THE RESPONSE MODEL

An operational model for towed array shape and attitude estimation validated on TABAT data

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Abstract

An operational model for array shape and attitude estimation, based on the continuous measurement of heading and depth at a single position in the array, is presented. This model, which we call the Response model has been validated against the results from an independent method, that makes use of the differences in travel times of explosive signals to the hydrophones. The heading, depth and travel time data was obtained during a sea trial.

The effectiveness of the Response model is shown when it is applied to correct the sonar beamformer during a tow ship manoeuvre. It is thus demonstrated that towed array sonar operations can be continued during manoeuvering, which is of great operational advantage.

1 Introduction

Processing of towed array sonar data is commonly based on the assumption of a straight towed array. But the orientation and shape will generally deviate from this ideal steady tow configuration, which results in a degradation in the acoustic performance of the array. This is particularly evident during tow vessel manoeuvres. Attitude deviations lead to a false bearing estimate, whereas shape deviations cause loss of array gain and the rising of sidelobe levels. In order to correct this degradation it is necessary to obtain continuous estimates of the orientation and shape of the array.

In this paper an operational model for array shape and attitude estimation is presented, the so-called Response model. The model is validated by comparing the results with the results from an independent method, the so-called 'shot-firing' method [1]. The measurement data are obtained from the TABAT-89 trial [2, 3, 4].

2 Principles of the response model

The modelling of the movements of a towed array requires, apart from classical mechanics, also empirical approximations from hydrodynamics. The hydrodynamic modelling leads to a set of partial differential equations under boundary conditions (ship movement, ocean current), which are difficult to solve. For a complete treatment of this problem see Brandenburg [5]. However, if a number of conditions is met (low frequency behaviour, no gravity effects and negligible acceleration), the array movement can be described with the Response model, that states that the array parameters (heading, pitch and depth) at position s on time t can be derived from these parameters at the position s-Δs and at the time t-Δt. The description makes use of transfer functions. Furthermore $\Delta s/\Delta t$ is equal to the tow velocity v of the array. This idea is visualised in Figure 1.

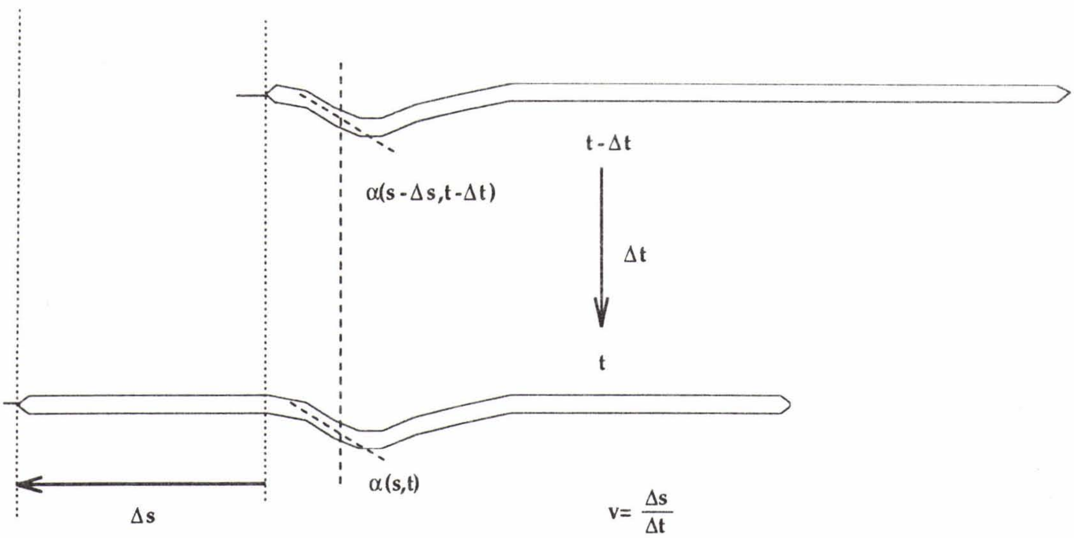

Figure 1: Visualisation of the Response model.

Consequently the model requires as input the heading and depth at a single position in front of the acoustic section and the array tow velocity, all as a function of time. The array pitch is not needed since it can be calculated from depth.

The calculation consists of two steps. Firstly the heading and depth at each point of the acoustic section of the array are estimated from the heading and depth at the measurement position. Secondly, using the estimated heading and depth, the array shape and attitude are calculated.

3 Validation of the response model

3.1 The experiment

The Response model has been validated against the results of shape and attitude measurements using the shot-firing method. The results of a 90^0 turn to port at a nominal tow speed of 10 knots have been used. Figure 2 presents the array configuration of this experiment. The array is equipped with a number of auxiliary sensors of which the positions of the heading sensors are indicated.
The shot-firing method allows the measurement of the position, shape and attitude of the array at certain instants of time. During this experiment a total of 33 snapshots of the array shape and attitude were taken [4]. Figure 3 gives an overview of the position of the tow ship and the position of the array relative to the tow ship during the manoeuvre.

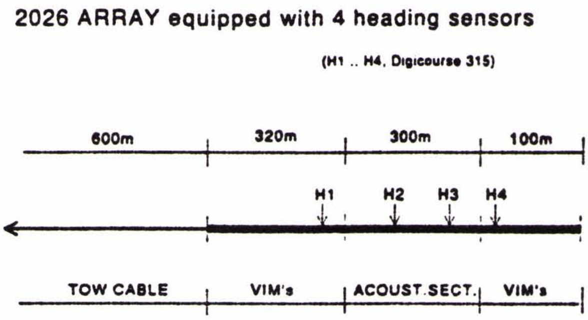

Figure 2: Array configuration of the experiment.

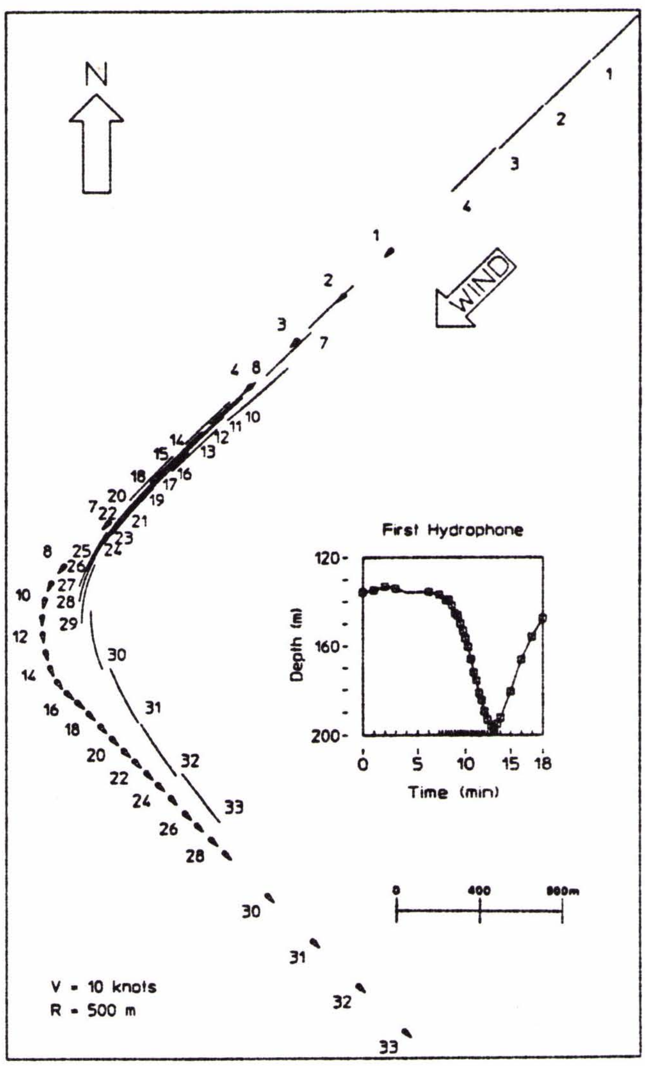

Figure 3: Overview of the tow ship and array positions during the experiment.

3.2 Spectral analysis of the transfer function

Considering array distortions in the frequency domain, the validity of the Response model will be limited to a certain highest frequency. To obtain this frequency, the transfer functions in frequency domain have been analysed. The amplitude of the transfer function between the heading of sensor 1 and 4 should be near to 1 if no severe damping occurs. The phase of the transfer function should show a straight line passing through the origin unless dispersion occurs. The slope of this line is determined by the velocity of propagation of the distortion. For this particular case, where the distance between the heading sensors is 323 m, the model holds for frequencies up to approximately 0.008 Hz, as may be inferred from Figure 4.

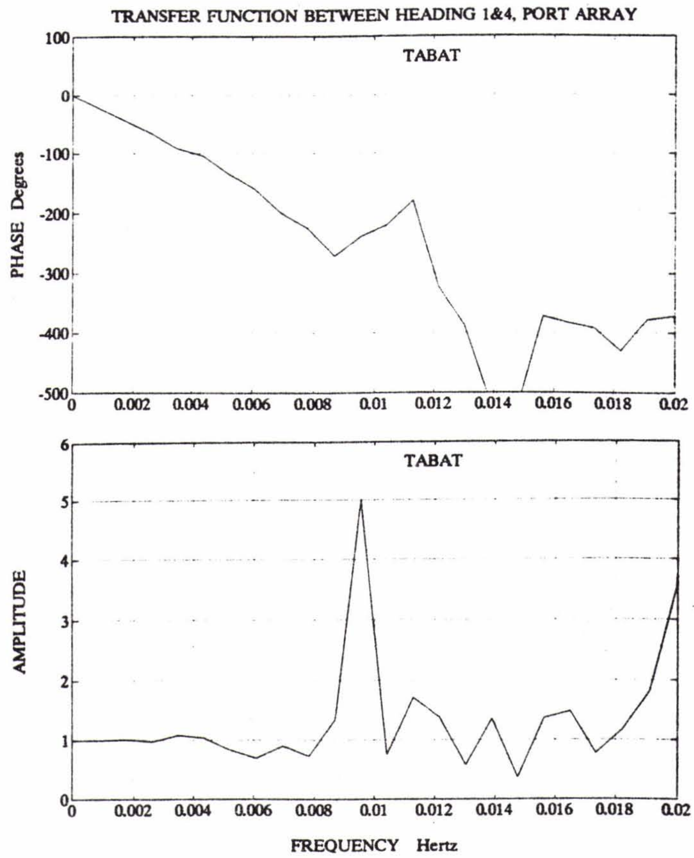

Figure 4: Amplitude and phase of the transfer function between the heading of heading sensor 1 and 4.

The slope of the line indicates an array velocity of 7.5 knots, which agrees with the ship's decreased speed during the manoeuvre. From the power spectrum of the heading sensor signal it can be observed that the main spectral contents of the distortions is also below 0.008 Hz, see Figure 5.

3.3 Comparison of shape and attitude estimation with the Response model with that of the shot-firing method

In Figure 6 a typical example of the attitude estimate by the Response model is compared to the corresponding results of the shot-firing method. In this figure the array attitude has

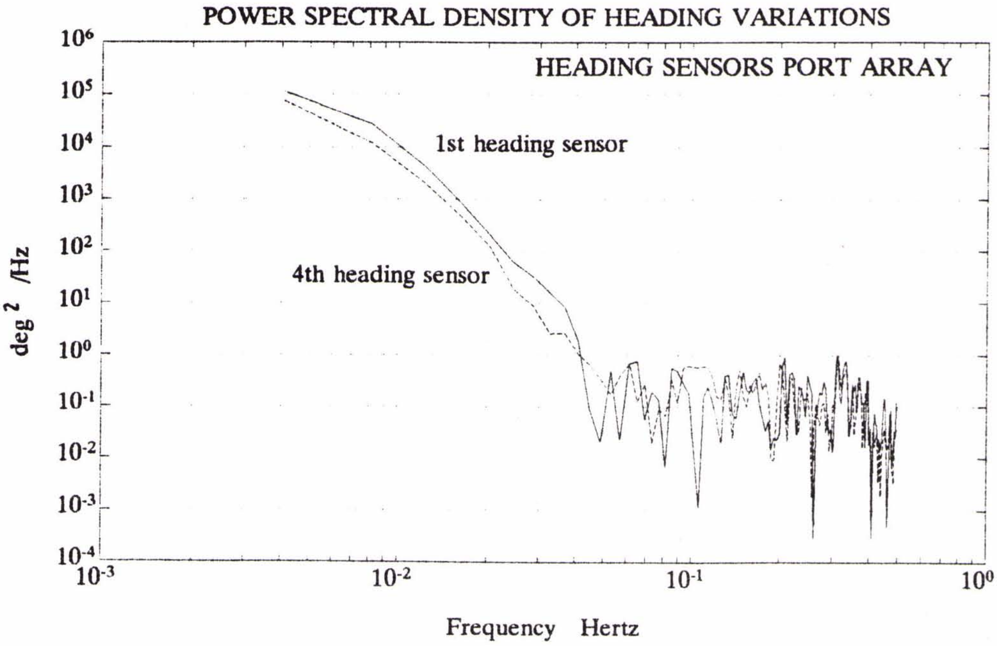

Figure 5: Power spectral densities of the heading sensor signals.

been projected in the horizontal plane. The position of the first hydrophone has been chosen to coincide with the origin and the negative x-axis points in the tow direction of the vessel. An overview of the results at all snapshot instants is obtained by calculating the angle of the least squares fitting straight lines through the attitude estimates like that of Figure 6. Thus the attitude estimates by the Response model are compared to those of the shot-firing method, Figure 7.

The shape estimation has been visualised by rotating the coordinate system such that the position of the last hydrophone is fixed on the positive x-axis. Taking the same snapshot for an example as that of Figure 6, the shape estimate from the Response model is compared to that from the shot-firing method in Figure 8.

The comparison of the shape estimates is extended to all snapshots instants in Figure 9 and 10. The heights of the contour lines indicate the deviation from a straight array. The differences between Figure 9 and 10 are presented in Figure 11.

From the above results we may conclude that the shape as well as the attitude estimates by the Response model are in good agreement with that of the shot-firing method.

3.4 Application to the beamformer

As mentioned before the beampattern will generally degrade, supposing the array is in a straight line. To show this effect, the beampattern of a typical hydrophone configuration of the array has been calculated. Figure 12 shows the beampattern at the moments of the snapshots. It is clearly visible that during the manoeuvre the height of the mainlobe drops and that of the sidelobes rises.

If the hydrophone positions, as calculated by the Response model, are taken into account, the results show that virtually no degradation of the beamformer output is observed, see Figure 13.

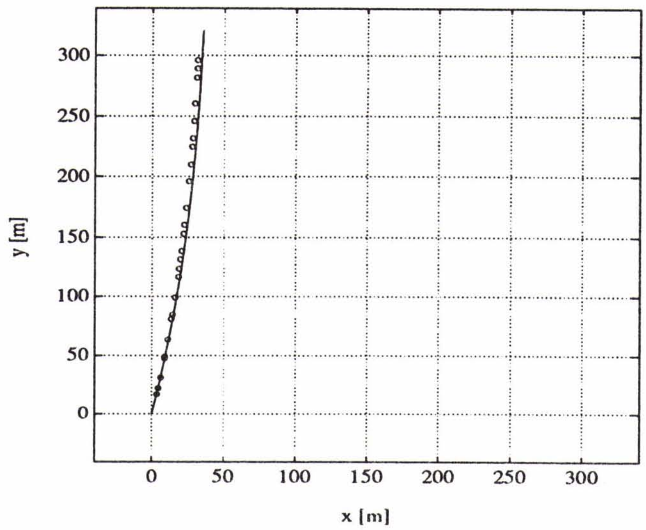

Figure 6: Attitude estimates during a typical snapshot, ooo: shot-firing method —: Response model.

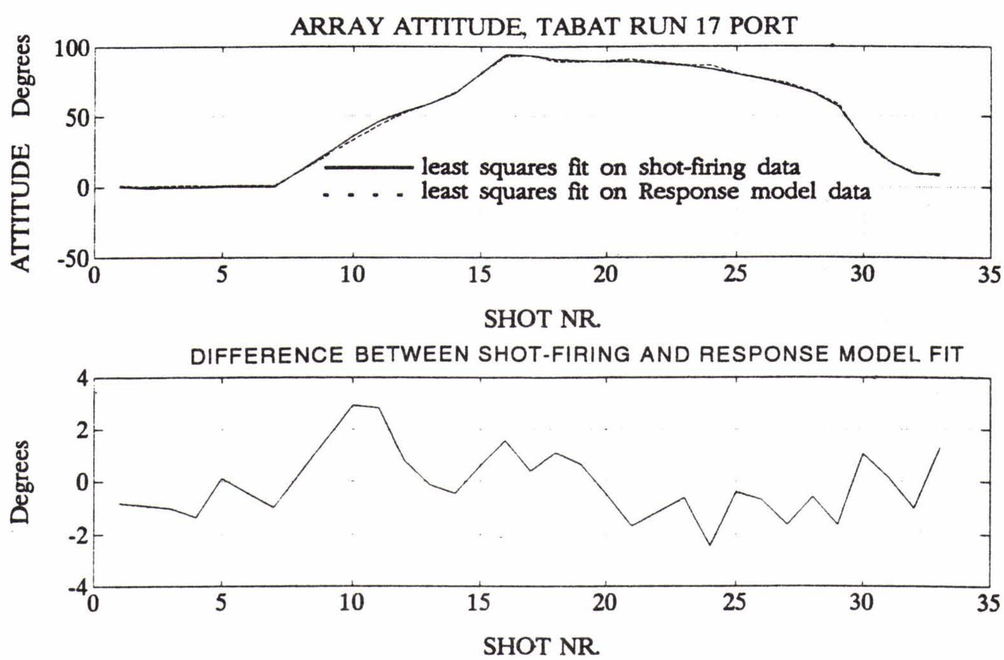

Figure 7: Overview of attitude estimates.

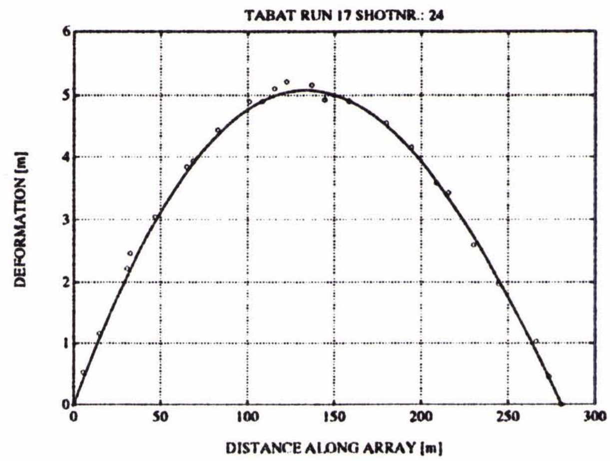

Figure 8: Shape estimates during a typical snapshot, ooo: shot-firing method —: Response model.

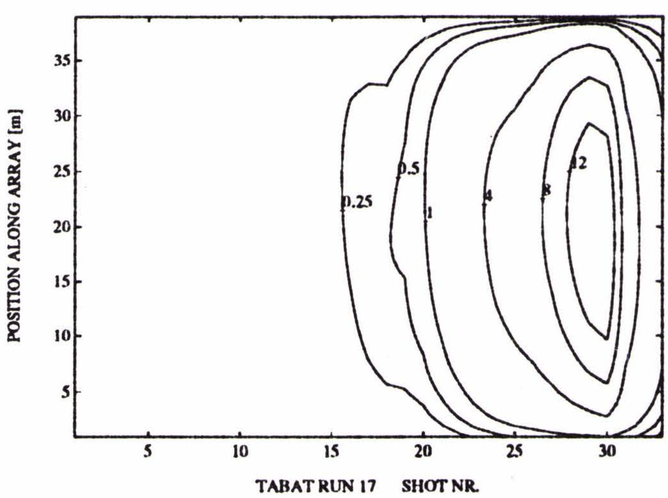

Figure 9: Overview of shape estimates by the Response model.

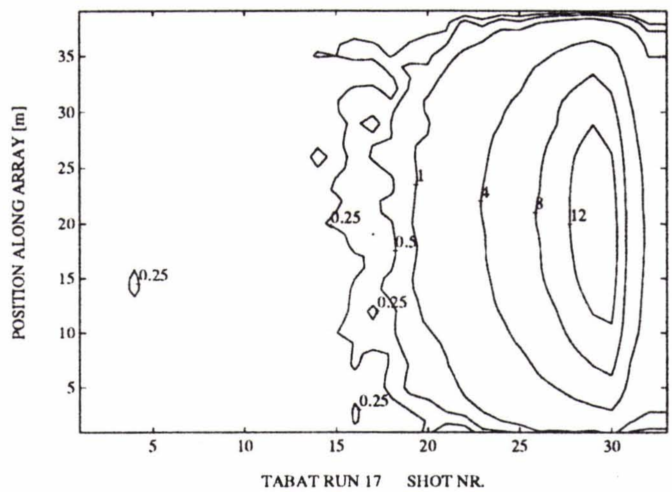

Figure 10: Overview of shape estimates by the shot-firing method.

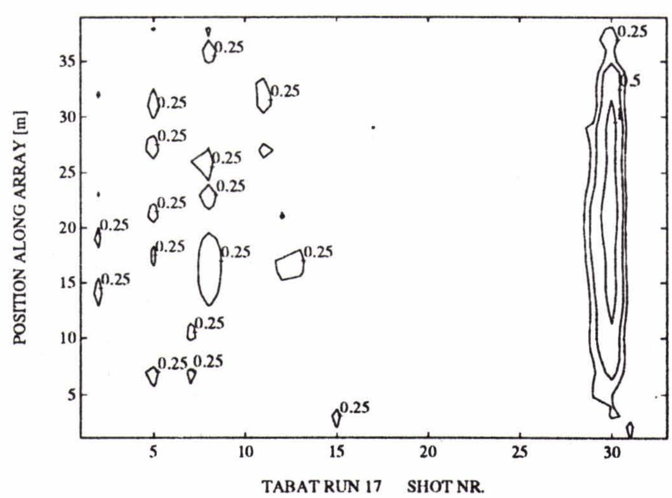

Figure 11: Overview of differences between shape estimates by the shot-firing method and the Response model.

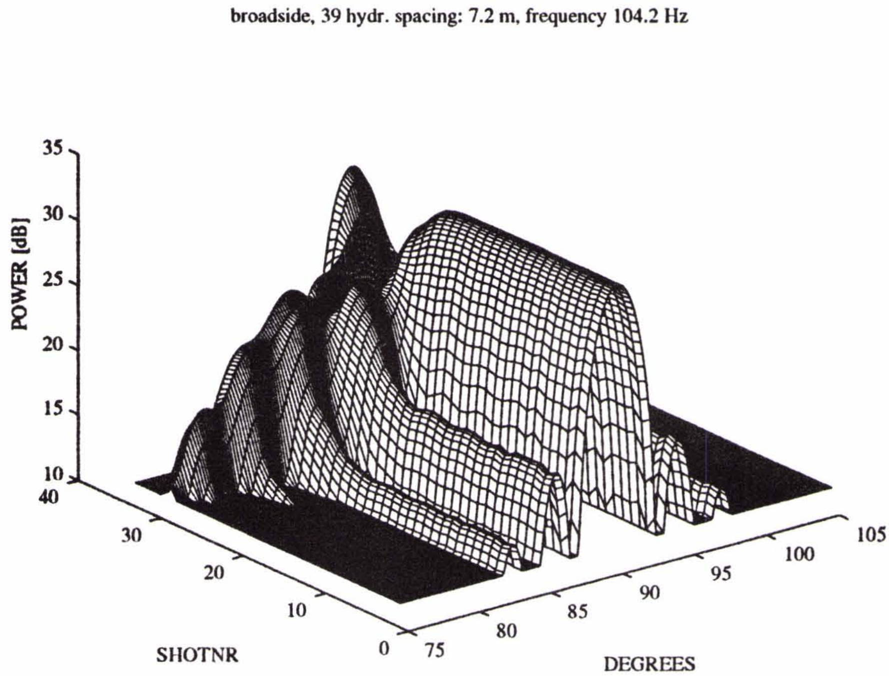

Figure 12: Beampattern processed as if array were straight.

4 Conclusions

The Response model, an operational model for array shape and attitude estimation, based on the measurement of heading and depth at a single position, has been presented. The model has been validated against the results of an independent array shape estimation method and it has been shown that the results compare well. The effectiveness of shape corrected beamforming, using the array shape and attitude obtained from the Response model, has been demonstrated. This allows towed array operations to be continued during manoeuvering, which is of great operational advantage.

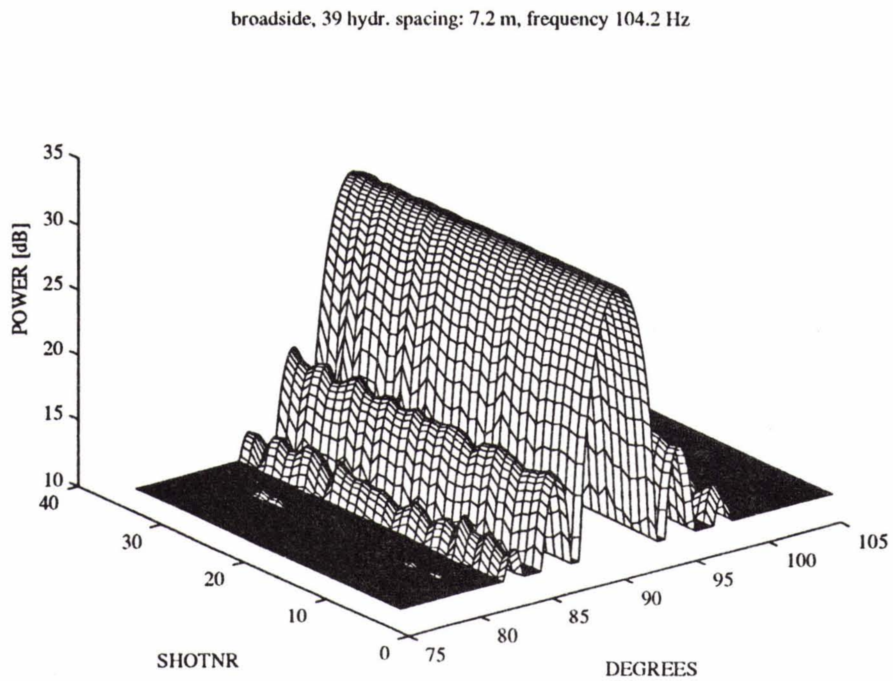

Figure 13: Beampattern processed as if array were straight.

References

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