Proceedings of the Institute of Acoustics

COMPARISON OF THE CONVENTIONAL AND THE MULTI ASPECT SIDE SCAN SONAR CONCEPT

Wolfgang Jans and Jochen Ziegenbein

Federal Armed Forces Underwater Acoustics and Marine Geophysics Research Institute (FWG), Klausdorfer Weg 2-24, 24148 Kiel, Germany

1. INTRODUCTION

Conventional side scan sonar systems use linear array antennas with interconnected transducers. Therefore the phase difference or delay time between the independent transducer signals is fixed, normally zero. These systems scan the seabed with a single (horizontal) narrow acoustic beam (Fig. 1.1). They generate an acoustic image of the seabed by moving through the water. Consecutive pings generate consecutive image lines.

In more advanced systems this linear array is divided into a number of subarrays. The phase difference or delay time between the independent subgroup signals is adjustable. In consequence a number of narrow sonar beams can be formed, closely spaced around the broadside beam in a small angular sector (Fig. 1.1). These beams are formed for the return signal from the same transmit pulse. A small azimuth sector can thus be scanned without loosing resolution. Multi beam systems therefore allow to increase the search speed.

A multi beam system turns into a multi aspect side scan sonar system (MASS system) by widening the azimuth scan sector (e.g. 28 or 42 degrees). In these systems the sonar beams are spread over a broader azimuth sector (Fig. 1.1). Each beam produces a different acoustic image of the seabed due to the different azimuth angle or angle of view. These images are generated simultaneously, but they cover the same area of the seabed at different times. In addition they are more or less distorted as compared to the conventional side scan sonar images. Furthermore the angle of view of the sonar beam can be scanned through the whole scan sector. Sector-shaped images therefore can be generated from the returns from just one ping of a MASS system.

The technical realisation of a MASS system is based on two principles:

- The sonar pulse is transmitted into the desired scan sector using a transmitting antenna with a corresponding beam pattern.
- The angular resolution of a MASS system is determined by the receiving antenna only.

Fig. 1.2 and 1.3 demonstrate the potential of a multi aspect side scan sonar system. In comparison to conventional systems MASS systems supply information quicker. In addition MASS systems are able to supply additional information. The first figure shows a conventional acoustic image of a sandy seabed. The whole image is based on roughly 120 consecutive pings. The image includes three objects: a big sphere, a cylinder target and a third object. A multi aspect side scan sonar image shows the same scenery (Fig. 1.3). The three objects can be found in this image as well. To generate this sector shaped image the sonar beam is scanned through the scan sector. Therefore this image is based on just one ping.

2. ADVANTAGES OF THE MASS - CONCEPT

MASS systems have some advantages over conventional side scan sonar systems since they scan a search area over a wider range of aspect angles thus supplying additional information on the seabed. Two main advantages of a multi aspect system are listed below:

COMPARISON OF THE CONVENTIONAL AND THE MULTI ASPECT SIDE SCAN SONAR CONCEPT

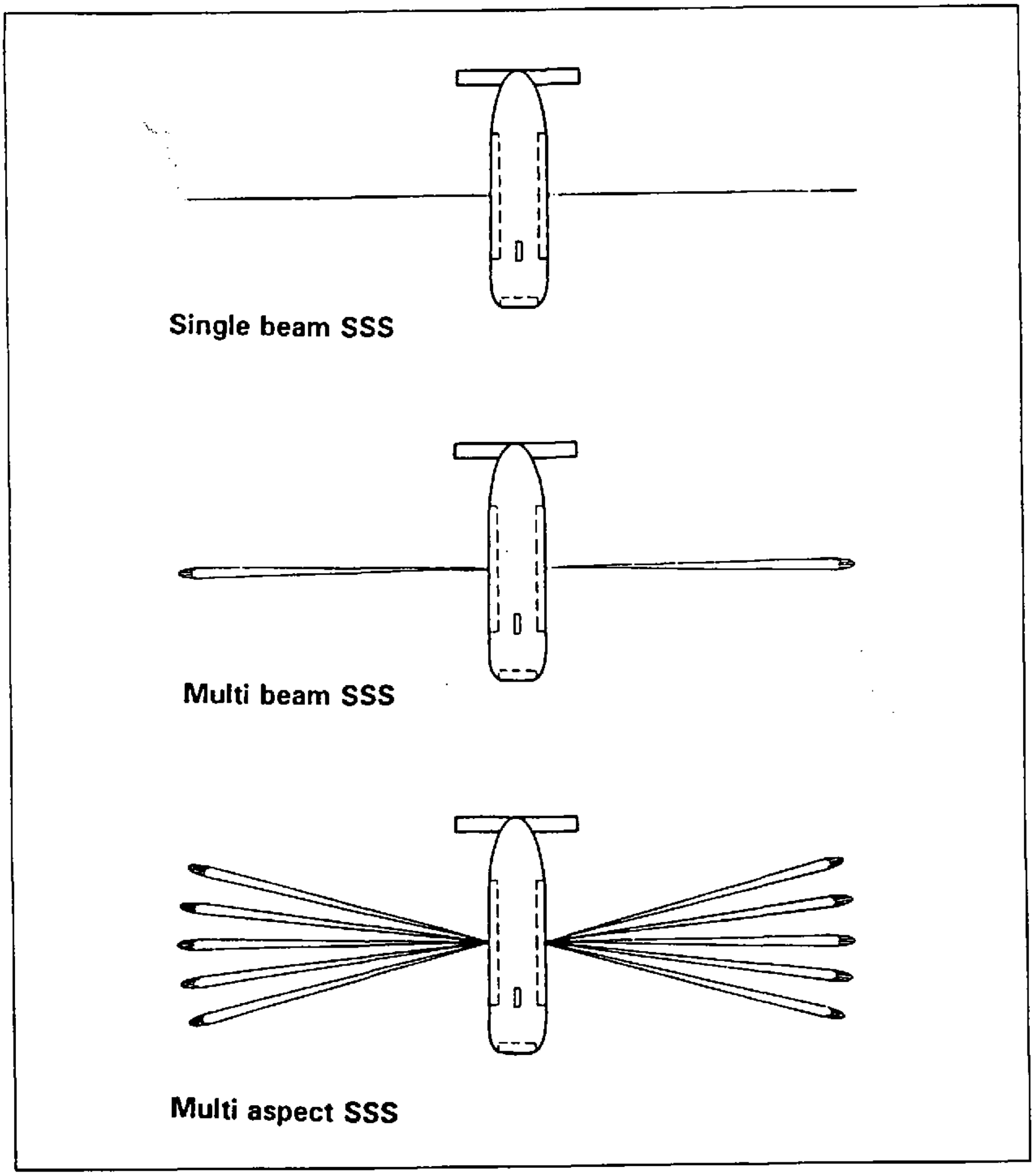

Figure 1.1: Hierarchy of Side Scan Sonar Systems (SSS)

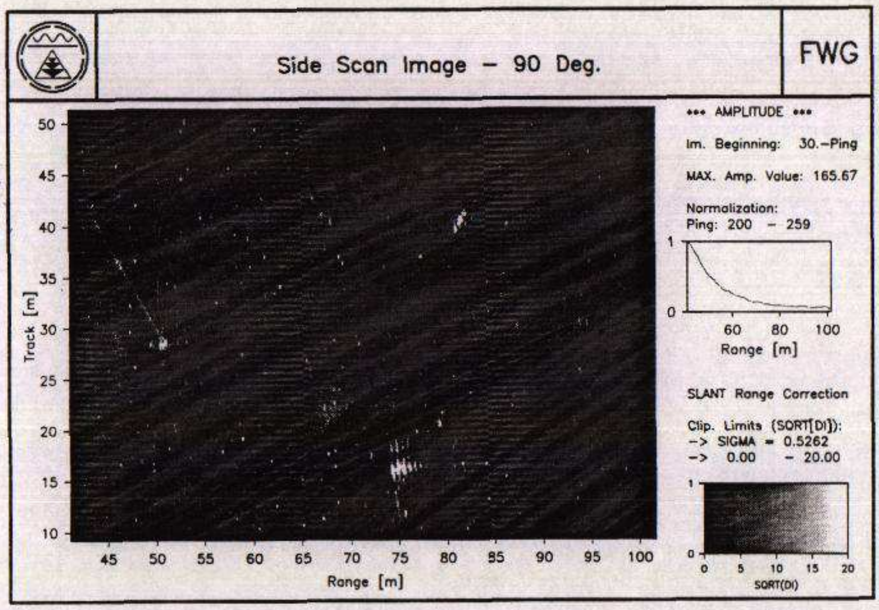

Figure 1.2: Conventional acoustical image of a sandy seabed. The image includes three objects: a big sphere, a cylinder target and a third object. The image is based on roughly 120 consecutive pings. A single broadside beam per ping is formed.

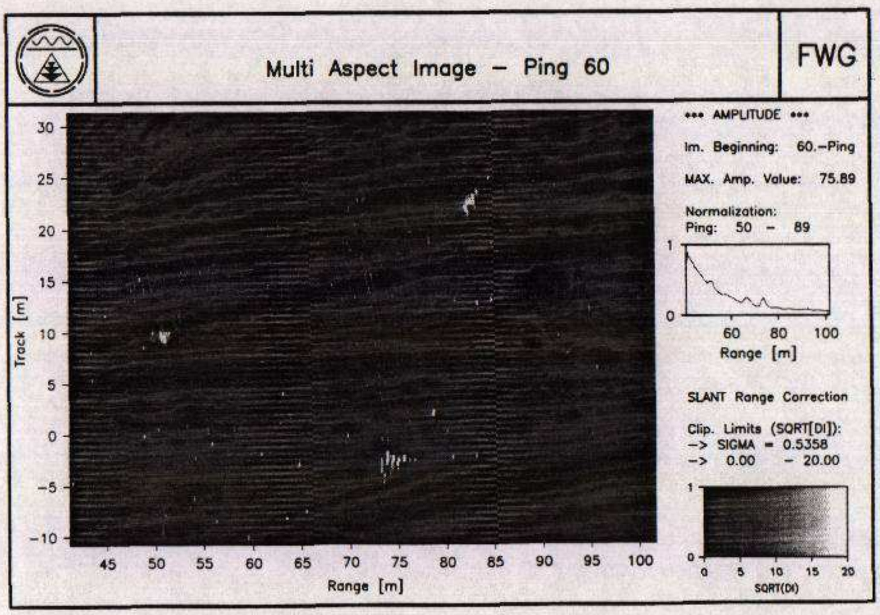

Figure 1.3: Sector-shaped image of the same scenery as in Fig. 1.2. The three objects can be found in this image as well. To generate this sector shaped image the sonar beam is scanned through the scan sector. Therefore this image is based on just one ping.

COMPARISON OF THE CONVENTIONAL AND THE MULTI ASPECT SIDE SCAN SONAR CONCEPT

I) - Large objects (e.g. boulders and sandwaves) or the bottom topography (e.g. ripples and valleys) produce an acoustic shadow zone in a conventional side scan sonar image. Targets which are located in this shadow zone are not detectable by a conventional system. If the difference between two angles of view in a multi aspect system is large enough, a shadow zone in the acoustic image from the first beam will eventually be illuminated by the second beam. This possible reduction of the effective shadow zone area due to angle diversity causes an increase of detection probability.

II) - Targets have to be detected against the background of the seabed. The contrast of a target echo within a side scan sonar image depends on the difference between the target strength and the backscattering strength of the seabed. The MASS concept in principle may lead to a better contrast in the images for two reasons:

- 1) The target strengths of many targets strongly depend on the aspect angle under which the target is seen. An example is the target strength of a cylinder (Fig. 2.4). A conventional side scan sonar system has one fixed look direction only. Therefore it may look at the target under a very unfavourable aspect angle, which is related to a minimum in the target strength. As a result the target appears with low contrast in a side scan sonar image or may not be detected at all.

  A multi aspect system "sees" the targets under different aspect angles. Moreover, if the scan sector is large enough, there is a good prospect to detect the target under at least one angle of view with a good contrast, which is related to a higher target strength.

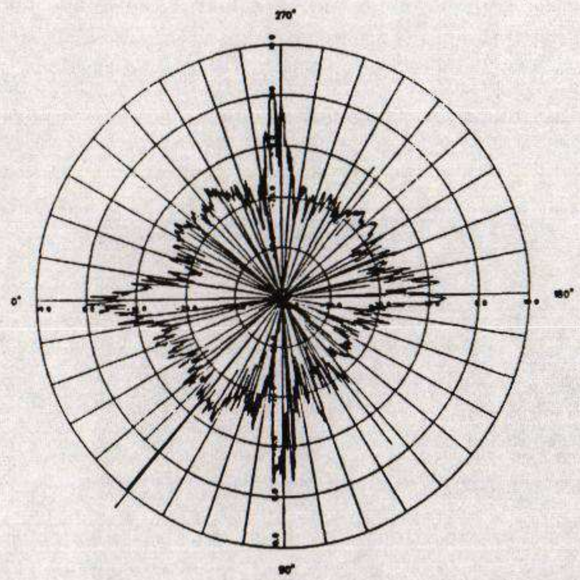

Figure 2.4: Measured target strength of a cylinder target as a function of aspect angle. Frequency 100 kHz; Beamwidth 0.2 degrees. Distance from line to line 10 dB. (Study AE - 7/92, Bremen)

- This effect can be verified from experimental data. To do so we focused on the cylinder target in Fig. 1.2. Sector- shaped images including this target - similar to Fig. 1.3 - are calculated for different positions along the track. The cylinder target appears in these images in the same location - but the aspect angle under which the target is seen is different (Fig. 2.5). Selecting the respective beam signals from both

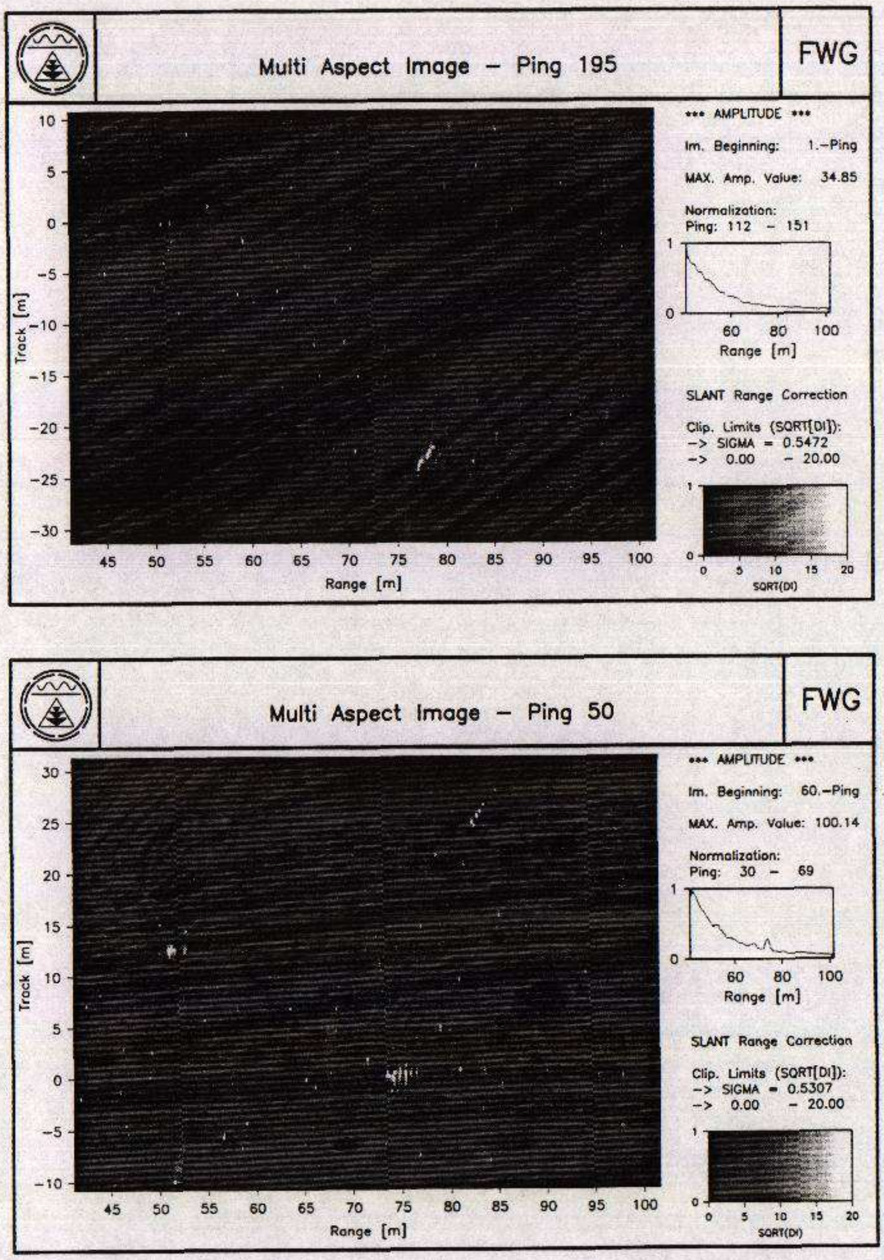

Figure 2.5: Multi aspect side scan sonar images for two positions along the track in Fig. 1.2. Both images are based on the returns from differnt pings. The cylinder target appears in the first image on top and in the second one on bottom of the scan sector.

images delivers the two echo signals from the same target (Fig. 2.6). The difference in the target echo level is clearly visible. The difference in the aspect angle is 33 degrees.

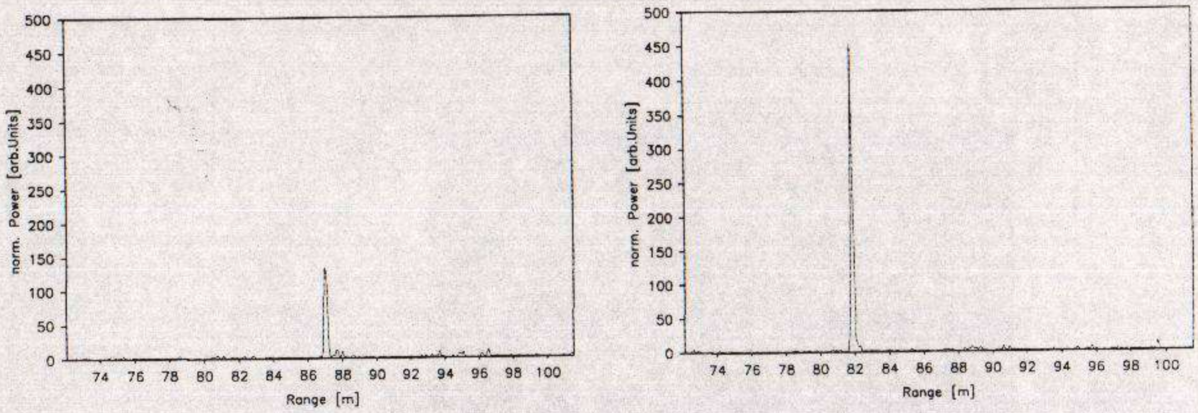

Figure 2.6: Echo signals from the same target with an aspect angle difference of 33 degrees

- 2) The detection threshold of a peak detector is derived from the measured backscattering strength which is a statistical value. MASS systems allow to get more independent measurements of that backscattering strength from a single ping as compared to conventional systems. MASS systems therefore enable one to estimate a better threshold and/or normalising factor.

3. A DISADVANTAGE OF THE MASS - CONCEPT

The effective sidelobe level of a conventional side scan sonar system may be much lower than that of a multi aspect system.

Conventional systems use the same narrow beam antenna both for the transmit and the receive mode.The effective side lobe level is, therefore, determined by the square of the directivity patterns of the array. This results in a very low effective sidelobe level and a very narrow beam.

For a multi aspect system the situation is different. Since the transmitting antenna has a broad main lobe the beamwidth and effective sidelobe level are determined by the receiving antenna only. The sidelobe generated components in the beam signal will therefore be larger than in conventional side scan sonar systems. For this reason a low sidelobe level of the receiving antenna is a very important design issue for MASS systems. Equally, the effective 6 dB - beam width of a MASS system will be almost 1.3 times larger than that of a conventional system having the same antenna dimensions.

4. INFLUENCE OF THE SIDELOBE LEVEL ON IMAGE QUALITY

The components of the beam signal that are received through the sidelobes can be interpreted as a "noise" signal. This is due to the fact, that these components come from a broad azimuth sector containing a large number of resolution cells. As a consequence of the central limit theorem the bottom backscattering signal received through the sidelobes can be treated as Gaussian noise. This corresponds to a Rayleigh distribution for the envelope of this signal.

Contrary the component of the beam signal that is received through the main lobe is related to an individual resolution cell. Therefore the amplitudes of this signal component very often do not show a Rayleigh distribution. This means, that sidelobe generated signal components lead to a constant "noise" content in side scan sonar images.

In the following we will try to describe the influence of the sidelobe levels on the acoustic images. For this purpose we are looking at the pixel statistics rather than at the image itself. The pixel statistics will be described by the amplitude histogram, or the normalized version which is the density function. Before calculating this density function we have to normalize the beam output signals to get rid of the decaying component of the backscattering signal.

First we calculated an amplitude density function for backscattering signals from a part of a flat muddy bottom. This bottom guarantees directional isotrophe of the bottom backscattering. The experimental data were collected during a sea trial with an experimental MASS system. Fig. 4.7 - left - and 4.7 -right - show the results for an angle of view of zero degree and of 20 degrees backwards, respectively. Both amplitude density functions were taken from the same bottom area. The values for mean, standard deviation and the higher central moments (Skewness and Kurtosis) are included in the figures. Additionally the Rayleigh and Log-Normal distribution are drawn. These distributions were calculated from the measured values for mean and standard deviation. The first 4 moments are given in the figures as well.

Figure 4.7: left) Measured amplitude density function for a part of a flat muddy bottom. Angle of view zero degree (broadside beam).right) Measured amplitude density function for the same part of a flat muddy bottom as in a). Angle of view 20 degrees (offbroadside beam). The Rayleigh and Log-Normal distribution are based on the measured values for the mean and standard deviation. (The statistical values for a Rayleigh distribution are: mean = 1.000, standard deviation = 0.523, skewness = 0.631 and kurtosis = 3.245)

Only for small amplitude values the measured density function in Fig. 4.7 - left - and the Rayleigh function for smaller amplitude values fit well. High amplitude values however are more frequent in the image of the broadside beam than they should be according to a Rayleigh density function. In this range of amplitude values the Log-Normal function fits better. It is well known that the statistics of sonar returns from the seabed can differ significantly from the Rayleigh envelope distribution. Different authors /1 - 4/ found that, for narrow beamwidths, the intensity distribution was better described by a Log-Normal law.

Comparing Fig. 4.7- left - and Fig. 4.7 - right - indicates, that the measured density function depends on the angle of view. The reason for this is, that the side lobe level went up for the 20 degrees beam. This is due to the fact that the grating lobes of the receiving antenna at this angle of view started moving into the scan sector that is illuminated by the transmitting antenna.

We will now try to model this sidelobe effect mentioned above by adding artificial Gaussian noise signal to the normalized broadside beam data. Fig. 4.8 show the resulting amplitude density functions after adding noise signals with mean amplitude values of 0.01, 0.707, 1.000 and 2.00, respectively. It can be seen that the amplitude density function is very sensitive to an increase in the noise component. The simulated density function approaches the theoretical Rayleigh distribution when increasing the additive noise signal amplitude.

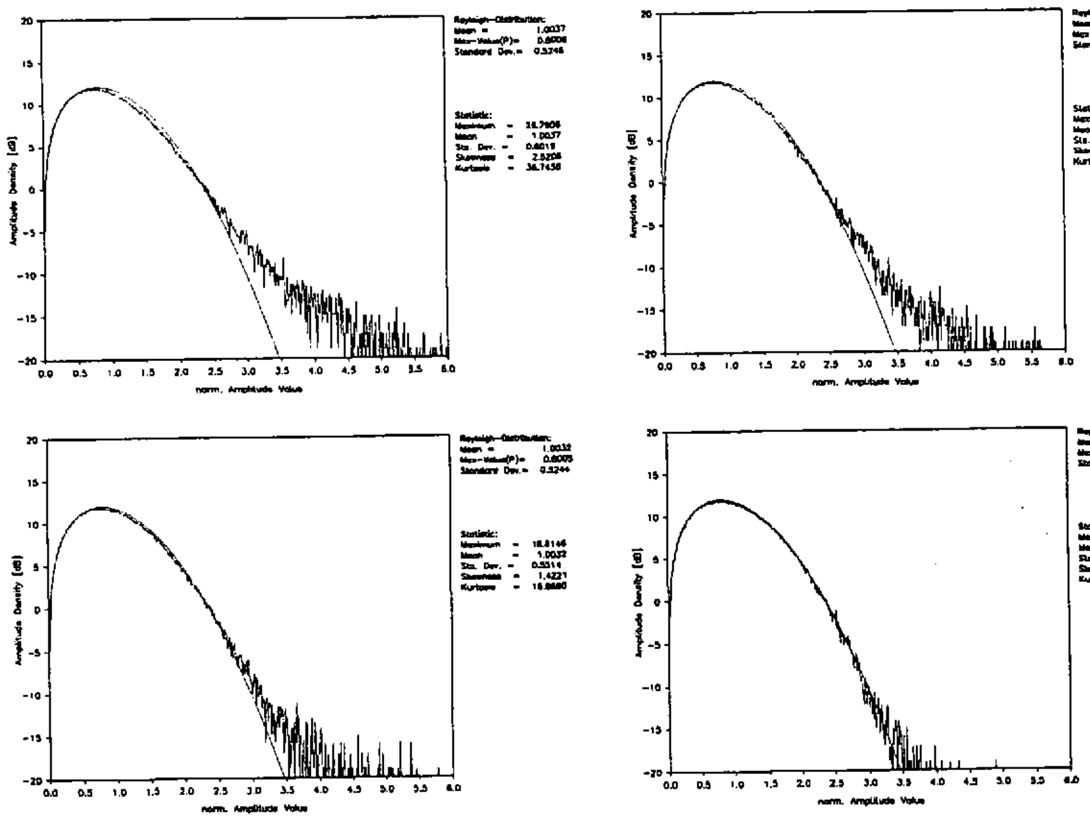

Figure 4.8: Amplitude density function for a part of a flat muddy bottom. An additional artificial Gaussian noise signal is added to the beam data for the broadside beam. Mean amplitude value of the noise signal top left) 0.01, top right) 0.707, bottom left) 1.000 and bottom right) 2.00.

5. CHARACTERISATION OF BOTTOM STRUCTURE

Histograms or amplitude density functions are also used to characterize different bottoms with respect to the backscattering statistic. Fig. 5.9 shows a conventional side scan sonar image. In this example the seabed consists of sand covered with a lot of stones and some boulders. A sandbank with a ripple structure on it can be seen as well. The period of this ripple structure is typically 50 cm - 70 cm.

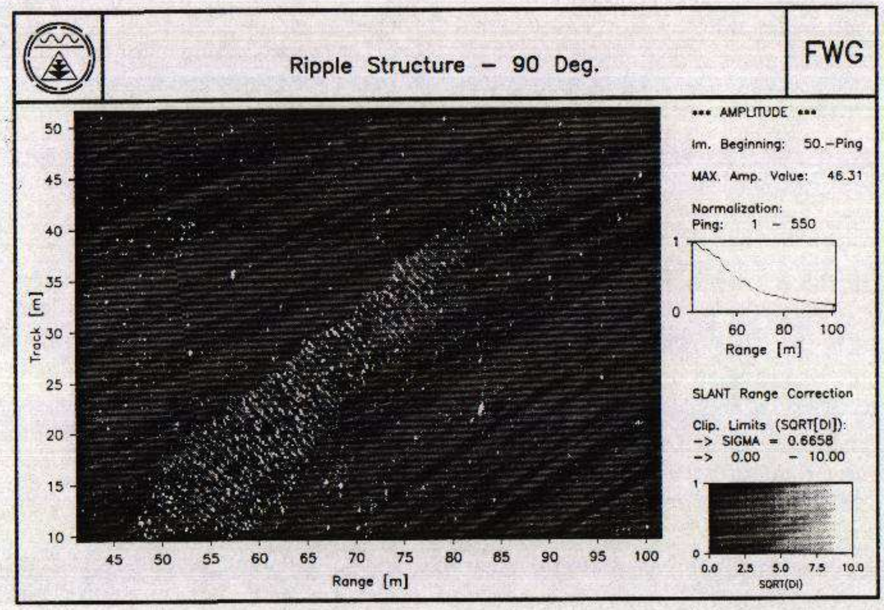

Figure 5.9: Conventional side scan sonar image. The seabed consists of sand covered with a lot of stones and some boulders. A sandbank with a ripple structure on it can be seen as well. The period of this ripple structure is typical 50 - 70 cm.

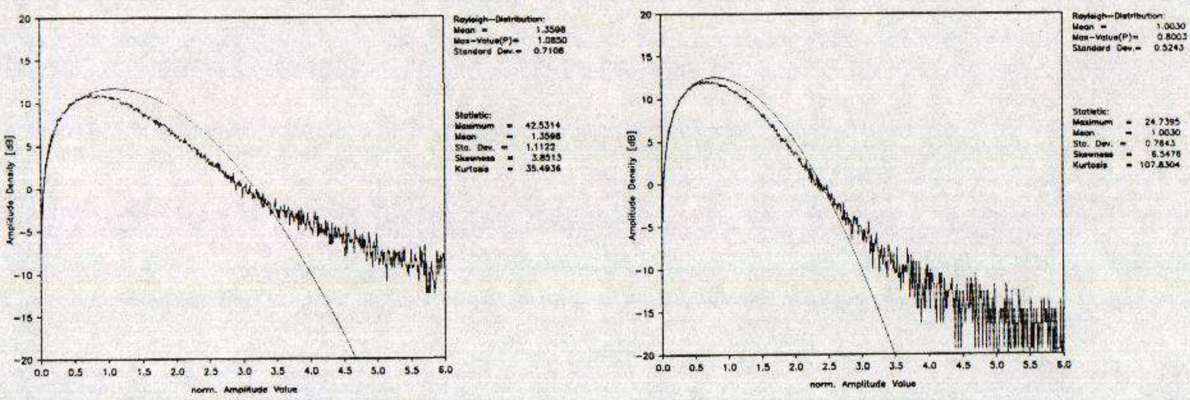

Figure 5.10: left) Measured amplitude density function for a section of the image shown in Fig. 5.9 including the ripple. right) Measured amplitude density function for a section of the image shown in Fig. 5.9 that comprises stones and boulders but no ripple structure.

For a section of this image including the ripple structure we calculated the amplitude density function. The result is shown in Fig. 5.10 - left-. The measured density function shows big differences as compared to the result for a flat muddy bottom (Fig. 4.7 - left -). It differs in a significant way from the Rayleigh distribution. Especially high amplitude values are more likely. These differences in the distribution, can be quantified by the values for means, standard deviations and the higher central moments (Skewness and Kurtosis) as well.

We than chose a second, section of the same image (Fig. 5.9). It is covered with stones and boulders and comprises no ripple structure. The calculated amplitude density function is shown in Fig. 5.10 - right -. A significant difference in comparison with the result for a sandy bottom with a ripple structure (Fig. 5.10 - left -) and a weaker difference in comparison with the result for a flat muddy bottom (Fig. 4.7. - left -) can be seen. The differences become even more evident in the values for the higher central moments of the distribution. This is due to the fact, that these values depend increasingly on the tail of the distribution.

6. SUMMARY

Multi aspect side scan sonar systems (MASS systems) in principle have some obvious advantages. The most important one is that they allow to view at a target from different aspect angles and thus lead to a higher detection probability. On the other hand MASS systems have higher sidelobe levels and a wider beamwidth (i.e. less angular resolution) than conventional side scan sonar systems having the same antenna dimensions.

It has been shown that the component of a beam output backscattering signal that originates from the sidelobes can be treated as Gaussian noise. For this purpose amplitude histograms for beam signals with varying sidelobe components have been calculated from data collected with an experimental MASS system.

Furthermore we have shown that the backscattering characteristics of different bottom types can be described in a statistical sense by looking at the amplitude statistics. The tail of the distribution may serve as an indicator for bottom (area) dependent problems that may occur with respect to high false alarm rates and classification. Although statistical parameters could thus be part of a bottom type descriptor, it should be mentioned, that the statistical parameters presented in this paper depend (besides on the bandwidth) on the beamwidth and the sidelobe level of the measuring system.

7. REFERENCES

/1/ N.P. Chatiros, H. Boehne, T.G. Goldsberry, S.P. Pitt, R.A. Lamb, A.L. Gorcia and R.A. Altenberg J. Acoust. Soc. Am. 77, 975 - 982 (1985)

/2/ H. Boehne and N.P. Chatiros J. Acoust. Soc. Am. 84, 1018 - 1029 (1988)

/3/ M. Gensane IEEE J. Oce. Engin. 14, 84 - 93 (1989)

/4/ S. Stanic and E.G. Kennedy IEEE J. Oce. Engin. 18, 95 - 99 (1993)