VOL. 10, NO. 4, MARCH 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MODELLING VERTICAL COHERENCE FOR SHALLOW WATER AMBIENT NOISE

V. G. Sivakumar
Department of ECE, Sathyabama University, Jeppiaar Nagar, Chennai, India
E-Mail: kaviks2004@yahoo.co.in

ABSTRACT

Ambient noise is the prevailing unsustainable noise in the sea. It is the background noise, typical of the location & depth against which a signal like the sound of a submarine or the echo from a target must be detected. Underwater ambient noise continuously varies in level and spectral content. It excludes self noise like electrical noise, current flow around measurement hydrophone. So we need to measure the ambient noise considering different factors like wind, precipitation, biological noise, tides etc. The ambient noise is measured using the vertically spaced hydrophones in the shallow water of the Arabian Sea region. Using these ambient noise measurements, vertical coherence is estimated. Theoretical model for vertical coherence is also calculated. In this paper comparison between the theoretical and the practical vertical coherence is done.

Keywords*:* ambient noise, Arabian Sea, hydrophone, under water acoustic, vertical coherence.

INTRODUCTION

Noise is unwanted background noise. Study of noise is very important for the design and development of the underwater acoustic instruments such as echo sounder, sonar etc.., and also for acoustics communication. Noise estimation in shallow water changes highly due to the presence of the surface winds, ship traffic, biological activity, due to the varying sound speed profile in the shallow water and also due to the multiple reflections from the sea bed and surface. Ocean ambient noise is an inseparable characteristic of the medium having no specific point source. It is the residual noise background in the absence of the individual identifiable sources that may be considered as the natural noise environment for hydrophone sensors. It contains a number of components that contribute to the noise level (NL) in varying degrees depending on the location of measurements [Urik R, 1983]. Ambient noise is measured using array of hydrophones placed either horizontally or vertically in the sea.

We calculate the ambient noise in sea so that we can enhance the signal to noise ratio of the acoustic based underwater instruments. Thus we can get the measurements correctly. Sound from the any source undergoes multiple reflections from the sea bed and also in the surface of the sea. These multiple reflected signals interact with each other. Thus the ambient noise field's spatial structure depends on the Geo-Acoustic properties of the sea bed [1].

Coherence gives the degree to which the noise pressures in the shallow water are invariant. It is an important property of noise field and forms the basis for finding the directivity of ambient noise. Coherence study also tells about the noise field invariance with respect to space and time. Sensors placed at various points will have identical outputs if the noise is perfectly coherent. Estimation of Vertical coherence in deep sea is being done from the 1960's. These calculations were done for the frequency ranges below 2 KHz [2], [3]. The vertical coherence is strongly related to the directivity of the signals received by the vertical line array (VLA) and is thus greatly influenced by ocean boundaries [4], [5].

Field measurement of ambient noise

The ambient noise is collected in the Arabian Sea region at latitude of N 15°23.97′ and longitude of E 73°45.03′ by the National Institute of Ocean Technology. Array of hydrophone are used to measure the ambient noise in that region. A data acquisition system is used for collection information's like wind speed, date, atmospheric temperature, depth of hydrophone, water depth etc in that region. The data acquisition system consists of the Central Processing Unit, embedded board for wind speed measurement and power control, memory for storing data, battery pack etc. Boat was anchored before the data collection to reduce the drift. During the period in which all the machinery in the boat and ships were switched off. Noise generating machineries present in the boat such as engine, generator etc are switched off before data collection. It is ensured that for every data collection, the mechanical fixture is not loading the cables of the hydrophones. Voltage level of the hydrophones is observed through Data Acquisition System or multi meter during the initial sage of the data collection.

Theoretical model for the vertical coherence of noise in shallow water

The amount to which the pressure is same in two points in the sea is given by the coherence. The coherence is the measure of the phase and the amplitude relationships between the set of acoustic waves. It also tells us about the spatial and the temporal variations in the sea. Temporal coherence describes about the variations in the received signal over a period of time. Spatial coherence directs to the changes in the signals received at different locations in the ocean at a given period of time.

ARPN Journal of Engineering and Applied Sciences

A plane wave noise field may be constructed theoretically by placing the infinite number of sources around the hydrophone in a sphere whose radius is considered to be infinite. The hydrophone is placed at the center of the sphere. In the hydrophone the noise field intensity is given by the direction density function. The direction density function A (θ, Φ, ω) depends on the polar angle (θ) measured from the upward vertical, azimuth angle (Φ), and angular frequency (ω).

It is assumed that the noise taken from the azimuthal angle is uniform. The white-noise fields have a directional density function that is independent of frequency. Thus the directional density function only depends on the polar angle A (θ). The polar angle (θ) extends over the range **0 ≤ θ ≤ π.** A standard normalization of the directional density function can be got by integrating A(θ) over all solid angles. The equation for this is given below.

$$\frac{1}{2}\int_0^{\pi} A(\theta)\cdot \sin\theta \, d\theta = 1 \qquad (1)$$

The vertical coherence of shallow water ambient noise can be estimated by taking the Fourier transform of the directional density function A (θ). The formula for vertical coherence is given below.

$$\Gamma(kd) = \frac{1}{2}\int_0^{\pi} A(\theta).\sin(\theta).e^{(-ikd.\cos(\theta))} d\theta \qquad (2)$$

In the above formula θ gives the vertical upward angle, K is the acoustic wave number in the water column. K can be calculated from the equation given below. Here c is the speed of sound in sea water.

$$k = \frac{2.f.\pi}{c} \qquad (3)$$

A (θ) varies depending upon the type of noise. The simplest kind of noise to deal with theoretically is isotropic noise, for which the correlation coefficient can be obtained by a simple integration. For the case of a single frequency uni-directional plane wave incident at an angle θ to the normal between two hydrophones spaced a distance d apart, A (θ) is given by

$$A(\theta) = P(\cos(\theta)) = 1 \qquad (4)$$

Substituting the A (θ) in the coherence equation (2) we get the following equation.

$$\Gamma(kd) = \frac{e^{(ikd)} - e^{(-ikd)}}{2 \times ikd} \qquad (5)$$

Incidentally this isotropic noise field is not the form of noise that takes place in shallow water. The isotropic noise contains only real component because it is symmetrical about the horizontal. The graph for this is shown in Figure-1.

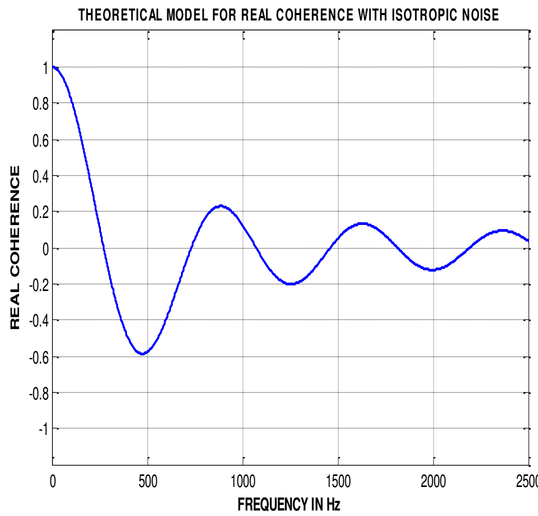

Figure-1. Theoretical Real Coherence for Isotropic Noise.

The noise field shows some vertical anisotropy in shallow water. Hence the coherence function is complex. The noise which propagates downwards does not get reflected from the bottom of the sea surface is called asymmetric noise.

Because of its asymmetric nature it has both the real and the imaginary component. For the asymmetric noise A (θ) can be calculated from the equation below.

$$A(\theta) = \begin{Bmatrix} 4\cos(\theta), 0 \le \theta \le \frac{\pi}{2} \\ 0, \frac{\pi}{2} \le \theta \le \pi \end{Bmatrix} \qquad (6)$$

Substituting the A (θ) in the coherence equation (2) we get the following equation.

$$\Gamma(kd) = -2\left\{\left(\frac{e^{[-ikd]} - 1}{i^2k^2d^2}\right) + \left(\frac{e^{[-ikd]}}{ikd}\right)\right\} \qquad (7)$$

The Figure-2 shows the theoretical real and imaginary coherence for asymmetric noise.

VOL. 10, NO. 4, MARCH 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

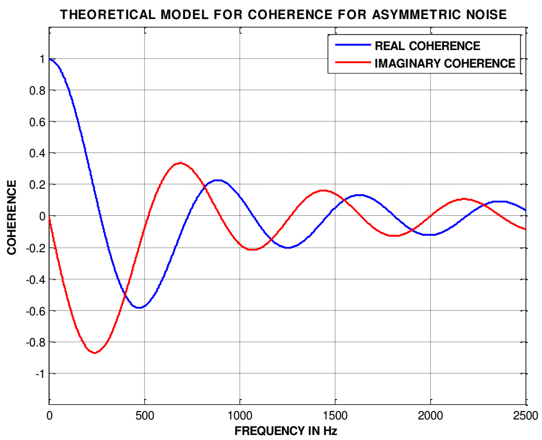

Figure-2. Theoretical Real and Imaginary Coherence for Asymmetric Noise.

Vertical Coherence Estimation and Comparison to Model Predictions

Coherence is the measure of degree to which the noise will be same at two points. The sonar signal can provide high signal to noise ratio than the individual hydrophone when the summing of responses from the array of hydrophones is taken. Coherent signals add while the inherent signals cancel each other. The gain value decreases if the unwanted signals are coherent. Hence coherence is necessary to estimate the performance of the sonar.

Vertical coherence can also be calculated using the cross power spectral density and the power spectral density [4].The coherence can be estimated using the given equation [6].

$$\Gamma(kd) = \frac{\langle S_{xy}(f) \rangle}{\langle \sqrt{S_{xx}(f)} * \sqrt{S_{yy}(f)} \rangle} \tag{8}$$

Where the Sxx (f), Syy (f) are the auto spectral density function and Sxy (f) is the cross spectral density function [7]. The equation for auto spectral density function and cross spectral density function is shown below.

I.

$$S_{xx} = \int_{-\infty}^{\infty} U_{xx}(\tau) \cdot e^{-j2ft\Pi} d\tau \tag{9}$$

$$S_{yy} = \int_{-\infty}^{\infty} U_{yy}(\tau) \cdot e^{-j2ft\Pi} d\tau \tag{10}$$

$$S_{xy} = \int_{-\infty}^{\infty} U_{xy}(\tau) \cdot e^{-j2ft\Pi} d\tau \tag{11}$$

In the above equations Uxx (τ), Uyy (τ) are the auto correlation functions and Uxy (τ) is the cross correlation function.

Vertical coherence is calculated using the data's recorded in the Arabian Sea region. These results are shown in the Figure-3, 4 & 5. Figure-3 shows the real coherence in the Arabian Sea region at 2.24 m/s wind speed. Figure-4 shows the imaginary coherence in the Arabian Sea region at 2.24 m/s wind speed. Figure-5 shows the real and imaginary coherence in the Arabian Sea region at 2.24 m/s wind speed.

In this Welch method is used. This is because the noise spectrum is different for different segments and hence it introduces a variance. To reduce the variance with increase in the data length it is necessary to average over many segments of data. This method consists of dividing the time series data into overlapping segments, computing a periodogram of each segment, and then averaging the PSD estimates.

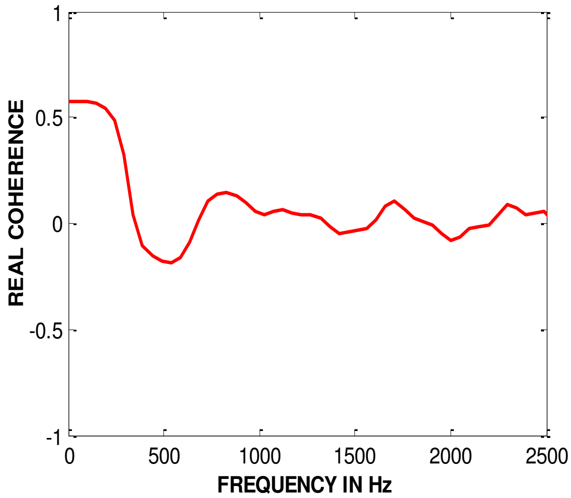

Figure-3. Real Coherence in the Arabian Sea Region at 2.24 m/s Wind Speed.

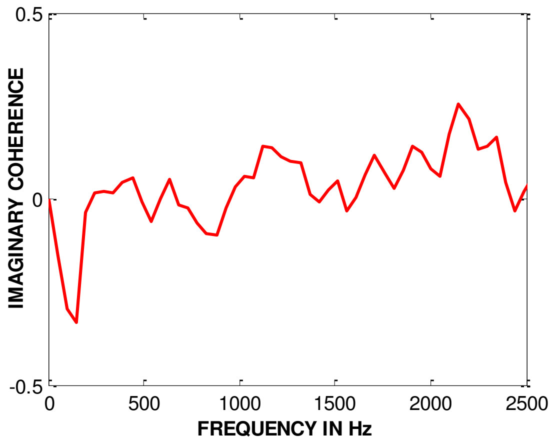

Figure-4. Imaginary Coherence in Arabian Sea Region with 2.24 m/s Wind Speed.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

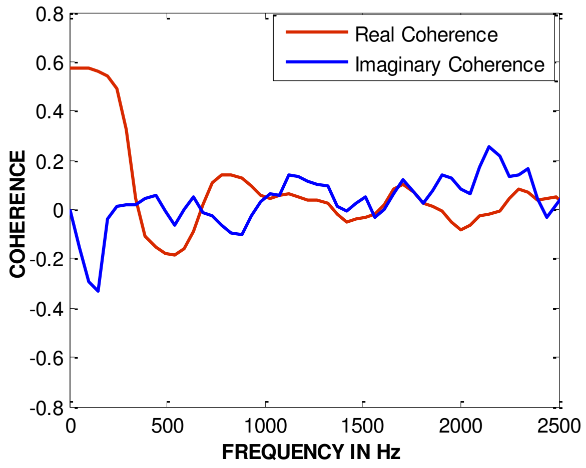

Figure-5. Real and Imaginary Coherence in the Arabian Sea Region at 2.24 m/s Wind Speed.

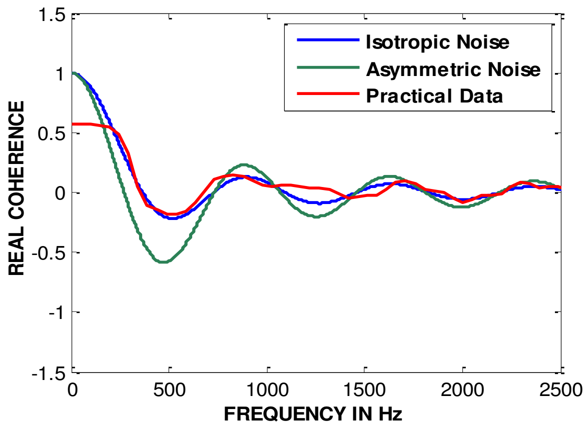

Figure-6. Comparison of the Theoretical and Practical Real Coherence.

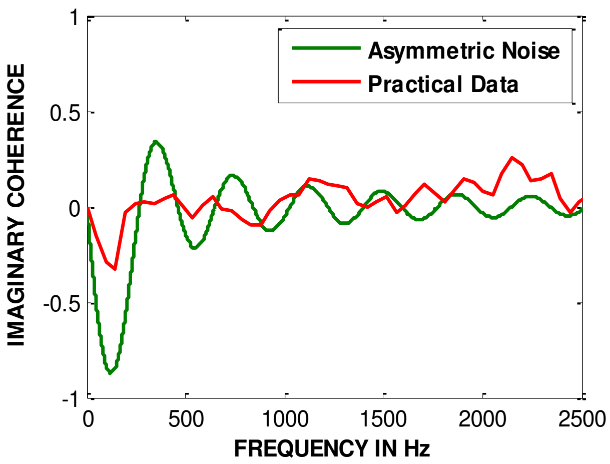

Figure-7. Comparison of the Theoretical and Practical Imaginary Coherence.

Figure-6 shows the comparison of the theoretical and the practical real coherence. The blue line represents the real coherence with respect to the isotropic noise. The green line represents the real coherence with respect to the asymmetric noise. The red line represents the real noise coherence in Arabian Sea region at 2.24 m/s wind speed.

Figure-7 shows the comparison of the theoretical and the practical imaginary coherence. The green line represents the imaginary coherence with respect to the asymmetric noise. The red line represents the imaginary noise coherence in Arabian Sea region at 2.24 m/s wind speed.

CONCLUSIONS

The measured Vertical coherence is compares with the theoretical prediction obtained from the wind driven surface noise model under the assumption that the shipping noise was negligible. The model prediction for frequencies from 700Hz agrees reasonably well with the measured coherence, which implied that the wind driven sea surface noise is a primary ambient noise. For higher frequencies the imaginary components of the model output oscillates near to zero, whereas those of the measured result oscillated lower than the model result. These discrepancies may come from the effect of the sound speed profile in the water column, which is assumed constant in the model. Snapping shrimp noise included in the ambient noise is another possible cause of the discrepancy.

REFERENCES

Estimating the compressional and shear wave speeds of a shallow water seabed from the vertical coherence of ambient noise in the water column," J. Accost. Soc. Am., Vol. 103, No. 2, February 1998.

T. Arase. and E. M. Arase. 'Deep-sea ambient-noise statistics. J. Acoust.Soc. Am. 44, 1679–1684 ~1968.

B. F. Cron., B. C. Hassell. and F. J. Keltonic. 'Comparison of theoretical and experimental values of spatial correlation. J. Acoust. Soc. Am. Vol.37, pp.523–529 ~1965.

G. B. Deane., M. J. Buckingham. and C. T. Tindle. Vertical coherence of ambient noise in shallow water overlying a fluid seabed. J. Acoust. Soc. Am. Vol. 102, No. 6, December 1997.

Jonathan M. Berkson. Measurements of coherence of sound reflected from ocean sediments. J. Acoust. Soc. Am. Volume 68, Issue 5, pp. 1436-1441 (1980).

Sungho Cho. and Jee Woong Choi. Vertical Coherence Measurements of Ambient Noise in Shallow Water off the East Coast of Korea. Japanese Journal of Applied Physics. 50 (2011).

R. J. Urick, Principles of Underwater Sound (McGraw-Hill, NewYork, 1983)3rded, Chap.7.