

## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION

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### 1. INTRODUCTION

One of the most important issues in passive underwater array processing is localisation, i.e. direction and range estimation, to emitted sources such as submarines and torpedoes. During the last decades several researchers have developed sensitive high resolution methods for directions of arrival estimation of impinging wave fronts, e.g. [1] and [2]. These techniques might be limited or even produce false bearings if the sensor array receive coherent waves formed by a complicated multipath. An often used pre-processing method [3] to circumvent the problem is smoothing along sensors in subarrays and/or along time samples of the array output. The method per samples redistribute the signal information along consecutive time blocks and per sensors decorrelate different parts of the array. The forward smoothing techniques studied by Shah and Kailath [3] require at least  $2K$  sensors to resolve  $K$  directions of arrival. The computational more burdensome forward and backward method developed by Pillai and Kwon [4] require less extra sensors compared with the aforementioned method but at least  $3K/2$  sensors are needed to resolve  $K$  directions. The disadvantage with smoothing techniques beside the higher computational costs is the reduced resolution in time and array aperture. Therefore, detection of the degree of multipath is important to decide the array processing scheme.

The multipath propagation effects formed by the velocity profile and the presence of the surface and the bottom are obvious even at fairly short ranges in shallow water acoustics such as in the Baltic sea. As the distance increase the impact on the received signals become more pronounced and complex. However, different sediments such as clay and silt in the bottom in some areas of the Baltic sea may produce a fairly high bottom loss with less reflections. Also, the surface is normally not a strong reflector for higher seastates. Furthermore, the time variability of the water as a wave propagation medium makes the ray paths to become more or less coherent as a function of time making the multipath effects strongly time dependent.

## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION

Therefore, the shallow water multipath effects can be variable both in time and space. The performance of a passive sonar array system for emitter localisation is related to the reliability of the estimates at a diversity of ranges and sites with more or less multipath and therefore possibly gained by a multipath detection and analysis scheme.

The purpose of this paper is to present a possible multipath detection and characterisation scheme for narrow band underwater acoustic signals by using a method based on a frequency domain kurtosis estimate combined with conventional spectrum analysis, [4] and [5]. The detection scheme used in this paper is the same as proposed by Dwyer, e.g. [4], and defined as

- a) If there is a strong peak in the power spectrum and if this frequency exhibit a kurtosis value larger than three the frequency is effected by a multipath wave propagation. In this case a pre-processing method might be employed to avoid degraded and false bearing estimates.
- b) If there is a strong peak in the power spectrum and if the kurtosis value is about 1.5 the sinusoid is less modulated and less effected by multipath wave propagation and no pre-processing need to be engaged.
- c) If no peaks are detected in the power spectrum but a high kurtosis value is present there might be randomly occurring transients such as cavitation pulses in the signal, Dwyer [6]. If no peaks are seen in both power spectrum and the frequency domain kurtosis exhibit a value around three only ambient Gaussian noise is present.

## 2. BEARING ESTIMATION

An important part of sonar signal processing is bearing estimation to underwater signal sources. During the last decades several researchers have developed sensitive high resolution methods with the bearing resolution within the array beam width, e.g. [1] and [2]. The input for the methods is normally the array output covariance matrix formed as

$$R_{xx} = E \{x(t) x^H(t)\}_N \quad (1)$$

## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION

with  $\mathbf{x}(t) = [x_1(t), x_2(t), \dots, x_M(t)]$  are the 'snapshots' at time  $t$  for all sensors  $M$  and  $E$  in (1) denotes the expectation value formed by the average of  $N$  snapshots and  $H$  the conjugate transpose. A popular and one of the first used high resolution methods is MUSIC developed by Schmidt [2]. This method is based on an orthogonal decomposition of the covariance matrix  $R_{xx}$  into a signal subspace  $R_{ss}$  and a noise subspace  $R_{nn}$ .

$$R_{xx} = R_{ss} + R_{nn} \quad (2)$$

$$R_{ss} = \sum_{r=1}^P \lambda_r V_r V_r^H \quad (3a)$$

$$R_{nn} = \sum_{r=P+1}^M \lambda_r V_r V_r^H \quad (3b)$$

The signal subspace (3a) formed by the  $P$  'largest' eigenvalues  $\lambda$  and eigenvectors  $V$  is separated from the noise subspace (3b) formed by the 'smallest' eigenvalues and vectors. One drawback with the subspace methods is the number of signals  $P$  need to be estimated or known a priori. The MUSIC bearing estimator as a function of bearing  $\Theta$  can be formulated [2] as

$$P_{\text{MUSIC}}(\Theta) = \frac{1}{\sum_{r=P+1}^M C^H(\Theta) V_r} \quad (4)$$

with  $C^H(\Theta) = [1, e^{-j\omega\Theta(1)}, \dots, e^{-j\omega\Theta(M-1)}]$  as the steering vector.

In a multipath environment the estimation of the number of signal sources is a complicated matter. If the number of sources  $P$  is too large or too small the decomposition of the signal subspace in (3a) and noise subspace in (3b) is wrong and false bearings may occur.

## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION

### 3. MULTIPATH DETECTION

A conventional method to perform frequency analysis of time series is to estimate the power spectral density. The recorded signal  $x(t)$  is partitioned into  $K$  data blocks all with a length of  $N$  samples and transformed to frequency domain via a discrete Fourier transform as

$$X(\omega) = \frac{1}{N} \sum_{k=1}^N x(k) e^{-j2\pi\omega k/N} \quad (5)$$

The power spectral density (PSD) is formed by the average over  $K$  blocks as

$$\text{PSD} = \frac{1}{K} \sum_{i=1}^K X_i(\omega) X_i^*(\omega) \quad (6)$$

A possible way to extract more information from a received signal is to use higher order statistics in the frequency domain. The PSD in (6) is the second order moment for both the real and imaginary part for each frequency component. The third and fourth order moments are also possible to use in the frequency domain in order to characterise different signal properties. In this study we use the measure frequency domain kurtosis (FDK) for distribution characterisation based on the fourth order moment normalised with the squared second order moment [4] as

$$\text{FDK} = \frac{\frac{1}{K} \sum_{i=1}^K (X_i(\omega))^4}{\left(\frac{1}{K} \sum_{i=1}^K X_i(\omega) X_i^*(\omega)\right)^2} \quad (7)$$

In equation (7) it is possible to use both the real part or the imaginary part of  $X(\omega)$  or a combination. In this study we use only the real part. For the multipath detection and characterisation we use the FDK value (7) in conjunction with the PSD estimate (6). If the ambient noise follows a Gaussian distribution the FDK returns a value of three. If there is a large peak in the PSD we concentrate the analysis to this particular frequency. With a FDK value who exceed three at this particular frequency gives a c-w signal effected by multipath otherwise the sinusoid is not composed by multipath contributions. Even if the ambient noise is not purely Gaussian the deviation from a FDK value of three is not large if the measured time series is long enough [7].

## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION

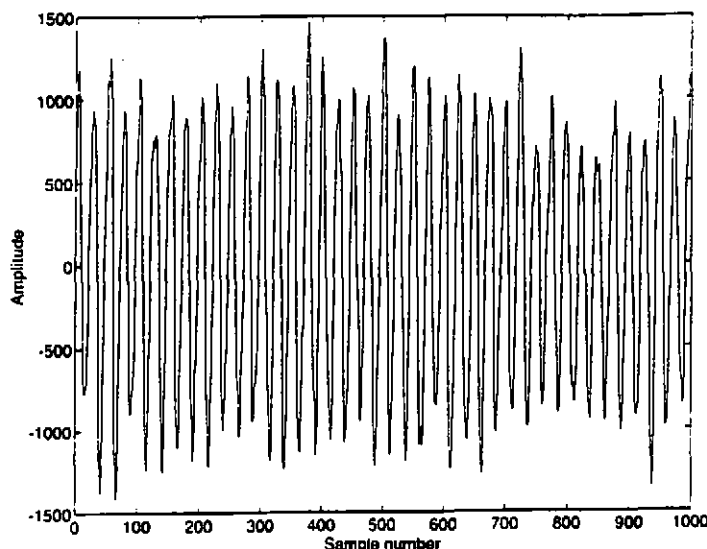
### 4. DATA ANALYSIS

#### 4.1 Experimental set up

The experimental site was in the south-east part of Sweden in the Baltic sea, between the mainland and the island Öland. The bottom at the site is fairly flat at a depth of 40 meter and horizontally stratified. A stationary vertical linear array with eight sensors at depths 5, 10, 15, 20, 25, 30, 35 and 40 meters was used. A 80 Hz c-w signal was used as source suspended from a ship at a depth of 20 meter. Data in this study is from a recording performed along a north-south profile at a distance of 1000 and 5000 meter. The source strength was about 170 dB and sampled by a frequency of 2 kHz.

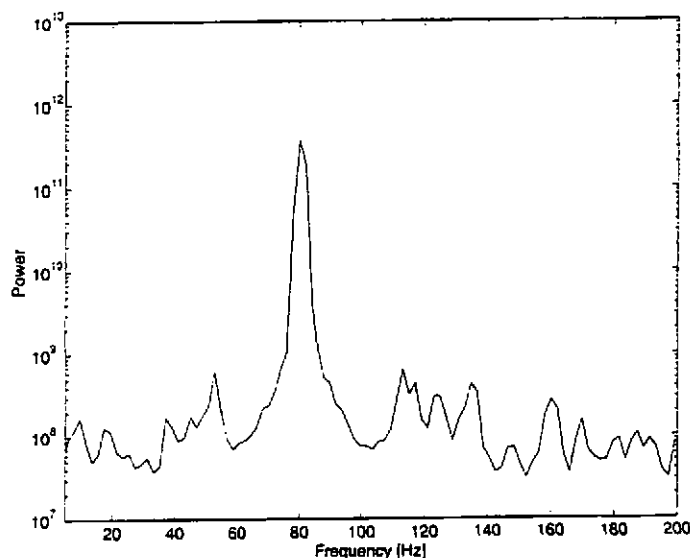
#### 4.2 Multipath detection

The data used in this study is chosen to be in a short range (1000 m) and in a long range (5000 m). An example of a time series generated at a depth of 20 meter and a distance of 5000 meter and recorded at a depth of 30 meter is displayed in Figure 1. The power spectral density in Figure 2 of this signal show a large predominated peak at the frequency of 80 Hz.



*Figure 1. Time series of a 80 Hz c-w signal generated at a distance of 5000 meter and at a depth of 20 meter and recorded at a sensor depth of 30 meter with a sampling frequency of 2 kHz.*

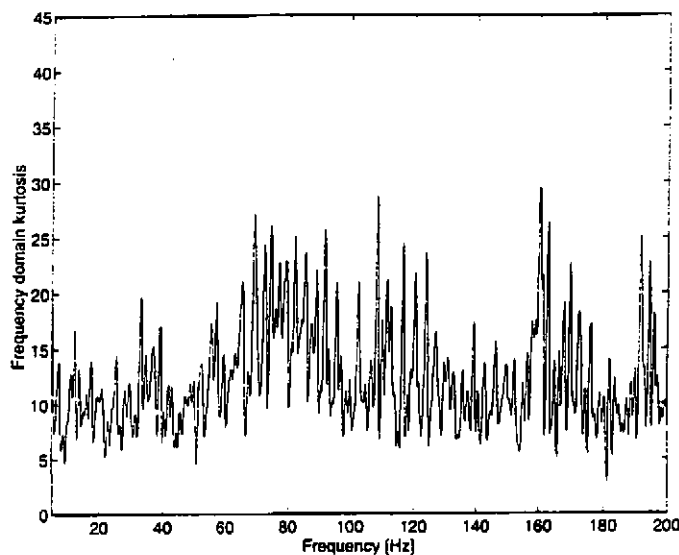
## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION



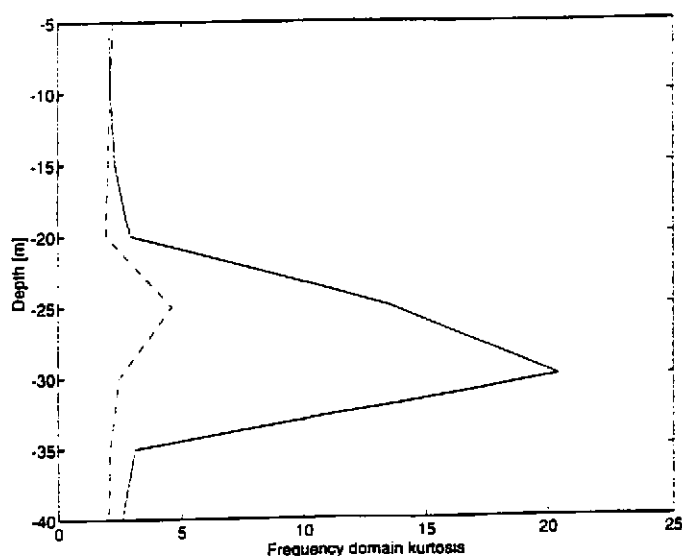
*Figure 2. Power spectral density of the time series in Figure 1 estimated from  $K=400$  blocks with a block length  $N=1024$ .*

The real part of the FDK estimate of the signal in Figure 1 and 2 is displayed in Figure 3. This part of the spectrum shown in Figure 3 exhibit large FDK values and around the signal frequency of 80 Hz the FDK reaches 20. Therefore, we declare this signal to be composed by strong multipath effects. In Figure 4 the FDK values at 80 Hz for all eight channels are displayed. The solid line is the FDK values for the signals recorded at the distance of 5000 meter and the dashed line at the shorter distance of 1000 meter. In the middle from a depth of 20 meter to 35 meter at the longer distance (solid line) there is a much higher FDK value compared with recordings at the bottom and the surface. The shorter distance (dashed line) exhibit a much smaller FDK value and are therefore less effected by multipath.

## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION



*Figure 3 FDK estimate of the real part of the time series in Figure 1 estimated from  $K=400$  blocks with a block length  $N=1024$ .*



*Figure 4 FDK estimate of the real part of time series recorded at a long distance of 5000 meter (solid line) and at a short distance of 1000 meter (dashed line) estimated from  $K=400$  blocks with a block length  $N=1024$ .*

## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION

### 4.3 Bearing analysis

The high resolution method MUSIC discussed earlier is sensitive to coherent signals caused by multipath effects. In Figure 5 the MUSIC bearing estimates are displayed from the signals at a long distance used in Figure 4. The dashed line is the estimate without any kind of smoothing and the solid line is based on smoothing along both time samples and along subarrays. The expected bearing is about zero degree. We use the a priori knowledge of only one source present. The bearing estimate without smoothing display two large false peaks larger then the true direction while the estimate based on smoothing only exhibit one peak in the expected direction. In Figure 6 the MUSIC bearing are estimated from the short distance signals at 1000 meter. The unsmoothed and the smoothed bearings are without false peaks and the main peaks are in the expected region of directions of arrival.

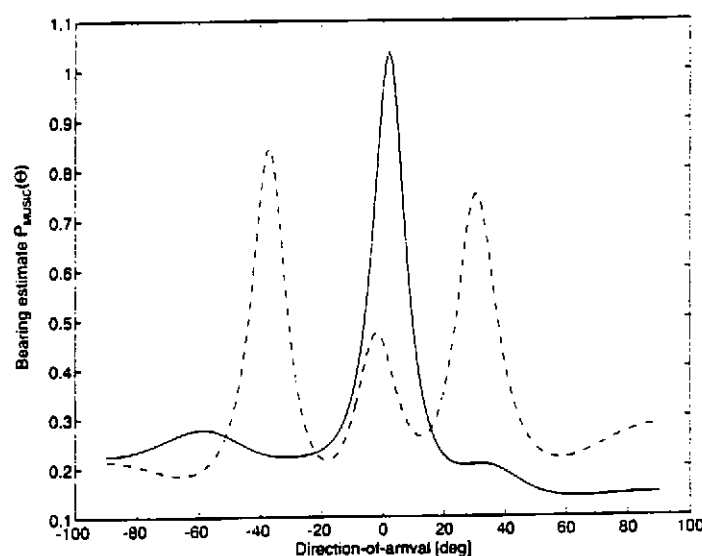


Figure 5 MUSIC bearing estimate of the signals at a long distance of 5000 meter. Unsmoothed (dashed line) and smoothed (solid line) are estimated from  $M=8$  channels with  $K=400$  blocks and a block length  $N=1024$ .

## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION

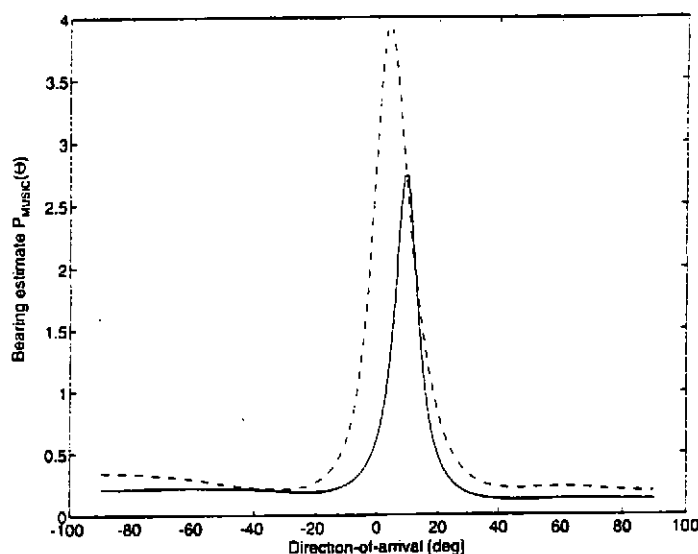


Figure 6 MUSIC bearing estimate of the signals at a 'short' distance of 1000 meter. Unsmoothed (dashed line) and smoothed (solid line) are estimated from  $M=8$  channels with  $K=400$  blocks and a block length  $N=1024$ .

### 6. CONCLUSIONS

The estimation of bearings with high resolution methods based on eigenvalue decomposition into signal subspace are sensitive to multipath effects. If it is a strong multipath effect on some channels the performance may be degraded and the algorithm may even produce false directions of arrival. In this case pre-processing methods such as smoothing are necessary to engage for a more stable eigenvalue decomposition. The frequency domain kurtosis estimate is a possible detector for multipath in prior to bearing estimations. In a real sonar array processing system with conventional frequency analysis available such a detector is possible to implement with a minor increase in computational burden.

## MULTIPATH DETECTION BY FREQUENCY DOMAIN KURTOSIS ESTIMATION

### 7. REFERENCES

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