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Improved Underwater Wireless Communication System Using OFDM Technique

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ABSTRACT:*The paper focuses on Orthogonal Frequency Division Multiplexing (OFDM) based modulation schemeto improve underwater wireless communication system. The scheme divides the available bandwidths into several number of overlapping sub-bands where the symbols duration takes long compared to the multipath spread of the channels. This multipath spread on the channels eliminates inter symbol interference thereby improves the available bandwidth. The process led to the use of the OFDM technique to reduce the choice of subcarriers in the channel expressed as bit error rate (BER) for a given signal to noise ratio(SNR). This technique was examine through the Gaussian noise to quantify the SNR at noisy underwater acoustic channel but did not give any reflections. The effect at the received signal causes distortion when inter-subcarriers interference varied wildly. This where determined by the use of MATLAB tool to carry out several simulations. The simulation results when compared with theoretical values identified improvement on performance with that technique in term of BER. The simulation showed that optimizing the number of sub OFDM block for a SNR would result in minimal BER. The result shows a good correlation between the theoretical models for OFDM underwater application and standard experimental parameters.*

Keywords: *Orthogonal Frequency Division Multiplexing; Quadrature Phase Shift Keying; underwater wireless acoustics; Signal to Noise Ratio;Bit error ratio*

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I. INTRODUCTION

Today, the need for underwater wireless communications exists in applications such as remote control in offshore oil and gas industry, pollution and climate monitoring in environmental systems, defence, collection of scientific data recorded at ocean-bottom stations and unmanned underwater vehicles, speech transmission between divers, and mapping of the ocean floor for detection of objects and discovery of new resources. Present underwater communication systems involve the transmission of information in the form of sound (acoustic),electromagnetic, or optical waves. Each of these techniques has advantages and limitations. Electromagnetic and optical waves propagate poorly in seawater, which leaves acoustic signalling as the only viable option for long-range underwater communication. Acoustic communication is the most versatile and widely used technique in underwater environments due to the low attenuation (signal reduction) of sound in water. On the other hand, the use of acoustic waves in shallow water can be adversely affected by temperature gradients, surface ambient noise, and multipath propagation due to reflection and refraction. The slowest speed of acoustic propagation in water, about 1500 m/s, compared with that of electromagnetic and optical waves, is another limiting factor for efficient communication and networking [30].

As earlier stated, electromagnetic radio frequency, waves do not work well in an underwater environment due to the conducting nature of the medium, especially in the case of seawater. However, if electromagnetic signals could be working underwater, even in a short distance, it has much faster propagating speed is definitely a great advantage for faster and efficient communication among nodes but will require large antennas and transmission power apart from the very high attenuation it suffers. Thus, attempts to deploy radio waves as means of underwater communication is capital intensive. Underwater acoustic (UWA) channel is unique, compared to radio communication channels, because of many distinctive features, where limited bandwidth has been the most significant that drives the algorithm design for UWA communication[23].Wireless underwater communicationsare established by transmission of acoustic waves. In contrast, with terrestrial wireless radio communications, the underwater wireless networks and communication channels are considerably affected by aquatic environments, noise, constrained or limited bandwidth, power resources, and often cause signal dispersion in time and frequency. Despite these limitations, underwater acoustic communications are a rapidly growing field of research and engineering [28].

Acoustic waves are not the only means for underwater wireless communication that can travelover a longer distances but other do.However, radio waves propagate over longer distance through conductive seawater at extra low frequency (30Hz-300Hz) which require large antenna and high transmitter powers, while higher-frequency signals will propagate over very short distances (few meters at10kHz). Optical waves propagate best in the blue-green region, but in addition to attenuation, they are affected by scattering, and are limited to distances of the order of a hundred meters [5]. Narrow laser beams are power-efficient but require high pointing precision, while simple light-emitting diodes are not as power-efficient. Thus, acoustic waves remain the single best solution for communicating underwater, in applications where tethering is not acceptable and a very short distance is to be covered.

Sound propagates as a pressure wave, and it can easily travel over kilometres, or even hundreds of kilometres but cover a longer distance at lower frequency. In general, acoustic communications areconfined to low bandwidths compared to the terrestrial radio communications. Acoustic modems used today operate in bandwidths at few kHz comparably low centre frequency. Although underwater acoustic communication over basin scales (several thousand kilometres) are established in a single hop; however, the attendant bandwidth is 10Hz [6]. Horizontal transmission is more difficult due to the multipath propagation, while vertical channels exhibit less distortion [6]. Frequency-dependent attenuation, multipath propagation, and low speed of sound (about 1500m/s) which results in a severe Doppler effect, make the underwater acoustic channel one of the most challenging communication media.

The idea of sending and receiving information underwater is trace back all the way to the time of Leonardo Da Vinci, who discovered the possibility to detect a distant ship by listening on a long tube submerged under sea.

This paper geared into developing efficient communications andsignal processing algorithms, design efficient modulation and coding schemes, and techniques for mobile underwater communications. In addition, multiple access communication methods are being developed for underwater acoustic networks, and network protocols are being designed for long propagation delays and strict power requirements encountered in the underwater environment. Finally, data compression algorithms suitable for low-contrast underwater images, and related image and video processing methods are expected to enable their near real-time transmission through band-limited underwater acoustic channels.

II. RELATED WORKS

In this section few related previous works in wireless underwater communication using OFDM Technique are reviewed. The methods and the results or outcome of their works are emphasized. Finally, methods to improve on some of the shortcomings of these techniques which will be based on the techniques that will be used in this research work is reviewed.

Underwater acoustic (UWA) communication is one of the most challenging environment for transmission and it is limited by three basic factors including (i) limited bandwidth because the signal attenuation increases by increasing distance and frequency, (ii) time variant multipath propagation, and (iii) the low speed of sound through water. These three factors results in to a very low link quality and long delay channel[10].

Limited bandwidth is a major problem in UWA channels, and acoustic waves in UWA environment are absorbed in high frequencies, while the noise is very strong at low frequencies. Consequently, the available bandwidth is limited to several kHz. Therefore, using methods that can improve the available bandwidth is very important. One of such effective method is the use of multi-carrier multiple-path orthogonal frequency division multiplexing (OFDM) system. multiple-input multiple-output (MIMO) OFDM technique increases spectral efficiency by parallel transmission of data through multiple transmitters [19].

Yuksel [36] considered simulation and testing of an underwater acoustic modem using ZP-OFDM (Zero Padded-Orthogonal Frequency Division Multiplexing). The receiver is built, where CFO (Carrier Frequency Offset) compensation, pilot-tone based channel estimation, and data demodulation are carried out on the basis of each OFDM block, simulation and testing of a pilot- tone based ZP-OFDM receiver, where CFO (Carrier Frequency Offset) compensation, channel estimation, and data demodulation are carried out on the basis of each OFDM block. The receiver was tested by simulations using Bellhop UWA (Underwater Acoustic) Channel model in order to investigate the system characteristics before underwater experiments. The method was tested in a shallow-water experiment at Bilkent Lake. Over a bandwidth of 12 kHz, the data rate was 13.92

kb/s with QPSK (Quadrature Phase Shift Keying) modulation, when the number of subcarriers was 1024. Bit-error-rate (BER) was less than 9x102 without using any coding.

Alessandro [3]investigated transmission scheme for OFDM. The advantage of employing adaptive transmission scheme is described by comparing their performance with fixed transmission system. A better adaptation algorithm is used to improve the throughput performance. This algorithm utilizes the average value of the instantaneous signal-to-noise ratio (SNR) of the subcarriers in the switching parameter. The results show an improved throughput performance with considerable BER performance.

Marwa,[16] discussed the performance improvement of OFDM communication system using different channel coding techniques through AWGN (Additive White Gaussian Noise) channel model. These coding techniques include Reed Solomon coding, Convolutional coding, Concatenated coding (by combining Reed Solomon with Convolutional), and Interleaved concatenated coding techniques. He, also produced a new algorithm to choose a good convolutional encoder design for a certain rate and memory registers.

Hamza [8]proposed a dynamic interference control method using the additive signal side lobe reduction technique and genetic algorithm (GA) in CR-OFDM (Cognitive Radio-OFDM) systems. Additive signal side lobe reduction technique is based on adding a complex array to modulated data symbols in the constellation plane for side lobe reduction in OFDM system. In the proposed method, GA generates optimum additive signal which can effectively reduce the out-of-bound(OOB) signal interference to the primary system. The results show that the side lobes of the OFDM-based secondary user signal can be reduced by up to 38dB and the PU interference tolerable limit can be satisfied at the cost of a minor addition in bit error rate (BER). The results further show that the proposed method delivers better performance as compared to non-GA additive signal method in terms of side lobe reduction as well as BER.

Dayal, [5] considered modeling of Doppler Effect as a nonlinear time warp. A procedure is developed to estimate the parameters of the time warp from the observed signal. These time warp parameters are then used to reverse the effect of the time warp. Two different methods for estimating the time warp parameters and correcting the Doppler are compared. The first technique uses sinusoids placed at the beginning and end of the signal to estimate the parameters of the warp that the signal undergoes. The second technique uses sinusoids that are present during the signal to estimate and correct for the warp. The frequencies of the sinusoids are outside of the frequency range used for the transmitted data signal, so there is no interference with the information that is being sent The transmitted data signal uses Orthogonal Frequency Division Multiplexing (OFDM) to encode the data symbols, but the Doppler Correction technique will in principle work for other kinds of wideband signals as well. The results, which include MATLAB based simulations and over-the-air experiments, show that performance improvements can be realized using the time warp correction model though at cost of data bandwidth.

In this paper, an OFDM modulation techniques that is based on Quadrature Phase Shift Keying (QPSK) with coding is deployed to tackle most of the challenges in the aforementioned techniques. Coding is deployed to improve the BER while Doppler effect is modelled as a nonlinear phenomenon to improve the transmitter design and hence improve the BER. QPSK is preferred against BPSK because of its better bit rate. Finally, series of BER against SNR is simulated with the number of OFDM subcarriers as constraint, so that the rightful number of subcarriers will be chosen for a given signal power within permissible BER.

In this paper the OFDM technique shall be employed to improve underwater communication, especially because of its frequency selectivity characteristic. Furthermore, the most effective method of enhancing this operation shall be the focus of the analysis.

III. METHODOLOGY

The main concept in OFDM is orthogonality of the sub-carriers. The "orthogonal" part of the OFDM name indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. It is possible to arrange the carriers in an OFDM signal so that the sidebands of the individual carriersignals overlap and the signals can still be received without adjacent carriers interference. In order to do this, the carriers must be mathematically orthogonal. The Carriers are linearly independent (i.e. orthogonal) if the carrier spacing is a multiple of $1/T_s$. Where, T_s is the symbol duration as shown in figure 3.1

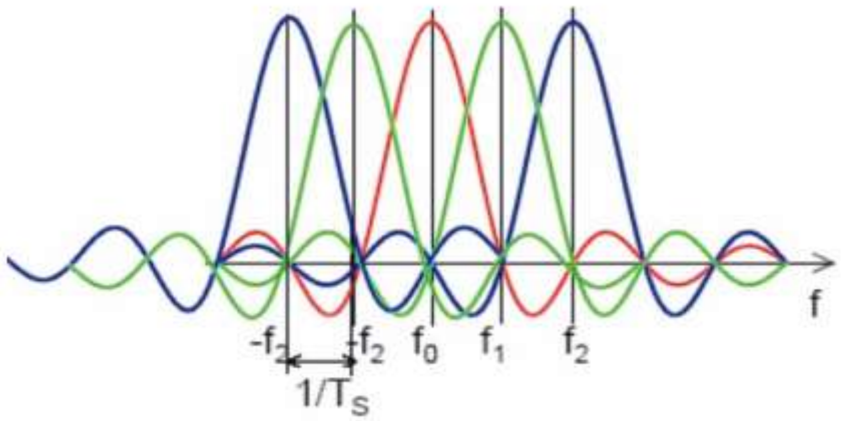


Figure 3.1: OFDM Spectrum with Five Orthogonal Carrier Frequencies [33]

The orthogonality among the carriers can be maintained if the OFDM signal is defined by using Fourier transform procedures. The OFDM system transmits a large number of narrowband carriers, which are closely spaced. Note that at the central frequency of each sub-channel there is no crosstalk from other sub-channels.The orthogonality allows simultaneous transmission on a lot of sub-carriers in a tight frequency space without interference from each other.

Since the carriers are all sine/cosine wave, we know that area under one period of a sine or a cosine wave is zero. This is easily shown in figure 3.2.

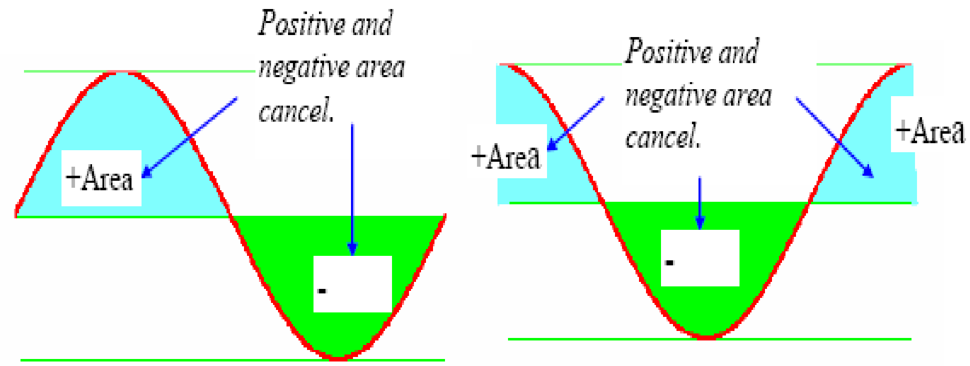


Figure 3.2: Area Under a Sine Wave and Cosine Wave Over One Periodic Cycle [33]

If a sine wave of frequency *m* multiplied by a sinusoid (sine or cosine) of a frequency *n*, then,

$$f(t) = \sin(m\omega t)\sin(n\omega t) \tag{3.1}$$

Where both *m* and *n* are integers, since these two components are each a sinusoid, the integral is equal to zero over one period. The integral or area under this product is given by

$$\int_0^{2\pi} \frac{1}{2}\cos(m-n)\,\omega t - \int_0^{2\pi} \frac{1}{2}\cos(m+n)\,\omega t = 0 - 0 = 0 \tag{3.2}$$

So when a sinusoid of frequency n multiplied by a sinusoid of frequency m *or* n, the area under the product is zero. In general, for all integers *n* and *m*, sin *mx*, cos *mx*, cos *nx*, sin *nx*are all orthogonal to each other.

IV. MEASUREMENT OF DIGITAL SIGNAL PERFORMANCE

In Digital communication, a digital signal is a continuous-time physical signal, alternating between a discrete number of waveforms representing a bit stream. It is therefore, significant to always measure the digital signal performance which include:

i. **Bit Error Rate (BER):** It is the number of bit errors divided by the total number of transferred bits during a studied time interval. It is a unitless performance measure, often expressed as a percentage. This term in digital communication shows the performance of the communication system. In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion or bit synchronization errors. The bit error probability *pe* is the expectation value of the BER. The BER can be considered as an approximate estimate of the bit error probability. This estimate is accurate for a long time interval and a high number of bit errors.

$$BER = \frac{numberof errors}{Totalnumberof bitssent} \qquad (3.3)$$

ii. **Signal to Noise Ratio (SNR):** is a measurement used in science and engineering that compares the level of a desired signal to the level of background noise, it is defined as the ratio of signal power to the noise power, as stated below, and it is often expressed in decibels.

$$SNR = \frac{E_b}{N_0}(dB) \qquad (3.4)$$

Where E_b is the energy in one bit, and N_0 is the noise power spectral density (which is the noise power in a 1 Hz bandwidth), They have the same unit, and thus *SNR* is unitless and therefore convenient to expressed in decibel.

i. **Spectral Efficiency:** It is the net bit rate or maximum through put divided by the bandwidth in hertz of a communication channel or a data link. It is measured in Bit per Hertz. It is also known as bandwidth efficiency, in OFDM, the greater the number of subcarrier the greater the spectra efficiency.

3.3 Simulation Tool (Matlab)

MATLAB is widely used in all areas of applied mathematics, in education and research at universities, and in the industry. MATLAB stands for MATrix LABoratory and the software is built up around vectors and matrices. This makes the software particularly useful for linear algebra but MATLAB is also a great tool for solving algebraic and differential equations and for numerical integration. MATLAB has powerful graphic tools and can produce nice pictures in both 2D and 3D. It is also a programming language, and is one of the easiest programming languages for writing mathematical programs. MATLAB also has some tool boxes useful for signal processing, image processing, optimization, etc. In Matlab, we represent continuous-time signals with a sequence of numbers, or samples, which are generally stored in a vector or an array. Before we can performance bit-error-rate test, we must precisely understand the meaning of these samples. We must know what aspect of the signal the value of these samples represents. We must also know the time interval between successive samples. For communications simulations, the numeric value of the sample represents the amplitude of the continuous-time signal at a specific instant in time.

3.4 Procedure For Simulation

1. Run Transmitter

The first step in the simulation is to use the transmitter to create a digitally modulated signal from a sequence of pseudo-random bits. Once we have created this signal, $x(n)$, we need to make some measurements of it.

2. Establish SNR

The signal-to-noise-ratio (SNR), *Eb* /*N*0, is usually expressed in decibels, butwe must convert decibels to an ordinary ratio before we can make further use of the SNR. If we set the SNR to *m* dB, then *Eb*/*N*0 = 10*m*/10. Using Matlab, we find the ratio, „ebn0‟, from the SNR in decibels, „snrdb‟, as: ebn0= 10^(snrdb/10). Note that *Eb*/*N*0 is a dimensionless quantity.

3. Determine *Eb*

Energy-per-bit is the total energy of the signal, divided by the number of bits contained in the signal. We can also express energy-per-bit as the average signal power multiplied by the duration of one bit. Either way, the expression for *Eb* is:

$$E_b = \frac{1}{Nf_{bit}} \sum_{n=1}^{N} x^2(n) \qquad (3.5)$$

where *N* is the total number of samples in the signal, and *fbit* is the bit rate in bits-per-second. Using Matlab, we find the energy-per-bit, „eb‟, of our transmitted signal, „x‟, that has a bit rate „fb‟, as: eb = sum(x.^2)/(length(x)∗fb). Since our signal, $x(n)$, is in units of volts, the units of *Eb* are Joules.

4. Calculate *N*0

With the SNR and energy-per-bit now known, we are ready to calculate *N*0, the one- sided power spectral density of the noise. All we have to do is divide *Eb* by the SNR, providing we have converted the SNR from decibels to a ratio. Using Matlab, we find the power spectral density of the noise, „n0‟, given energy-per-bit „eb‟, and SNR „ebn0‟, as: n0 = eb/ebn0. The power spectral density of the noise has units of Watts per Hertz.

5. Calculate

The one-sided power spectral density of the noise, $N0$, tells us how much noise power is present in a 1.0 Hz bandwidth of the signal. In order to find the variance, or average power, of the noise, we must know the noise bandwidth. For a real signal, $x(n)$, sampled at fs Hz, the noise bandwidth will be half the sampling rate. Therefore, we find the average power of the noise by multiplying the power spectral density of the noise by the noise bandwidth:

$$\sigma_n = \frac{N_0 f_s}{2} \qquad (3.6)$$

Whereσ_n is the noise variance in W, and N_0 is the one-sided power spectral density of the noise in W/Hz. Using Matlab, the average noise power, „*pn*‟, of noise having power spectral density „*n0*‟, and sampling frequency „*fs*‟, is calculated as: *pn= n0∗fs/2*. The average noise power is in units of Watts.

6. Generate Noise

Although the communications toolbox of Matlab has functions to generate additive white Gaussian noise, we will use one of the standard built-in functions to generate AWGN. Since the noise has a zero mean, its power and its variance are identical. We need to generate a noise vector that is the same length as our signal vector $x(n)$, and this noise vector must have variance W. The Matlab function *„randn‟* generates normally distributed random numbers with a mean of zero and a variance of one. We must scale the output so the result has the desired variance, σ_n.To do this, we simply multiply the output of the *„randn‟* function by *p¾n*. We can generate the noise vector „*n*″, as*: n = sqrt(pn)∗randn(1,length(x));*.
Like the signal vector, the samples of the noise vectorσ_n have units of volts.

7. Add Noise

We create a noisy signal by adding the noise vector to the signal vector. If we are running a fixed-point simulation, we will need to scale the resulting sum by the reciprocal of the maximum absolute value, so the sum stays within amplitude limits of ±*1.0*. Otherwise, we can simply add the signal vector „*x*‟ to the noise vector „n‟ to obtain the noisy signal vector *„y″* as: *y = x+n;*

8. Run Receiver

Once we have created a noisy signal vector, we use the receiver to demodulate this signal. The receiver will produce a sequence of demodulated bits, which we must compare to the transmitted bits, in order to determine how many demodulated bits are in error.

9. Determine Offset

Due to filtering and other delay-inducing operations typical of most receivers, there will be an offset between the received bits and the transmitted bits. Before we can compare the two bit sequences to check for errors, we must first determine this offset. One way to do this is by correlating the two sequences, then searching for the correlation peak. Suppose our transmitted bits are stored in vector *„tx″*, and our received bits are stored in vector „*rx″*. The received vector should contain more bits than the transmitted vector, since the receiver will produce (meaningless) outputs while the filters are filling and flushing. If the length of the transmitted bit vector is *ltx*, and the length of the received vector is *lrx* , the range of possible offsets is between zero and *lrx* −*lt x* −1. We can find the offset by performing a partial cross-correlation between the two vectors. Using Matlab, we can create a partial cross-correlation, *„cor‟*, from bit vectors *„tx″* and *„rx″,* with the following loop:

```
for lag= 1 : length(rx)−length(tx)−1,
cor(lag)= tx∗rx(lag : length(tx)−1+lag)';
end.
```

The resulting vector, *„cor‟*, is a partial cross-correlation of the transmitted and received bits, over the possible range of lags*: 0 : lrx −ltx −1*. We need to find the location of the maximum value of *„cor‟*, since this will tell us the offset between the bit vectors. Since Matlab numbers array elements as *1 : N*instead of as *0 :N−1,* we need to subtract one from the index of the correlation peak. Using Matlab, we find the correct bit offset, „off‟, as:

off= find(cor== max(cor))−1.

10. Create Error Vector

Once we know the offset between the transmitted and received bit vectors, we are ready to calculate the bit errors. For bit values of zero and one, a simple difference will reveal bit errors. Wherever there is a bit error, the difference between the bits will be ±1, and wherever there is not a bit error, the difference will be zero. Using Matlab, we calculate the error vector, „err‟, from the transmitted bit vector, *„tx‟,* and the received bit vector*, „rx‟,* having an offset of *„off‟*, as:
err= tx−rx(off+1 : length(tx)+off);.

11. Count Bit Errors

The error vector, *„err‟* contains non-zero elements in the locations where there were bit errors. We need to tally the number of non-zero elements, since this is the total number of bit errors in this simulation. Using Matlab, we calculate the total number of bit errors, „*te‟*, from the error vector *„err‟* as:
te= sum(abs(err)).

12. Calculate Bit-Error-Rate

Each time we run a bit-error-rate simulation; we transmit and receive a fixed number of bits. We determine how many of the received bits are in error, then compute the bit-error-rate as the number of bit errors divided by the total number of bits in the transmitted signal. Using Matlab, we compute the bit-error-rate, „*ber‟*, as:
ber= te/length(tx),
where „*te‟* is the total number of bit errors, and *„tx‟* is the transmitted bit vector.

3.5 Evaluation Of Simulation Results

Performing a bit-error-rate simulation can be a lengthy process. We need to run individual simulations at each SNR of interest. We also need to make sure our results are statistically significant.

1. Statistical Validity

When the bit-error-rate is high, many bits will be in error. The worst-case bit-error-rate is 50 percent, at which point, the modem is essentially useless. Most communications systems require bit-error-rates several orders of magnitude lower than this. Even a bit-error-rate of one percent is considered quite high. We usually want to plot a curve of the bit-error-rate as a function of the SNR, and include enough points to cover a wide range of bit-error-rates. At high SNRs, this can become difficult, since the bit-error-rate becomes very low. For example, a bit-error-rate of 10^{-6} means only one bit out of every million bits will be in error. If our test signal only contains 1000 bits, we will most likely not see an error at this bit-error-rate. In order to be statistically significant, each simulation we run must generate some number of errors. If a simulation generates no errors, it does not mean the bit-error-rate is zero; it only means we did not have enough bits in our transmitted signal. As a rule of thumb, we need about 100 (or more) errors in each simulation, in order to have confidence that our bit-error-rate is statistically valid. At high SNRs, this can require a test signal containing millions, or even billions of bits.

2. Plotting of Performance Evaluation Responses

Once we perform enough simulations to obtain valid results at all SNRs of interest, we will plot the results. We begin by creating vectors for both axes. The X-axis vector will contain SNR values, while the Y-axis vector will contain bit-error-rates. The Y- axis should be plotted on a logarithmic scale, whereas the X-axis should be plotted on a linear scale.

V. RESULTS AND DISCUSSIONS

In this Chapter we carried out the MATLAB simulation of the models developed in the methodology from transmission, reception and channel estimation, and ascertain the performance of the various methods adopted. We also adopt the use of signal to noise ratio (SNR) as well as Bit error rate (BER) as a measure of performance evaluation of the QPSK OFDM adopted underwater communication system.

4.1 OFDM Signal Transmission

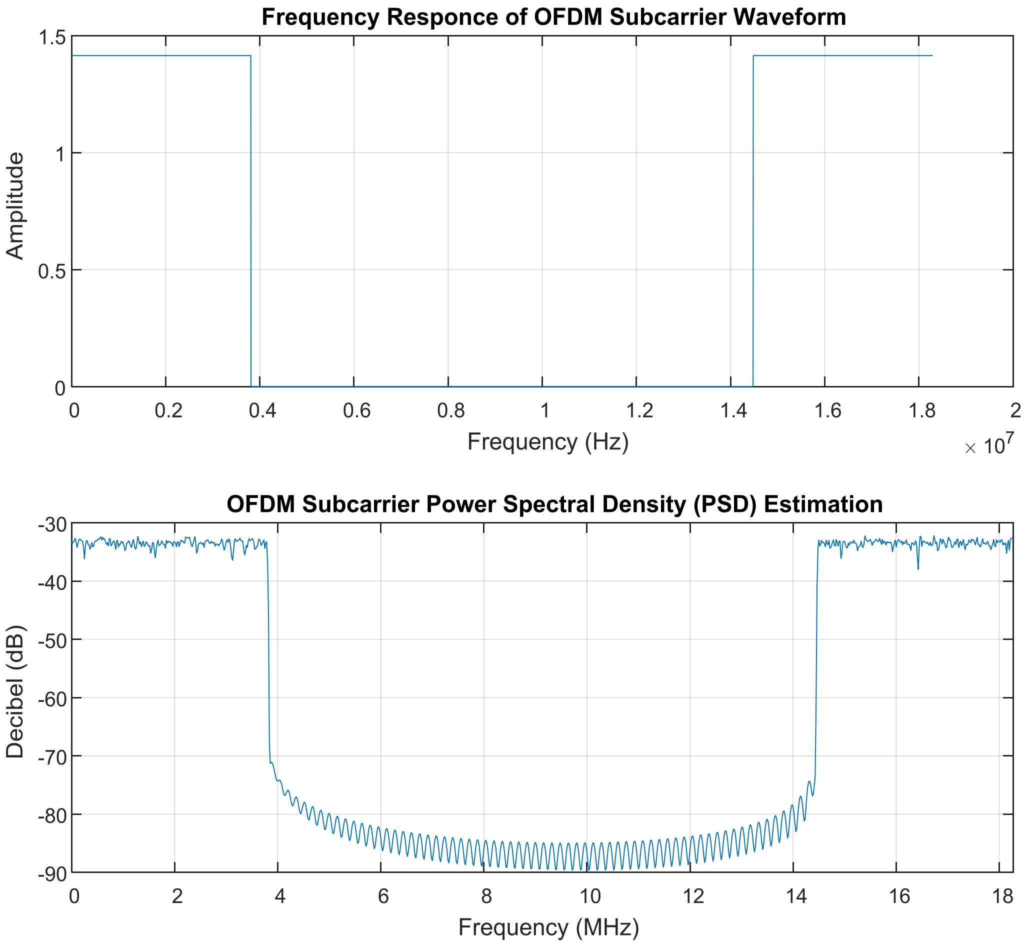


Figure 4.1: .Frequency and PSD Responses of OFDM Signal Carrier

Figure 4.1 shows the frequency response of the OFDM sub-carriers required for the implementation of the IFFT modulation, as well as the power spectral density (PSD) of the subcarrier signal at the OFDM transmitter. The main task is to centre the OFDM spectrum on the carrier frequency which is evident in the graph above. The mapping and digital encoding facilitates the serial-to-parallel conversion of the input data, and at the transmitter output the frequency response is converted into time response, and then from parallel-to-serial.

Figure 4.2: BER Vs SNR of OFDM QPSK Performance through Simulation

Figure 4.2 presents the result of a software simulation in Matlab using some validated underwater model parameters. The parameters have been applied for underwater acoustic experiments other than OFDM. These parameters were adopted for the purpose of this study and serve the basis of software simulation.The simulation represents the entire OFDM transmission and reception processes including the channel properties, modulation, demodulation and the use of zero-padding. The evaluation is based on BER versus SNR. In this study, these two parameters shall be deployed throughout as means of performance evaluation. Also, at some points, the use of minimum mean square error may be introduced as a complimentary performance analysis index. The performance response shows a good BER behaviour and a very flexible SNR.

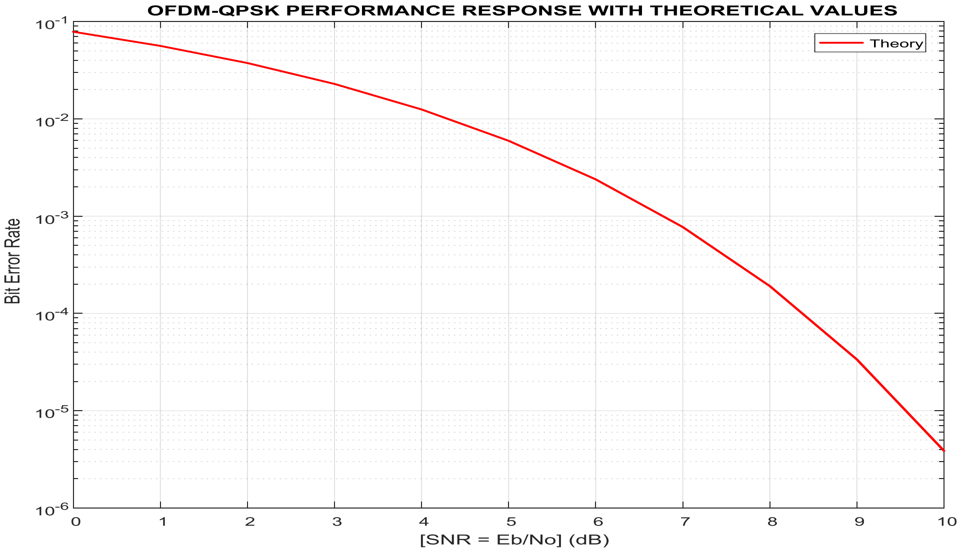


Figure 4.3: BER Vs SNR of OFDM QPSK Performance through Theoretical Values

Figure 4.30 presents the BER versus SNR performance of the OFMA QPSK system using the developed theoretical models and values generated. The performance response shows a very good correlation with that of the simulation. It simply implies the performance of the OFDM QPSK is optimal across the most challenging underwater channels.

VI. CONCLUSION

From the results of simulation, it can be seen that for a given SNR and hence signal power, the BER increases as the number of sub carrier increases. Hence, more signal power is required by a system with more sub carrier than one with a less OFDM subcarrier to achieve the same BER performance. Also, since the greater the number of subcarriers, the greater the spectra efficiency for a given SNR. It implies that we can improve our underwater OFDM design by making an optimal choice between signal power, spectra efficiency and number of subcarrier base on what is readily available for our design as well as preferential design parameter. Also, there is considerable improvement in BER compared to most existing method with similar number of subcarriers as a result of the OFDM improved design. The proposed technique can achieved a BER of 1.975×10^{-2} which is a great deal of improvement compared to many existing designs.

APPENDICES

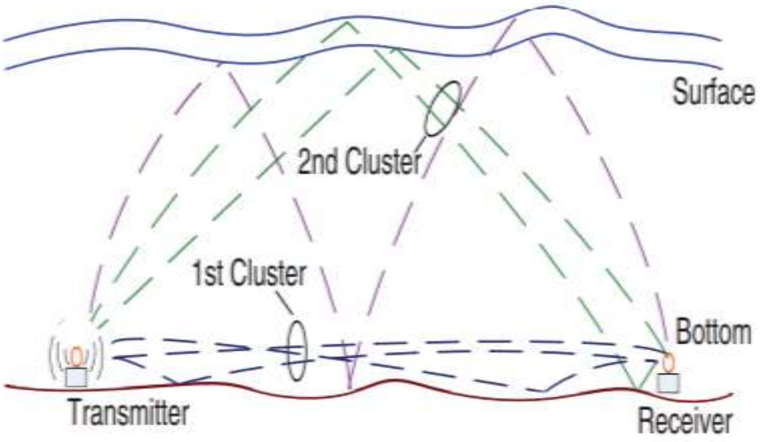


Fig. Aunderwater Ofdm System Model (Culled From Dayal, 2016)

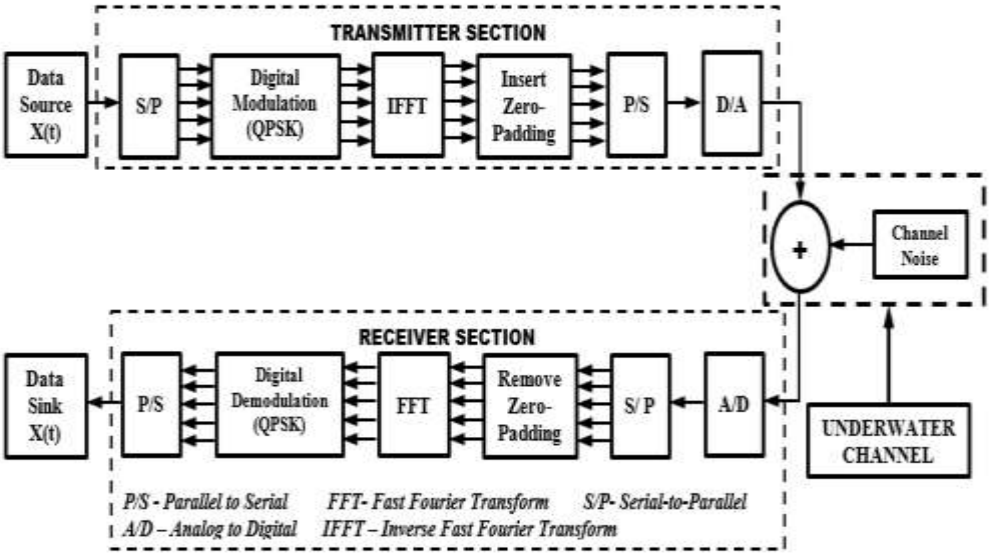


Fig. Bofdm Signal Flow Block Diagram [31]

EQUATION 1.1CONTINUOUS TIME (ANALOGUE) MODEL

$$y(t) = e^{j2\pi f_k t}, z(t) = e^{-j2\pi f_k t}, f_k = K/T, 0 \le t \le T$$

EQUATION 1.2 CONTINUOUS TIME (ANALOGUE) MODEL

$$\frac{1}{T}\int_0^T y(t)z(t)dt = \frac{1}{T}\int_0^T e^{j2\pi f_k t}\, e^{-j2\pi f_k t} dt = \frac{1}{T}\int_0^T e^{j2\pi \frac{k}{T} t}\, e^{-j2\pi \frac{i}{T} t} dt = \frac{1}{T}\int_0^T e^{j2\pi \frac{(k-i)}{T} t} dt = \begin{cases} 1, & \forall\, integer\ k = i \\ 0, & if\ integer\ k \neq i \end{cases}$$

EQUATION 3Discrete Time (Digital) Model

$$t = nT_s = nT/N, n = K = 0,\ 1,\ 2,\ \ldots.,\ N-1$$

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi\frac{k}{T}.nT_s}\, e^{-2\pi\frac{i}{T}.nT_s} = \frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi\frac{k}{T}.\frac{nT}{N}}\, e^{-j2\pi\frac{i}{T}.\frac{nT}{N}} \frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi\frac{(k-i)}{N}n} = \begin{cases} 1, & \forall\, integer\ k = i \\ 0, & if\ integer\ k \neq i \end{cases}$$

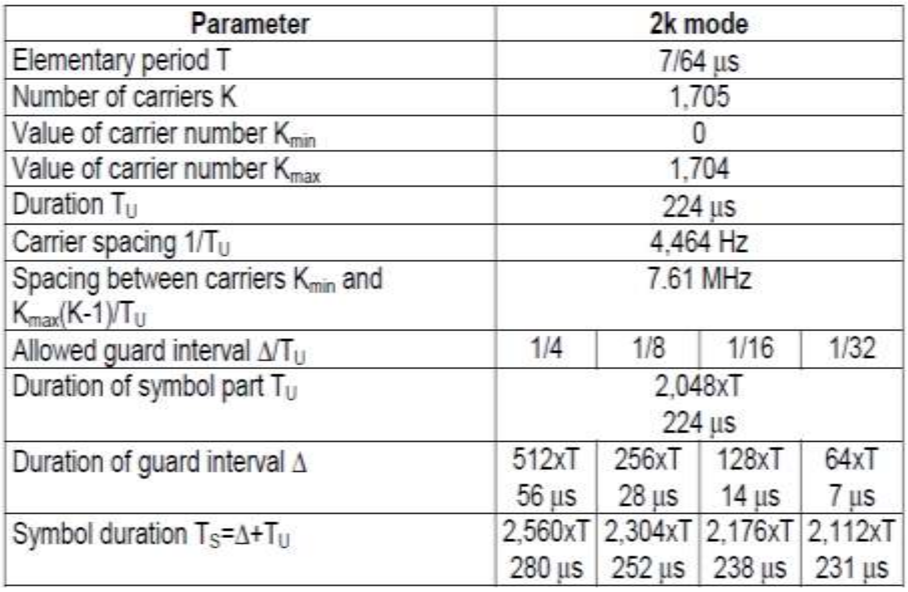
EQUATION 4 IN-PHASE (I) COMPONENT

$$\emptyset_1(t) = \sqrt{\frac{2}{T_s}}\cos(2\pi f_c t)$$
$$= I$$

EQUATION 5 QUADRATURE (Q) COMPONENT

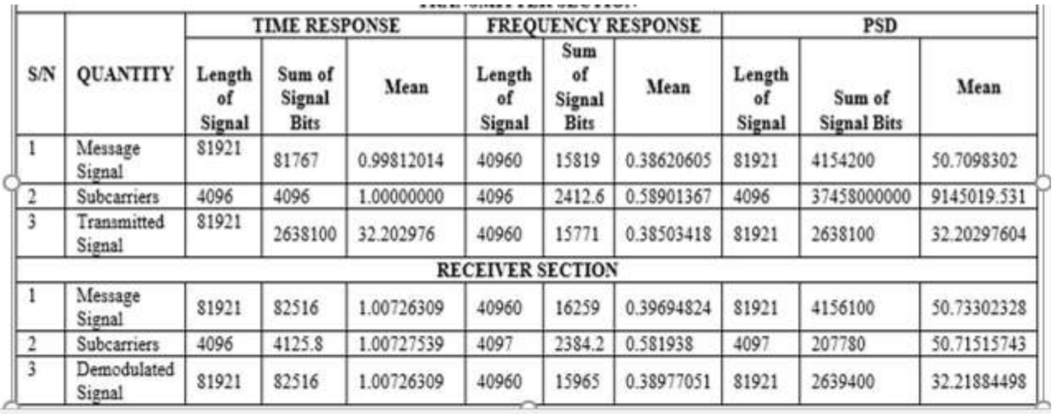
$$\emptyset_2(t) = \sqrt{\frac{2}{T_s}}\sin(2\pi f_c t)$$

Table 1:Standard Parameters for OFDM Design (*Murad, 2015)*



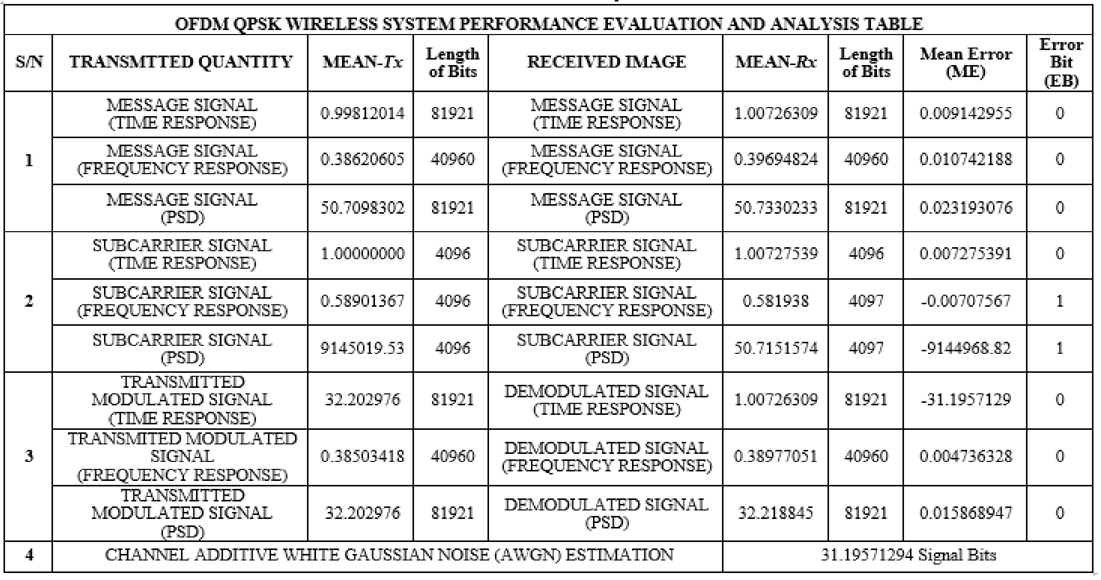
Parameter	2k mode			
Elementary period T	7/64 µs			
Number of carriers K	1,705			
Value of carrier number K_{min}	0			
Value of carrier number K_{max}	1,704			
Duration T_U	224 µs			
Carrier spacing $1/T_U$	4,464 Hz			
Spacing between carriers K_{min} and $K_{max}(K-1)/T_U$	7.61 MHz			
Allowed guard interval Δ/T_U	1/4	1/8	1/16	1/32
Duration of symbol part T_U	2,048xT 224 µs			
Duration of guard interval Δ	512xT 56 µs	256xT 28 µs	128xT 14 µs	64xT 7 µs
Symbol duration $T_S=\Delta+T_U$	2,560xT 280 µs	2,304xT 252 µs	2,176xT 238 µs	2,112xT 231 µs

TABLE 2: Results From Matlab Simulation Transmitter Section



S/N	QUANTITY	TIME RESPONSE			FREQUENCY RESPONSE			PSD		
		Length of Signal	Sum of Signal Bits	Mean	Length of Signal	Sum of Signal Bits	Mean	Length of Signal	Sum of Signal Bits	Mean
1	Message Signal	81921	81767	0.99812014	40960	15819	0.38620605	81921	4154200	50.7098302
2	Subcarriers	4096	4096	1.00000000	4096	2412.6	0.58901367	4096	37458000000	9145019.531
3	Transmitted Signal	81921	2638100	32.202976	40960	15771	0.38503418	81921	2638100	32.20297604
RECEIVER SECTION										
1	Message Signal	81921	82516	1.00726309	40960	16259	0.39694824	81921	4156100	50.73302328
2	Subcarriers	4096	4125.8	1.00727539	4097	2384.2	0.581938	4097	207780	50.71515743
3	Demodulated Signal	81921	82516	1.00726309	40960	15965	0.38977051	81921	2639400	32.21884498

TABLE 3: Calculation Of Me And Eb



OFDM QPSK WIRELESS SYSTEM PERFORMANCE EVALUATION AND ANALYSIS TABLE								
S/N	TRANSMTTED QUANTITY	MEAN-*Tx*	Length of Bits	RECEIVED IMAGE	MEAN-*Rx*	Length of Bits	Mean Error (ME)	Error Bit (EB)
1	MESSAGE SIGNAL (TIME RESPONSE)	0.99812014	81921	MESSAGE SIGNAL (TIME RESPONSE)	1.00726309	81921	0.009142955	0
	MESSAGE SIGNAL (FREQUENCY RESPONSE)	0.38620605	40960	MESSAGE SIGNAL (FREQUENCY RESPONSE)	0.39694824	40960	0.010742188	0
	MESSAGE SIGNAL (PSD)	50.7098302	81921	MESSAGE SIGNAL (PSD)	50.7330233	81921	0.023193076	0
2	SUBCARRIER SIGNAL (TIME RESPONSE)	1.00000000	4096	SUBCARRIER SIGNAL (TIME RESPONSE)	1.00727539	4096	0.007275391	0
	SUBCARRIER SIGNAL (FREQUENCY RESPONSE)	0.58901367	4096	SUBCARRIER SIGNAL (FREQUENCY RESPONSE)	0.581938	4097	-0.00707567	1
	SUBCARRIER SIGNAL (PSD)	9145019.53	4096	SUBCARRIER SIGNAL (PSD)	50.7151574	4097	-9144968.82	1
3	TRANSMITTED MODULATED SIGNAL (TIME RESPONSE)	32.202976	81921	DEMODULATED SIGNAL (TIME RESPONSE)	1.00726309	81921	-31.1957129	0
	TRANSMITED MODULATED SIGNAL (FREQUENCY RESPONSE)	0.38503418	40960	DEMODULATED SIGNAL (FREQUENCY RESPONSE)	0.38977051	40960	0.004736328	0
	TRANSMITTED MODULATED SIGNAL (PSD)	32.202976	81921	DEMODULATED SIGNAL (PSD)	32.218845	81921	0.015868947	0
4	CHANNEL ADDITIVE WHITE GAUSSIAN NOISE (AWGN) ESTIMATION				31.19571294 Signal Bits			

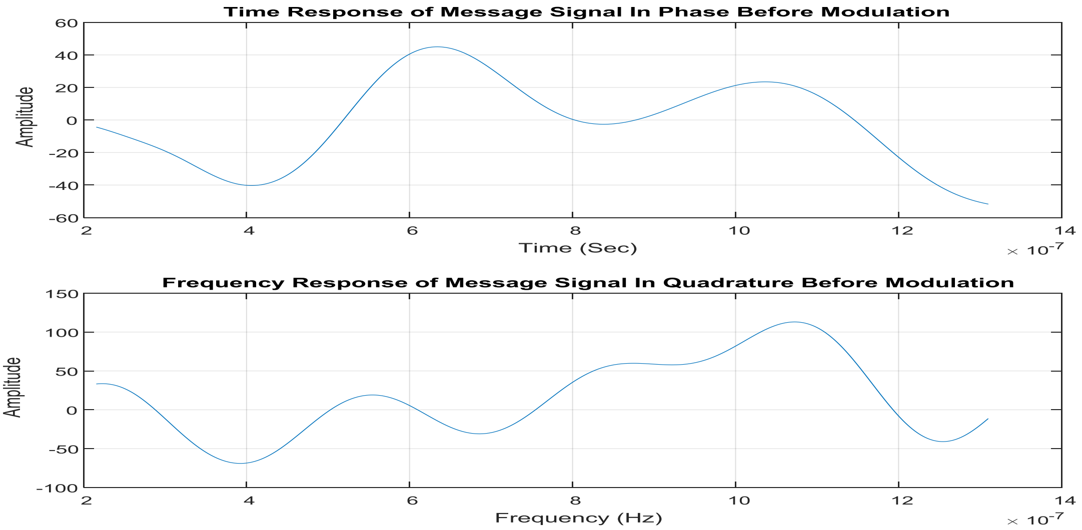
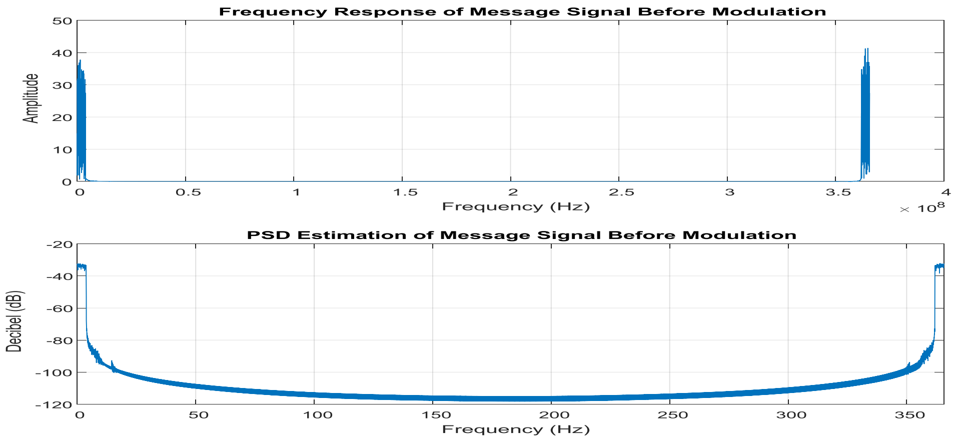


Figure C: Time Response Of Message Signal



FigureD: Frequency Response Of Message Signal

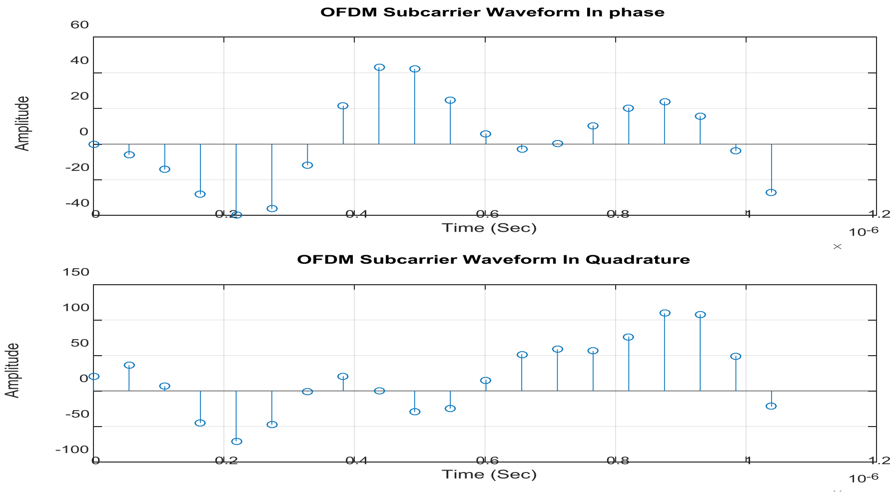
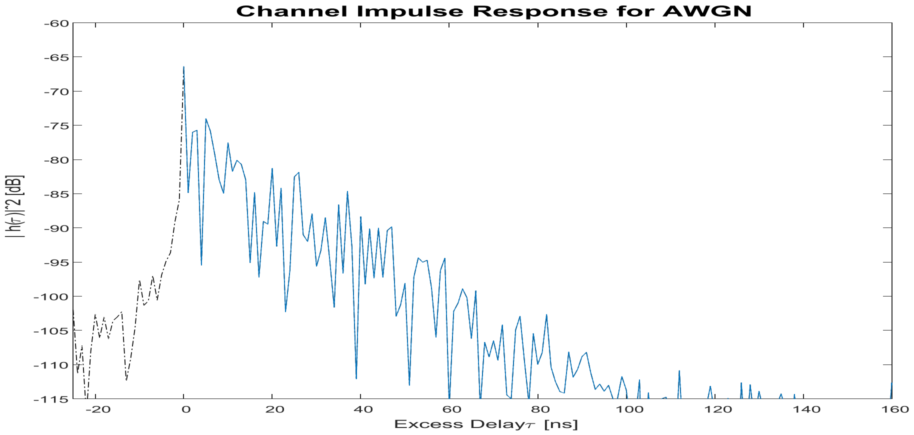
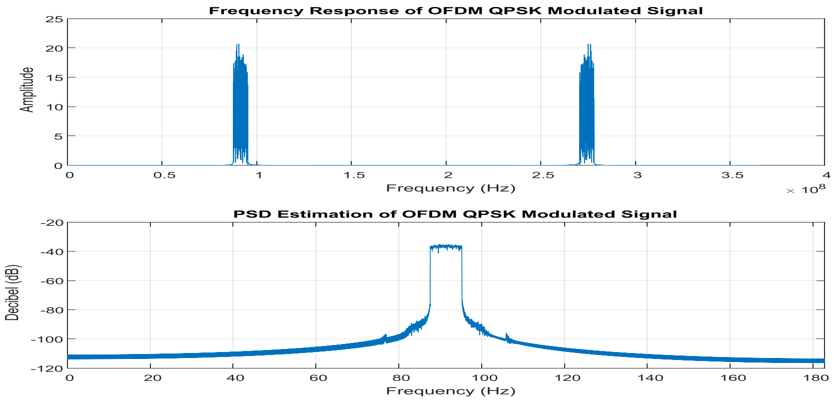


Figure E Time Response Of Subcarrier Signal



FigureF: Response Of Ofdm Underwater Channel Awgn



FigureG: ofdm transmitted modulated signal

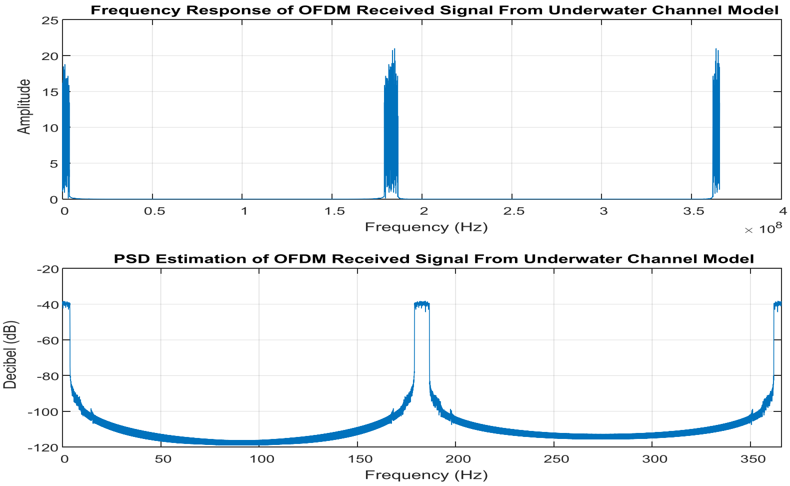


Figure H: Ofdm Received Demodulated Signal Image

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