Selection of Suitable Signals for Passive and Active sonar detection from deep and shallow water communication systems

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Abstract

In this paper, we propose a frame synchronization method for underwater acoustic communication on mobile platform. When a source signal transmitting at arbitrary depth in shallow water and deep water then the influence on the acoustics signal processing is analysed. The acoustic signal propagation is different in shallow water and deep water due to variation of different factors such as sound speed profile (SSP), depth of the ocean, range, Multipath effect and Doppler effect. When a target is moving towards an acoustic receiver in underwater, the time-frequency representation of the received signal exhibits a striation pattern that can be useful in numerous applications such as ship localization. This new method involves transmitting signal based on hyperbolic frequency modulated (HFM) signal as a preamble of the frame, while the receiver uses a correlator which is matched to the transmitted signal. This method can provide us with good signal detection ability which is very important in Underwater Acoustic (UWA) channels, and can provide Doppler scale estimation for accurate synchronization. It can also provide multiple access capability for Underwater Acoustic communication network. We analyze and simulate the performance of the HFM signal. A contrast is made with the Linearly-Frequency Modulated (LFM) signal compared to the LFM based method. The proposed method works with a robust correlation output of the Doppler effect and is suited to handle the presence of dense multi-path channels. Measured sound speed profiles off Indian coasts were used in ray based Bellhop model to mimic the environment with Multipath and Doppler effect. The model was developed and implemented in MATLAB® software.

Keywords: Broadband Reverberation, Broadband Noise, Deep water profile, shallow water profile, Multipath Effect, Doppler Effect, Ray theory, Bellhop model, Sound Speed profile

1. Introduction

Surface waves are among several environmental parameters that can have significant influence on the propagation of high frequency underwater acoustic waves. Quantifying the impact of sea surface roughness on the acoustic wave propagation is an important step in both determining performance levels of underwater acoustic instrumentation and developing techniques for using acoustic waves to measure sea surface roughness. This research involves a combined approach based on experimental observation and modeling of both surface waves and acoustic waves in order to assess the detail of acoustic signal interaction with the sea surface. During the experimental research, acoustic signals were transmitted between source-receiver tripods deployed on the acoustic tank, while highly calibrated

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environmental data was collected simultaneously from a nearby oceanographic observation platform. Source-receiver tripods were carefully spaced in range so rays with a single surface interaction were easily distinguished in received signals. Extensive analysis of the single surface reflected portion of received signals shows correlation between signal fluctuations and wind speed. In order to further understand the interaction of acoustic waves with the rough air sea boundary, a combined acoustic-ocean surface model has been employed to simulate the time-angle fluctuations observed in shallow water acoustic transmissions. The model combines the BELLHOP[10] ray-based acoustic model and an empirical wind driven sea surface model.

2. Acoustical signals used in underwater communications

2.1 Continues Wave signal

CW signals are pure sine waves with constant frequency transmitted during with limited time usually with constant amplitude. A CW pulse (narrow band pulses) is the most commonly used the underwater acoustics signal since it is well suited to narrow band transducers [Lurton][1]. The major limiting factor of CW signal is its very poor spectral content; this limits the usage of the same for advanced processing to characterize targets. Furthermore, it requires relatively high input SNRs[Lurton].

Sinusoidal data can be defined mathematically by a time-varying function of

$$x(t) \ = Acos(2\pi f_0 t) \qquad (1)$$

Where A is amplitude, t is time, f_0 is cyclic frequency in cycles per unit time.

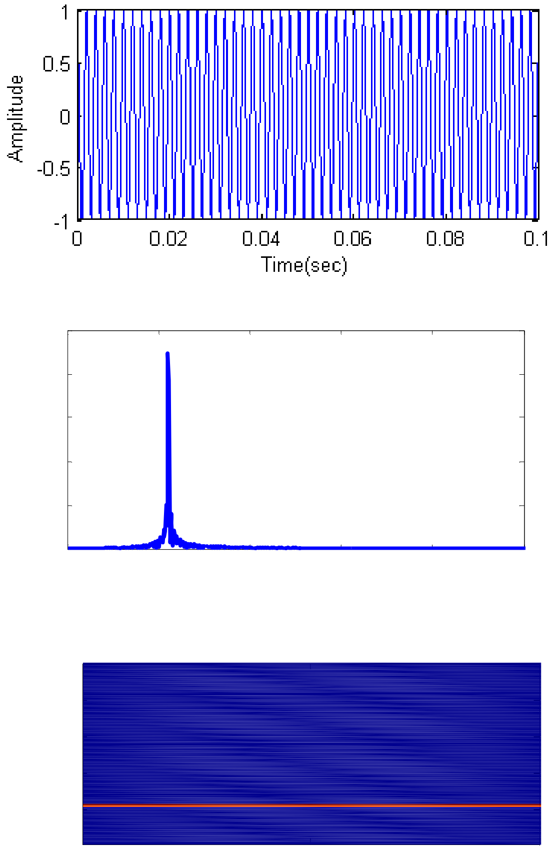


Fig.1 - Continuous Wave (CW) time domain signal and FFT signal & its spectrogram.

2.2 LFM signal

LFM signal is also called chirp signal which is widely used in radar, sonar and underwater communications. LFM is a type of frequency modulation where the signal sweeps linearly from a one frequency to another frequency. LFM signal created by concatenating small sequences each with a frequency higher than the last. LFM signal created by concatenating small sequences each with a frequency higher than the last. LFM signal can be expressed as:

$$x(t) = Acos(2\pi f(t)t + ø) \qquad (2)$$

Where, $f(t) = \frac{kt}{2} + fmin \qquad (3)$

k is signal slope: $k = (fmax - fmin)/T$.

$fmin$ is the starting frequency,

$fmax$ is the end frequency,

T is pulse length.

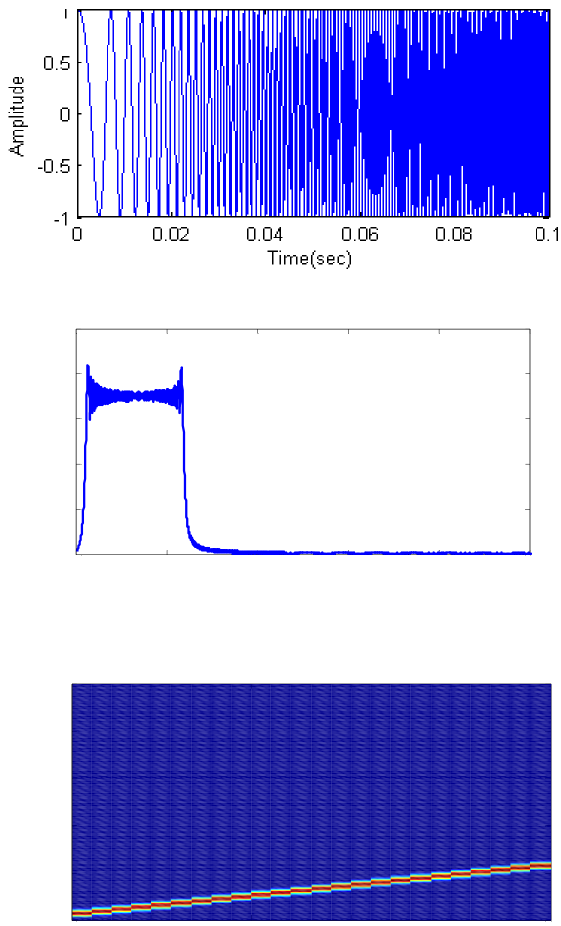


Fig.2 - LFM signal time domain signal and FFT signal & its spectrogram.

LFM signal can be created from original equation for sinusoid given by $x(t) = Acos(2\pi f(t)t + \o)$. Here Instantaneous phase given by $(2\pi f(t)t + \o)$, changes linearly with time. If we make the phase as quadratic then the sinusoid equation is no longer. This equation's frequency changes linearly with time[2]. Time domain representation of LFM signal with its spectrogram & FFT is shown at (Fig.2 (a) & (b)).

2.3 HFM signal

HFM is a type of frequency modulation where the signal sweeps hyperbolically from a one frequency to another frequency. We can create an HFM signal by concatenating small sequences each with a frequency higher than the last. HFM signal is a logarithmic representation of LFM signal. It is used in active acoustic systems. The following example illustrates the difference between a sinusoidal signal and an HFM signal. HFM signal can be expressed as[3]

$$x(t) = co\,s\left[2\pi \frac{ln\left(kt + \frac{1}{fmin}\right)}{k}\right] \quad (4)$$

Where k is the signal slope

$k = (fmin - fmax)/(T * fmin * fmax)$,

$fmin$ is starting frequency,

$fmax$ is end frequency.

If $fmin < fmax$ then HFM signal sweeps up.

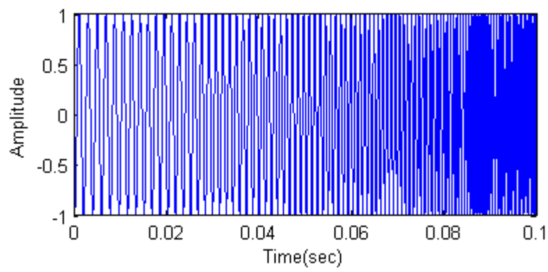
If $fmin > fmax$ then HFM signal sweeps down.

The signal instantaneous frequency is

$$f_i(t) = \frac{1}{kt + \left(\frac{1}{f_{min}}\right)} \quad (5)$$

Instantaneous frequency is in the interval $[fmin\ fmax]$ over time to change in the hyperbolic form.

HFM signal with its time-frequency representation is shown (Fig.3).



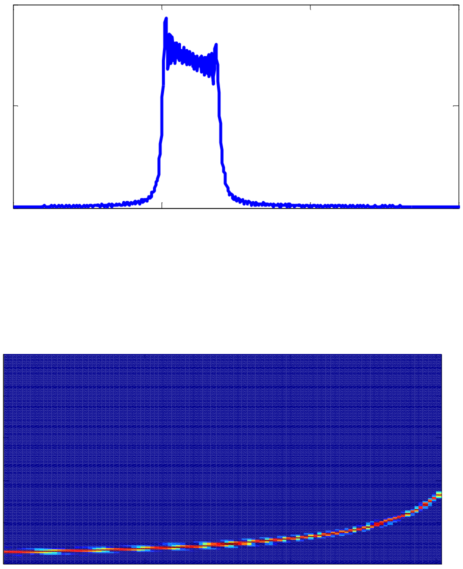


Fig.3 - HFM time domain signal and FFT signal & its spectrogram

3. Acoustic communication chanel modeling

As the performance of a chosen waveform depends on the impulse response function of a channel, it needs to be modeled for evaluating system performance. Although there are several theories to model the channel, the most popular ones are Ray-tracing[10] and Normal Mode theories. However, as the aim of the paper is to characterize various waveforms in high frequency range (> 20 kHz) a ray theoretical model is best suited for this application. However, Gaussian-beam based methods provide a substantial improvement over ray methods but they are not sufficiently accurate at low frequencies[10]. A thumb rule adopted for this low frequency cutoff is when the water depth is less than 20 wavelengths the model cannot be used. In the current study the frequency of interest is >20 kHz which transpires to a wave length of ~75mm which is very small compared to the water depths of interest. Therefore, a Gaussian – beam based model Bellhop developed by Michael B. Porter can used in the current studies and is part of Acoustic Toolbox[19] (http://oalib.hlsresearch.com/modes/acoustictoolbox/at.zip).

Two different sound speed profiles measured in Indian waters one in deep water(Fig.4A) and the other in shallow(Fig.4B) waters along with their sediment properties listed at Table - I are used in estimating the impulse response function.

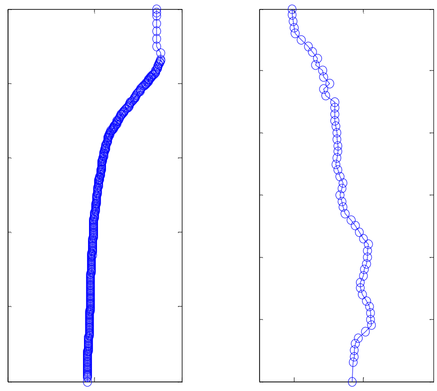


Fig.4 - Sound Speed profile measured of Indian Oceans in deep and shallow water profile

Table - 1.Geo-acoustic parameters of the bottom type used in the simulations.

Geo-Acoustic Parameters	**Deep**	**Shallow**
Sediment type	Sand	Silt
Compression sound speed	1650m/s	1575 m/s
Ratio of sand density to seawater density (ρ)	1.9	1.7
Compression attenuation (α)	0.8 dB/λ	1.0 dB/λ

4. LFM and HFM signals under various Acoustic channel characteristics

Since the aim of the paper is to characterize the signal performance under various environmental conditions like low SNRs, influence of Multi-path and the effect of Doppler in both shallow and deep waters off Indian coast. Signals were simulated using the equations 1-5 of CW, LFM, HFM signals and the same were convolved with the impulse response function estimated for both shallow and deep waters as explained at section above to arrive at resultant time series. This time series was used to estimate the self-correlation peaks (Matched Filter output). This information was used to deduce the performance results.

4.1 Effect of low SNRs on Matched Filter

It is known that the amplitude and the width of central pulse in Matched Filer (MF) output depends on the bandwidth and the pulse width of the signal. The higher the signal bandwidth, the sharper the central pulse will be and also the higher the amplitude. Therefore, in case of very low SNRs both LFM and HFM with larger pulse width and higher bandwidth will yield desirable results.

4.2 Bellhop Model

These factors include variation of sound speed with depth causing changes in refractive index, presence of ocean boundaries causing multipath and scattering effects, high temporal and spatial variability of ocean environment causing fading of signal, presence of different types of sediments at the bottom boundary causing different attenuations etc., In addition the movement vessel causes Doppler[14]. In an effort to study the impact of noise on marine mammals, a simulation model (VirTEX) based on ray theory was developed by John C. Peterson and Michael B. Porter.

The model generates a time-series of transmitted signals as heard by a marine mammal and it is capable of simulating both multipath and Doppler imposed by source/receiver motion. The algorithm uses the outputs of BELLHOP[10] ray tracing model for predicting the receiver output time series. Therefore, authors have adopted this model to simulate the effect of environment, multipath due to boundaries and the Doppler due to ship's motion.

As VirTEX uses ray based theory, the authors are fully aware of the limitations of ray theory based models. In the absence of a unified theory which is applicable in both low and high frequency regimes the authors have resorted to using BELLHOP model.

4.3 Multipath Fffect

The transmitted signal gets effected by multipath and Doppler effect which is challenge to simulate the Target movement. The analysis of acoustic signal effected by these factors is difficult. The sea is a bounded medium in which the sea bottom boundary is very different from surface boundary. The surface consists of waves, wind action, currents whereas the bottom consists of mud, sand, hard coral and volcanic rock.

The sound transmitted from a source in underwater undergoes multiple reflections, refractions by the moving sea surface, the bottom surface boundaries and also by other reflectors (fish, whales, snapping shrimp, air bubbles, etc.,) and reaches the receiver in several distinct paths in various time durations during its propagation in underwater. This phenomenon is known as "Multipath effect". For a large range between the transmitter and receiver, the transmitted signal propagates to the receiver via various paths. The delay associated with each path depends on its geometry and prevailing ocean conditions and the sound speed profile in the region. In passive sonar due to multipath effect the detection ability reduces. So the target recognition and function ranging becomes difficult. The transmitted signal frequency from the source gets distorted due to transient Doppler effects caused by expansion and contractions of the sea surface reflected transmission paths or the Doppler shift caused due to the movement of either transmitter or receiver or both. The Doppler Effect corresponds to a shift of the apparent signal frequency after propagation, due to a change in the duration of the source – receiver paths during transmission time, caused by the relative displacement of the source and the receiver, or the source and the target. Multipath propagation of signal occurs due to sound reflections from sea surface, bottom and any objects. This signal received by hydrophone is a pressure field data. This data can be represented as sum of

Marrival amplitudes $A_m(\omega)$ and their corresponding delays τ_m (ω).

$$P(\omega) = S(\omega)\sum_{m=1}^{M} A_m e^{j\omega\tau_m} \qquad (7)$$

Where S (ω) is spectrum of the source, A_m is arrival amplitude.

Convolution theorem is product of two signals resulting in a third signal. This third signal is the area of overlap of the other two signals. If two signals are convolved in time domain, then the Fourier transform of the convolution is just the product of two original Fourier transforms[8].

To convolve, we need time domain representation of the above data. Thus, the time domain representation is

$$P(t) \quad = \sum_{m=1}^{M} A_m S(t-\tau_m) \qquad (8)$$

Where $S(t)$ is the source waveform, A_m is a real time data consisting of complex numbers. Thus, proper representation of this data can be where convolution with respect to real and imaginary data has to be taken into account to observe the phase shifts associated with the samples.

$$P(t) = \sum_{m=1}^{M} Re\{A_m\}S(t-\tau_m) - Im\{A_m\}S^{+}(t-t_m) \quad (9)$$

Where $S^{+} = H(S)$ is the Hilbert transform of $S(t)$. Hilbert transform of any signal is the 90^0 phase shifted signal. From real part of pressure data we can obtain the arrival amplitudes and from the imaginary part we can obtain the delays of the arrival amplitudes.

4.4 Multipath effect in Deep water profile

A measured sound speed profile shown at (Fig.4A) along with the measured sediment type is used for estimating the impulse response function. The sediment type found at the measurement site is silt. Therefore, the geo-acoustic parameters used in the channel modeling are density (ρ) is $1.7g/cm^3$, compressional wave speed(c) is 1575 m/sec and the compressional wave attenuation (∝) is 1.0 dB/λ. Multipath signal was simulated as brought out in the preceding section

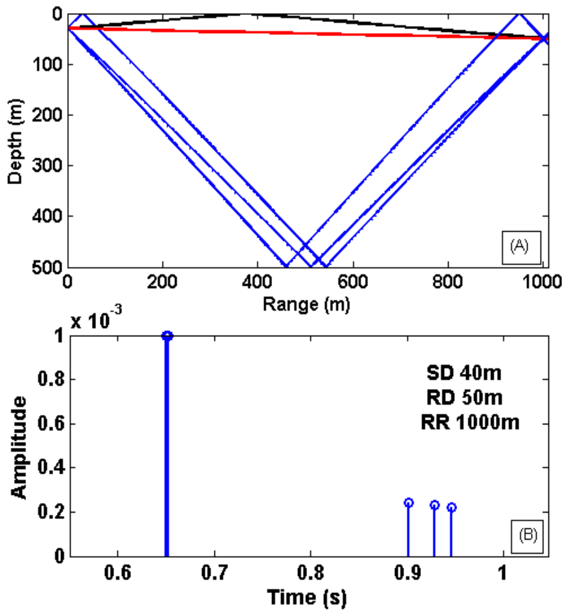


Fig.5 - Eigenray (a) and impulse response (b) of deep water for a source depth of 40m, Receiver depth of 50m and receiver range of 1000m

Performance of CW, LFM and HFM were evaluated using the different source receiver combinations. One such response function is shown at (Fig.5 (a) & (b)) for a source receiver combination of source depth being at 40m and receiver position being 50m depth at distance of 1000m. It is evident from Eigen ray plot that very few rays are connecting source and receiver and the delays are of the order of 0.2 seconds between the direct path (red color line) and the bottom reflected paths. Further, the bottom reflected paths got attenuated more than the surface reflected path

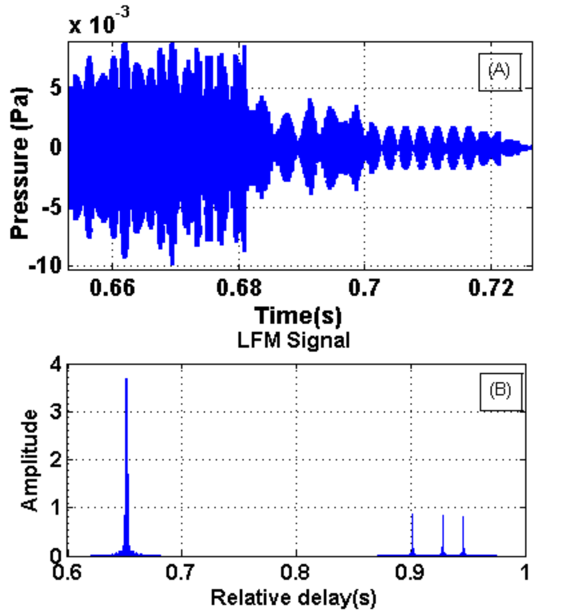


Fig.6 - The LFM signal influence of multipath on self-correlation peak for deep water profile

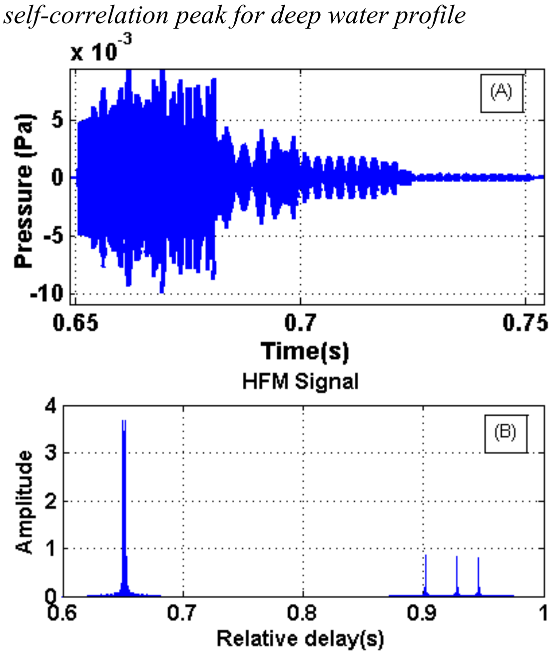


Fig.7 - The HFM signal influence of multipath on self-correlation peak for deep water profile.

As far as the performance of LFM and HFM in deep waters is concerned, it is apparent from (Fig.6 (a) & (b)), both have shown very good resistance to multipath. Therefore, these signals can be very good candidate signals for the applications in multipath prone deepwater environments.

5.5 Multipath effect in Shallow water profile

In shallow waters, mesured sediment type is found to be sand. Accordingly, the geo-acostic parameters used in computioan are density (ρ) is 1.9 kg/m^3, compressional wave speed(c) is 1650m/s and compressional wave attenuation ($\propto$) is 0.8 dB/λ.

Usually, the shallow waters are more prone to multi-path and degrade the system performance. (Fig.8 (A)) shows the Eigen rays which represents the underwater acoustic signal reflections in shallow water and (Fig.8(B)) shows the impulse response of multipath simulation in shallow water. Acoustic signal transmitting through such shallow waters will be badly be effected by multipath as the received signal impulse response shows more surface and bottom reflected paths of source signal with different less time delays. (Fig.9(A) & Fig.10(B)) shows that the matched filter output of LFM and HFM signals reveals that both gave good anti-multipath capability in shallow water. However, CW's performance is worse than both LFM and HFM signal

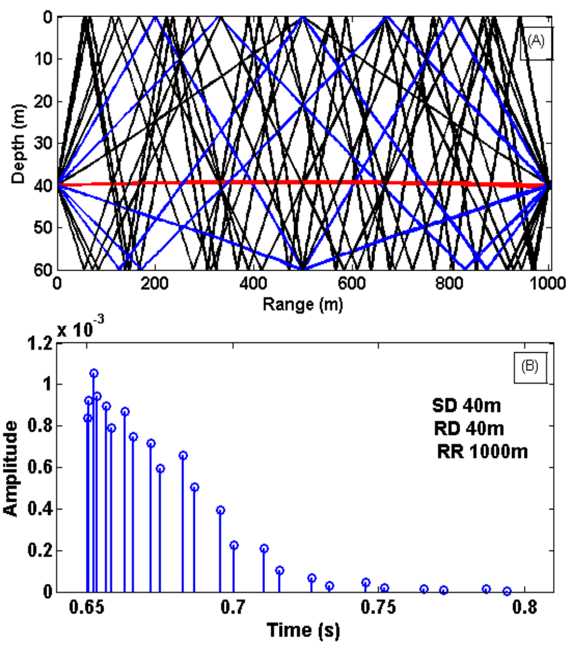


Fig.8 - Eigenray (a) and impulse response (b) of deep water for a source depth of 40 m, Receiver depth of 40 m and receiver range of 1000m.

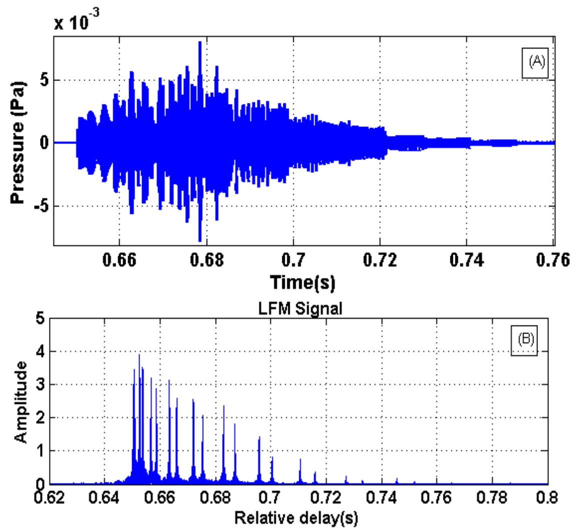


Figure.9 The LFM signal influence of multipath on self-correlation peak for shallow water profile

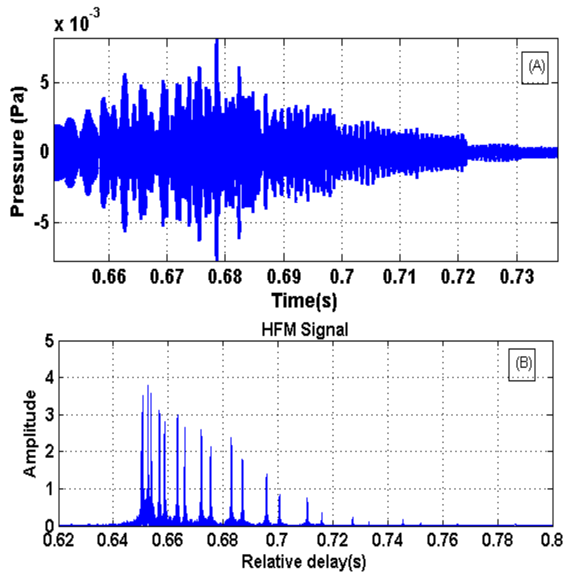


Fig.10 - The HFM signal influence of multipath on self-correlation peak for shallow water profile

6. Doppler Effect

In addition to the performance degradation caused by the changes in environmental parameters, motion of transmitter or receiver causes either time compression or spreading of the signal which is known as Doppler Effect. The magnitude of the Doppler Effect is proportional to the ratio $a = v/c$ of the relative transmitter-receiver velocity to the speed of sound[20].

5.1 Generating Time-Series Data with Motion

Due to the effect of the Doppler shift the time series data has been shifted to t amount where $t = d/v$, d=distance travelled by the ship and v= velocity with which ship travelled.

$$p(t) = \sum_{n=1}^{N} Re\{A_n(t)\}\ s[t - \tau_n(t)] - Im\{A_n(t)\} s^{+}\left(-\tau_n(t)\right) \quad (10)$$

The position $(p(t))$ of the receiver $(r = vt)$ varies with respect to time delays and amplitudes where
$A(r) = 1/r$ is amplitude and $\tau = r/c$ is the time delay.

$$p(t) = A(r)s[t - \tau(r)] = \frac{1}{r}\, s\left(t - \frac{r}{c}\right) \quad (11)$$

Substituting $r = vt$

$$p(t) = \frac{1}{vt}\, s\left[t\left(1 - \frac{v}{c}\right)\right] \quad (12)$$

For a sinusoidal source function, $s(t) = \sin\,(\omega_0 t)$, the received time series is

$$p(t) = \frac{1}{vt} \sin\left[\omega_0 t\left(1 - \frac{v}{c}\right)\right] \quad (13)$$

This time series shows the Doppler frequency shift of $\omega = \omega_0(1 - \frac{v}{c})$.

For the surface path arriving at angle θ, $A(r) = cos\theta/r$ and $= \frac{r}{c} cos\theta$, the received time series in the case of transmitted sine wave is

$$p(t) = \left[\frac{cos\theta}{vt}\right] s\left[t\left(1 - \frac{v}{c\ cos\theta}\right)\right] \quad (14)$$

It is well known that a Doppler sensitive waveform such as CW burst is used for estimating the target velocity. However, as shown in preceding sections CW is susceptible to multipath, reverberation and additive noise. Therefore, one needs to look for alternative waveforms which can resolve Doppler reasonably well with fairly good reverberation resistant capabilities

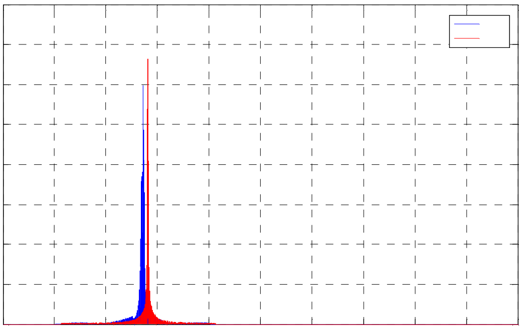


Fig.11-The influence of the Direct path on self-correlation peak of LFM and HFM signal

In an effort to study the impact of noise on marine mammals, a simulation algorithm based on ray and normal mode theories was developed by Martin Siderius and Michael B. Porter[10]. In a similar effort, effect of time varying sea surface on broadband acoustic transmissions was studied by the same group[10]. Basing on the formulations developed vide the two reference given above, a model called Virtual Time series Experiment (VirTEX) [19] was developed to predict the receiver's response when a known time series (waveform) is transmitted from a hypothetical source in an underwater acoustic channel.The algorithm computes the time series that would be observed at a hypothetical receiver, taking into account the effects of multipath and also Doppler introduced by motion of source/receiver. The algorithms utilize the outputs produced by the BELLHOP ray tracing model[18] for predicting the receiver output time series.

In the current study the authors have used VirTEX model for evaluating the performance of CW, LFM and HFM in both shallow and deep waters off Indian coast. In a set of numerical experiments, CW signal of required Frequency and LFM / HFM signals with required frequency of bandwidth at a central frequency of required frequency and pulse length of 30msec were transmitted and the signals were received at various speeds ranging from 0 to 30m/s in steps of 5m/s. In these numerical experiments, the source depth and receiver range were kept constant at 30m and 1km respectively. The receiver depth varied from 10m in shallow to 200m in deep to study the depth dependent performance of different waveforms.

Similar to the studies carried out in the preceding section, MF output was estimated for each case and MF peak was normalized with zero velocity's MF peak value. This process will bring out the waveform's ability to resist Doppler very clearly. The process was carried out for various speeds for both shallow and deep water cases. LFM and HFM have behaved entirely differently in the presence of Doppler. LFM has shown moderately strong resistance to Doppler whereas HFM has exhibited very strong resistance to Doppler. However, in shallow water case although, the performance of CW remained same, LFM and HFM has shown similar degree of resistance to Doppler with HFM being slightly more resistant than LFM.

In an effort understand the depth dependence; the receivers were numerically placed at 10m, 30m and 50m depths in shallow waters and 10m, 50m and 200m depths in deep waters. Although the results did not show considerable depth dependence in deep waters LFM and HFM have shown greater resistance to Doppler when the receiver is close to the surface.

7. Conclusion

In this paper, the CW, LFM and HFM signal propagation characteristics are compared in deep water & shallow water profile underwater acoustic simulation channels. It is observed that CW signal is greatly influenced by multipath effect so it is not effectively used in shallow water acoustic propagation channels as in shallow water the multipath effect is more due to less depth of the sea. Whereas, the HFM and

LFM signals are very slightly effected by multipath effect. But the observation of Doppler effect on signals propagating in shallow water is complex compared to deep water communication. From the simulation results it is observed that the acoustic signal propagation in deep water is mostly influenced by Doppler effect so HFM signal is suitable for communication in deep water as it has anti-Doppler capability. So the simulation results shows that CW has good Doppler resolution, but poor range resolution. CW signal is greatly influenced by reverberation. LFM signal has good anti-multipath capability but influenced by Doppler shift. Whereas HFM signal has strong resist towards the influence of Doppler so used for communication. And HFM signal has excellent anti-multipath capability same as LFM signal.

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References

[1] Xavier, Lurton, An Introduction to Underwater Acoustics Principles and Applications, Praxis Publishing Chichester, UK, (2002), 26-28.2.

[2] Michael Ainslie, Principles of Sonar Performance Modeling, Springer Publications.

[3] L. Berkhovskikh and Y. Lysanov, Fundamentals of Ocean Acoustics, Springer, 1982.

[4] Urick, Robert, Principles of Underwater Sound for Engineers, Third Edition, Los Altos; Peninsula Publishing. (1996).

[5] Milica Stojanovic, J. Catipovic, and J. Proakis, Adaptive Multichannel Combining and Equalization for Underwater Acoustic Communications, J. Acoust. Soc. America, vol. 94, no. 3, Sept. 1993, pp. 1621–31.

[6] Milica Stojanovic, Low Complexity OFDM Detector for Underwater Acoustic Channels, Proc. IEEE Oceans Conf., Sept. 2006.

[7] Milica Stojanovic, On the Relationship Between Capacity and Distance in an Underwater Acoustic Channel, ACM SIGMOBILE Mobile Comp. Commun. Rev., vol. 11, no. 4, Oct. 2007, pp. 34–43.

[8] M. Chitre, A High-Frequency Warm Shallow Water Acoustic Communications Channel Model and Measurements, J. Acoust. Soc. America, vol. 122, no. 5, Nov. 2007, pp. 2580–86.

[9] Yuan Fei, Wang Wen-Jun, Characteristics Analysis of HFM Signal over Underwater Acoustic Channels: Key Laboratory of Underwater Acoustic Communication and Marine Information. Technology, Xiamen University, Ministry of Educatio., 11(2013), pp. 1173-1180.

[10] Michael B. Porter and Homer P. Bucker, Gaussian bean tracing for computing ocean acoustic fields, The Journal of the Acoustical Society of America., 82(1987) 1349-1359.

[11] Finn B.Jensen, William A. Kuperman, Michael B.Porter, Henrik Schmidt, Modern Acoustic and Signal Processing: Computational Ocean Acoustics, Second Edition, Springer New York Dordrecht Heidelberg London., 38-39.

[12] Lydia Sari, Effects of Puncturing Patterns on Punctured Convolution Codes. TELKOMNIKA Indonesia Journal of Electrical Engineering, (2012).

[13] Milica Stojanovic, Preisig James, Underwater Acoustic Communication Channels: Propagation Models and Statistical Characterization, communication Magazine, woods Hole oceanographic Institution, (2009).

[14] Martin Siderius and Michael B. Porter Modeling Techniques for Marine-Mammal Risk Assessment, IEEE Journal of oceanic engineering, 31(2006)., 50-51

[15] Underwater Acoustic Communication Channels: Propagation Models and Statistical Characterization, Milica Stojanovic,

Northeastern University, James Preisig, Woods Hole Oceanographic Institution, January 2009.

[16] Eric Sorensen, Helen H. Ou, Lisa M Surk and Martin Siderius, "Passive Acoustic Sensing for Detection of Small Vessels," IEEE Oceans, pp. 1-8, 2010.

[17] Urick, Robert, Principles of Underwater Sound for Engineers, Third Edition. Los Altos; Peninsula Publishing, 1996

[18] Michael B. Porter and Homer P. Bucker, "Gaussian Bean Tracing for Computing Ocean Acoustic Fields", J. Acoust. Soc. Am., Vol. 82, pp. 1349-1359, 1987.

[19] John C. Peterson and Michael B. Porter, "Virtual Timeseries EXperiment (VirTEX) - Quick Start,"http://www.hlsresearch.com/,July 2014.

[20] Raju. R.P ; Nair, P.V & Das, M.K. An experimental study on the effect of multipath propagation on RC detection processing of LFM Signals: A SONAR Perspective, NSA-1015, October 7-9 2015,NIO-Goa.

[21] Raju, R P, "Underwater Acoustic Propagation of LFM Pulse :An Active Sonar Perspective",NPOL, Kochi, DRDO Science Spectrum, Feb 2016, pp.246-254.

[22] Signal Processing Toolbox, MATLAB® ,Mathworks