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OFDM along with Steering Sinusoids for Underwater Acoustic Communication

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Abstract: Among the different modulation techniques used for acoustic communication underwater, Orthogonal Frequency Division Multiplexing (OFDM) still happens to be the best and an extremely effective modulation scheme. However, the major hurdle which the underwater acoustic (UWA) communication encounters is the challenges posed by the dynamic nature of the sea, which degrade the quality of the signal. The non-uniform effects of the sea dynamics due to wind or platform motion may result into inter-carrier interference causing a complete distortion of the signal. To avoid such distortions, relative changes in terms of Doppler factors need to be tracked properly and included in the system designing. Adopting to this ideology, a new OFDM approach based on Steering Sinusoids has been introduced in this paper. The Steering Sinusoids will be able to track and correct the fast oceanic variations incurred within a symbol length. These recorded changes, either uniform or non-uniform, are used to reduce the intensity of the Doppler spreads. The proposed system can be analyzed using the MATLAB simulation along with self-induced Doppler. Bellhop Ray Tracing algorithm has been used for generating static multipath channel models.
Keywords: OFDM, UWA, Steering Sinusoids, BER, sea dynamics, Doppler spreads, multipaths, Bellhop ray tracing, ZP-OFDM

I. INTRODUCTION

Underwater communication is a field which demands extensive research for different applications related to ocean monitoring and information exchange. UWA channel poses challenges for communication due to the obstacles like strong multipaths, Doppler spreads due to sea dynamics, very limited bandwidth due to absorption effect and so on. Recent research work shows that OFDM modulation scheme is considered as a key scheme which has an ability to achieve rectification of major drawbacks suffered by oceanic channel [1][2]. However, the major challenge in using OFDM is to minimize the multipath spreading effects, like Inter-Symbol Interference (ISI) and provide simpler process for equalization at the receiver side. Thus, any kind of obstacles offered by the UWA channel causing the loss of the orthogonality of signal must be monitored and adopted in the design of OFDM based communication. Also, to keep the subcarriers orthogonal and practical for UWA communication, the temporal variations occurring within the signal must be properly phase tracked and need to be compensated [3][4].

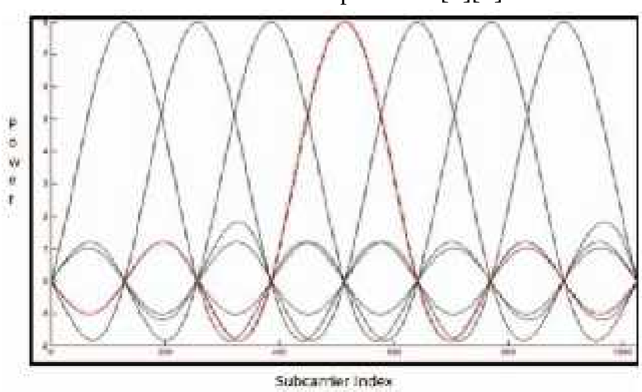

Fig. 1 Orthogonal Frequency Division Multiplexing (OFDM)

Keeping the above-mentioned design aspects in mind, we propose a novel and an efficient approach called Steering Sinusoids based OFDM scheme for UWA communication. These sinusoids are appended within the data frame, which measure the relative time change and respective Doppler scale factor and track the changes incurred by the channel to nullify the same from the entire signal.

In this proposed method, known sinusoidal signals are appended within a frame to measure the relative time change and respective Doppler scale factor. The number of these appended sinusoids depend upon the variation magnitude of oceanic channel. Thus, higher the variations, more closely are the sinusoids placed. Once the changes suffered by the channel are tracked by the sinusoids,

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their effect can be cancelled from the complete signal even for the fast variations captured within symbol length. For a relative motion velocity varying linearly over a packet in oceanic variations, frequency/time changes almost linearly and the uniform expansion or contraction based Doppler correction might not work in a desired way [5]. The rest of the paper consists of channel model generation in section II and conventional OFDM receiver performance in section III. Section IV consists of a novel concept of Steering Sinusoids based approach for lowering the effects of Doppler shifts. Section V contains conclusions and outcomes of the proposed system.

II. CHANNEL MODEL GENERATION

The coast of Arabian Sea near Konkan Coast Line has been selected for simulation and analysis of the proposed system. The depth of the sea near the Konkan coastline is approximately 1000 meters. The bottom of the ocean floor is mostly sandy and rocky. Bellhop algorithm has been used to try and generate the channel model near the Konkan Coast with a view of studying the complexities of this oceanic floor. This study is essential for working out a suitable communication technique. Bellhop ray tracing algorithm is an efficient tool which performs two-dimensional acoustic ray search for generating a sound speed profile for UWA communication. Bellhop.exe is executed using MATLAB program which provides us with an output of travel time and multipath amplitudes reflected from the seabed.

A. ENV File Generation from Data obtained from World Ocean Atlas

The sound speed profile of the selected region has been obtained from the provided data base of the World Ocean Atlas at 1-degree resolution, extended at the depth up to 5500 meters. The high-resolution sound speed profile can be obtained by using the cubic-spline interpolation in MATLAB. The environmental (ENV) files are generated which contain information about maximum floor depth, source (transmitter) depth and collector (receiver) depth, range of communication and the number of beams that need to be transmitted. The ENV files are further useful in finding out the channel frequency response and impulse response with the help of Bellhop ray tracing algorithm.

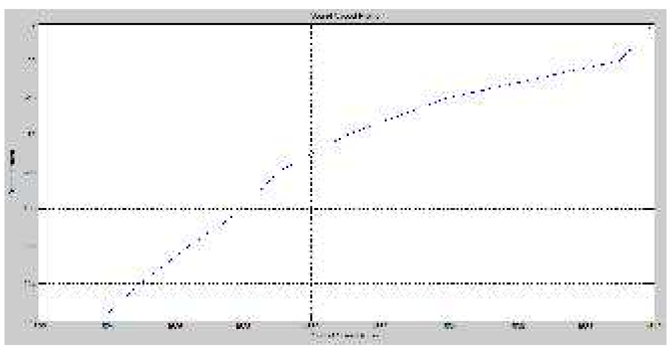

Fig. 2 Sound Speed Profile near Konkan Coast

B. Channel Model Generation

Beam tracing is same as that of ray tracing, however it only considers finite width beam paths than infinite width rays. Propagation time and amplitudes of multiple paths need to be obtained which explain reflection from the ocean surface and seabed. This provides us with the channel impulse response. Assuming every acoustic path to be a low pass filter, the overall impulse response can be defined as:

$$h(\tau,t) = \sum_{p=0}^{K} h_p(t)\delta(t-\tau_p(t)) \qquad (1)$$

where $h_p(t)$ is the time varying path gain and τ_p is the path delay of the p^{th} path.

Should few of the coefficients of $h_p(t)$ be relatively small or zero, their corresponding estimates must be discarded. This reduces the problem of dimensionality to the point governed by the laws of propagational physics. If J coefficients out of K are selected whose magnitude is higher than a defined threshold, sparse channel response $h_s(t)$ is obtained, which is truncated in magnitude.

$$h_s(\tau,t) = \sum_{p=0}^{J} h_p(t)\delta(t-\tau_p(t)) \qquad (2)$$

III. ZERO-PADDED OFDM BASED COMMUNICATION FOR UWA CHANNEL

We have formulated a method for reliably detecting the OFDM signal received from Doppler distorted and time varying channels. Hence, in order to mitigate the Doppler distortions at the selected location, the actual expressions of these distortions must be sorted out on the basis of change in time scale of transmitted waveforms.

A. Transmitting Signal based on ZP OFDM

The total OFDM block can be represented as:

$$T_{total} = T+T_g \qquad (3)$$

where T is the symbol time and T_g is the guard interval.

In pass band OFDM, the transmitting signal can be expressed as:

$$s(t) = Re\left\{\sum k\epsilon K_N \left[d[k]e^{i2\pi k\frac{t}{T}}\right]g(t)e^{i2\pi f_c t}\right\}, \text{ for } t\epsilon 0, T+T_g \qquad (4)$$

where g(t) is the zero-padding operation as g(t) = 1 for $t \in \{0,T\}$ and g(t) = 0 for $t \in \{T, T_g\}$.

B. Doppler Factor Expression with its Addition in Transmitting Signal

The Doppler affected signal can be expressed as a change in original time scale quadratically:

$$T_{Doppler} = (1+\alpha+\beta T_{Original})\, T_{Original} \qquad (5)$$

Thus, Doppler factor *a* can then be expressed as:

$$a = \alpha+\beta T_{Original} \qquad (6)$$

The time warp signal generated based on values of α and β is either expanded or contracted in time. The Doppler scaling factor for all paths can be expressed as:

$$\tau_p(t) = \tau_p - at \qquad (7)$$

Thus, the modelling of the Doppler induced transmitted signal without multipath can be done as:

$$s_{Doppler}(t) = Re\{\sum k\epsilon K_A \left[d[k]e^{i2\pi k\Delta f t(1+\alpha+\beta)}\right]g(t(1+\alpha+\beta t))e^{i2\pi f_c t(1+\alpha+\beta t)}\}; \text{ for } t\epsilon\{0, T+T_g\} \qquad (8)$$

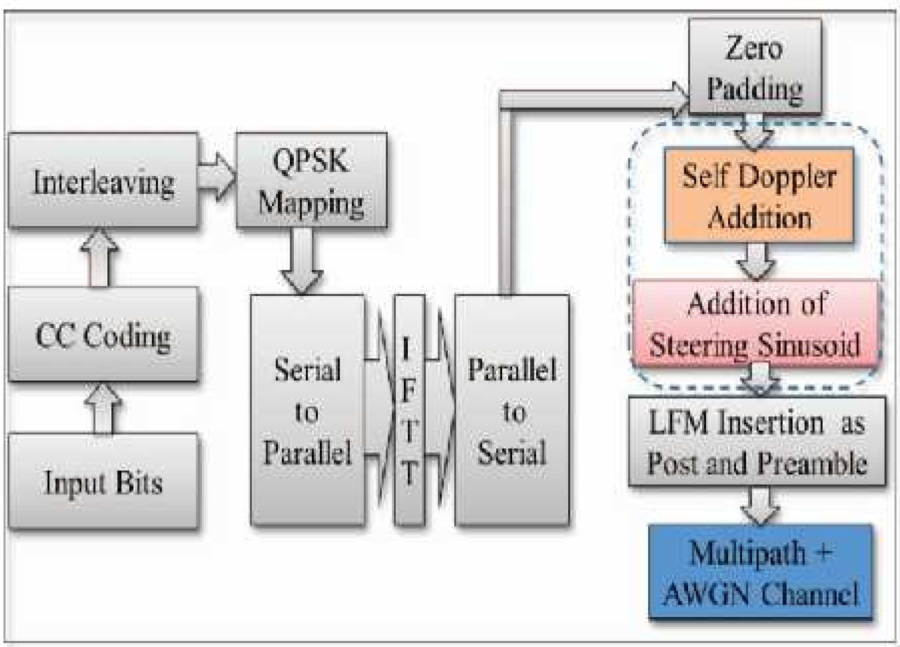

Fig. 3 Block Diagram for the OFDM Transmitter

IV. RECEIVER DESIGN

A. Approach Based On Steering Sinusoids

The steering sinusoids monitor the change the change in parameters α and β. The baseband signal on the receiver side can be expressed as:

$$z(t) = \sum_{p=0}^{J} h_p \{\sum_{k \epsilon K_A} [d[k] e^{i2\pi k\Delta f (t_{Doppler} - \tau_p)} g(t_{Doppler} - \tau_p)] e^{i2\pi f_c (t_{Doppler} - 1 - \tau_p)}\} + n(t)$$

(9)

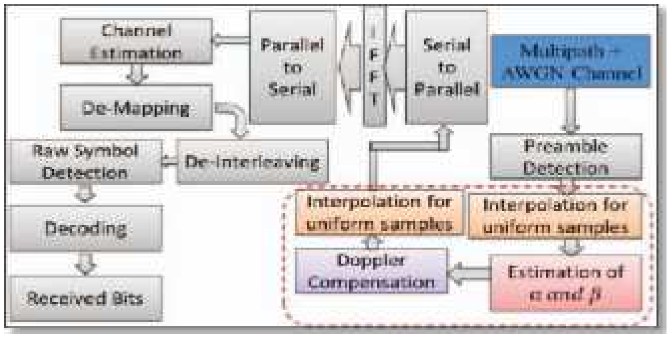

Fig. 4 Block Diagram of the Proposed Receiver

B. Estimating α and β

For correcting Doppler induced signal, desired estimated values of α and β are used by simple inversion method. Time warp effect is analyzed on a single period T' of a sinusoid in order to formulate and simplification purpose. Sinusoidal output from a time warped period $\tilde{T}$ can be expressed as:

$$\tilde{T} = T'(1 + \alpha + \beta T') + 2\beta T' t \qquad (10)$$

The above expression can be used to for computing the estimates of α and β for two different instants t_0 and t_1. Substituting these parameters in equation (10) we get

$$\tilde{T}0 = T'(1 + \alpha + \beta T') + 2\beta T' t0 \qquad (11)$$

$$\tilde{T}1 = T'(1 + \alpha + \beta T') + 2\beta T' t1 \qquad (11.a)$$

In this, t1=t0+T_c, where T_c is length of transmitted packet. Thus, substituting this value in equation (11.a), we get:

$$\tilde{T} = T'(1 + \alpha + \beta T') + 2\beta T'(t0 + Tc) \qquad (12)$$

V. SIMULATION RESULTS

Following are the results obtained in the simulation of the proposed system. It can be clearly seen that the QPSK modulation scheme provides better BER results as compared to the BPSK modulation. Also, the Doppler effects are reduced to a great extent in the QPSK modulation.

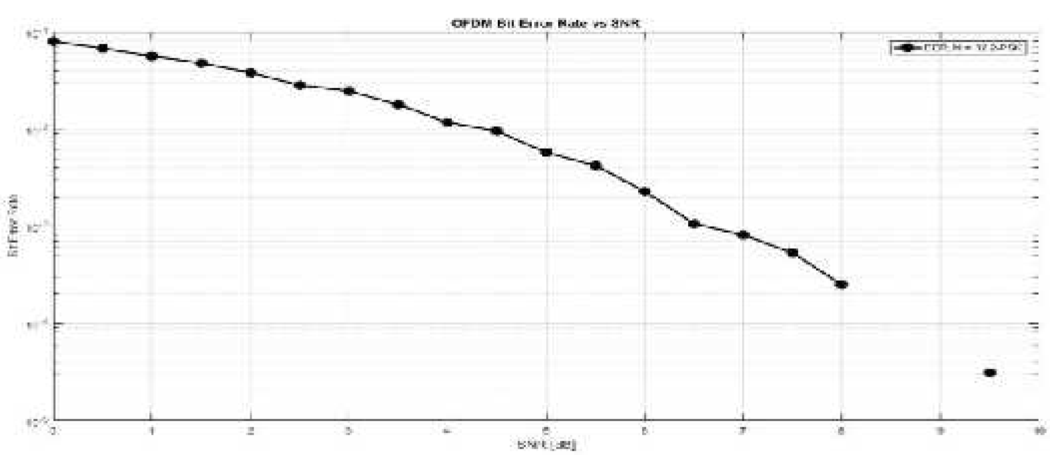

Fig. 5 BER when modulation scheme as BPSK with T = 5, Z = 100

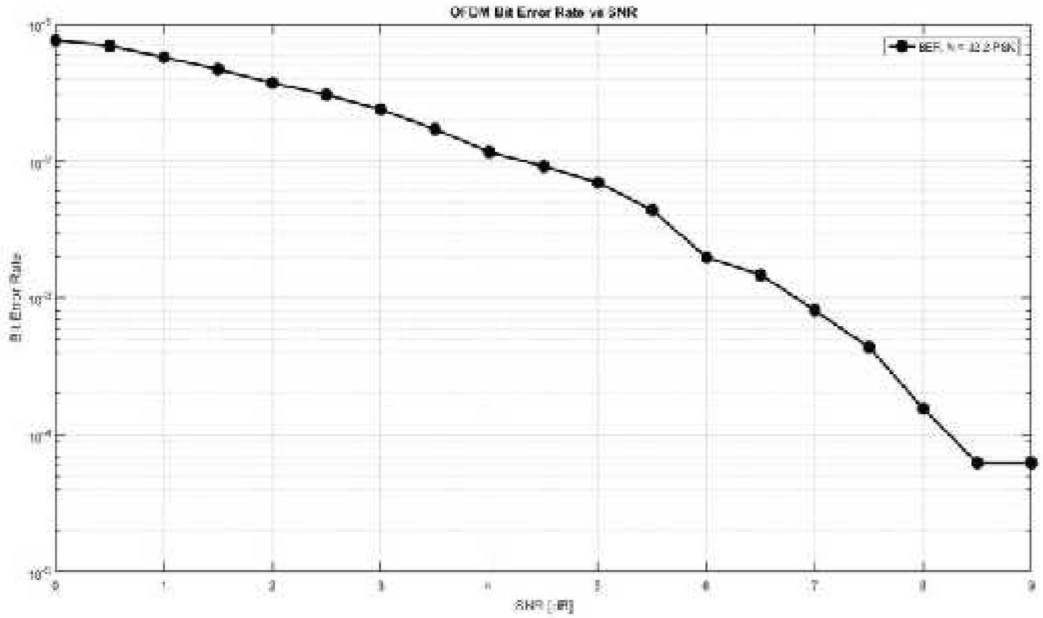

Fig. 6 BER when modulation scheme as BPSK with T = 25, Z = 100

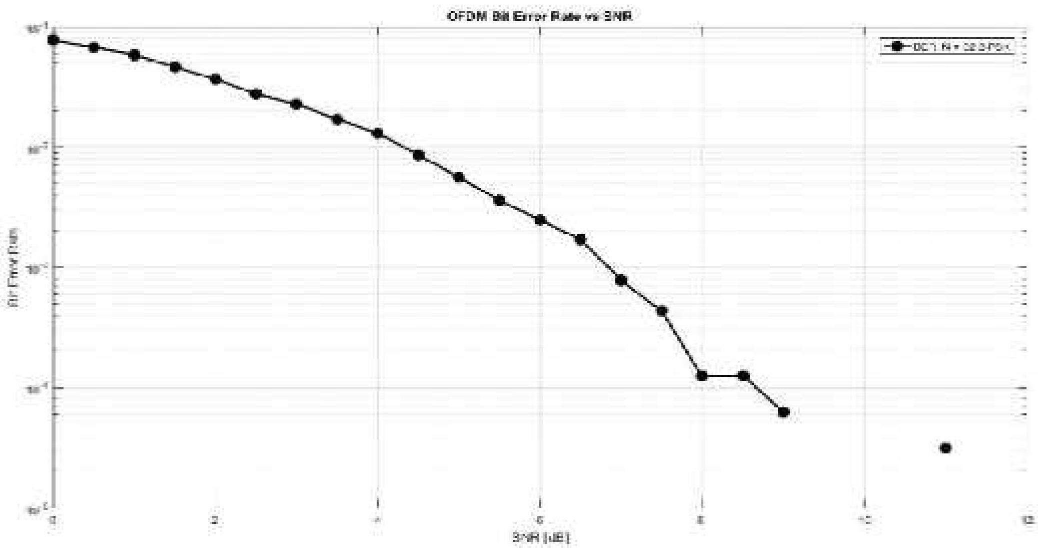

Fig. 7 BER when modulation scheme as BPSK with T =5, Z = 200

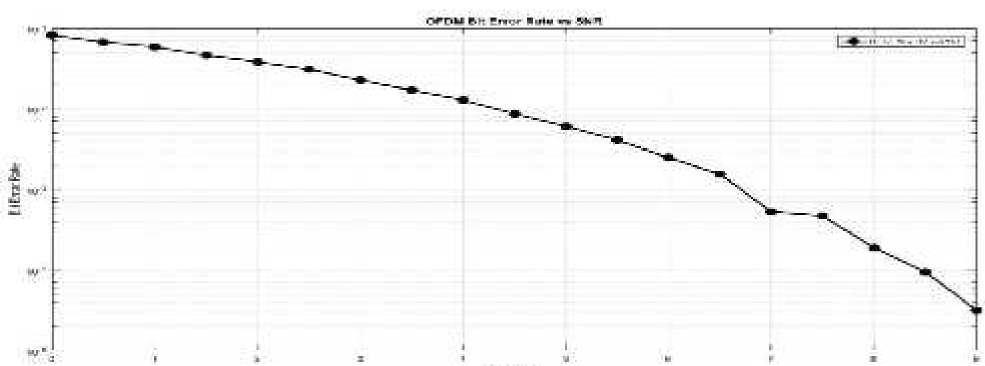

Fig. 8 BER when modulation scheme as BPSK with T =25, Z = 200

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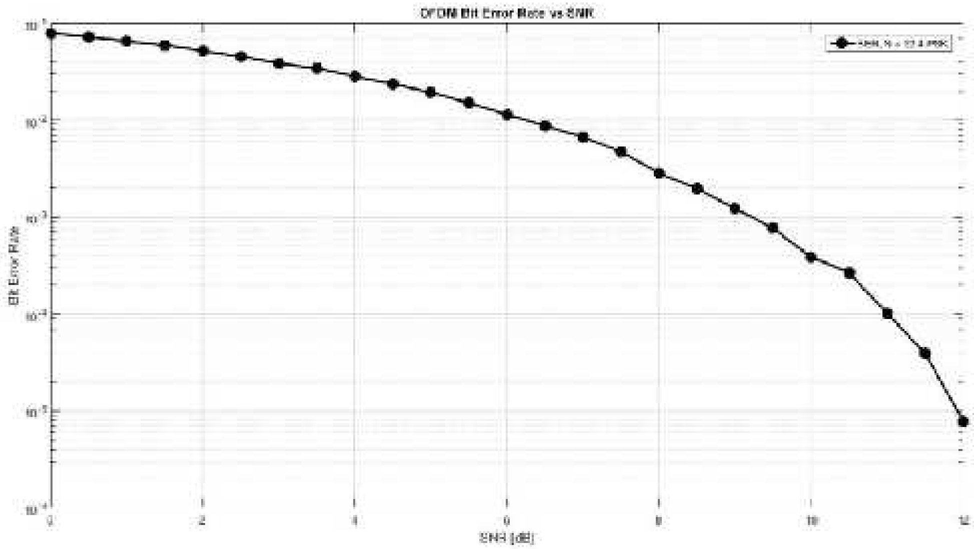

Fig. 9 BER when modulation scheme as QPSK with T =5, Z = 100

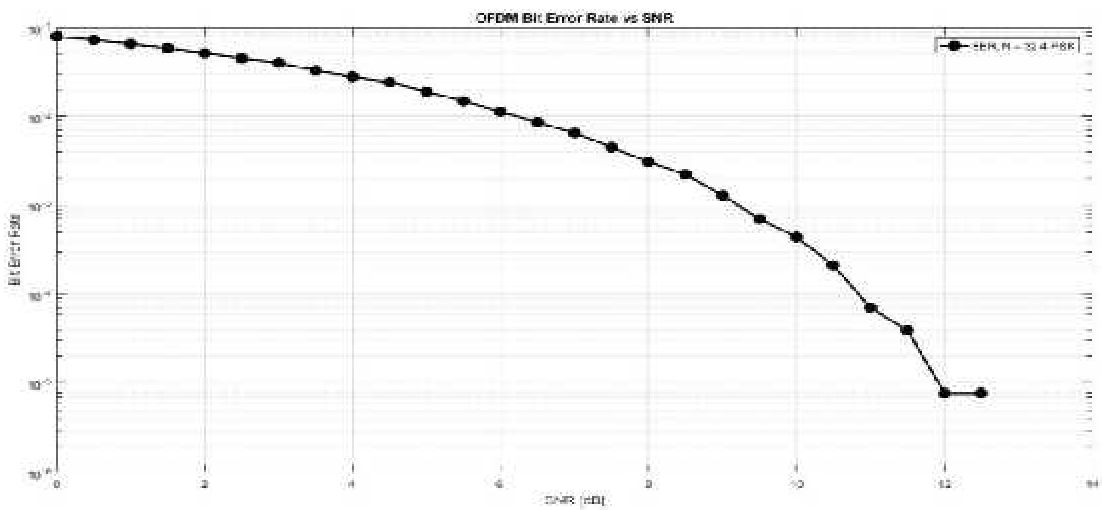

Fig. 10 BER when modulation scheme as QPSK with T =25, Z = 100

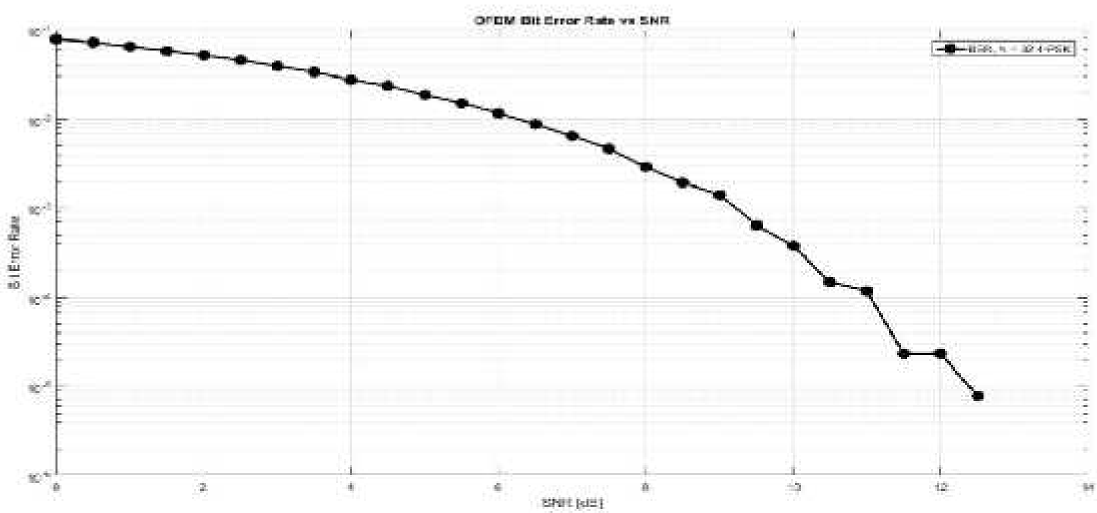

Fig. 11 BER when modulation scheme as QPSK with T =5, Z = 200

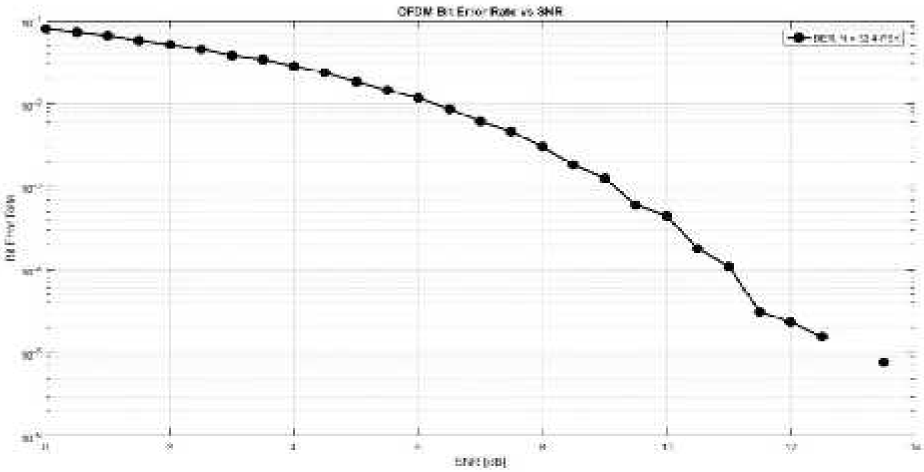

Fig. 12 BER when modulation scheme as QPSK with T =25, Z = 200

The above results indicate that as the signal power is increased, a fall in the bit error rate can be observed. For higher signal powers, the errors in the transmitted signal fall drastically. Also, the observed Doppler shift in the signal can be seen reducing drastically.

VI. FUTURE SCOPE

1) *Refraction Model:* One of the most interesting and unique phenomena in underwater acoustic physics. Sound propagation in air is not affected by this as much as underwater is. A model of refraction would significantly add to the realism of the simulator. Temperature variations due to whether could also be implemented.
2) *Scattering:* Again, this is another major source of distortion of underwater sound waves. Backscattering, where sound waves reflect back to the source as it travels forward, is one of the problems that signal processors must take account of for sources that are also receivers. The backscatter can add a significant amount of reverberation to the final received signal. No scattering model will be complete without a model of scattering from rough surfaces such as the ocean bed and sea surface. The roughness of the sea surface would also be a function of the weather.
3) *Statistic Reverberation and Fluctuations:* There are some parts of underwater acoustic physics that are computationally too intensive to be performed by today's current technology. This includes a thorough reverberation model (since there can be an infinitesimal amount of reflections) and random fluctuations caused by particles in the water medium. These can all be implemented statistically using probability like Geng and Zielinski.
4) *Occlusion:* This will be the proper implementation of the reflection and transmission coefficients. The reflection model will need to be rewritten, as there will no longer just be a top and bottom reflective boundary.
5) *Visualisation:* As the complexity of the simulator increases, there is more need to visualise its results. Stettner and Greenberg provide a good overview on methods of visualise acoustic space. A graphical user interface for the configuration of the simulator would be useful as well.

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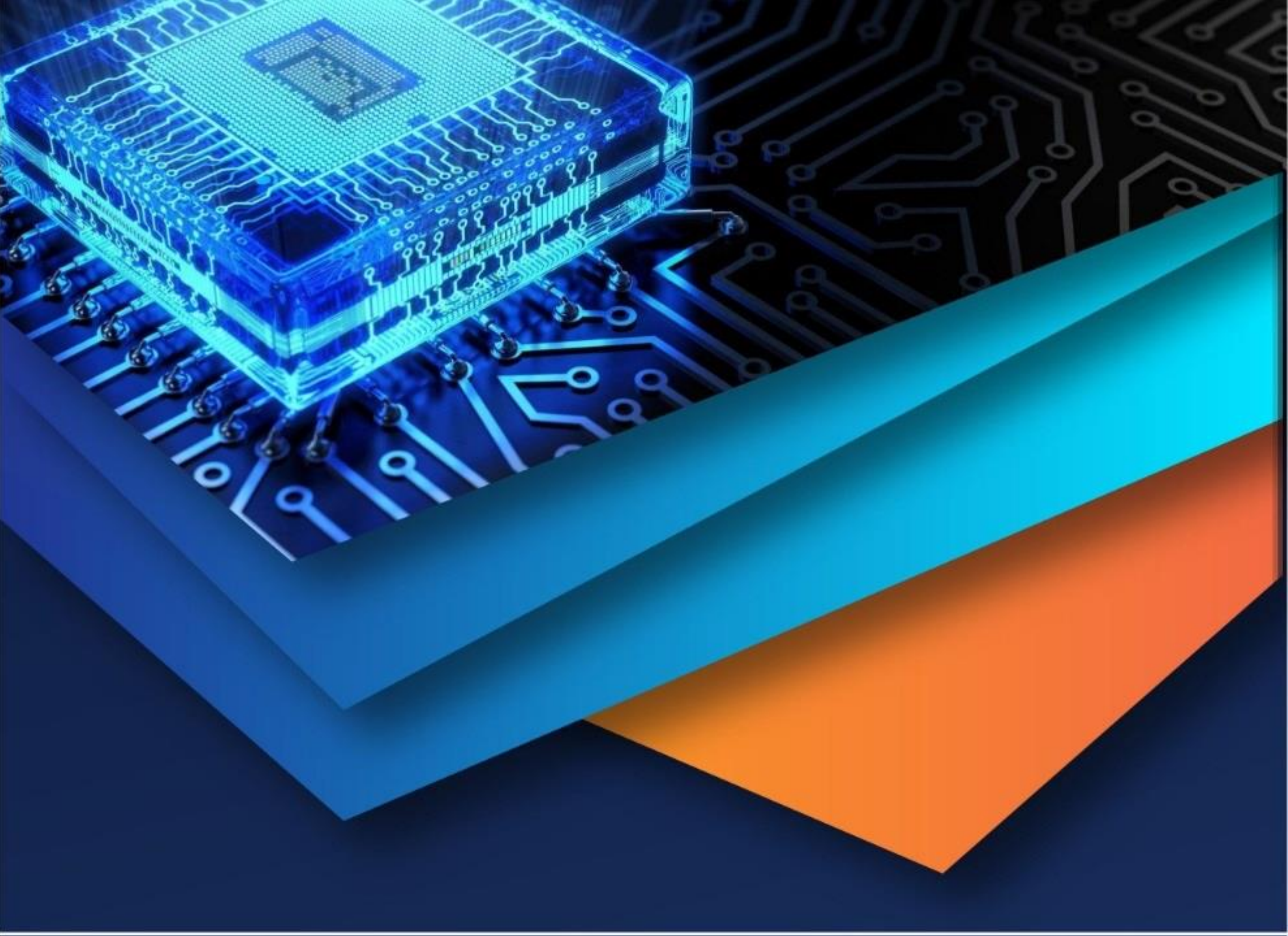

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