SURVEILLANCE ARRAYS FOR SHALLOW WATER: COMPARISON OF PLANAR VS. LINE BOTTOMED ARRAYS

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ABSTRACT

A number of different array architectures, including horizontal and vertical line arrays and planar arrays, are currently being developed for shallow water applications. An objective of the work is to assess the performance of the different array architectures. To achieve this the arrays were tested during a sea trial (RDS-2) that took place in the Timor Sea in November 1998. This paper compares the broadband detection performance of two designs of array, a planar array (Octopus) and a Horizontal Linear Array (ULRICA HLA), at the RDS-2 site. Noise statistics and signal threshold levels presented here are obtained from ambient noise data. Significant differences in the dependence of threshold on azimuth are shown between the Octopus and ULRICA arrays and are attributed to the different geometries and hence beampatterns of the arrays. Signal data, obtained from a submerged sound source, are used in conjunction with the noise data to determine detection performance at a range of source levels. The results indicate that the detection performance of 16 element ULRICA and Octopus arrays is comparable at the RDS-2 site.

SOMMAIRE

Il y a plusieurs différentes architectures de réseau, des réseaux linéaires horizontaux, verticaux ainsi que des réseaux plans, qui sont présentement en voie de développement pour des applications en eaux peu profondes. Un objectif de ce travail est d'évaluer la performance des réseaux ayant des architectures différents. Pour accomplir ceci des réseaux on été mis à l'épreuve durant un essai en mer (RDS-2) qui a eu lieu dans la mer de Timor en novembre 1998. Ce traité compare la performance de détection à large bande de deux types de réseaux, un réseau plan (Octupus) et un réseau horizontal linéaire (ULRICA) au site RDS-2. Les statistiques de bruits et les niveaux de seuil des signaux présentés ici on été obtenus de données de bruit ambiant. Des différences significatives de la dépendance du seuil sur l'azimuth sont démontrées entre le réseau Octopus et ULRICA. Ces différences sont attribuées aux géométries distinctes et par conséquent la mise en forme de faisceau des réseaux. Les données du signal, obtenu d'une source acoustique submergée, sont utilisées en conjonction avec les données de bruit pour déterminer la performance de détection pour une gamme de niveau d'émission. Les résultats obtenues au site RDS-2 inidquent que la performance de détection des réseaux à 16 éléments ULRICA et Octopus sont comparables.

INTRODUCTION

A collaborative program of work on Rapidly Deployable Systems (RDS) is currently taking place under the Technical Cooperation Program (TTCP). The object of the work is to demonstrate the concept of RDS. This includes building and testing prototype RDS arrays, demonstration of packaging and deployment, developing processing algorithms and an accurate modeling capability for RDS systems. Part of the work is to assess the performance of different architectures of RDS arrays deployed in shallow water.

A sea trial, RDS-2, was performed in November 1998 in the shallow water of the Timor Sea [1]. A number of different RDS systems were deployed by the participant nations including a planar Octopus array, ULRICA arrays that can either be configured as horizontal or vertical line arrays, a large aperture horizontal array (ULITE) designed for matched field processing, and various environmental sensors.

A set of experiments was performed to determine the detection performance of the different systems. One objective is to compare the detection performance of the Octopus planar array and the ULRICA Horizontal Linear Array (HLA) array at the RDS-2 site. This paper presents some of those results.

Noise statistics and threshold levels were obtained from a section of ambient noise data recorded at similar times on both arrays. Different signals were transmitted from a submerged source at a number of ranges from the receivers. These signals were attenuated to correspond to different

source levels and then injected into the noise data from different beams. The broadband detection performance of the two arrays is evaluated and compared. Results are presented using two different constant false alarm rate (CFAR) threshold settings: 1) based on setting individual threshold levels in each beam and 2) on setting a single omni-directional threshold level. Conclusions are given concerning the analysis.

OCTOPUS PLANAR ARRAY

The experimental Octopus array is under development by SPAWAR Systems Center in San Diego, US. This acoustic array is an autonomous, bottom mounted, planar disk. The array consists of eight arms containing 16 hydrophones. The array weighs approximately 100 kg in air and has an outside diameter of 5.5 m. The hub of the array is a pressure housing containing the data recording system. The retrieval system is mounted on the top of the pressure housing.

The hydrophone sensitivity is –135 dB V/μPa and the array's frequency response is 40-1200 Hz. The recording system consists of an analog to digital card installed in a computer with 16 channels of 16 bit A/D with a sample rate of 3005 Hz and 8 gigabytes of storage.

The deployment procedure consists of booming the array over the water, lowering it into the water, letting the free flood areas fill, and then releasing the array. The array free falls to the bottom. Average time for a deployment takes 10 to 15 minutes.

The retrieval system consists of a pop-up buoy, which has a submersible light, VHF radio beacon, and a radar reflector. The primary release is acoustically commanded from the surface via a transponder. The secondary release is a timed burn wire release that can be set in one-hour increments. The buoy is then released from the array, floats to the surface, but is still attached by a line to the array. This line is then used to pull the array to the surface. The array is reattached to the boom and hoisted on to the deck of the boat.

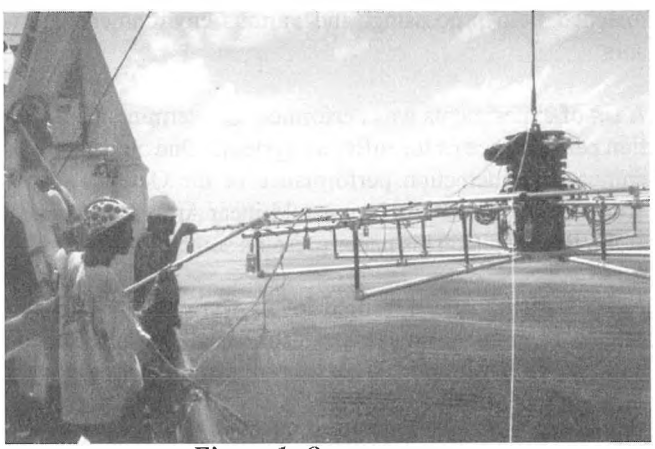

Figure 1 Octopus array.

Figure 1 shows the Octopus array being deployed. The eventual fleet system would be a low cost, lightweight, air deployed array consisting of between 16 and 32 sensors.

ULRICA HLA

The ULRICA array is under development at DERA Winfrith in the UK. It is a lightweight, low cost, deployable array system that can be configured as either a horizontal or vertical array [2]. The ULRICA array is autonomous and can either be programmed prior to deployment or remotely from the trials ship via an acoustic link. A photograph of the ULRICA array and the Octopus array prior to deployment is shown in figure 2.

The array contains 32 omni-directional Benthos AQ4 hydrophone sensors with a sensitivity of -201 dB re 1 V/μPa. The nominal spacing of the hydrophones is 1.25 m. However, since the HLA is not rigid, sensor positions must be determined after deployment. The ULRICA array contains an electrical cable, to which the sensors are attached, and a separate Kevlar strain member. The sensors are interfaced to a PC unit housed in a two piece pressure housing weighing 65 kg. A Benthos acoustic release mechanism is attached to a small buoy to enable recovery. Lead weights are attached to the cabling and close to the sensor casings in the horizontal arrays to increase the specific gravity.

Experimental results are presented in this paper from two separate deployments of ULRICA arrays. Ambient noise measurements were obtained from array (HLA05) deployed 19 km from the trials site. Signals transmitted from a submerged projector were recorded on array (HLA09) deployed at the trials site.

After the deployment of each array, the sensor positions

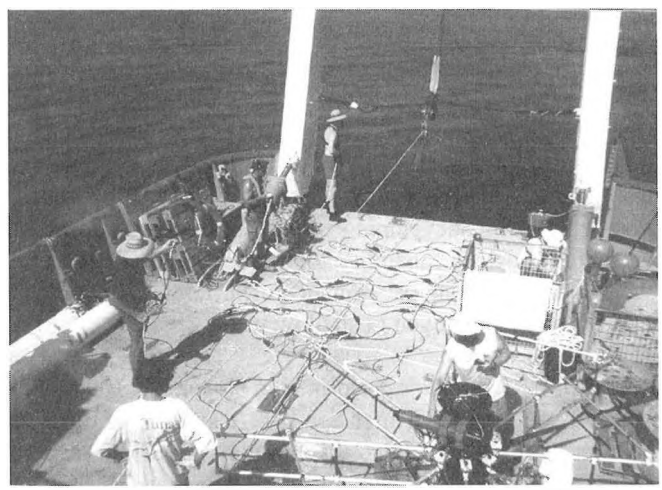

Figure 2 ULRICA and Octopus arrays on deck

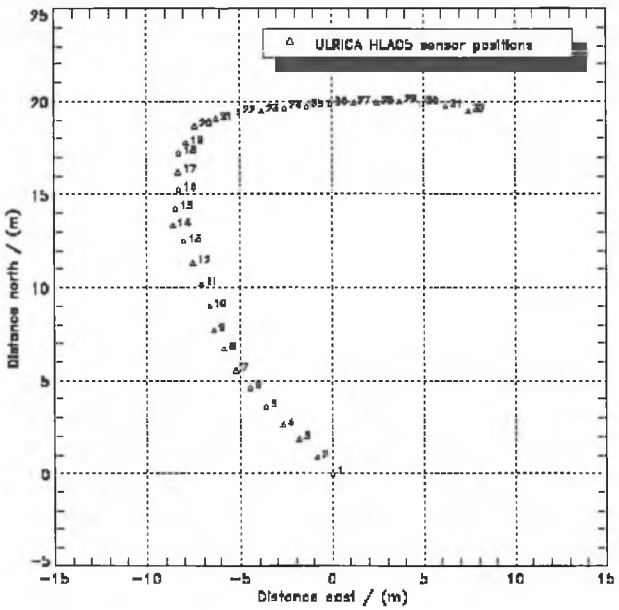

Figure 3 Location of sensors in ULRICA HLA05

were determined from experimental data [2]. The trials ship *Pacific Conquest* circled each array at a distance of 500 m and provided a broadband source of noise. The sensor positions were determined by measuring the phase response between pairs of hydrophones and applying a least squares fit to the data. The positions of the source were obtained from GPS.

Figure 3 shows the estimated sensor positions in ULRICA HLA05 relative to the first sensor in the array. The array is in the shape of a boomerang. The mean sensor spacing is 1.13 m. ULRICA HLA09 was also not straight and the shape was similar to that of HLA05. In the analysis considered in this paper, sensor positions were taken into consideration and shape corrected beamforming was applied.

THE EXPERIMENT

A set of experiments was performed to evaluate the detection performance of the different RDS systems. An Octopus array and a horizontal ULRICA array (HLA09) were deployed close together at the trials site. The water depth was 105 m. The seabed was very flat, with a slope of less than 4 m over a range of 9 km. A sound source, the Sonar Research Projector (SRP), was deployed to a depth of 50 m from the *Southern Surveyor*, one of the trials ships.

The SRP was used to generate several narrow band and broadband signatures whilst the trials ships were in a quiet state. Recordings were obtained at seven locations at different ranges from the arrays. Results are presented here at two ranges, 4.27 km (denoted as test PD5), and 9.0 km (test PD8).

A sequence of recordings was made for each projector location. Each signal was transmitted continuously for 5 minutes. Two sets of narrow band tones were transmitted; a quiet narrow band spectrum denoted NB1 and a louder spectrum NB2. NB1 contained source levels representative of current and future threat signatures while NB2 contained narrow band signatures at the maximum output of the projector. Two broadband spectra were transmitted, a quiet spectrum BB1 and a higher spectrum level BB2. Ambient noise was also recorded while the trials ships were in a quiet state.

Only short sections of ambient data were recorded during the PD sequences. The ambient noise recordings were insufficiently long to provide a good estimate of the noise distribution. A separate experiment was performed to obtain ambient noise data over an extended period. An Octopus array and a horizontal ULRICA array (HLA05) were deployed 19 km to the NNW of the trials site. Ambient noise conditions were recorded over 2 days.

THE NOISE

The ambient noise used in the analysis was obtained between 00:00 CST and 04:20 CST on November 6, 1998. Ambient noise conditions were relatively quiet during this period and the wind speed was from 5 to 7 knots. The band average level of about 61 dB SPL is consistent with wind speed noise. However, biological noise was in evidence sporadically. In the ULRICA case, the noise section was 27 minutes sampled continuously, starting at 00:00 CST. In the Octopus case, the noise section consisted of 64 seconds every 5 minutes over 3 hours 20 minutes, starting at 01:00 CST.

Neither data from the ULRICA array or the Octopus array were shaded in the space domain prior to beamforming. A conventional beamformer employing array shape correction was used in all the processing. For both data sets the integration period for each update was 15 seconds.

In the analysis given here, the noise distribution and threshold levels, obtained from the noise sections were static. The static threshold condition was required because of the fact that our source was stationary. One of the bases for using CFAR is that a target will create dynamic features (changing beams with time), with time scales short (minutes to 10 s of minutes), compared to changing noise time scales that are much longer. In practice, thresholds would be set on a slowly varying time scale, and therefore would adapt to changes in ambient conditions.

Figure 4 shows beam noise intensity (linear scale) from the Octopus array integrated over the band 200-400 Hz for the first 2 hours. The graph shows that the general background level is relatively low and steady with a 2-3 dB higher level

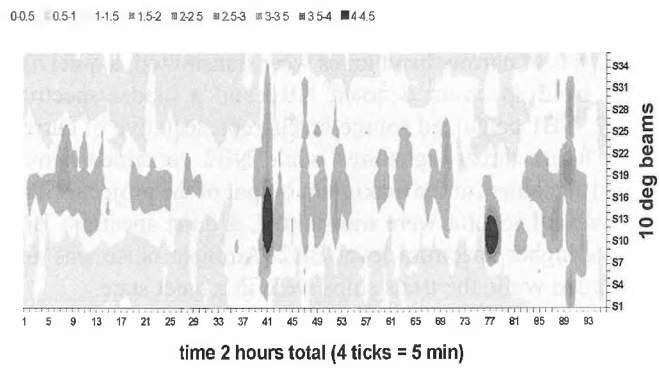

Figure 4 Beam noise intensity from Octopus array in the band 200-400 Hz from 01:00CST 6/11/1998

to the North (Beam 14) and East (Beam 23) directions. The time history (horizontal axis) contains some short duration 'outbursts' of noise that are believed to be due to biologics.

Figure 5 shows the beam noise pressure from the ULRICA array (HLA05) in the band 200-400 Hz from 00:00 CST on 6/11/1998. The beam noise response is displayed as the mean intensity in a 1 Hz band between 200 and 400 Hz as opposed to the integrated power in this bandwidth. The array response was calculated from only 16 of the 32 channels in the ULRICA array (channels 16-31) for two reasons. Firstly, for comparison purposes, only 16 channels were considered since the Octopus array comprised 16 channels and secondly the selected channels from the ULRICA array were approximately linear (figure 3). The graph shows that the variation (from lowest to highest) in noise levels with bearing is typically 5 dB. Lower noise levels are obtained near the endfire directions (to the east and west). The array response is almost symmetrical about the endfire directions because the array is approximately linear. High noise levels are obtained in all directions in a single update 590 s from the start. This transient event was found to be due to vibration of the sensors resulting from current flow over the array. Many more transient events were recorded in the band 100-200 Hz (not shown).

The results show that there are significant differences in the beam response of the Octopus and ULRICA arrays to the noise. This is likely to be due to the different beam-patterns of the arrays. A planar array such as the Octopus array can resolve beams in azimuth without ambiguity and have some discrimination in the vertical plane, although the beams will be wider than a corresponding line array. A horizontal line array that is deployed in a straight line is symmetric and has an ambiguity in the beampattern. In addition, energy is admitted from a wide range of elevation angles, except in the endfire direction.

Figure 6 shows pressure spectra from a single channel in the ULRICA array on two different days, 6/11/1998 at 00:00 CST and 8/11/1998 at 14:07 CST. At the first of these times, the array was deployed 35 km from the trials site. The trials ships were therefore at some distance from the array. The spectrum level is relatively low. Higher levels are obtained between 550 and 700 Hz and around 800 Hz due to energy arriving from the NE. At the second of these times, the trials ships were much closer to the array but were in a quiet state prior to an acoustic transmission from the projector (PD5). Higher noise levels were obtained at this time above 350 Hz due to biological activity. In particular croaker fish were identified. Similar results were obtained from the Octopus

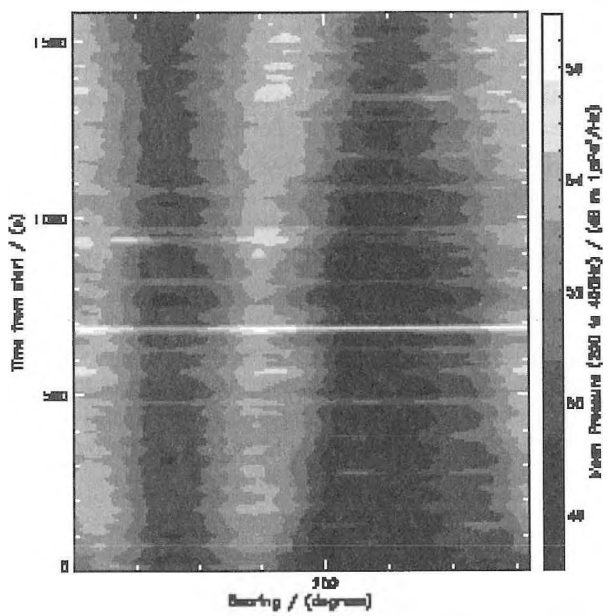

Figure 5 Beam noise pressure from channels 16-31 in ULRICA HLA05 in the band 200-400 Hz from 00:00 CST 6/11/1998

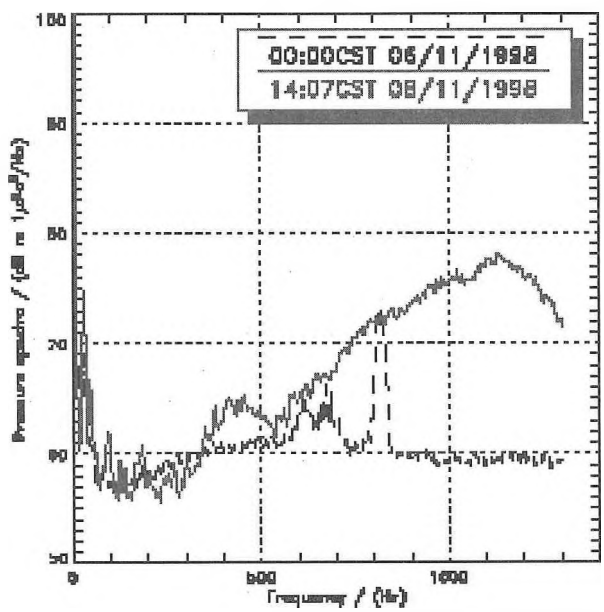

Figure 6 Pressure spectra from single channel in ULRICA during ambient noise recordings on two different days

array, but are not included.

CFAR THRESHOLDS

Noise data from the Octopus array (a sample of which is shown in figure 4) were used to calculate the noise distribution. The noise distribution was formed from 160 updates (15 s segments) in each beam. Threshold levels were then set for each beam based on a specified Probability of False Alarm (PFA). The threshold levels (in intensity units, right vertical axis) for the Octopus array data in the band 200-400 Hz are shown in figure 7 as a function of beam number. The probability that a 15 s time (update) would have an intensity greater than that level is indicated by the gray-scale. The large area in the upper portion of the graph shows the probability of exceeding the threshold is from 0.0-0.05. Following the lower edge of this region for each beam yields the threshold level (right axis) for that beam for a PFA of 0.05. As the threshold levels decrease, there is a corresponding increase in the PFA. Specifying the PFA specifies the threshold in an autonomous fashion.

The noise distribution in the ULRICA array was formed from the 108 updates shown in figure 5. Figure 8 shows the threshold levels in 16 channels of the ULRICA array in the band 200-400 Hz as a function of bearing and PFA. The threshold levels are given as the mean power in a 1 Hz band between 200 and 400 Hz. The threshold levels vary by 5 dB

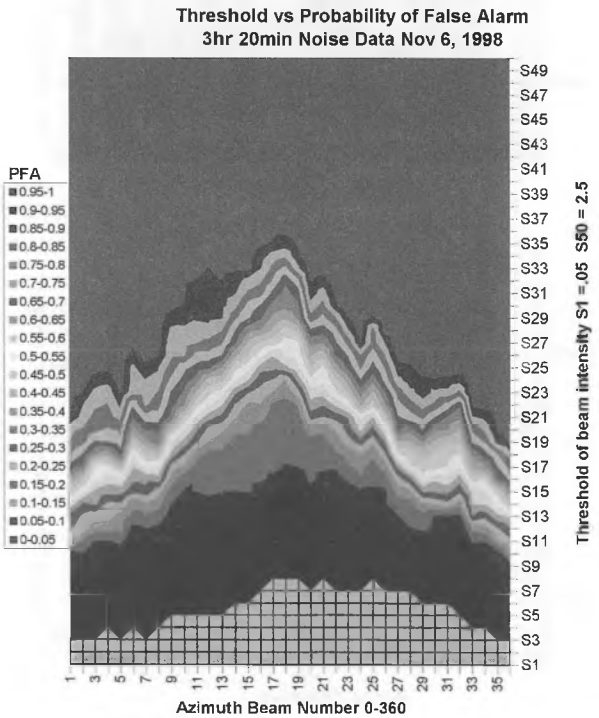

Figure 7 Octopus beam thresholds in the band 200-400 Hz for different probabilities of false alarm

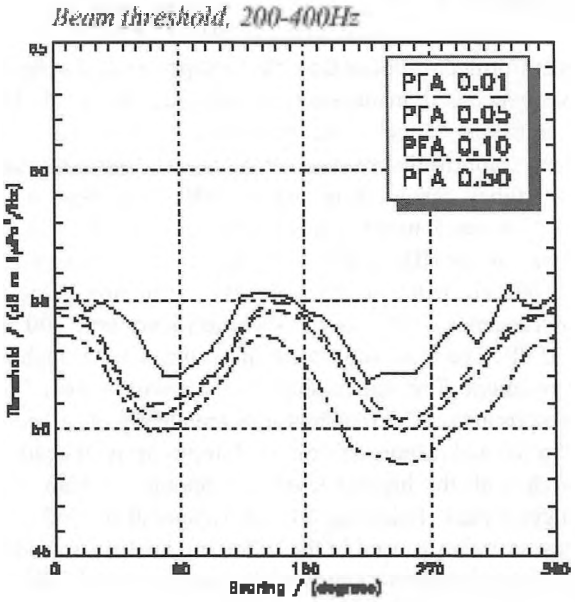

Figure 8 Beam thresholds in 16 channels of ULRICA in the band 200-400 Hz

with bearing. The highest thresholds are approximately in the north and south directions, broadside to the array. The lowest thresholds are in the east and west directions at end-fire.

The difference in the form of the threshold levels with bearing between the two arrays (figures 7 and 8) is due to the different beampattern of the arrays. It should also be noted that the noise distributions were obtained at slightly different times. Similar results are obtained in the band 100-200 Hz (figure 9), although the threshold levels are slightly higher for low PFA. This is due to the higher levels of transient noise in the 100-200 Hz band.

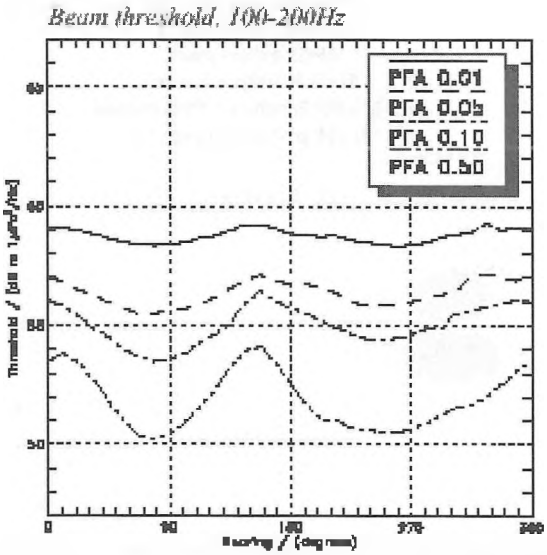

Figure 9 Beam thresholds in 16 channels of ULRICA in the band 100-200 Hz

THE SIGNAL

The beamformed response from the Octopus array during the PD5 sequence of transmissions is shown in figure 10. The range from the source to the array was 4.27 km. The PD5 sequence comprised continuous transmissions for 5 minutes of low signal narrow band tones (NB1), ambient noise (AN1), high signal narrow band tones (NB2) and high signal broadband noise (BB2). BB2 transmissions were from 100 Hz to 1000 Hz with a 6 dB per octave reduction going to higher frequencies. The source spectrum level near 300 Hz was 122 dB. The trials ships were in a quiet state throughout the experiment. The source ship was in beam number 7 of the Octopus array. The transmissions are clearly observed in the beamformed response from the Octopus array in beam 7. The peak with the highest level corresponds to NB2. The next highest peak, following NB2, corresponds to BB2. The BB2 transmission is used in the following analysis to calculate the detection performance of the Octopus and ULRICA arrays.

Figure 11 shows beam spectra from the Octopus array during the BB2 transmission. Beams were formed which were directed towards and away from the source. The spectra have been smoothed in frequency with a 20 Hz running mean. The structure in the signal spectra between 100 and 400 Hz is believed to be due to multi-path interference. Over the range 100 to 400 Hz, the response in the signal beam is typically 10 dB higher than the response in the noise beam. Above 500 Hz, ambient noise dominates over the signal. High levels of biological noise were present during the PD5 sequence and this accounts for the large increase in both the beams above 500 Hz.

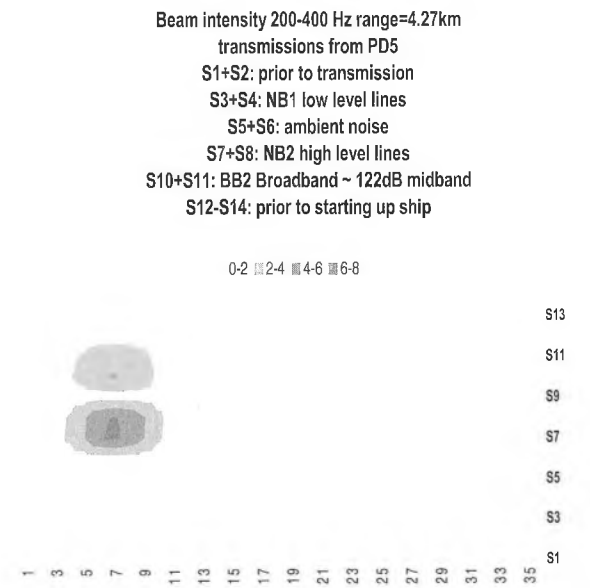

Figure 10 Beamformed response from Octopus array during PD5 sequence in the band 200-400 Hz

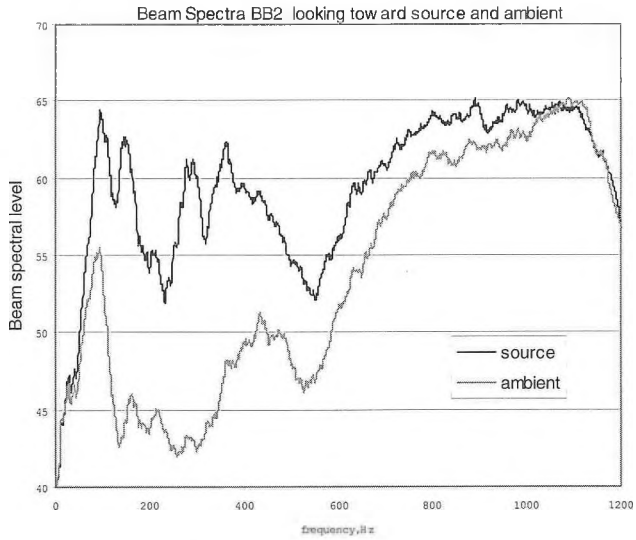

Figure 11 Octopus beamformed response directed towards and away from source during BB2 transmissions

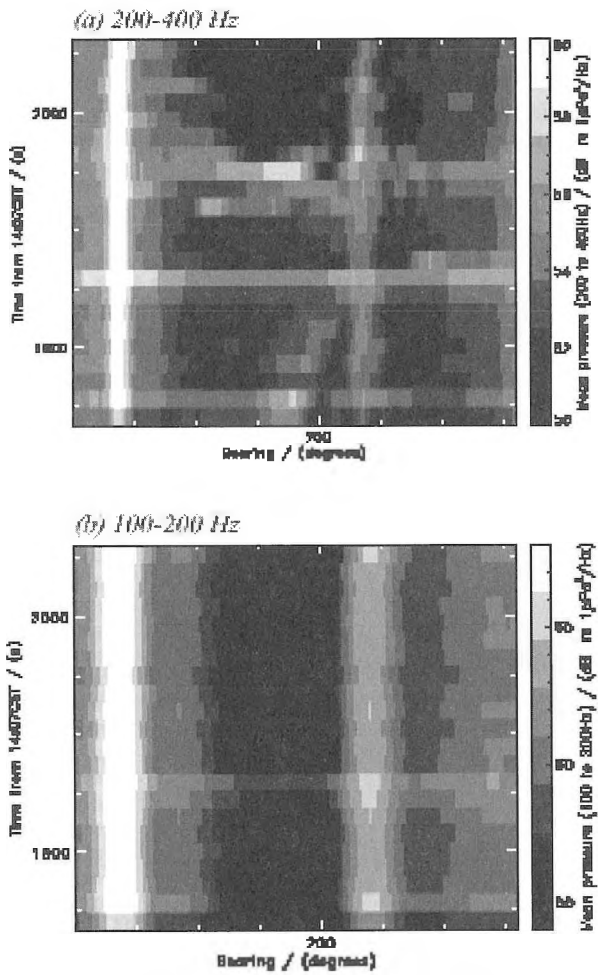

Figure 12 Beamformed response from ULRICA array during BB2 transmission in the bands (a) 200-400 Hz and (b) 100-200 Hz

Figure 12 shows the beamformed response from the ULRICA array during the BB2 transmission in the bands 200-400Hz and 100-200 Hz. The array response was calculated from all the sensors in the array. Data from the sensors were not shaded prior to beamforming. The integration period was 15 s and a total of 22 updates are shown. The signal is clearly identified in the band 200-400 Hz at a bearing of 35 deg. The signal level varies by typically less than 1dB during the transmission. The array is not straight and high side lobes result in energy leakage from the source. This is observed as a second peak, 6 dB lower than the main response, at a bearing of 235 deg. A number of 'bursts' of energy are present in the 200-400 Hz band at different bearings and times. These transient events are thought to be due to biological noise from croaker fish. Lower noise levels from biological sources are present in the band 100-200 Hz.

DETECTION

So far we have examined the noise distribution from which we have set our thresholds. We now determine the detection performance by adding the signal and noise distributions. Threshold levels were set for a false alarm rate (FAR) of 5%. The received signal from the BB2 transmission was injected into the noise data in a specified beam for a variety of source levels.

Figure 13 shows the probability of detection in the band 200-400 Hz for a source injected in beam 18 of the Octopus array. Signal data were obtained by subtracting an estimate of the noise during the BB2 transmission from the BB2 data. This reduced the apparent signal level by approximately 1 dB. The source spectral level during the BB2 transmission was assumed to be 122 dB at mid-band and the signal data were adjusted to simulate the specified source levels. To reduce false detections resulting from transient events, such as the biological noise outbursts already observed in the data, each sample in the signal-plus-noise data was examined. A detection was said to be obtained if 3 samples out of 4 consecutive samples exceeded the threshold level. The results indicate that a probability of detection of 0.5 is obtained for a source level between 112 and 113 dB at range of 4.27 km. The width of the peak is due to the beam width of the array at 200-400 Hz. The false alarm rate is about 5% for beams that do not contain the signal. This is to be expected since a false alarm rate of 5% was specified in setting the threshold levels.

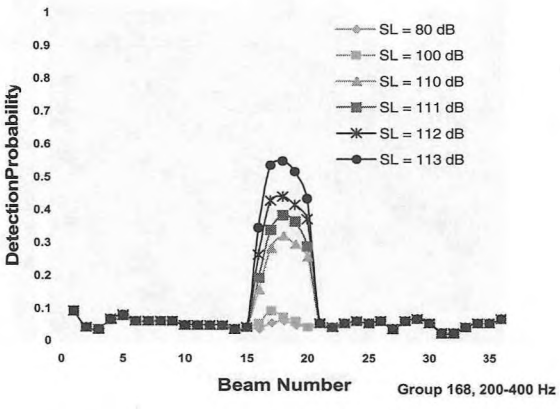

Figure13 Probability of detection in the band 200-400 Hz for source at range 4.27 km in beam 18 of Octopus array, FAR 5%

Figure 14 shows the relation between source level, probability of detection, and beam number in the Octopus array at a range of 4.27 km. The signal has been injected in a number of different beams and the probability of detection in that beam calculated for different source levels. The graph shows that there is significant variation in detection with beam number due to the different ambient beam levels.

At a range of 9.0 km, the source levels required to give the same probability of detection are 10 to 11 dB higher than at a range of 4.27 km (results not shown). Theoretical predictions of propagation loss were obtained for the site using the model RANDI2 [2]. This is an ambient noise model which originated in SACLANTCEN and incorporates the mode-based propagation model SUPERSNAP. Although not presented here, theoretical predictions of transmission loss between the ranges of 4.27 and 9.0 km indicate a value of 9 dB at the site [2]. The predicted transmission loss is in quantitative agreement with the results.

Data from the Octopus and ULRICA arrays were processed independently (personnel, processing programs, assumptions, etc.). In the ULRICA array analysis it was assumed that the source level during the BB2 transmission was 123 dB. This is 1 dB higher than assumed in the Octopus array analysis. In addition, an estimate of the noise level during the

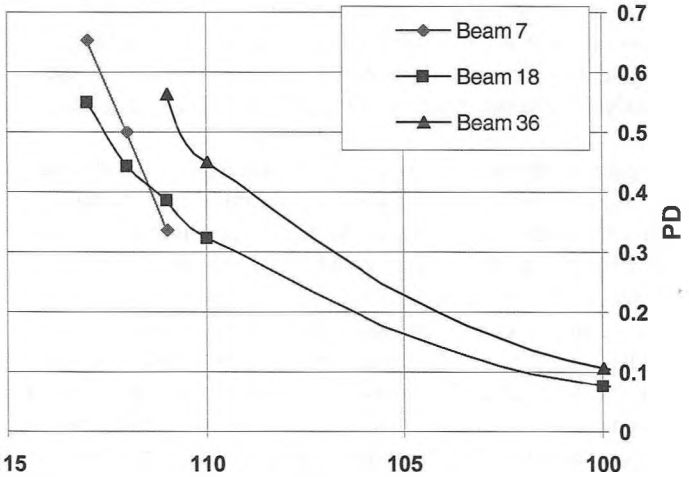

Figure 14 Probability of detection in the band 200-400 Hz versus source level and beam number in Octopus array at 4.27 km range

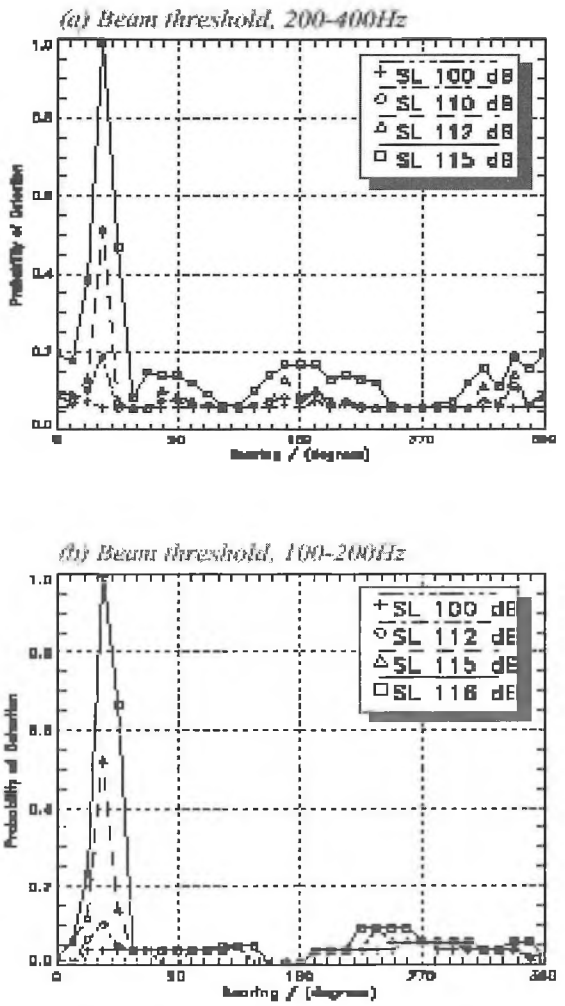

Figure 15 Probability of detection in 16 channels of the ULRICA array in the bands (a) 200-400 Hz and (b) 100-200Hz for source at bearing of 35^0, range 4.27 km, FAR 5%

BB2 transmission was not subtracted from the signal data, as was the case in the Octopus array analysis. This reduced the signal level by approximately 1 dB in the Octopus array analysis. The net effect of these differences is negligible.

Figure 15 shows the probability of detection in 16 channels of the ULRICA array for a source at range 4.27 km injected at a bearing of 35 degrees. The false alarm rate was 5%. In the band 200-400 Hz, a probability of detection of 0.5 is obtained for a source level of 112 dB. This is very close to the results from the Octopus array, where a source level of between 112 and 113 dB gave the same probability of detection at this range. However, the probability of detection in beams that do not contain the signal is between 0.05 and 0.2. This is because data from the ULRICA array contained biological noise in the band 200-400 Hz (figure 12). Note that in the ULRICA array analysis, an estimate of the noise during the BB2 transmission was not subtracted from the signal data. Consequently, the probability of detection is observed to increase as the source level increases in beams that do not contain the signal. Lower levels of biological noise were present in the band 100-200 Hz. The probability of detection is close to 5% in beams that do not contain the signal in the band 100-200 Hz. Higher source levels are required to achieve the same probability of detection in the band 100-20 0Hz than in the band 200-400 Hz.

The signal was then injected into each beam in turn and the probability of detection calculated as a function of source level. Figure 16 shows the probability of detection at a range of 4.27 km in 16 channels of the ULRICA array versus bearing and source level. The false alarm rate was 5%. The probability of detection is dependent on bearing and source level. A probability of detection of 0.5 is obtained for source levels in the range 111 to 114 dB. A probability of detection of 0.95 is obtained for source levels in the range 112 to 116 dB. The variation in source level with bearing required to achieve a given probability of detection is typically 3 to 4 dB for PD greater than 0.2. As might be expected, this is similar to the variation in threshold level with bearing. Higher source levels are required to achieve the same probability of detection in directions that have higher noise levels. For probabilities of detection lower than 0.2, the variation in source level with bearing is greater. This is due to false detections resulting from biological noise in the signal data.

Figure 17 shows the detection performance of 16 channels in the ULRICA array at the same range of 4.27 km but for threshold levels that are independent of bearing. In this case

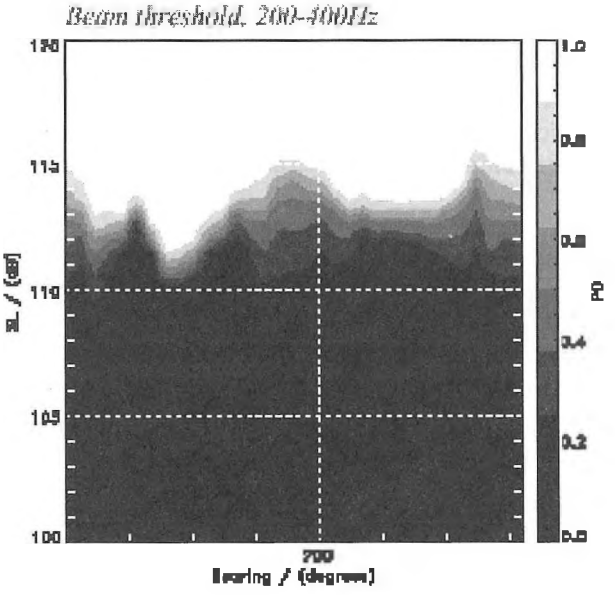

Figure 16 Probability of detection for different source levels at range 4.27 km in 16 channels of ULRICA array in the band 200-400 Hz using beam threshold levels

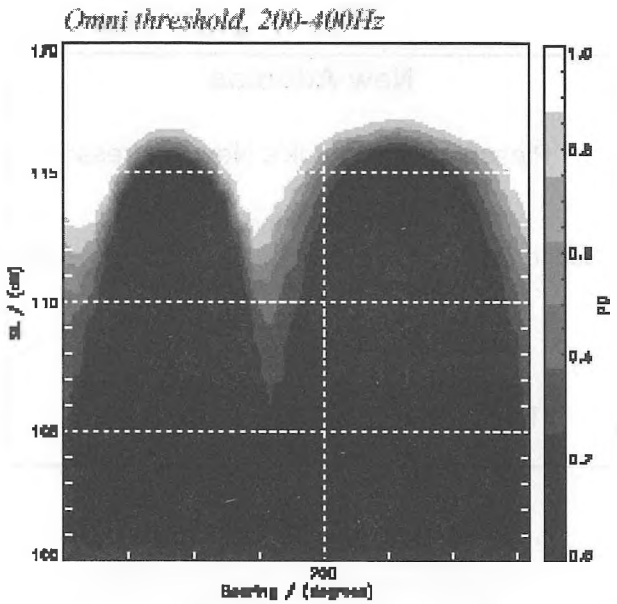

Figure 17 Probability of detection for different source levels at range 4.27 km in 16 channels of ULRICA array in the band 200-400 Hz using omni threshold levels

the distribution of the noise data was obtained using data from all the beams. A single threshold level was applied to all the beams corresponding to a probability of false alarm of 5%. The source level now varies with bearing in an opposite sense to the noise response of the array. The graph suggests that to achieve the same probability of detection, lower source levels are required in directions that contain higher noise levels (for example at bearings of 0 and 160 deg). This is clearly not the case and is because the threshold level was calculated from data from all the beams. Consequently, beams with high noise levels result in false detections when the noise levels exceed the threshold level. Conversely, beams with low noise apparently require higher source levels to achieve the same probability of detection.

When the entire aperture of the ULRICA array is employed, comprising 32 hydrophone elements, the source levels are reduced by 3 dB (results not shown).

CONCLUSIONS

This paper has compared the broadband detection performance of 2 different bottomed array geometries: that of the Octopus (compact planar) and ULRICA (line) arrays at the RDS-2 site. A section of noise data was used to set individual threshold levels in each beam. An experiment employing a submerged sound source provided signal data, which were injected into noise data from different beams at a range of source levels. The detection performance of the arrays was evaluated in the band 200 to 400 Hz.

The responses of both the Octopus and ULRICA arrays to the noise were dependent on bearing. The variation in array response to noise with azimuth was up to 5 dB in the band 200-400 Hz. Much higher variations in ambient noise directionality are expected in littoral or shallow water sites close to shipping lanes or to ports. If a single threshold is set for all the beams based on the total noise distribution, beams that contain high noise levels result in false detections when the noise exceeds the threshold. Increasing the threshold so that an acceptable false alarm rate is obtained in all the beams then results in lower probabilities of detection in beams that contain lower noise levels. The results have demonstrated the importance of setting thresholds in each beam for anisotropic noise distributions.

The dependence of threshold on bearing was significantly different in the Octopus and ULRICA arrays. This is principally due to a difference in beampattern between arrays. The beampattern of the Octopus array is almost independent of steer direction because the array is planar. However, the beampattern of the ULRICA array is dependent on steer direction due to its linear configuration.

The results indicate that the detection performance of 16 element ULRICA and Octopus arrays is very similar. Experimental data were examined in the band 200 to 400 Hz at the RDS-2 site for a false alarm rate of 5%. At a range of 4.27 km a source level of typically between 112 and 113 dB is required to achieve a probability of detection of 0.5 in both systems.

Increasing the aperture (and number of elements) of the array reduces the source level required to achieve a given probability of detection. For a 32-element ULRICA array, the source levels are reduced by 3 dB compared to a 16-element array. Similarly, it is expected that a larger Octopus array than that tested during RDS-2, comprising 32 elements, would obtain a similar increase in performance.

The results have shown that to achieve the same probability of detection as the range increases from 4.27 to 9.0 km requires an increase of 10 to 11dB in the source level. This is thought to be due to the high transmission loss at the RDS-2 site.

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