoustic operations e.g. defense (mine countermeasures), environmental investigations (habitat mapping and protection), have a necessity for prediction of the bottom backscattering phenomena at the area of interest.

Although generally well-recognized, and regardless of a large number of experimental and theoretical investigations, the angular and frequency relationships of backscattering strength with sediment type, in particular for complex signals, is not fully parameterized.

The designer of any bi or multistatic hydroacoustic systems, should take into account the setup purpose, environmental conditions, and a number of acoustic characteristics - as the wind waves statistics, sound speed profile [2] and sea bottom properties. Other acoustic characteristics needed in the design procedure are the pulse type, its bandwidth or operating frequency.

The measurements and analysis of the backscatter in the Southern Baltic Sea were carried out intensively in the past [5] yet almost all measurements were taken out for vertical sounding.

In the paper the experiments performed in Polish Economy Zone of the Baltic Sea with emphasis on the inner areas of the Gulf of Gdansk are presented.

Two types of signals: CW pulses and signals with frequency linearly modulated in time were used to determine the backscattering reverberation as a function of the incident wave grazing angle and frequency.

1. EXPERIMENTAL SETUP

The transmitter-receiver setup was used in different variants. In the variant under investigation the transmitter and receiver were nearly collocated and mounted on a frame at the distance between their centers equal to 40 cm. Two broadband transducers RESON TC2116 were used - as the transmitter and as the hydrophone. The main parameters of the TC2116 are: conical beam width 13.5˚± 2˚ at f=50 kHz, transmitting sensitivity: 172dB ±3dB re 1μPa/V at 1m and receiving sensitivity: -177dB ±3dB re 1VμPa at the same frequency.

Due to short distance between the transducer's centers the system works as a monostatic echosounder. The frame was attached firmly to the ship board or suspended from a ship crane. There was an option to change the tilt of a frame with transducers - every 15 degrees and the incident/scattered angles ranged from the vertical sounding to the lowest 15 degrees. The lesser angular value was dependent on the transducer's beam pattern (θ_{-3dB}=. 7.5 deg) at 50 kHz. The actual position of transducer's head was monitored by the compass/inclinometer attached to the frame.

The transmitter was powered by a L-2 Instr. Inc. power amplifier. During the presented experiments the typical acoustic pressure at 1m distance from the transducer was in the order of $p(r = 1m) \cong 50\,kPa$, thus the generated acoustic power is much below the limit at which the cavitation at the transducer may occur.

To obtain statistically significant back-scattering cross-section measurements in any area, it was necessary to perform many series of experiments with different pulse duration and at different distance between the transducers and the sea bottom. Scheme of the bottom backscattering experiments is presented in Fig. 1.

According to the definition [8], the bottom backscattering strength is a function of incident/received grazing angle (1):

$$BBS(\theta) = 10\log_{10}\frac{I_{TOT\_SC}(\theta)}{I_{IN}(\theta)} \tag{1}$$

Theoretically $I_{TOT\_SC}(\theta)$ is the acoustic intensity referenced to one meter, scattered from the bottom, and I_{IN} is the intensity of the incident acoustic plane wave.

In fact, backscattering strength *BBS* is obtained by averaging scattered signal over scattering area, corrected for geometric loss and in case of large distances - for attenuation in water.

The transitory scattered signals should be in tune to temporary changes in the real scattering bottom area, thus ensonified area at the time t is estimated step by step using the pulse length, the transmitted and received beam patterns. The *BBS* values for each grazing angle are calculated using following formula [1] ,

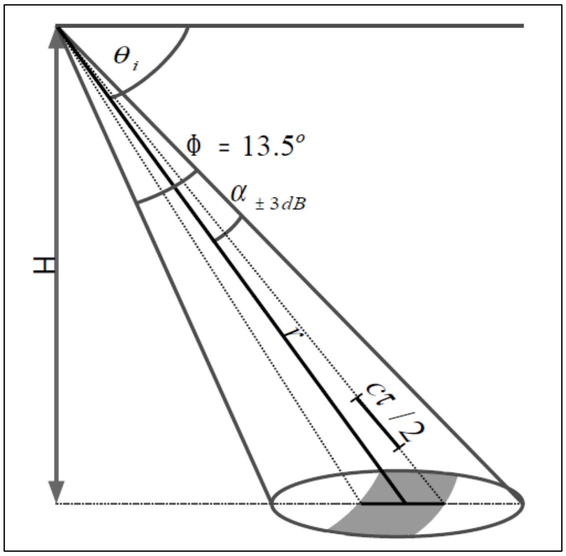

Fig.1. Backscattering experiment geometry

$$BBS(\theta) = 10\log\frac{I_{sc}(\theta)R^4 10^{2\alpha R/10}}{I_{inc}(\theta)\iint G_1(\varphi,\vartheta)G_2(\varphi,\vartheta)dA} \quad (2)$$

where - *BBS* is the bottom backscattering strength in dB at a grazing angle θ, *R* is the distance from the receiver to an elemental scattering area, α is the sea water absorption coefficient, and $G_1(\theta)$ and $G_2(\theta)$ are the source-and-transmit beam patterns, *dA* – the elemental footprint of the acoustic beam on the bottom.

In the case of short signals, when not a whole scattering area is ensonified, the scattered intensity is a function of time:

$$I(t) \approx I_0 \frac{\sigma_B([x(t+c\tau/2)-x(t)][<y(t+c\tau/2),y(t)>]_R}{(R_1+R_2)^2} 10^{(-\alpha(R_1+R_2)/10)} \quad (3)$$

where σ_B is backscattering cross section, *x* and *y* are coordinates of points of intersection of ellipsoidal bottom area and spherical cone, representing acoustic wave surface propagating towards the bottom plane. Here, with the satisfactory precision, the estimation of *dA* - the scattering surface of the annulus sector, at a time *t*, has been replaced by the trapezium surface. In the monostatic case $R_1 \cong R_2$.

The bottom backscattering strength in logarithmic form is then given by:

$$BBS(\theta_{inc}) = RL - SL + 2TL - 10\log(A\,G_1(\psi)G_2(\psi)) \quad (4)$$

where *RL* is the received signal level in dB, *SL* is the source level in dB//1 Pa at 1 m along the acoustic axis of the transducer, *TL* is the one-way transmission loss in decibels. Here, *A* is the area ensonified by the pulse at the time *t*, and G_1 and G_2 are the beam patterns of the receiver and transmitting arrays respectively.

In case of experiment arrangement, using two TC2116 almost indistinguishable transducers, we put $G_1(\theta) \approx G_2(\theta)$, and due to the fact that transducers are circular, the main lobe could be approximate by a simple cone function with the equivalent two-way beam or by a Gaussian function:

$$G_1(\psi) = b \exp(\psi / a) \tag{5}$$

where a and b are the parameters of the curve best fitting to the beam patterns given by the manufacturer (RESON). Both functions were used to calculate the bottom backscattering strength (Fig. 2). The time series of ensonified areas for given grazing angle θ and a pulse length can be then estimated numerically.

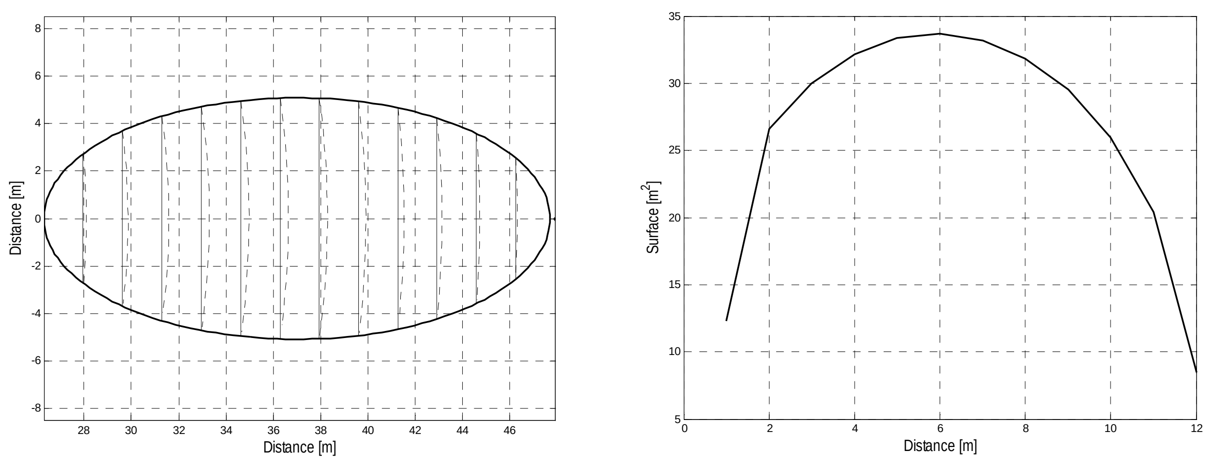

Fig.2. Example how an ensonified area is changing in time. On the left, as is seen from the above of the bottom. Time series of the values of the backscattering surface for pulse length τ=1 ms (on the right). The illustration is for transducers 20 m above the bottom and grazing angle θ=60 deg

2. SIGNALS AND COLLECTING DATA

In backscattering measurements two waveforms were used – narrowband pulses (CW) transmitted at 40, 60 or 80 kHz with 0.3 ms pulse duration (0.44 m at c=1450 m/s) and Linear Frequency Modulated signals (LFM) transmitted typically in frequency range from 40 to 60 kHz, or across full bandwidth of TC2116 transducers, that is from about 40 kHz to 80 kHz. The frequency was changing linearly in time, from lower to higher end of the bandwidth. The pulse duration was 3, 15 or 20 ms. (4.35, 22 or 29 m respectively at 1450 m/sec speed of sound)

Both CW and chirp signals were successively emitted with 2 pulses per second repetition. In each of the series one pulse was a chirp and the next one a single constant CW frequency signal. As a result, one block of the data consists of 100 pings (50 CW and 50 chirp pulses).

Digitization was performed using NI 6251 card with parameters – 16 bits resolution, to provide adequate dynamic range for spectral estimation and with 350 kHz sample rate in every channel.

Oversampling rate was selected to provide sufficient resolution for phase measurements between channels and to provide sufficient compressed pulse resolution

The digitized echosignals were entirely recorded on the hard disk. The signals quality were also monitored in real time on a computer display.

In spite of high resolution of receiving system which allows to perform the implementation of the software TVG function, the hardware block executing time-varied-correction with analog filters was launched for small incident angle.

In signal processing received signals were filtered digitally and envelope for each ping was computed using Hilbert transform. Since the experiment geometry was almost stable from ping to ping, as a final result an average over an ensemble of 50 envelopes was computed. For each transducer deployment the time series were repeated several times.

The backscattering was counted at time intervals equal to $c\tau/2$. In case of low grazing angles, due to scattering geometry it is possible to calculate the backscattering strength for several angles in the region of θ_i which corresponds to grazing angles of the acoustic axis of the transmitter.

3. AREA OF EXPERIMENTS

Backscattering reverberation experiments were conducted mostly in the inner part of Gulf of Gdansk. Detailed studies of grain size analysis based on hundreds samples were performed in the area by Marine Branch of the Polish Geological Institute. The results were published in [6] and [9] as examples. It was found that in shallow waters fine grained sands (median diameter 0.25-0.125 mm) prevails. However, both medium and coarse sand also are widely distributed. Moreover, in the deeper area (h>50m) marine silty clays are common. During measurements the water depth was from 20 and 60 m and the sites were chosen so that at the sites the bottom was composed of different size of sand, silt and clay sediments [7].

The maps of the measurement sites are presented in Fig.3. Furthermore, in Table 1. particular positions of backscattering experiments and sediment class according to the data from PGI are given.

The transducers were deployed at the distance from the bottom in the range 20-40 m.

4. RESULTS

Examples of measurement results from a single site Wi1, where the bottom sediments are homogeneous marine fine grained sand, are shown in Figs. 4-5. The water depth and source depth at the site are 20 and 15 m respectively. In the Fig.4, averaged received pressure time series for CW at f=40 kHz and chirp signals (40-60 kHz) for different grazing angles of the beam are presented. Zero distance in the figure corresponds to the beginning of a signal.

Generally for most sites the shape of the angular dependence of the bottom backscattering strength follows the predictions from high frequency models developed by Jackson et al. [3].

The model employed for comparison of obtained experimental data was the APL model. The APL model incorporated several submodels taken from the literature data [1,4] properly modified and joined together. It generalizes previous model which was a simplification of the work of Jackson et al [4]. Equation for bottom backscattering strength embodies two types of backscattering cross sections – one considering interface roughness and the other considering volume scattering from below the interface [1]: $BSS(\Theta) = 10\log_{10}(\sigma_r(\Theta) + \sigma_v(\Theta))$, where $\sigma_r(\theta)$ and $\sigma_v(\theta)$ are backscattering cross sections per unit solid angle per unit area due to interface roughness and volume scattering from below interface respectively.

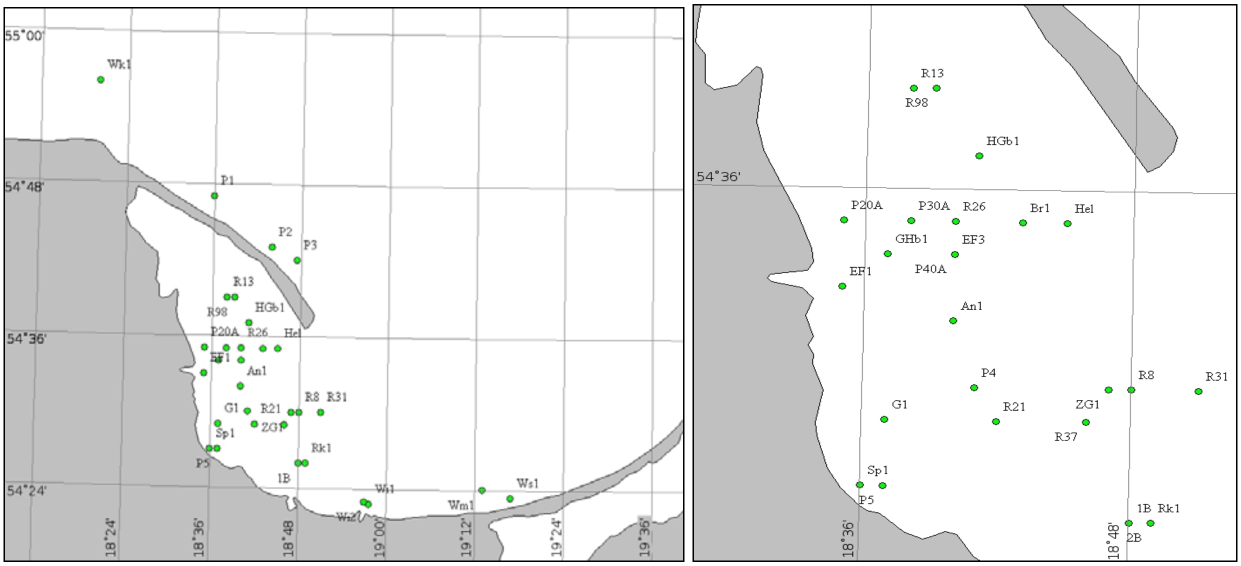

Fig.3. The backscattering measurement sites

Tab.1. Dataset of station names their coordinates and sediments type where backscattering measurement were performed

Station	Coordinates	Sediments	Station	Coordinates	Sediments	Station	Coordinates	Sediments
R31	18°51'0E 54°30'7N	Marine coarse-grained sands	**Sp1**	18°36'1E 54°28'0N	Marine coarse-grained sands	**2B**	18°49'2E 54°26'4N	Marine fine-grained sands
R8	18°48'2E 54°30'0N	Marine medium-grained sands	**EF1**	18°35'1E 54°33'5N	Marine fine-grained sands	**Wk1**	18°20'1E 54°56'6N	Marine fine-grained sands
ZG1	18°47'1E 54°30'8N	Marine coarse-grained sands	**EF3**	18°40'3E 54°34'1N	Marine silty clay	**Hel**	18°45'8E 54°35'6N	Marine clayey silt
R37	18°46'7E 54°29'8N	Marine medium-grained sands	**An1**	18°40'2E 54°32'9N	Anthropogenic sand and silt	**Ws1**	19°15'2E 54°22'7N	Marine fine-grained sands
G	18°37'3E 54°29'5N	Marine fine-grained sands	**P1**	18°36'1E 54°47'5N	Marine fine-grained sands	**Wm1**	19°13'5E 54°24'9N	Marine medium-grained sands
R21	18°42'3E 54°29'3N	Marine fine-grained sands	**P2**	18°44'4E 54°43'3N	Marine silty sand	**Br1**	18°43'9E 54°35'9N	Marine clayey silt (gassy sediment)
R13	18°38' 0E 54°39' 0N	Marine clayey silt	**P3**	18°45'3E 54°41'5N	Marine silty sand	**P40A**	18°41'0E 54°34'4N	Marine silty clay
R98	18°39'0E 54°39'6N	Sand-silt-clay-marine sediments	**P4**	18°41'3E 54°30'3N	Marine medium-grained sands	**P30A**	18°38'3E 54°35'0N	Sand-silt-clay-marine sediments
R26	18°40'0E 54°35'0N	Marine silty clay	**P5**	18°37'1E 54°27'8N	Marine medium-grained sands	**P20A**	18°36'0E 54°35'3N	Marine fine-grained sands
Wi1	18°56'9E 54°22'9N	Marine fine-grained sands	**Rk1**	18°49'2E 54°26'4 N	Marine fine-grained sands	**Ghb1**	18°37'0E 54°35'0N	Sand-silt-clay-marine sediments
Wi2	18°57'1E 54°23'8N	Marine fine-grained sands	**1B**	18°48'6E 54°26'2N	Marine medium-grained sands	**HGb1**	18°41'1E 54°37'1N	Marine silty clay

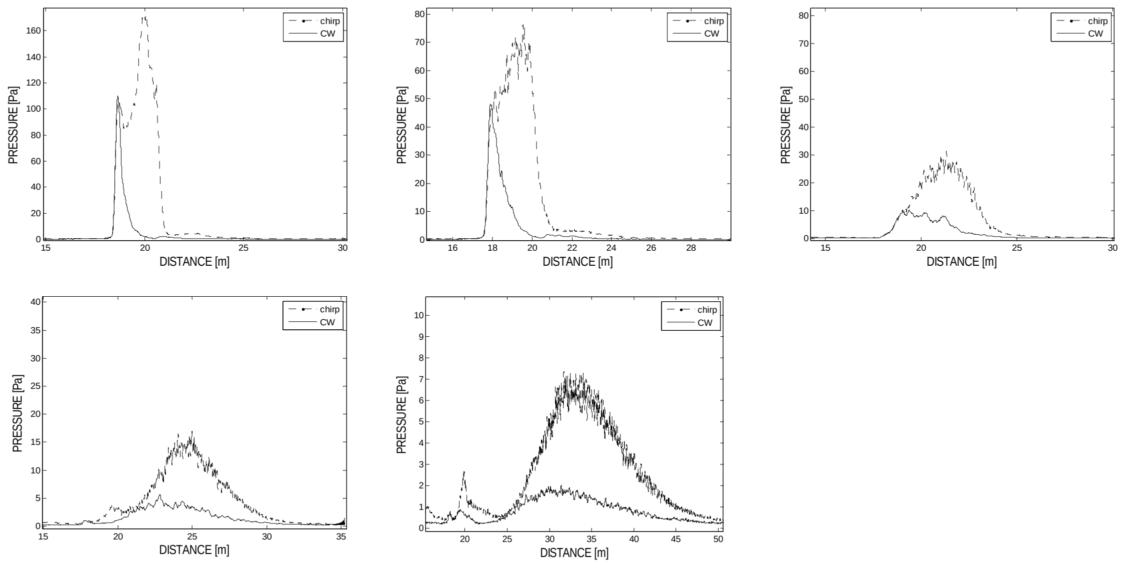

Fig.4. Time series of back-scattered signals at the marine fine-grained sand. Grazing incident angles are 0, 15, 30, 45 and 60 degrees

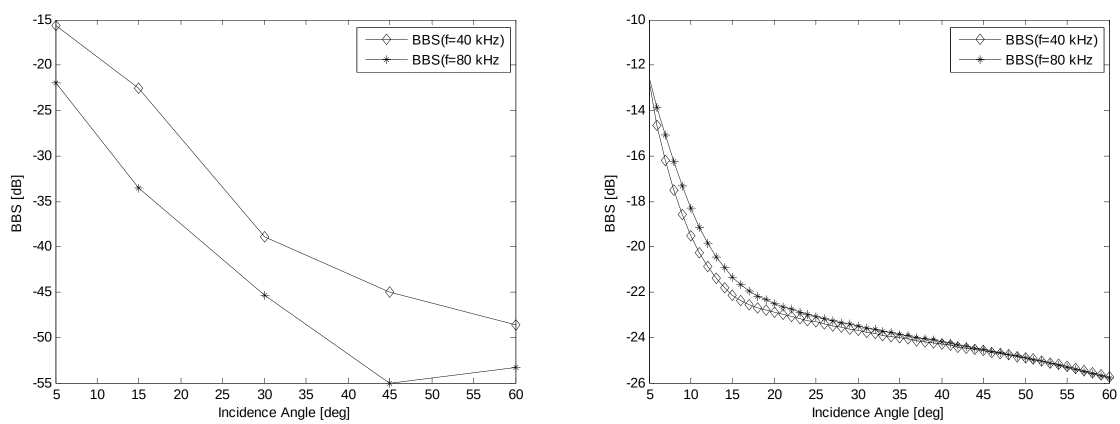

Fig.5. Angular dependence of the bottom backscattering strength at frequencies 40 and 80 kHz. On the left, data from the same station as in Fig.4, on the right – prediction of the BBS obtained from the APL model

5. SUMMARY

We have performed experiments and collected data relating to bottom backscattering strength at more than 30 stations placed mostly in the Gulf of Gdansk. The signals were CW or LMF pulses covering the broad frequency range from 40 to 80 kHz. Measurements were taken at a diverse kind of sediments from hard bottom comprised of marine coarse-grained sands to semiliquid soft sediments typical for Baltic Deeps. In the areas where gassy sediments were recognized measurements at grazing angles 15, 30, 45, 60, 75 and at normal incidence were also completed. However, was observed and not explained yet, some inconsistency between measured and predicted from the Johnson model the bottom backscattering strength. The results and discussion is collected in Data Base of experiments.

Comparisons between CW signals, raw chirp data and chirp data after matched filtering also accomplished.

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