Article

Detection of Embedded Objects Using Parametric Sub-bottom Profilers

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Different applications require the detection and location of objects embedded in the sediments of rivers, lakes or coastal areas. The importance of searching for objects, such as large rocks, in areas of underwater building sites (e.g. offshore wind mills) is increasing. The search for pipelines, the measurement of the thickness of the overburden material and the monitoring of pipeline and cable routes are some of the demands during dredging and are also important for maintaining the safety of water ways. Archaeologists have an interest in the detection of embedded ship wrecks. Surveys are required of historical places to find embedded objects, such as historical buildings or structures.

The exact determination of the position and dimension of such objects is necessary for further examinations or removal of the embedded artifacts.

During the last two years Innomar Technology GmbH has carried out many surveys in order to search for embedded objects by using the parametric sediment echo sounder SES-96. The use of parametric acoustics offers many advantages in searching for embedded objects. Some technical questions and experiences will be described in the following.

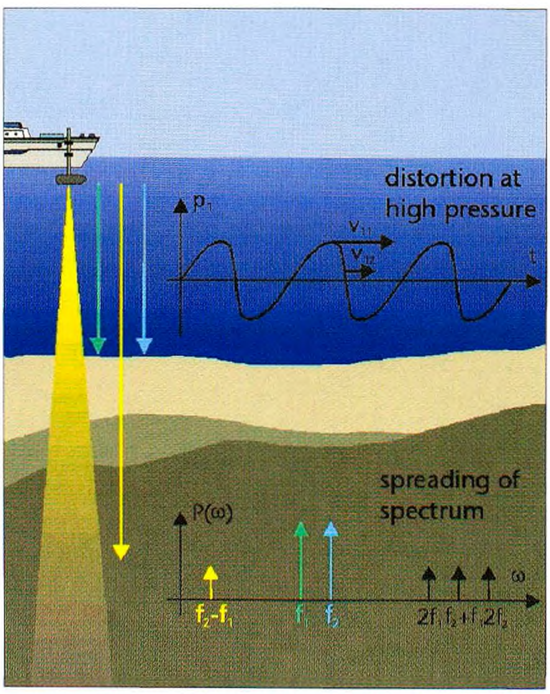

Figure 1: The principle of parametric acoustics

Difficulties in Searching for Objects

In general, there are numerous problems which occur during the detection of embedded objects. Some of the most important difficulties are:

- Small dimensions of objects and unknown or only imprecisely known positions
- Unfavourable position near layer limits, such as the bottom or layer boundaries
- Weak echo strength due to the acoustic attenuation in the sediment
- Small reflection coefficients due to small acoustic difference which means that the product of the density and the sound velocity differs hardly from the one of the surrounding material

By using common linear acoustic systems these difficulties can not or hardly can be solved because they have some disadvantageous properties due to physical conditions.
- Low frequency transducers have a wide beam width and therefore a low horizontal resolution. The reverberation level increases at higher beam width and causes small objects, especially those near the bottom surface or layer boundaries to be hidden by the surrounding noise
- Caused by the small system bandwidth, the transmitter pulses are long and the vertical resolution is low. The best vertical resolution is determined by half the bandwidth. The bandwidth of a linear system is mainly limited by the bandwidth of the transducer

These disadvantages often cause small objects not be detected by using linear sub bottom profilers.

Parametric Acoustics

For the detection of embedded objects it is advisable to use parametric systems which are able to send and receive very short transmitting pulses with a narrow acoustic beam using low frequencies.

The principle of parametric transmitting is as follows: Simultaneously two different frequencies with high acoustic frequencies f1 and f2 will be transmitted from a transducer. Due to non-linear interactions in the water column under the transducer, new frequencies are developed in the water. One of them is the sum frequency f1 + f2, which is a high frequency; and the other is the difference frequency f2 – f1 which is a low frequency (Figure 1). The absolute bandwidth of the primary and secondary frequencies is nearly the same. So it is possible to transmit very short, low frequency signals using small transducers.

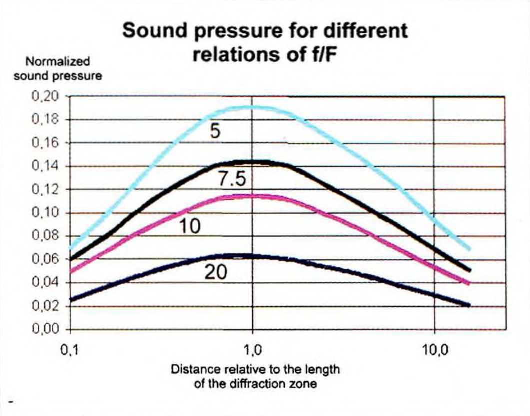

Figure 2: Parametric sound field

The parametric sound field is formed in the interaction area in front of the transducer. The sound pressure of the difference frequency along the acoustic axis grows continuously up to the length of the diffraction zone and, after that, sinks continuously. The smaller the ratio between primary and secondary frequency, the greater the sound pressure of the difference frequency becomes. (Figure 2).

Advantages of Parametric Systems

The difference frequency is able to penetrate the sea bottom and therefore can be used for detection. It is possible to transmit very short pulses with a small beam width – despite a small active sound area of the transducer. Parametric systems can provide high penetration depth and excellent resolutions both in the horizontal and vertical direction.

The use of parametric acoustics provides the possibility of detecting embedded objects with the following advantages:
- Due to the parametric effect it is possible to create narrow beams of low frequencies with small and portable transducers
- A narrow beam results in less volume and bottom reverberation and increases the achievable signal to noise ratio for the detection of weak reflectors
- The directivity of the parametric transducer has no side lobes during transmission

Short signals without ringing effects can be transmitted, due to the high system bandwidth of parametric systems

Figure 3: System unit SES-96 standard

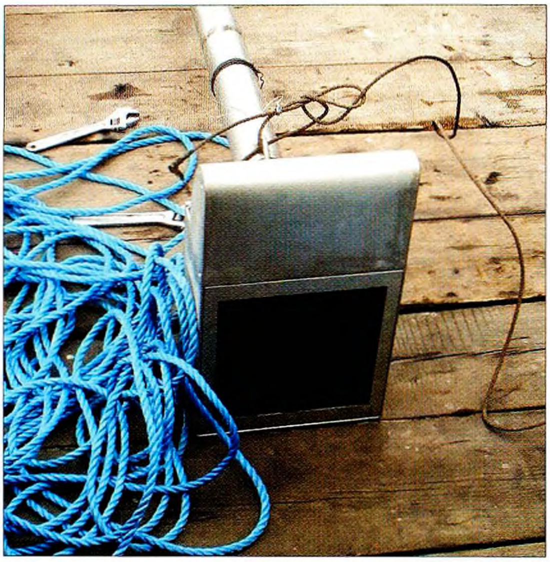

Figure 4: Parametric transducer

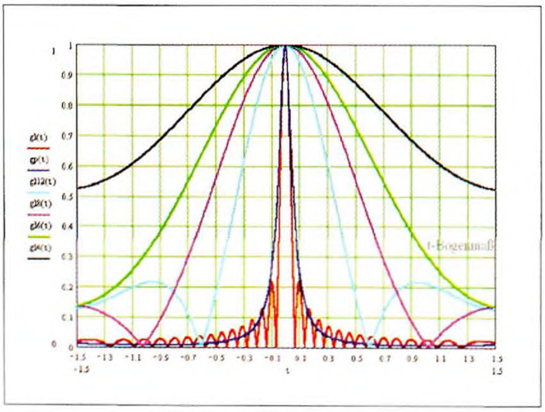

Figure 5: Comparison of directivities at an active sound area of 500cm²

Particularly small beam widths are generated if high primary frequencies are used. To use the advantages of parametric systems efficiently, electronic stabilisation and electronic beam steering are needed.

Innomar's product series SES-96 and SES-2000 are based on parametric acoustics and can be used in shallow waters (1m – 1500m depending on type) also for detecting embedded objects.

Figure 3 shows the system unit and Figure 4 the 100 kHz phased array of the SES-96 with the possibility for electronic beam stabilisation.

The transducer is housed in a streamlined body. A support pipe makes it possible to mount the transducer on the side of small survey vessels. This transducer offers the possibility to generate short pulses in a frequency range of 4 to 15 kHz. The shortest pulse length takes only the time of one period of a sine wave, which means in the order less than 70µs.

With the same dimensions of the transducers the differences of the half power beam width between linear and parametric transducers become especially obvious, Figure 5.

The half power beam width of linear transducers is many times greater than the one for parametric transducers. In comparison with it, the half power beam width of the high frequency and the low difference frequencies of the parametric transducer are nearly the same. Besides the narrow acoustic beam of the parametric transducer it can be seen that there are no side-lobes in the directivity.

The differences in the horizontal resolution between a linear and a parametric echo sounder can be

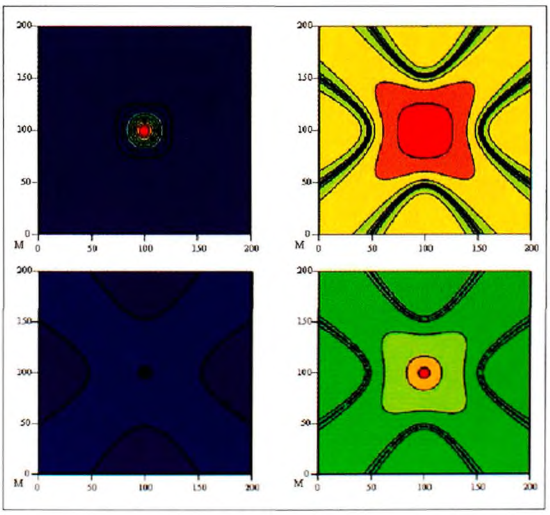

Figure 6: Comparison of directivities at transceiving

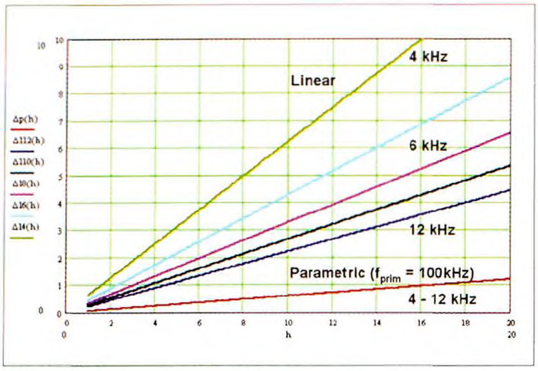

Figure 7: Horizontal resolution

recognised especially well when having a look at the sounded bottom area. Figure 6 shows the final directivity resulting from the product of the directivities while transmitting and receiving. The two pictures on the left have a linear scaling, the pictures on the right a logarithmic one. The diagrams above were calculated for the linear transducer, the diagrams below for the parametric transducer.

However, compared with the linear system the resolution remains substantially higher, Figure 7.

The horizontal resolution depends on the beam width and on the water depth. The diagram shows the horizontal resolution versus object distance. The smaller the transmitting frequency of a linear

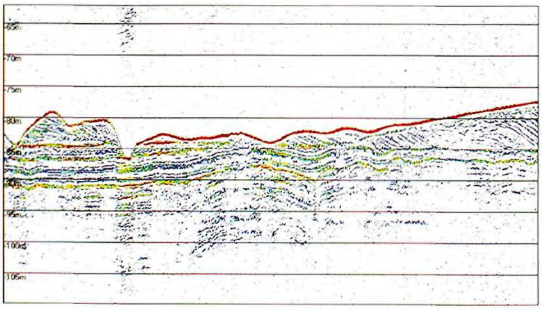

Figure 8: Example for horizontal and vertical resolution

system becomes, the worse the horizontal resolution becomes.

An example of the high horizontal and vertical resolution of a parametric sub-bottom profiler was obtained in the south of Chile, Figure 8. The vertical range is 50 metres. Even very small geological structures can be interpreted well. Under the red bottom line there is a number of marine sediment layers and rubble from the last ice-age. In one place there can be seen the disturbed bottom line caused by tectonic events in recent times.

Another example (Figure 9) shows a profile from the North Sea, where a 36"- pipe was crossed.

The transducer of a SES-96 systems was mounted in the moon pool of a survey vessel.

The pipe is clearly visible on the bottom surface even though the water depth was 128m and the speed of the ship was more than 4m/s. This is only possible with a good signal to noise ratio (low reverberation level) and at a high ping rate.

Other problems in object detection are disturbances due to reverberation effects of the bottom

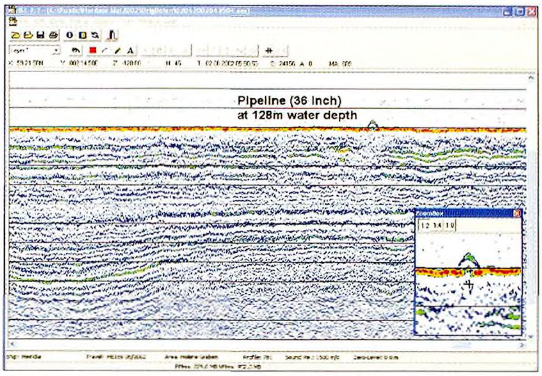

Figure 9: Example for horizontal and vertical resolution

surface. If the beam hits the bottom surface, undesirable back scattering occurs because of sidelobes of the directivity, the so-called bottom surface reverberation. The back scattering strength depends on the roughness of the surface and on the angle of incidence. To discover embedded objects, the echo strength has to be higher than the reverberation level. Here the parametric system reveals advantages once again. To compare both systems, the echo strength and reverberation were calculated for the stated detection situation for two different transmitting frequencies. Both diagrams show the echo and the reverberation level versus the thickness of a sand layer at a water

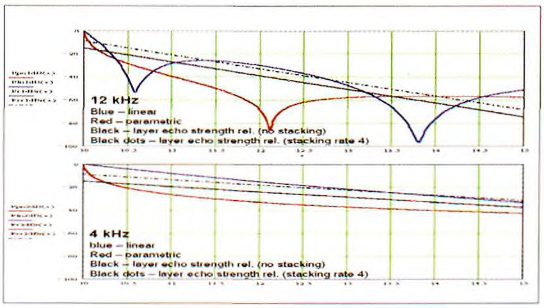

Figure 10: Reverberation and echo strength

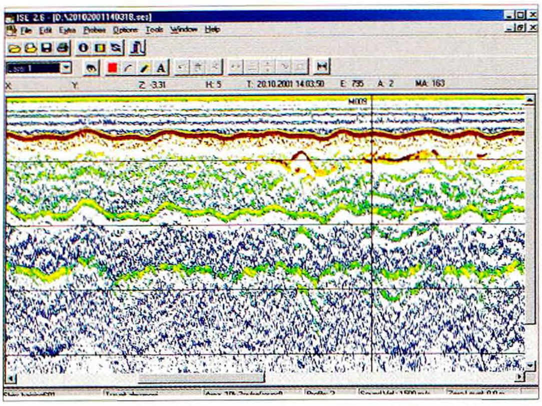

Figure 11: Pipeline survey in China

Figure 12: Pipeline which should be detected in a German lake

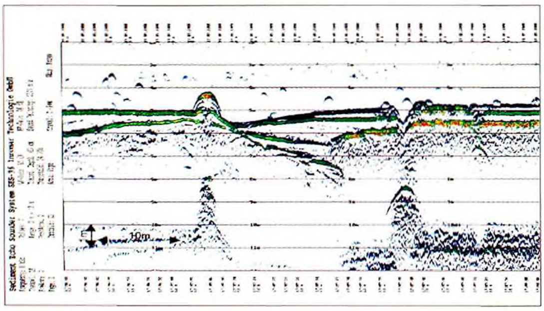

Figure 13: Pipeline survey in a German lake

depth of 10 metres.

In most cases, Figure 10, the reverberation of the parametric system is smaller than the one of the linear system and then the signal to reverberation ratio is greater than one. Even objects near the bottom can be detected with the parametric system.

The probability of detection can be increased by stacking the received signals. The signal-to-noise ratio depends on the square root of the stacking rate. The maximum stacking rate depends on how often the objects are hit. Therefore it is advantageous to have a ping rate which is as high as possible.

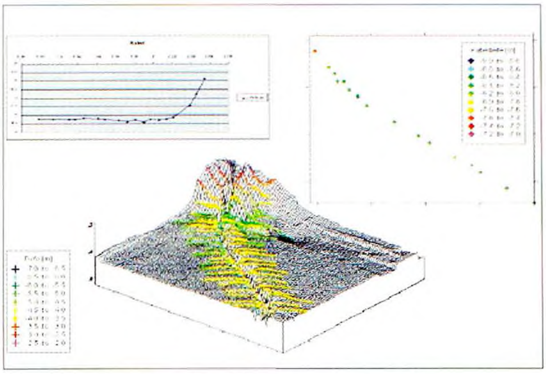

Figure 14: Result of a pipeline survey in the German lake

Examples and Results

A few examples are provided to demonstrate the efficiency of parametric systems for the detection of embedded objects. During the surveys the SES-96 light or standard systems were used. The equipment was similar to that in Figures 3, 4. The main task during many of the surveys was the search for pipelines.

Figure 11 shows a pipeline which was detected in very shallow water and just below the bottom surface. The water depth was only 1.5 metres.

The next three figures (Figure 12 – 14) show a pipe with a diameter of 40cm, one echoprint and the final result of the digitised pipe. With the SES-96 equipment a number of parallel profiles across the pipeline trench were carried out. The task was to determine the depth of the pipe in the whole lake. The on-line result is the echoprint as shown in Figure 13. Two pipelines can be seen. One of them is above the bottom, the other one is embedded approximately 3 metres below the bottom surface. As a result of the parallel profiles a map can be produced during post-processing, Figure 14.

Parametric Sub-bottom Fan Profiler

Further progress in object detection can be achieved by working with a multi-beam sub-bottom profiler. The search width can be enormously increased. Parametric transducers are perfectly

Figure 15: Transducer to generate a fan of beams

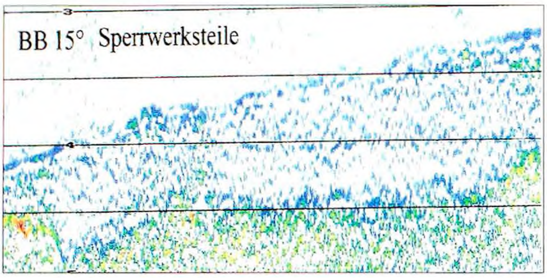

Figure 16: Echoprint from a Viking barrier (port 15°)

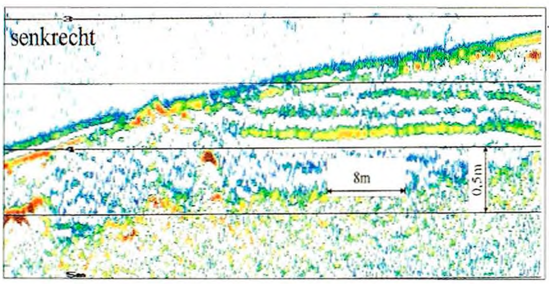

Figure 17: Echoprint from a Viking barrier (vertical beam)

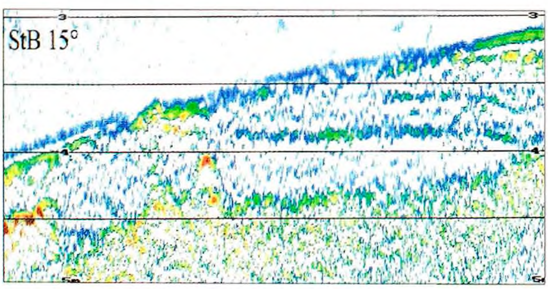

Figure 18: Echoprint from a Viking barrier (star board 15°)

suitable for the conduct of such systems because – despite the small transducer dimensions – it is possible to transmit fan-shaped low frequencies by electronic beam steering.

The detection of old embedded wrecks made of wood is especially difficult in shallow water. The differences of the acoustical impedance between the objects and the surrounding materials, especially mud, is very weak. Using a linear system

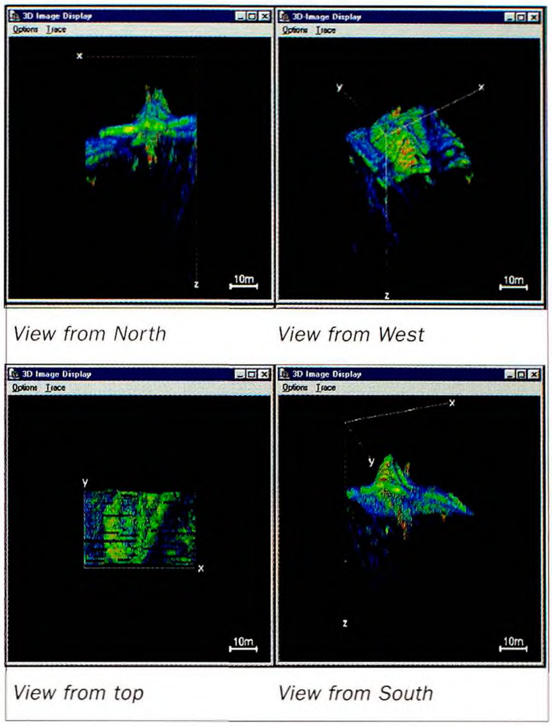

Figure 19: 3D Visualisation of parts of a wooden wreck

means that a ringing of the transmitting pulse occurs which covers the weak sound signals. For this purpose a parametric fan-sub-bottom profiler is well suited At the moment, such a system is in operation in a German lake. The transducer consists of three parts which cover the range from +/- 45°. The searching width is twice the water depth. Figure 15 shows the transducer.

An example for an archaeological project to locate old wooden structures can be found in the detection of wooden wrecks from the Viking era, (Figure 16 – 18).

Small objects can be seen particularly well with oblique sound beams. The reason is that the sound strength from the bottom and from sediment layer boundaries decreases with an oblique sound beam, yet the back scattering level of small objects remains.

In this example the position of the wooden structure is under the vessel and on the starboard side. Problems arising while using a fan-sub-bottom profiler are the huge amount of data and the presentation of the results. In this case appropriate methods for visualisation must be used. A further stage of the visualisation is the 3D-presentation with which the whole bottom is illustrated. Beside the information from a fan sonar to generate a view of the bottom surface, we have to also illustrate the information of the sub-bottom.

The figures below show different views from a wooden wreck, with parts above and below the bottom surface. In this application the 3D-views should give a better impression of the wreck parts before starting diving activities.

At present, the 3D-animation is under development and is only available during offline processing.

Summary and Prospect

This report was meant to give an overview of the properties and advantages of parametric sub-bottom profilers for the detection of small objects or pipelines.

The results of the parametric sub-bottom profiler SES-96 have shown the possibility for detecting embedded objects.

This knowledge and the experiences of current field tests with the fan-sub-bottom profiler will be used in a product (SES-2000 fan) very soon.

Searching for objects or wrecks as well as the tracking of pipes are only a few tasks for which the use of the parametric effect is suited. Other applications include:

- Investigations for dredging tasks (thickness of mud, search for rock layers or weathered rock)
- Looking for mineral resources (sand, gravel)
- Environmental investigations
- Survey at underwater building sites
- Geological/ geophysical investigations

Biographies

Sabine Müller obtained a M.S. degree in electrical engineering from Rostock University in 1990 and specialised in Underwater Acoustics and Signal Processing. Since 1997 she is the Managing Director of Innomar Technologie GmbH.

Jens Wunderlich received a M.S. degree in electrical engineering from Rostock University in 1995. Today he is research assistant at the Underwater Acoustics Research Group of Rostock University. His field of interest is non-linear acoustics and digital signal processing for underwater applications.

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