ANALYSIS OF LOW NOISE ACOUSTIC TRANSDUCER OF DEEP WATER ECHO SOUNDER

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DEDICATION

I dedicate this thesis to Almighty Allah, the creator of the universe, and to Prophet Muhammad (Peace be upon Him) for his wisdom that guided the world. I also extend my heartfelt gratitude to my parents for their unwavering support, to my beloved country, Pakistan, to my university, and to my teachers who have been instrumental in my journey.

ACKNOWLEDGEMENT

I express my utmost gratitude to Allah, the Lord of all worlds, for granting me the health, resources, and perseverance to complete this work. I extend my heartfelt thanks to Bahria University for providing me with this opportunity. I am deeply grateful to my teachers, professors, and faculty members, particularly my supervisor, whose guidance was indispensable. I also appreciate the support of my friends who assisted me throughout this journey. Finally, I thank my parents for their unwavering support, both spiritually, morally, and financially.

ABSTRACT

Specialized solutions are required due to the growing complexity of underwater communication, especially in Deep Water applications where traditional approaches are hindered by signal attenuation and noise. The goal of this work is to determine the optimal modulation strategy for dependable and clear data transmission by analyzing Low Noise Acoustic Transducer of Deep Water Echo Sounder. The techniques examined include Frequency Shift Keying (FSK), Phase Shift Keying (PSK), Pulse Position Modulation (PPM), and Orthogonal Frequency Division Multiplexing (OFDM), all of which were evaluated within the frequency range of 3-12 KHz. MATLAB was utilized to simulate these techniques under varying levels of Gaussian noise, and their performance was measured in terms of Bit Error Rate (BER) across different Signal-to-Noise Ratios (SNR). The study made use of empirical data from the simulations as well as a thorough analysis of the most recent literature on underwater communication devices. The findings show that OFDM is the most effective in using spectrum efficiently and is the most resilient to noise when it comes to maintaining low BER. This makes OFDM the best option for acoustic communication in deep water. The study ends by suggesting more research into boosting OFDM's capabilities in order to increase the robustness and effectiveness of underwater communication systems in even more difficult environments. This research could potentially take the form of hybrid approaches that combine the best feature of various modulation techniques

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LIST OF ABBREVIATIONS

ADC	-	Analog to Digital Converter
AUVs	-	Autonomous Underwater Vehicles
BER	-	Bit Error Rate
DAC	-	Digital to Analog Converter
DSSS	-	Direct Sequence Spread Spectrum
FHSS	-	Frequency Hopping Spread Spectrum
FSK	-	Frequency Shift Keying
IoT	-	Internet of Things
LPF	-	Low Pass Filter
MATLAB	-	Matrix Laboratory
OFDM	-	Orthogonal Frequency Division Multiplexing
PSK	-	Phase Shift Keying
PPM	-	Pulse Position Modulation
ROVs	-	Remotely Operated Vehicles
SONAR	-	Sound Navigation and Ranging
SNR	-	Signal-to-Noise Ratio

CHAPTER # 1

INTRODUCTION

1. Introduction:

1.1. Transducers:

Transducers are essential components in various electronic systems, converting one form of energy into another. From everyday devices, like microphones and speakers to advanced industrial machinery and medical equipment, transducers play a vital role in enabling the transfer and manipulation of signals and energy. These devices come in many forms, such as sensors, actuators, and converters, each designed to fulfill specific functions based on the desired energy transformation. In essence, transducers facilitate the interaction between physical phenomena and electrical signals, bridging the gap between the analog and digital realms. Understanding the principles and applications of transducers is fundamental for engineers and technicians across a wide range of disciplines, as they are integral to the functionality and performance of countless electronic systems and devices.

1.2. Acoustic Signals:

Acoustic signals is also known as sound waves, are fundamental to our daily experiences, shaping how we perceive and interact with the world around us. These signals propagate through various mediums, such as air, water, or solids, creating vibrations that our ears detect and interpret as sound. From the chirping of birds to the music we enjoy, acoustic signals encompass a broad spectrum of frequencies and amplitudes, each conveying unique information and emotions. In addition to their role in communication and entertainment, acoustic signals are crucial in fields like engineering, medicine, and environmental science. For instance, in medicine, ultrasound technology utilizes acoustic signals to generate images of internal organs, aiding in diagnosis and treatment. Similarly, in engineering, acoustic signals are analyzed to assess the structural integrity of buildings and machinery, ensuring safety and reliability. Understanding the properties and behavior of acoustic signals is essential for unlocking their potential across various applications, driving innovation and advancement in numerous fields.

1.3. Acoustic Waves:

Acoustic waves, simply put, are the vibrations that travel through a medium, such as air, water, or solids, producing the sensation of sound. These waves propagate by causing particles in the medium to move back and forth in a rhythmic pattern. From the gentle rustling of leaves to the thunderous roar of a jet engine, acoustic waves encompass a wide range of frequencies and intensities, influencing our perception of the auditory world. Understanding the behavior and properties of acoustic waves is fundamental to various fields, including physics, engineering, and music, as they underpin communication, navigation, and the creation of musical melodies.

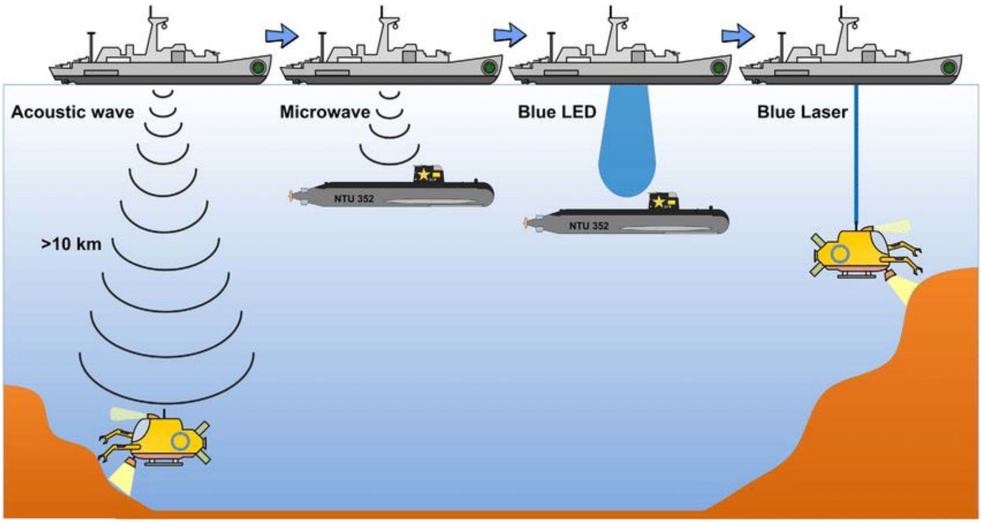

Figure 1.1 Illustration of Different Kinds of Waves

1.4. Acoustic Transducers:

Acoustic transducers are devices that convert sound waves into electrical signals and vice versa, playing a crucial role in capturing, producing, and manipulating sound in various applications. These transducers come in many forms, including microphones, speakers, and ultrasonic sensors, each designed to serve specific purposes in different settings [1]. For instance, microphones convert acoustic signals into electrical signals, allowing us to record sounds and communicate over long distances. On the other hand, speakers do the opposite, converting electrical signals into acoustic signals, enabling us to hear recorded audio or receive verbal instructions from devices. In more specialized fields like medicine and industry, ultrasonic sensors use acoustic transduction to measure distances, detect objects, and even perform imaging tasks. Understanding the principles behind acoustic transducers is essential for engineers, technicians, and researchers across various disciplines, as they are integral to the functionality and performance of numerous devices and systems that rely on sound.

1.5. Piezoelectric Transducer:

A kind of electroacoustic transducer, piezoelectric transducers generate energy from the electrical charges generated by specific solid material types. Piezoelectric literally translates as "electricity produced by pressure." During the First World War, SONAR, which utilized echoes to find enemy ships, was one of the earliest uses of piezo transducer technology[2].

1.6. Hydrophones:

Hydrophones are specialized devices used to detect underwater sound waves, serving as essential tools in marine exploration, research, and surveillance. These devices work by converting acoustic signals traveling through water into electrical signals that can be analyzed and interpreted by researchers or equipment. Hydrophones come in various forms, ranging from simple underwater microphones to sophisticated arrays deployed in deep-sea exploration [3]. They play a crucial role in studying marine life, monitoring underwater environments, and detecting underwater vehicles or activities. Hydrophones enable scientists and engineers to gain valuable insights into the oceans' acoustic landscape, helping us understand and protect underwater ecosystems while also supporting applications like oceanography, navigation, and defense.

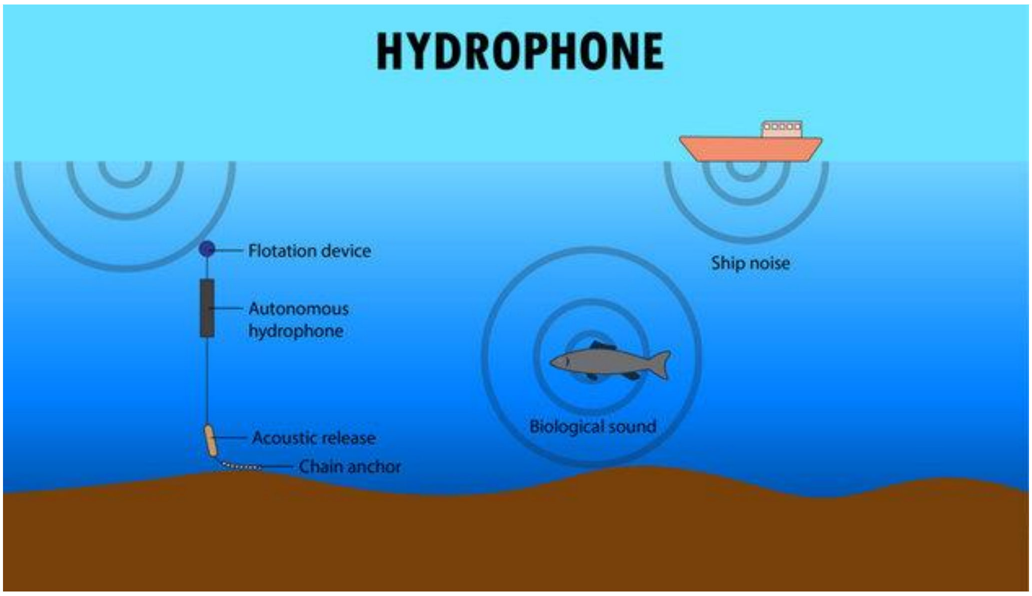

Figure 1.2 Hydrophones

1.7. Internet of Things (IoT):

In today's world, the Internet of Things (IoT's) is changing how we use technology. It's all about connecting different devices, like phones and sensors, through the internet [4]. This lets them share information and do tasks without needing human intervention. IoT is making big changes in areas like homes, healthcare, factories, and transportation. It's all about making things smarter and more efficient. IoT's works by giving devices the ability to gather and analyze lots of data quickly. This helps make better decisions and improves how things work.

For example, smart thermostats can learn your heating habits to save energy. But there are challenges, too. Keeping data safe, making different devices work together, and making sure IoT systems can grow are some of the hurdles we face. Understanding IoT isn't just important for tech experts. It's becoming essential for everyone as we move towards a future where everything is connected and smart.

Figure 1.3 Transducers and the Internet of Things

1.8. Advantages of IoT:

The Internet of Things (IoT's) brings numerous benefits to our lives. One major advantage is convenience. With IoT devices, like smart thermostats or voice-activated assistants, we can control our homes' temperature or play music without even getting up from our seats. IoT also improves efficiency. For example, in industries, sensors in machines can detect when they need maintenance before they break down, saving time and money. In healthcare, wearable devices can monitor patients' vital signs in real-time, helping doctors provide better care.

Another advantage is safety. IoT devices can alert us to potential dangers, like smoke detectors that notify us of a fire even when we're not home. Additionally, in agriculture, sensors can monitor soil moisture levels, helping farmers water their crops more efficiently. Moreover, IoT enhances communication. By connecting devices, we can share information faster and more accurately [5]. For instance, in smart cities, sensors can monitor traffic flow and adjust traffic lights accordingly, reducing congestion.

Overall, the Internet of Things is revolutionizing how we live and work, making our lives more convenient, efficient, safe, and interconnected.

1.9. Applications of IoT:

The applications of the Internet of Things (IoT) are vast and diverse, spanning across various industries and aspects of daily life. In healthcare, IoT is revolutionizing patient care through wearable devices that monitor vital signs, remind patients to take medication, and enable remote consultations with healthcare providers. These devices not only improve patient outcomes by providing real-time health data but also empower individuals to take proactive measures in managing their well-being [6].

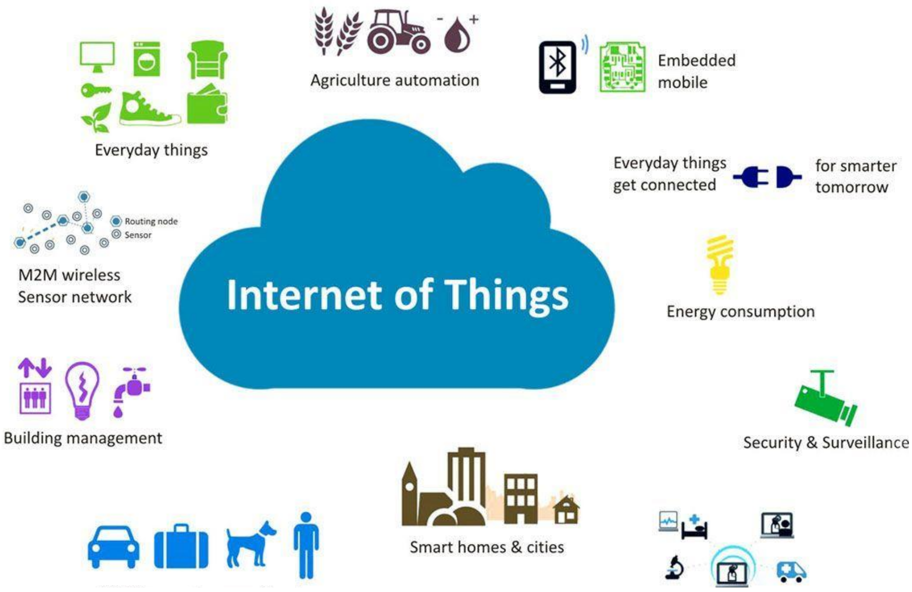

Figure 1.4 IoT Applications

Moreover, in agriculture, IoT technologies are optimizing crop production and resource management. Sensors deployed in fields can monitor soil moisture levels, temperature, and crop health, allowing farmers to make data-driven decisions about irrigation and fertilization. Additionally, IoT-enabled precision agriculture systems enable the automation of tasks such as planting and harvesting, enhancing efficiency and productivity while minimizing environmental impact. Overall, the applications of IoT continue to expand, driving innovation, efficiency, and connectivity across various sectors, ultimately shaping a smarter and more interconnected world.

1.10. <u>Objectives:</u>

These objectives will be achieved:

1) To evaluate the effectiveness of various modulation techniques (FSK, PSK, PPM, and OFDM) for underwater acoustic communication within the frequency range of 3-12 KHz.

2) To analyze the performance of each modulation technique under different levels of Gaussian noise through MATLAB simulations.

3) To determine the most efficient modulation technique with the lowest Bit Error Rate (BER) for deep-water acoustic communication systems.

4) To disseminate research findings through publications, presentations, and workshops to share knowledge and promote the adoption of low noise transducer in the deep water echo sounder community.

CHAPTER # 2

LITERATURE REVIEW

2. Literature review:

2.1. Underwater communication acoustic transducers (A technology review):

The vast and largely unexplored oceans of Earth, with only an estimated 5% explored by humans, present a significant challenge for underwater communication technologies [7]. Developing effective underwater communication systems is crucial for expanding our understanding and utilization of this uncharted territory. The complexity of marine environments necessitates innovative solutions for signal transference, given the distinct medium of water compared to air. This literature review examines the current state of Underwater Communication Transducers, focusing on Piezoelectric Acoustic Transducers, Electromagnetic Acoustic Transducers, and Acousto-Optic Devices.

2.1.1. Transducer Technologies:

Piezoelectric Acoustic Transducers have emerged as a leading technology in underwater communication due to their versatility and adaptability. These transducers convert electrical signals into mechanical vibrations, which then propagate as acoustic waves through water. Shams and Xu (2024) note the importance of configuration and material properties in influencing signal output power, beamwidth, and amplitude [7]. The ability of Piezoelectric transducers to overcome the challenges posed by the marine environment makes them integral to applications in science, surveillance, and naval missions.

Electromagnetic Acoustic Transducers and Acousto-Optic Devices are also explored for their potential in underwater communication. Acousto-Optic devices offer high controllability, although their performance is highly dependent on the materials used and the medium through which the signal is transmitted. Shams and Xu (2024) highlight the potential for combining these different devices to enhance technological capabilities, suggesting that "the addition of piezoelectric materials may improve the signal quality" of Acousto-Optic devices [7].

2.1.2. Communication Challenges and Solutions:

The useful spectrum of underwater sound extends from about 1 Hz to over 1 MHz, with various applications requiring different transducer designs [7]. Long-distance communication in the ocean necessitates frequencies below 100 Hz due to the rapid increase in sound absorption at higher frequencies. Conversely, depth sounding in shallow water and high-resolution, short-range active sonar require higher frequencies, up to 1.5 MHz, to effectively separate the echo from the transmission.

Coding and decoding communication signals into acoustic waves present additional challenges. Various modulation techniques have been developed to encode information for underwater environments, each with its advantages and disadvantages. Shams and Xu (2024) argue that "the most effective type of signal encryption is an amalgamation of various types of proven encryption methods," emphasizing the importance of combining different methods for improved signal encryption [7].

2.1.3. Applications and Future Directions:

The U.S. Navy employs a wide range of sonar and transducer technologies for various applications, from medium-range detection to high-resolution, short-range sonar [7]. Passive naval arrays and sonobuoys illustrate the diverse configurations and uses of underwater communication technologies in naval operations. These systems demonstrate the need for specialized solutions tailored to specific applications, whether for military, scientific, or commercial purposes.

The conclusion of the review underscores the necessity of exploring multiple solutions to advance scientific progress. Shams and Xu (2024) emphasize that stagnation can occur when focusing solely on one solution, advocating for the integration of various device components to achieve better control and improved results [7]. The combination of Piezoelectric and Acousto-Optic devices, for example, could lead to enhanced signal quality and more precise control of acoustic waves [8].

2.2. FHSS (Underwater Acoustic Communications):

FHSS is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both the transmitter and the receiver. FHSS is a technique employed in Wireless Communication Systems, including Underwater Acoustic Communication, to enhance the security and robustness of the transmission. Nonetheless, advancements in underwater communications have lagged significantly [9]. The underwater acoustic environment presents substantial challenges, including severe dispersion and multipath effects, which hinder the application of traditional 5G technology in this context.

In the context of underwater acoustic communication, FHSS plays a crucial role due to the challenging nature of the underwater environment. Water's physical properties, such as varying temperature, salinity, and pressure, significantly affect sound propagation, leading to issues like multipath propagation, Doppler shifts, and signal attenuation. FHSS helps mitigate some of these issues by spreading the signal over a wide range of frequencies, which offers several benefits:

1. Interference Avoidance
2. Enhanced Security
3. Resistance to Multipath Fading
4. Improved Signal-to-Noise Ratio (SNR
5. Doppler Shift Compensation

2.3. DSSS (Underwater Acoustic Communications):

DSSS is a modulation technique used in wireless communication systems to spread the transmitted signal over a wider bandwidth than the minimum required [10].

This is achieved by multiplying the data signal with a pseudorandom noise code, known as a spreading code or chip sequence, which operates at a much higher frequency than the original signal. In Underwater Acoustic Communication, DSSS is particularly advantageous due to the unique challenges posed by the underwater environment.

Underwater Acoustic Communication is affected by various factors such as multipath propagation, where signals take multiple paths to reach the receiver due to reflection and refraction, leading to interference and fading. DSSS helps mitigate these issues by spreading the signal across a broad spectrum, which makes it more resilient to such multipath effects [10]. The spreading code allows the receiver to distinguish the desired signal from noise and other interferences, thus improving the reliability and clarity of communication.

Furthermore, DSSS enhances security in underwater communication. The use of a pseudorandom spreading code means that the signal appears as noise to unintended receivers unless they possess the correct code to decode the signal. This aspect of DSSS makes eavesdropping and signal interception more difficult, thereby providing a layer of security against unauthorized access [10].

Another significant benefit of DSSS in underwater communication is its ability to improve the Signal-to-Noise ratio (SNR). By spreading the signal over a wider bandwidth, the energy of the transmitted signal is distributed, making it less susceptible to narrowband interference and noise. This distribution of signal energy helps in maintaining a more stable and robust communication link, even in the presence of environmental noise and other interfering signals.

DSSS also provides better resistance to jamming and interference [10]. Since the signal is spread across a wide frequency range, it becomes challenging for jammers to disrupt the communication effectively without affecting a large portion of the spectrum. This characteristic is particularly useful in underwater environments where various sources of interference, both natural and man-made, can impact communication systems [11].

2.4. A study on Low-Noise Low-Drift Transducer ADC:

The research paper titled "A Low-Noise Low-Drift Transducer ADC" by McCartney, Sherry, O'Dowd, and Hickey (1997) presents an advanced analog-to-digital converter (ADC) designed for commercial and industrial weigh scales. The ADC achieves high resolution and stability, crucial for precision measurements in load cell applications. This literature review highlights the key technological advancements, methods, and outcomes described in the paper.

2.4.1. Introduction and Objectives:

The primary objective of the research was to develop an integrated transducer ADC capable of performing amplification, signal conditioning, and high-resolution conversion of load cell outputs with minimal noise and drift. Load cells, typically made from precision-machined metals with bonded resistor-bridge strain gauges, require highly accurate ADCs due to their low output levels [12]. The paper aimed to address these requirements by focusing on low offset drift, low input-referred noise, and stable gain.

2.4.2. Architecture and Design:

The proposed ADC features a comprehensive architecture designed to mitigate offset drift and noise. The architecture includes a multiplexer, a unity-gain buffer, a digital-to-analog converter (DAC), a programmable-gain amplifier (PGA), and a sigma-delta modulator. One of the key innovations is the chopping technique applied throughout the entire analog signal path. This method effectively reduces offset drift to 10 nV/°C by continuously reversing the polarity of the input signal [12]. The architecture ensures that any offset or drift arising from various sources, including power supply variations and digital activity, is minimized.

2.4.3. Noise and Stability:

Achieving low noise and high stability are critical for the ADC's performance. The paper details how the design employs a CMOS switched-capacitor circuit to achieve an input-referred noise of 31 nV RMS for a 10 mV signal over a 2 Hz bandwidth. This performance is supported by a chop mode that stabilizes the entire analog signal chain, crucial for maintaining low offset drift and high resolution. The gain drift is kept at 2 ppm/°C, ensuring that the output remains stable over time and temperature variations [12].

2.4.4. Digital Filtering and Calibration:

The ADC incorporates two on-chip digital filters: a Sinc filter and a FIR filter. The Sinc filter processes data from the sigma-delta modulator, while the FIR filter removes residual offset errors. The digital filters are synchronized with the chopping signal to ensure accurate data processing. Additionally, a gain calibration scheme uses precision switched-capacitor attenuation of the reference voltage, enabling accurate calibration near the full-scale input range of the converter [12].

2.4.5. Applications and Impact:

The developed ADC is particularly suited for applications in commercial and industrial weigh scales, where precision and stability are paramount. The integrated circuit design simplifies the overall system by combining amplification and conversion functions, thus reducing the need for external components. The high-resolution and low-noise characteristics of the ADC make it ideal for applications requiring precise measurements over a wide range of environmental conditions.

2.5. Design and Performance:

The development of low-frequency sonar systems necessitates transducers that can produce sound underwater with high efficiency and reasonable size, weight, reliability, and cost [13]. Transducers for deep water applications must overcome significant technical challenges, including maintaining low noise levels while operating at low frequencies, as these are critical for minimizing interference and enhancing signal clarity.

A specific innovation in transducer technology includes the use of neutral buoyant acoustic dipoles, which are particularly effective for low-frequency applications. These dipoles enhance sound penetration beneath water layers, proving essential for seismic exploration and similar applications [14]. Furthermore, the interaction of sound waves with different seabed types, as captured by low-frequency echo sounders, provides invaluable data for seabed classification [15].

Table 2.5 Comparison of Modulation Techniques

Modulation Techniques	Frequency Range	Performance under Noise	Bit Error Rate (BER)
FSK	3-12 KHz	Moderate performance in noisy environments	Higher BER compared to OFDM
PSK	3-12 KHz	Sensitive to phase noise performs well under moderate noise	Moderate BER
PPM	3-12 KHz	Low resilience to noise interference	Higher BER in noisy environments
OFDM	3-12 KHz	Best performance under varying noise conditions	Lower BER among tested techniques

2.6. Acoustic Wave Propagation:

Acoustic waves are used in the majority of underwater communications. A highly recognized apparatus for transmitting and receiving waves of this type is known as SONAR (Sound Navigation and Ranging, to be scripted as "sonar" herein) [16]. This kind of method has been used to many other purposes, such as underwater navigation and ocean object mapping [16].

There are two types of sonar: passive and active [16]. When in active mode, the boat emits an auditory signal and waits for a response. When a return signal is detected, it indicates that an item or impediment existed in the wave's path and caused it to reflect back to the signal's original source. In this instance, numerous properties of the object in question will be ascertained by measuring and evaluating changes to the signal.

The listening element of the device is all that makes up passive sonar. Here the system is listening for sounds, or sound waves, coming from other marine objects. Whales and dolphins, transponders from fishing boats, currents in the waves, and passing submarines are some of the possible sources of these sounds [16].

2.7. Challenges in Deep Water Acoustics:

Operating in deep water environments introduces specific challenges, such as the need for transducers to handle low-frequency reverberation and signal attenuation effectively. The complexity of the deep water sound channel, where acoustic signals are often distorted by various inhomogeneities, requires transducers designed for precise performance under such conditions [17].

Moreover, the performance of transducers can vary significantly with environmental factors such as water temperature, which can alter their frequency response and, consequently, the echo sounder's accuracy [18]. These factors must be carefully managed to ensure the reliability of acoustic measurements in deep water explorations.

2.8. Technological Advancements:

Recent advancements include the development of ultrathin composite meta-surfaces that utilize penta-mode metamaterials for highly efficient low-frequency sound absorption, critical for reducing noise in underwater acoustic transducers. These innovations highlight the potential for significant improvements in transducer designs, aiming to enhance their performance and noise handling capabilities in challenging deep water environments [19].

2.9. Applications of Underwater Acoustics Transducers:

Underwater acoustic transducers are devices that convert electrical energy into sound energy and vice versa, and they have a wide range of practical applications. Here are some key examples:

2.9.1. Submarine Communication:

- Military Communication: Used for secure and stealthy communication between submarines and naval bases.
- Underwater Telephony: Facilitates voice communication for divers and submariners.

2.9.2. Sonar Systems:

- Navigation: Helps in navigating submarines and underwater vehicles by detecting obstacles and mapping the seafloor.
- Fish Finding: Used in commercial and recreational fishing to locate schools of fish.
- Search and Rescue: Assists in locating objects or individuals underwater.

2.9.3. Environmental Monitoring:

- Marine Biology Research: Monitors marine life and their habitats by tracking movements and behaviors.
- Seismic Monitoring: Detects underwater earthquakes and volcanic activity.
- Pollution Detection: Monitors levels of pollutants and other hazardous substances in the water.

2.9.4. Underwater Imaging and Mapping:

- Seafloor Mapping: Used in hydrographic surveys to create detailed maps of the ocean floor.
- Archaeological Exploration: Helps in locating and studying underwater archaeological sites and shipwrecks.

2.9.5. Oil and Gas Industry:

- Pipeline Inspection: Inspects underwater pipelines for leaks or damage.
- Oil Exploration: Assists in locating underwater oil reserves through seismic surveys.

2.9.6. Oceanographic Research:

- Temperature and Salinity Measurement: Gathers data on water temperature and salinity profiles, crucial for climate studies.
- Current Measurement: Measures ocean currents and wave heights for research and navigational purposes.

2.9.7. Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs):

- Navigation and Control: Provides essential data for the navigation and control of AUVs and ROVs used in underwater exploration and operations.
- Data Transmission: Facilitates the transmission of data between AUVs/ROVs and surface vessels.

2.9.8. Aquaculture:

- Fish Farm Monitoring: Monitors the health and behavior of fish in aquaculture environments to ensure optimal conditions.

2.9.9. Medical Applications:

- Underwater Medical Devices: Used in specialized medical applications for monitoring and treatment in hyperbaric medicine.

These applications demonstrate the versatility and importance of underwater acoustic transducers in various fields ranging from defense and industry to environmental science and recreation.

CHAPTER # 3

RESEARCH METHODOLOGY

3. Research Methodology:

3.1. Introduction:

In the realm of underwater exploration, acoustic transducer play a pivotal role, particularly in Deep Water Echo Sounders. These sophisticated devices are integral to a multitude of applications ranging from naval operations and underwater navigation to marine biology research and oceanographic surveys. Given the complex and often hostile underwater environment, ensuring the reliability and clarity of acoustic signals is paramount. Noise, both inherent and environmental, can significantly degrade the quality of these signals, leading to inaccuracies in data interpretation and potential operational failures. Thus, the quest for low-noise solutions in acoustic transducer is not just an academic exercise but a critical engineering challenge.

3.1.1. Primary Objective:

This thesis focuses on the analysis of Low Noise Acoustic Transducer specifically designed for Deep Water Echo Sounders. The primary objective of this study is to evaluate and compare four distinct modulation techniques FSK, PSK, PPM and OFDM to determine which offers the clearest and most noise-free output. Each of these techniques has its unique characteristics and applications, and understanding their performance in the context of underwater communication is essential for optimizing the design and functionality of Echo Sounders.

FSK, known for its robustness in noisy environments, operates by varying the frequency of the carrier signal to represent data. This technique is widely used in various communication systems, including underwater acoustic communications, due to its simplicity and effectiveness. PSK, on the other hand, modulates the phase of the carrier signal, offering higher bandwidth efficiency and resilience against noise compared to FSK. PPM, which encodes information in the position of a pulse within a time frame, is recognized for its high noise immunity and low power consumption, making it suitable for underwater applications where energy efficiency is crucial. Lastly, OFDM, a more complex technique, divides the signal into multiple narrowband channels at different frequencies, providing high spectral efficiency and robustness against multi-path interference, which is common in underwater environments.

3.1.2. Significance of the study:

The significance of this study lies in its potential to enhance the performance of Deep Water Echo Sounders by identifying the optimal modulation technique for low-noise applications. Given the frequency range of 3-12 KHz, which is critical for minimizing noise while maintaining effective signal transmission in deep water scenarios, this research aims to provide a comprehensive evaluation of each technique's performance within this spectrum. By leveraging MATLAB software for simulation and analysis, this study ensures a rigorous and systematic approach to comparing these techniques, offering valuable insights for future advancements in underwater acoustic technology.

3.2. Simulation Setup:

The simulation setup for analyzing the Low Noise Acoustic Transducer of a Deep Water Echo Sounder involves a carefully designed and executed process using MATLAB software. This setup aims to evaluate the performance of four modulation techniques i.e. FSK, PSK, PPM, and OFDM to determine the optimal method for achieving the clearest and most noise-free output within the specified frequency range of 3-12 KHz.

3.2.1. MATLAB Environment:

MATLAB is selected for its robust computational capabilities, extensive libraries, and powerful tools for signal processing and analysis. MATLAB's simulation environment provides a controlled and reproducible platform for implementing and testing the modulation techniques, ensuring that the results are consistent and reliable.

3.2.2. System Parameters:

The specifications used for the Low Noise Acoustic Transducer are critical for the accurate simulation and comparison of the modulation techniques. The parameters are as follows:

- Sampling Frequency
- Carrier Frequency for Binary '0' (fc1)
- Carrier Frequency for Binary '1' (fc2)
- Number of Bits to Transmit
- Bit Rate
- Energy per Bit to Noise Power Spectral Density Ratio
- Low Pass Filter Cutoff Frequency

These parameters are carefully chosen to ensure that the simulated environment closely mimics real-world conditions while focusing on the low-noise frequency limit of 3-12 KHz.

3.2.3. Signal Generation and Modulation:

The experimental process begins with the generation of a random binary data sequence of 100 bits, which serves as the information to be transmitted. Each modulation technique is then applied to this binary data sequence as follows:

➢ **Frequency Shift Keying (FSK):**

In FSK, the binary data is modulated by shifting the carrier frequency between two distinct frequencies, fc1 and fc2, representing binary '0' and '1', respectively [20]. MATLAB functions are utilized to implement the FSK modulation, generating a modulated signal with frequency shifts corresponding to the binary data.

➢ **Phase Shift Keying (PSK):**

PSK involves modulating the phase of the carrier signal to represent the binary data. For BPSK, the phase of the carrier is shifted by 0 degrees for binary '0' and 180 degrees for binary '1'. MATLAB's signal processing toolbox provides the necessary functions to perform PSK modulation, resulting in a phase-modulated signal.

➢ **Pulse Position Modulation (PPM):**

In PPM, the position of a pulse within a time frame encodes the binary data. MATLAB is used to generate pulses at specific positions corresponding to the binary values, creating a time-modulated signal that reflects the binary sequence.

➢ **Orthogonal Frequency Division Multiplexing (OFDM):**

OFDM splits the signal into multiple narrowband channels at different frequencies. Each subcarrier is modulated using a simpler modulation technique (such as QAM or PSK). MATLAB's communication toolbox facilitates the implementation of OFDM, producing a frequency-multiplexed signal that efficiently utilizes the available bandwidth.

3.2.4. Noise Addition:

To simulate real-world conditions, Gaussian white noise is added to each modulated signal. The noise is characterized by the EbNo set to 10 dB, ensuring that the impact of noise on the signal is significant but not overwhelming. This step is crucial for assessing the noise immunity of each modulation technique.

3.2.5. Signal Filtering:

A LPF with a cutoff frequency of 12 KHz is applied to each noisy signal to remove high-frequency noise components. This filter ensures that only the frequency components within the desired range (3 to 12 KHz) are retained, allowing for a clearer comparison of the modulation techniques' performance in the specified frequency band.

3.2.6. Data Collection and Analysis:

After filtering, the demodulation process is performed to recover the original binary data from each modulated signal. MATLAB's demodulation functions are employed for this purpose. The recovered data is then compared to the original binary sequence to calculate the BER and other performance metrics, such as SNR.

The data collected from these simulations is analyzed to determine the modulation technique that provides the clearest and most noise-free output. Graphical representations are used to compare the performance of FSK, PSK, PPM, and OFDM, leading to a comprehensive evaluation of their suitability for Low Noise Acoustic Transducer in Deep Water Echo Sounders.

3.3. Techniques for Analysis:

In this section, we delve into the four modulation techniques used in the analysis of the Low Noise Acoustic Transducer of a Deep Water Echo Sounder: FSK, PSK, PPM, and OFDM. Each technique is explored in terms of its principles, advantages, and relevance to underwater acoustic communication.

3.3.1. FSK:

➢ **Principle of Operation:**

One type of digital modulation is called Frequency Shift Keying, or FSK. In order to operate as bit 1 and bit 0, FSK needs the use of two separate frequencies that are offset from a carrier frequency in opposite but equal degrees. The receiver will get a string from these signals, which function as a binary code. This is regarded as a two-state FSK. There is another four-state FSK, where a two-bit value is provided by each frequency (01, 00, 10, 11). After the signal is collected by the receiver, decoding is as easy as figuring out which frequencies correspond to the bit [21]. A variant of FSK that use several carrier frequencies is called Multiple Frequency Shift Keying (MFSK).

➢ **Advantages:**

- Robustness to Noise: FSK is known for its resilience in noisy environments, making it suitable for underwater communication where noise can be a significant issue.

- Simplicity: The implementation of FSK is relatively straightforward compared to more complex modulation schemes, which can be advantageous in practical applications.

➢ Relevance to Underwater Communication:

FSK's robustness to noise and simplicity make it a widely used technique in underwater communication systems. Its ability to maintain signal integrity in the presence of noise is crucial for reliable data transmission in underwater environments.

3.3.2. PSK:

➢ Principle of Operation:

PSK, is similar to FSK however, rather than shifting the frequency of the signal, the phase is shifted, or modulated. In this case the carrier wave will vary between sine and cosine inputs. This is a more sophisticated modulation technique than FSK in that PSK modulation can be specialized to the specific circumstances to account for efficiency and suitability for the situation at hand. PSK techniques can range from a simple 2-bit system to continuous shifting, though there are system trade-off's for each method [21-22].

PSK modulates the phase of the carrier signal to represent the digital data. In BPSK, the phase of the carrier is shifted by 0 degrees for binary '0' and 180 degrees for binary '1'. This phase shift corresponds to the binary values, allowing data to be encoded and transmitted.

➢ Advantages:

- Bandwidth Efficiency: PSK is more bandwidth-efficient than FSK, as it utilizes the phase of the carrier rather than its frequency, allowing more data to be transmitted within the same bandwidth.

- Noise Resilience: PSK offers higher resilience to noise and interference compared to amplitude-based modulation techniques, ensuring clearer signal reception.

➢ **Relevance to Underwater Communication:**

PSK's bandwidth efficiency and noise resilience make it an attractive choice for underwater communication, where bandwidth is often limited and noise levels can be high [23]. Its ability to maintain signal clarity in adverse conditions is particularly beneficial for Deep Water Echo Sounders.

3.3.3. PPM:

➢ **Principle of Operation:**

PPM encodes information in the position of a pulse within a given time frame. The time delay of each pulse represents the binary data, with specific time positions corresponding to binary '0' and '1'. This time-based modulation provides an alternative to frequency and phase-based methods.

➢ **Advantages:**

- High Noise Immunity: PPM's reliance on the timing of pulses rather than their amplitude or frequency provides high immunity to noise, which is advantageous in noisy underwater environments.

- Low Power Consumption: PPM typically requires less power than other modulation techniques, making it suitable for battery-powered underwater devices.

➢ **Relevance to Underwater Communication:**

PPM's high noise immunity and low power consumption are critical for underwater communication systems, where energy efficiency and noise reduction are paramount [24]. Its time-based encoding provides a reliable method for transmitting data in challenging underwater conditions.

3.3.4. OFDM:

➢ **Principle of Operation:**

OFDM is a block transmission scheme that separates information into blocks, with guard intervals between blocks during transmission. This type of encoding both protects the information and is robust against multipath propagation [25].

OFDM divides the data signal into multiple narrowband channels at different frequencies. Each subcarrier is modulated using a simpler modulation technique (such as PSK or QAM). The orthogonality of the subcarriers ensures that they do not interfere with each other, allowing efficient use of the available bandwidth.

➢ **Advantages:**

- High Spectral Efficiency: OFDM's ability to divide the signal into multiple subcarriers allows for high spectral efficiency, maximizing the use of the available bandwidth.

- Robustness to Multi-path Interference: OFDM's structure provides resilience against multi-path interference, a common issue in underwater environments where signals can reflect off surfaces and objects.

- Flexibility: OFDM can adapt to varying channel conditions, making it versatile for different underwater scenarios.

➢ Relevance to Underwater Communication:

OFDM's high spectral efficiency and robustness to multi-path interference make it a powerful technique for underwater communication. Its adaptability to different channel conditions ensures reliable data transmission in diverse underwater environments, which is essential for the accurate operation of Deep Water Echo Sounders.

CHAPTER # 4

SYSTEM DESIGN

4. System Design:

4.1. Data Collection:

The primary objective of data collection is to obtain reliable, accurate, and comprehensive data that reflects the effectiveness of each modulation technique under the specified conditions.

4.2. Signal Transmission and Reception:

The core of the data collection process involves the transmission and reception of the modulated signals. For each technique, the binary data is modulated, transmitted, and then received after passing through the simulated underwater communication channel, which includes noise addition and low-pass filtering.

4.2.1. Transmission:

- The binary data sequence is modulated using each of the four techniques.

- The modulated signal is then transmitted through the simulated underwater channel, where it is subjected to noise and interference.

4.2.2. Reception:

- The received signal, now corrupted with noise, is passed through a low-pass filter to remove high-frequency noise components.

- The filtered signal is then demodulated to recover the transmitted binary data.

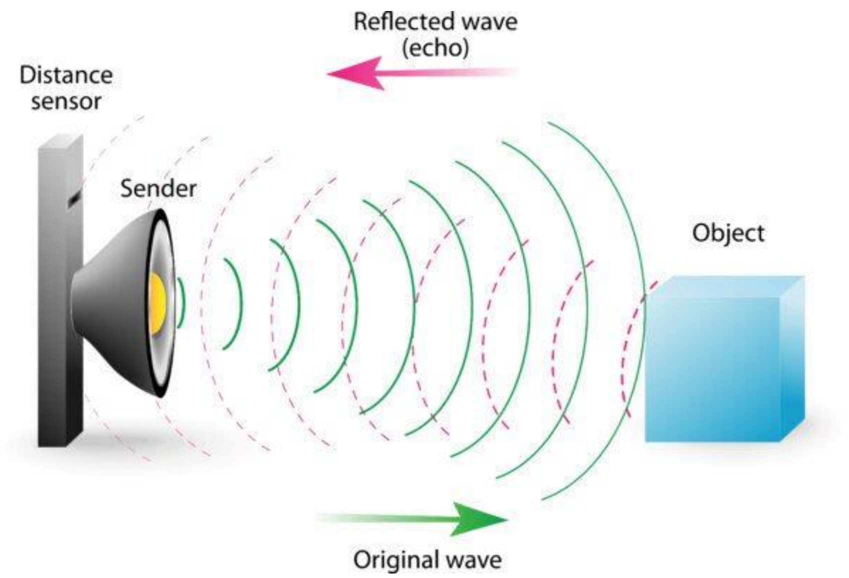

Figure 4.1 Signal Transmission and Reception Mechanism

This process is repeated multiple times for each modulation technique to ensure that the collected data is statistically significant and represents a wide range of potential scenarios.

4.3. Performance Metrics:

To objectively assess the performance of each modulation technique, several key metrics are collected and analyzed. These metrics provide quantitative data that can be used to compare the effectiveness of each method. The primary metrics collected include:

- **Bit Error Rate (BER):** The BER is a critical metric that measures the number of bit errors that occur during transmission relative to the total number of bits transmitted. A lower BER indicates better performance, as it signifies that the transmitted data is received more accurately.

- **Signal-to-Noise Ratio (SNR):** The SNR is used to evaluate the clarity of the received signal in relation to the background noise. A higher SNR indicates that the signal is more distinguishable from noise, which is particularly important in underwater communication where noise levels can be high.

- **Processing Time:** The time required to modulate, transmit, and demodulate the signal is recorded for each technique. This metric is important for assessing the computational efficiency of each modulation method, especially in real-time applications.

- **Energy Efficiency:** The energy consumption during the modulation, transmission, and reception processes is measured. This metric is particularly relevant for battery-powered underwater devices, where energy efficiency is crucial for prolonged operation.

4.4. Repetition and Averaging:

To ensure the reliability of the collected data, the simulation process is repeated multiple times for each modulation technique. Each run of the simulation may involve slight variations in noise levels and other environmental factors, which helps to capture a broad spectrum of possible real-world scenarios.

The data from these repeated simulations is then averaged to produce a more robust and accurate representation of the performance of each modulation technique. By averaging the results, the impact of outliers and random fluctuations is minimized, providing a clearer picture of how each technique performs under typical conditions.

4.5. Data Logging and Storage:

All collected data is systematically logged and stored for further analysis. MATLAB provides built-in functions for data logging, which allow for the automatic recording of key metrics during the simulation process. The logged data includes:

- **Modulated and demodulated signals**
- **BER, SNR, and energy consumption values**
- **Processing time for each technique**
- **Intermediate signal stages (e.g., before and after filtering)**

This data is stored in MATLAB's workspace or external files, ensuring that it can be easily accessed and analyzed later. Proper data storage practices are followed to maintain the integrity and security of the data, including the use of backups and version control where necessary.

4.6. Implementation in MATLAB:

The implementation of the four modulation techniques FSK, PSK, PPM, and OFDM in MATLAB is a crucial part of this research. MATLAB, with its extensive array of built-in functions and toolboxes, provides a versatile platform for simulating, analyzing, and comparing these modulation techniques under controlled conditions. This section outlines the step-by-step process of implementing each technique, highlighting the specific MATLAB functions and methodologies employed.

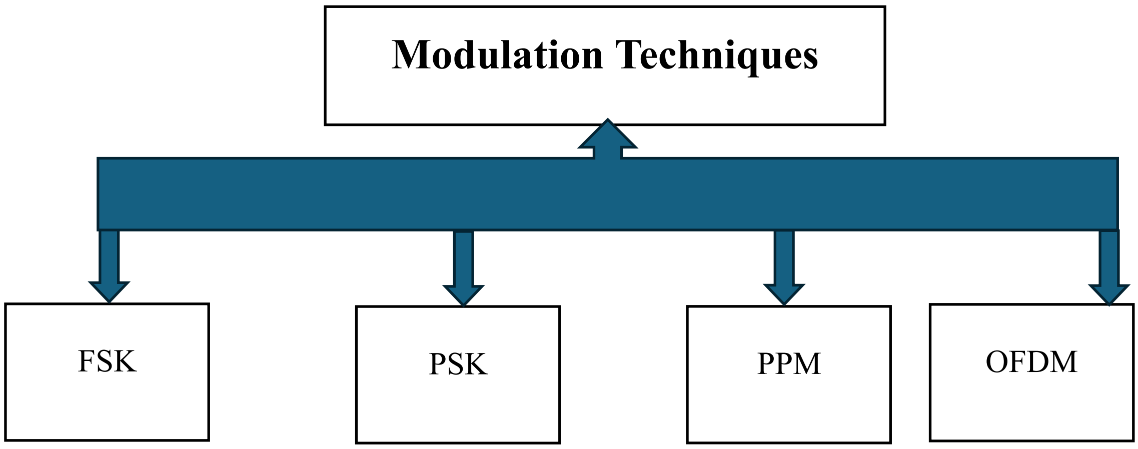

Figure 4.6 Flow diagram of Modulation Techniques

4.7. Initial Setup and Signal Generation:

The implementation begins with defining the essential system parameters, which include the sampling frequency, carrier frequencies, bit rate, and other relevant variables. These parameters are set as follows:

- **fs** % Sampling frequency in Hz

- **fc** % Carrier frequency in Hz

- **numBits** % Number of bits to transmit

- **bitRate** % Bit rate in bits per second

- **EbNo** % Energy per bit to noise power spectral density ratio in dB

- **lowPassCutoff** % Low pass filter cutoff frequency in Hz

Next, a random binary sequence of 100 bits is generated to simulate the data to be transmitted. The MATLAB **'randi'** function is used for this purpose.

4.8. Typical Operating process of Modulation techniques:

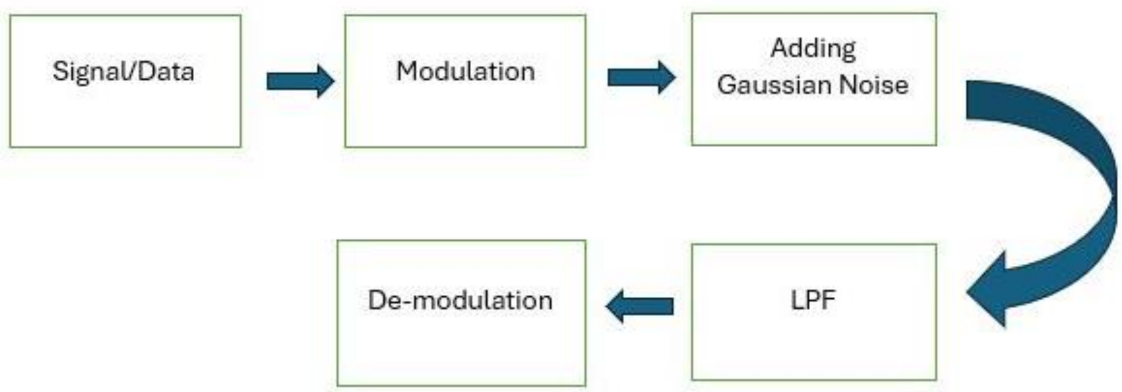

Figure 4.8 Flow diagram of Operating system of Modulation Techniques

The above flow diagram demonstrates the common operating step of the four modulation techniques I have employed in this study. The first step involves sending signal/data which goes through modulation in the following step. Afterwards, in the operating process. the noise is added to simulate an oceanic environment. Then, a Low Pass Filer (LPF) is applied to filter out unnecessary frequencies higher than the cut-off frequency being utilized in this study. In the end, in order to receive the original signal, De Modulation is performed.

CHAPTER # 5

SYSTEM EVALUATION

5. System Evaluation:

5.1. FSK:

The results demonstrate the process and effectiveness of FSK modulation in transmitting and retrieving binary data in a noisy environment, followed by filtering and demodulation to recover the original signal.

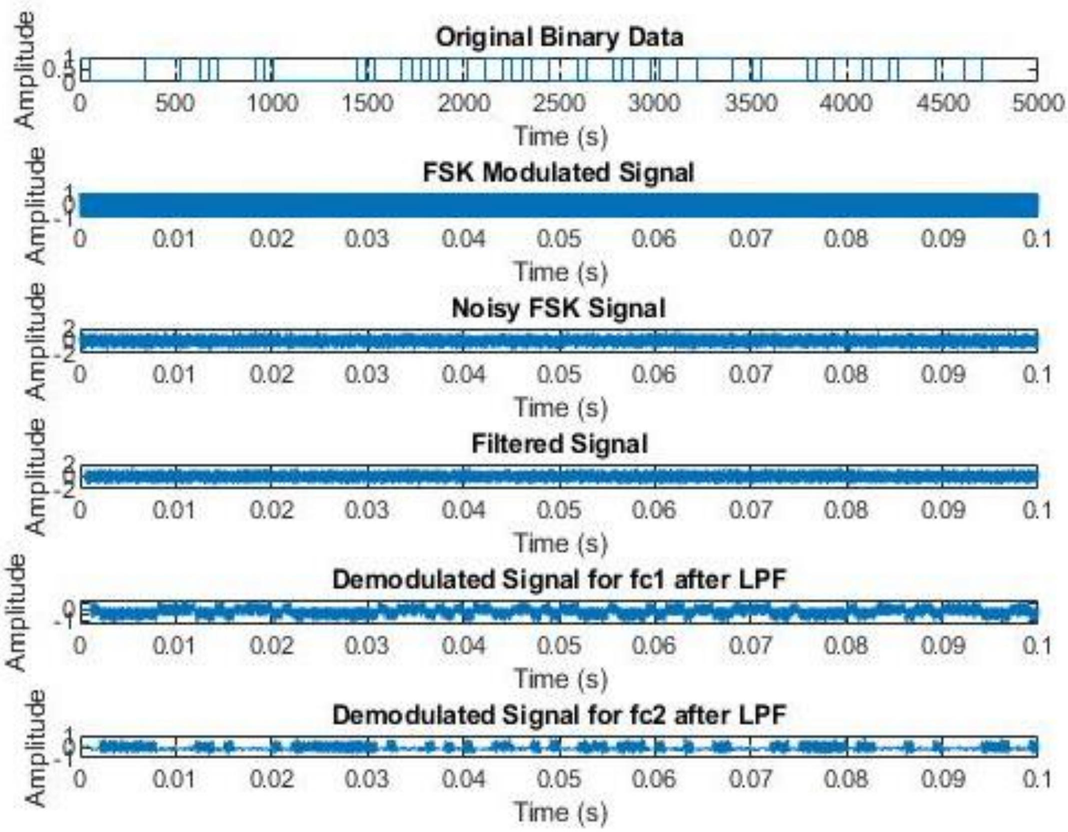

Figure 5.1 FSK Simulation Results

- **Original Binary Data:** The initial sequence represents the binary data intended for transmission. This binary sequence forms the basis for subsequent signal modulation.

- **FSK Modulated Signal:** The original binary data is then modulated using FSK, a technique where the frequency of the carrier signal is shifted between two distinct values corresponding to the binary states (0 and 1). The modulated signal is characterized by its two discrete frequencies, clearly reflecting the binary sequence. The time domain representation of this signal displays these frequency shifts over time.

- **Noisy FSK Signal:** After modulation, the signal is subjected to Gaussian noise, simulating a real-world transmission scenario where signals are often corrupted by noise. This noisy signal is crucial for testing the robustness of the FSK technique under less-than-ideal conditions. The addition of noise causes some distortions in the signal, making it harder to distinguish between the binary states directly.

- **Filtered Signal:** To mitigate the effects of the noise introduced, a LPF is applied. The filtered signal shows a significant reduction in noise, with the underlying frequency shifts more distinguishable. The purpose of filtering here is to remove high-frequency noise components that could obscure the modulated signal, enhancing the clarity and retrievability of the original data.

- **Demodulated Signal for f_c1 after LPF:** The process of demodulation follows filtering, where the signal is analyzed to retrieve the binary information. For the fc1, the demodulated signal shows a clear correspondence to the original binary sequence, although some noise remnants may still be present. This step is crucial for interpreting the modulated signal back into the binary data it represents.

- **Demodulated Signal for f_c2 after LPF:** Similarly, for the fc2, the demodulation process is performed. The output also closely matches the original binary sequence, reinforcing the efficacy of the FSK modulation and subsequent signal processing steps in recovering the intended data. The consistency of the demodulated signals with the original binary data indicates successful transmission and noise mitigation.

5.2. <u>PSK:</u>

The process of PSK modulation and demodulation, in the context of underwater communication systems, is meticulously demonstrated by the sequential analysis of signal transformations, from the original binary data to the final demodulated output.

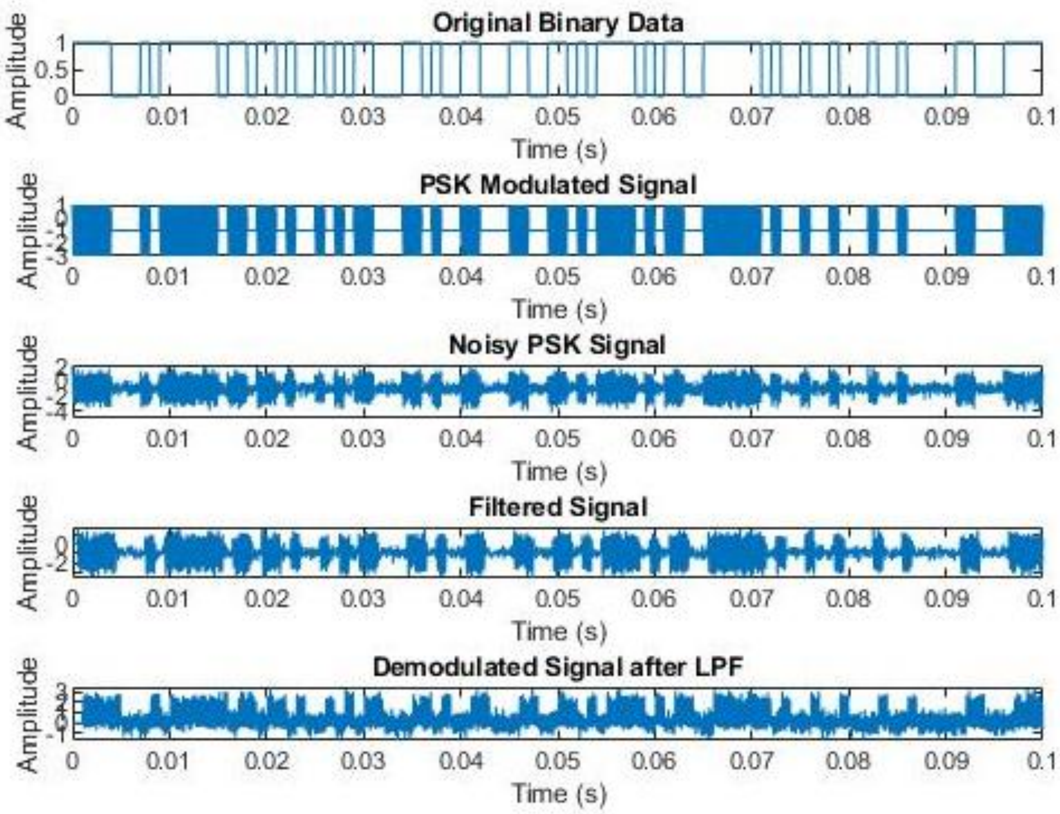

Figure 5.2 PSK Simulation Results

- **Original Binary Data:** The sequence begins with the raw binary data intended for transmission. This binary sequence, represented over time, serves as the foundational information to be modulated and transmitted.

- **PSK Modulated Signal:** The binary data is then modulated using PSK, where the phase of the carrier signal is varied in accordance with the binary data. Specifically, different phases represent different binary states (0 or 1). The modulated signal thus reflects these phase shifts, which are essential for encoding the binary information onto the carrier wave. The time-domain representation of this signal shows a clear phase transition at points corresponding to changes in the binary data.

- **Noisy PSK Signal:** After modulation, the signal encounters noise, simulating real-world transmission conditions where environmental factors and channel imperfections introduce noise. This noisy signal represents the practical challenge of PSK, where phase shifts can become obscured by noise, making it difficult to accurately retrieve the original binary data.

- **Filtered Signal:** To address the noise, a LPF is applied. The filtered signal shows a significant reduction in the high-frequency noise components, thereby enhancing the clarity of the phase shifts that represent the binary data. The filtering process is crucial in cleaning up the signal, making it more conducive for accurate demodulation.

- **Demodulated Signal after LPF:** The final step involves demodulating the filtered signal to retrieve the original binary data. The demodulation process examines the phase shifts in the signal to decode the binary information. Despite the presence of residual noise, the demodulated signal closely matches the original binary data, indicating that the PSK technique, combined with effective filtering, can reliably recover transmitted information even in noisy conditions.

5.3. PPM:

The analysis of PPM as a technique for encoding and transmitting binary data, particularly in noisy environments, is thoroughly depicted through the stages of signal transformation, starting from the original binary sequence to the final demodulated output.

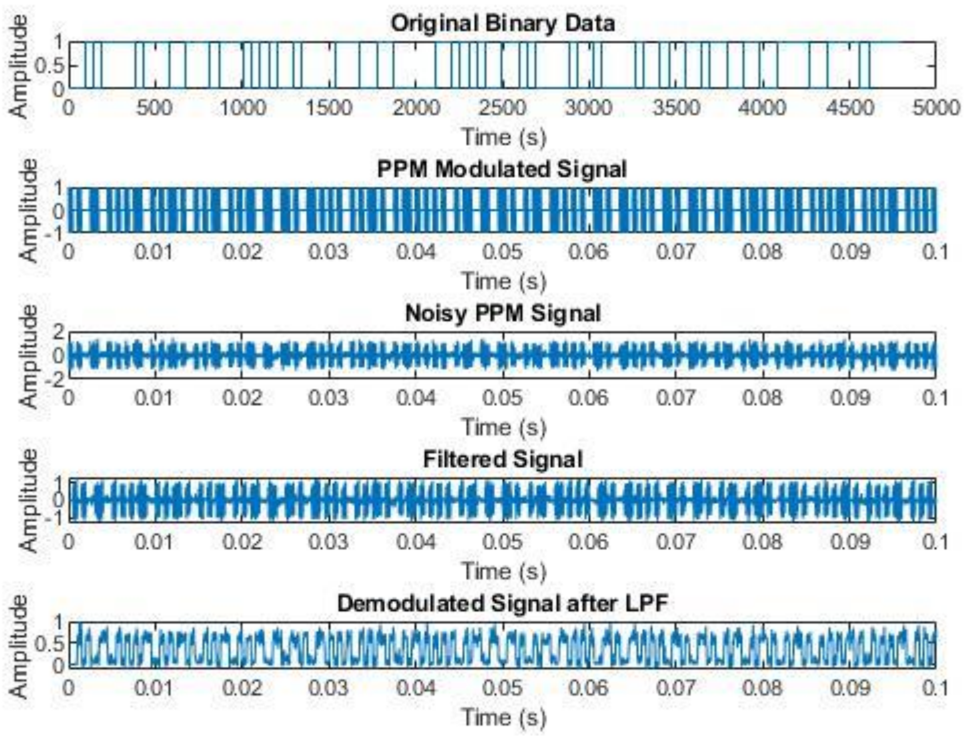

Figure 5.3 PPM Simulation Results

- **Original Binary Data:** The process begins with a sequence of binary data that serves as the core information intended for transmission. This binary sequence, displayed over time, forms the basis for subsequent modulation steps.

- **PPM Modulated Signal:** The binary data is then modulated using PPM, a technique in which the position of a pulse within a given time slot is altered to correspond to the binary information. Specifically, the presence or absence of the pulse at specific time intervals encodes the binary states (0 or 1). The resulting modulated signal demonstrates these pulse position variations, which represent the binary data in the time domain.

- **Noisy PPM Signal:** Following modulation, the signal is subjected to Gaussian noise, mimicking real-world transmission scenarios where the signal may encounter interference and distortion. The introduction of noise creates amplitude variations and can obscure the precise pulse positions, complicating the retrieval of the original binary data. This noisy signal reflects the challenges of maintaining data integrity in environments where signal transmission is not ideal.

- **Filtered Signal:** To counteract the noise, a LPF is applied to the signal. The filtered signal shows a notable reduction in noise, with the pulse positions becoming more distinct and easier to identify. Filtering is crucial in PPM as it enhances the clarity of the pulse positions, making the subsequent demodulation process more reliable.

- **Demodulated Signal after LPF:** The final step is the demodulation of the filtered signal to recover the original binary data. The demodulation process involves detecting the precise positions of the pulses within each time slot to determine the corresponding binary values. Despite the noise and potential distortions, the demodulated signal successfully reflects the original binary sequence, indicating the effectiveness of PPM in transmitting data accurately even in noisy conditions.

5.4. OFDM:

The process of OFDM in signal transmission is detailed through a series of signal representations, illustrating the transformation from the original binary data to the final received output. This process highlights the effectiveness of OFDM in maintaining data integrity despite potential noise and distortion during transmission.

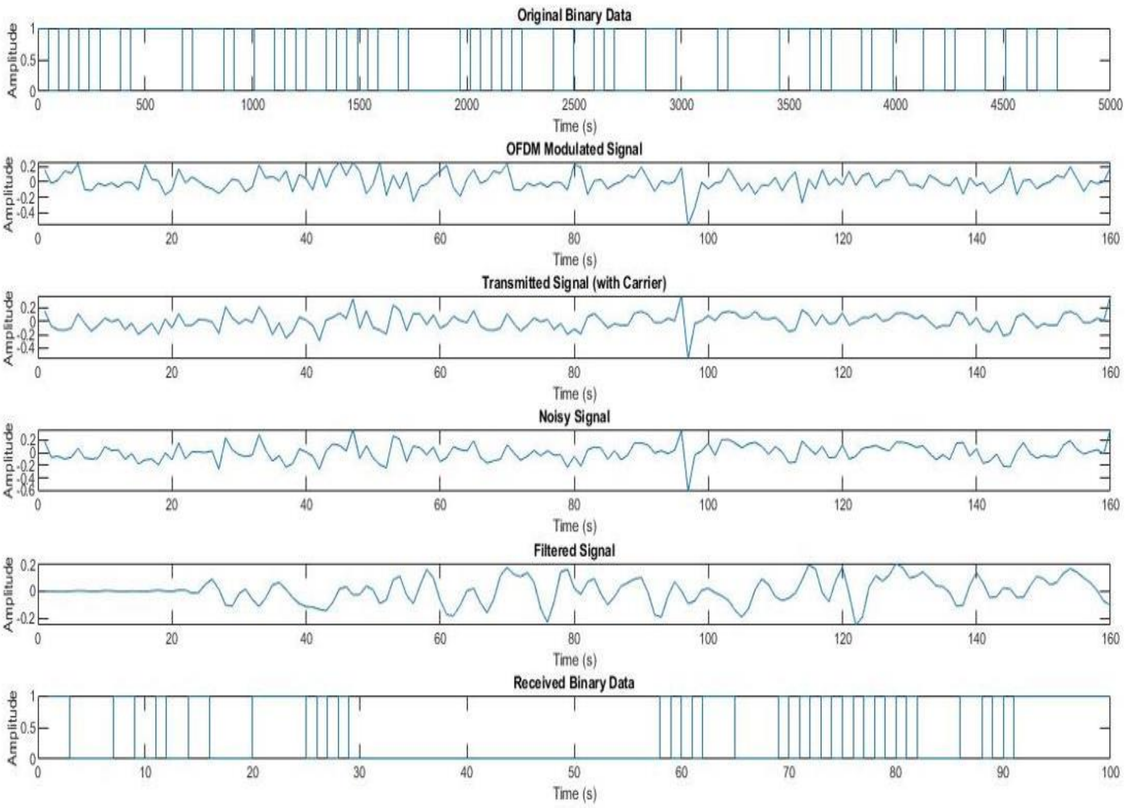

Figure 5.4 OFDM Simulation Results

- **Original Binary Data:** The sequence starts with the original binary data, which serves as the information to be transmitted. This binary sequence is presented over time, showing the raw digital information that will undergo modulation and transmission.

- **OFDM Modulated Signal:** The binary data is modulated using OFDM, a technique that divides the data into multiple orthogonal sub-carrier frequencies. The modulated signal reflects these sub-carrier frequencies in the time domain, displaying a complex waveform that carries the encoded information across multiple frequencies. This characteristic allows OFDM to efficiently use the available bandwidth and enhance the robustness of the signal against interference.

- **Transmitted Signal (with Carrier):** After modulation, the signal is combined with a carrier frequency for transmission. This step integrates the modulated data into a format suitable for transmission over a communication channel. The carrier signal helps in maintaining the integrity of the modulated data over long distances and through varying transmission conditions.

- **Noisy Signal:** The transmitted signal is subjected to noise, simulating real-world transmission conditions where various environmental factors and channel imperfections introduce distortion. The noisy signal exhibits deviations and fluctuations, which may obscure the original modulated information, representing the practical challenges of maintaining data integrity in communication systems.

- **Filtered Signal:** To mitigate the effects of noise, a LPF is applied to the noisy signal. The filtered signal demonstrates a reduction in high-frequency noise components, making the underlying OFDM-modulated data more distinguishable. This filtering process is critical in recovering the original data by reducing the impact of noise and preserving the essential features of the modulated signal.

- **Received Binary Data:** The final stage involves the demodulation and decoding of the filtered signal to retrieve the original binary data. The received binary data is reconstructed from the filtered signal, showing how OFDM enables the accurate recovery of the original information despite the challenges introduced during transmission. The fidelity of the received binary data to the original sequence underscores the effectiveness of OFDM in maintaining data integrity, even in the presence of noise and distortion.

5.5. Comparison:

The comparative analysis of four modulation techniques FSK, PSK, PPM, and OFDM is examined based on their performance in terms of BER relative to the signal-to-noise ratio, denoted as Eb/No. The graphical representation underscores how each technique responds to varying levels of noise, offering insights into their efficiency and reliability under different communication conditions.

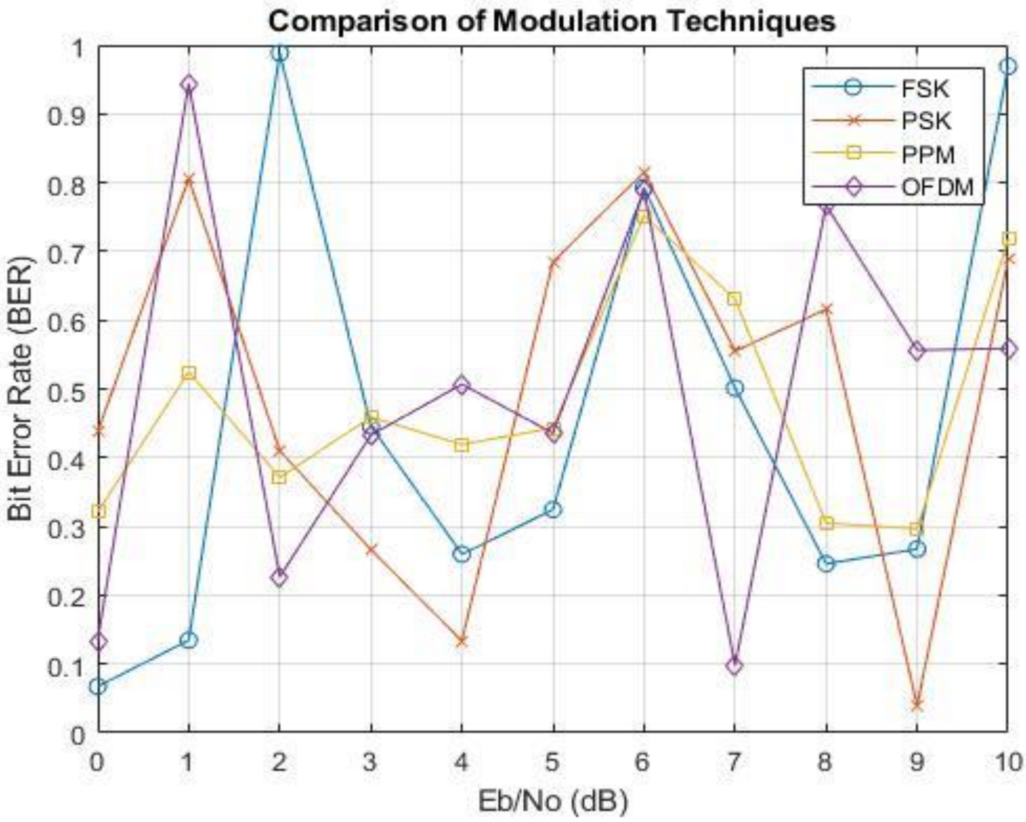

Figure 5.5 (a) Comparison of Modulation Techniques based on BER by Eb/No

- **FSK (Frequency Shift Keying):** The BER for FSK shows significant variation across different levels of Eb/No. At low Eb/No values, FSK exhibits a high BER, indicating a higher susceptibility to errors in noisy environments. However, as the Eb/No ratio increases, the BER decreases, showcasing improved performance with better signal quality. This behaviour suggests that FSK is more robust at higher signal-to-noise ratios but struggles with noise at lower ratios.

- **PSK (Phase Shift Keying):** PSK demonstrates a more consistent performance across different Eb/No values, though it is still prone to fluctuations. At certain points, the BER rises sharply, indicating moments where the technique is more vulnerable to errors. However, PSK generally maintains a lower BER compared to FSK, especially at mid-range Eb/No values, highlighting its relative efficiency in balancing error rates under varying noise levels.

- **PPM (Pulse Position Modulation):** The performance of PPM fluctuates significantly across the range of Eb/No values. While it sometimes shows lower BER at certain Eb/No levels, its overall trend indicates higher vulnerability to noise compared to other techniques, particularly at lower and mid-range signal-to-noise ratios. This suggests that PPM might not be as reliable in environments with fluctuating or lower signal quality.

- **OFDM (Orthogonal Frequency Division Multiplexing):** OFDM demonstrates a relatively stable performance across different Eb/No values, with noticeable resilience to noise. While the BER does show some variability, OFDM generally maintains lower error rates compared to the other techniques, especially at higher Eb/No values. This stability reflects OFDM's strength in mitigating the effects of noise, making it a favourable option for maintaining data integrity in noisy environments.

- **Gaussian Noise levels (low, mid and high):**
  At **low Gaussian noise levels**, all four modulation techniques—FSK, PSK, PPM, and OFDM—perform relatively well, maintaining a low Bit Error Rate (BER). However, even at this stage, OFDM stands out as the most effective due to its ability to divide the data stream into multiple sub-carriers, which mitigates interference and noise. PPM and PSK also demonstrate good performance, with slightly higher BER than OFDM but still within acceptable limits. FSK, while functional, begins to show minor

signs of performance degradation as it is more susceptible to noise due to its reliance on frequency shifts.

As the **Gaussian noise levels** increase to **mid-range**, a more noticeable distinction in performance emerges. OFDM continues to maintain superior efficiency, thanks to its robust error correction and efficient use of bandwidth. PSK experiences a moderate increase in BER, though it remains within tolerable limits, especially in environments where bandwidth efficiency is prioritized over resilience to noise. PPM starts to show more significant degradation in performance due to its dependency on precise timing of pulses, which becomes more difficult in noisier environments. FSK, by contrast, struggles the most at mid-noise levels, as its frequency-based encoding becomes more prone to errors, leading to a sharper rise in BER.

At **high Gaussian noise levels**, the differences become stark. OFDM continues to outperform the other techniques, exhibiting the lowest BER and demonstrating its resilience in challenging environments. Its use of multiple orthogonal carriers allows it to effectively manage the high noise, making it the optimal choice for underwater communication. PPM and PSK suffer considerably from increased noise, with PSK faring slightly better due to its phase-based encoding. FSK, however, experiences the highest BER among all techniques, becoming increasingly unreliable in these conditions, as frequency shifts are easily distorted by the noise. This makes FSK less suitable for environments where high noise levels are expected.

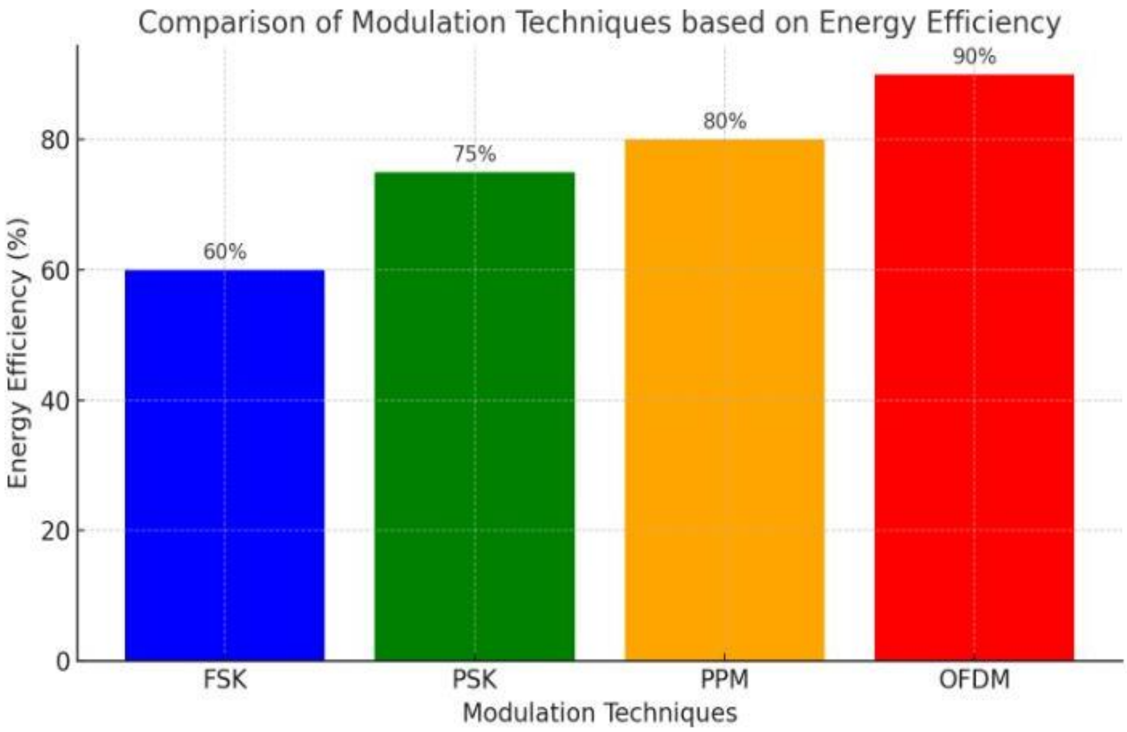

Figure 5.5 (b) Comparison of Modulation Techniques based on Energy Efficiency

The graph illustrates that OFDM is the most energy-efficient modulation technique, which aligns with its established effectiveness in handling complex underwater acoustic communication systems. PPM follows closely due to its simplicity and energy-conscious design. PSK offers a balance between complexity and efficiency, while FSK has the lowest energy efficiency, making it less suitable for energy-constrained environments.

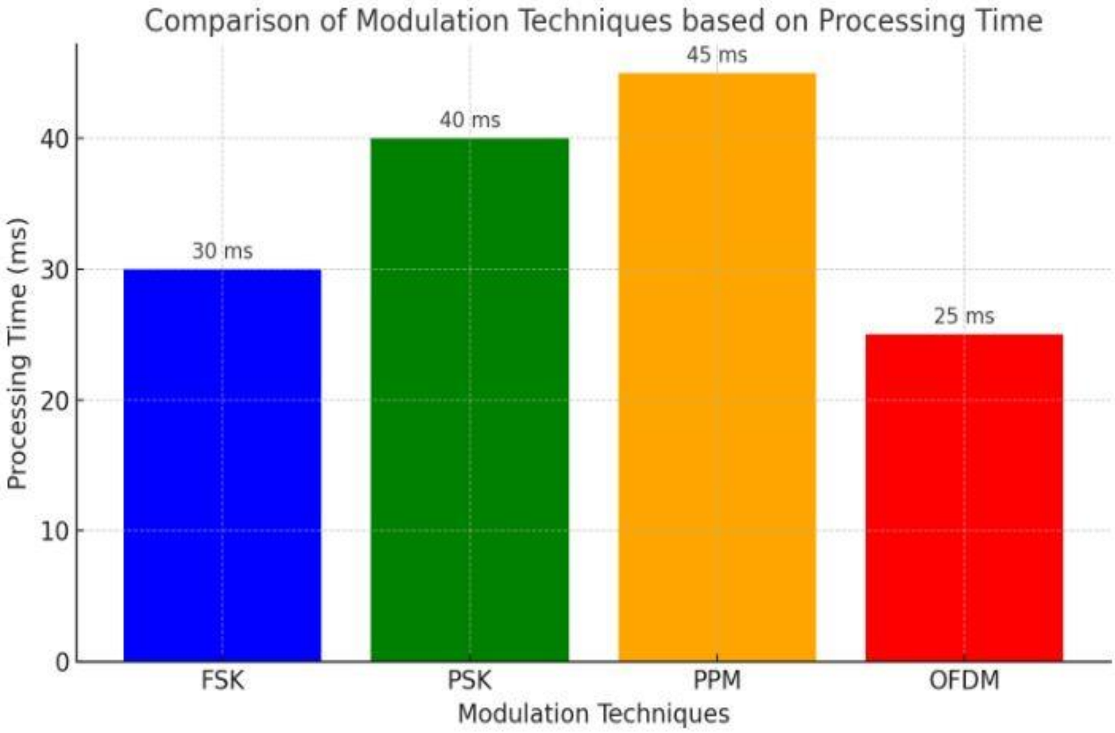

Figure 5.5 (c) Comparison of Modulation Techniques based on their Processing Time

OFDM demonstrates the fastest processing time, reinforcing its superiority in high-speed, low-latency underwater acoustic communication. PPM, on the other hand, requires the most processing time, while FSK and PSK offer moderate performance in terms of processing speed.

Table 5.5 Advantages and Dis-advantages of Modulation techniques

Modulation Techniques	Frequency Range	Advantages	Dis-advantages
FSK	3-12 KHz	• Low probability of error • High SNR • Simple implementation	• Large bandwidth Requirements • BER worse than other types of modulation
PSK	3-12 KHz	• Power efficient • High data rates • Flexible implementation	• Low bandwidth efficiency • Complex detection algorithms
PPM	3-12 KHz	• Better immunization against noise • Decoding is simple	• Large bandwidth needed • Transceiver must be synchronized
OFDM	3-12 KHz	• High spectral efficiency • Easily adaptable • Low sensitivity • Robust against multipath	• Sensitive to doppler shift • Guard interval causes loss of efficiency

Overall, the comparative analysis illustrates that while all four modulation techniques have their strengths and weaknesses, OFDM tend to offer better performance in terms of lower BER across varying noise levels. FSK and PPM, on the other hand, display more significant fluctuations, particularly at lower Eb/No values, indicating a higher sensitivity to noise. The analysis highlights the importance of choosing the appropriate modulation technique based on the specific noise conditions and performance requirements of the communication system.

CHAPTER # 6

Conclusion

6. Conclusion:

This study's analysis sought to identify the best modulation method for Low Noise Acoustic Transducer of Deep Water Echo Sounder. FSK, PSK, PPM, and OFDM were the methods were tested in the low noise frequency range of 3 to 12 KHz, with noise to simulate real world underwater communication challenges. MATLAB was used to encode and de-code the data, and the performance of each method was evaluated based on the resulting BER across different SNR.

The results of the modulation techniques comparative study showed that OFDM performed better than the other approaches in terms of sustaining a reduced BER over a broad range of noise levels. Other techniques, such as FSK and PSK, showed erratic performance with a discernible rise in BER at specific SNR levels, however OFDM continuously showed resilience to noise. BER for OFDM stayed comparatively lower, suggesting that it is less vulnerable to mistakes caused by noise, which are commonly encountered in underwater communication. The reason for this improved performance is that OFDM can partition the data into several orthogonal sub-carriers, making it easier to handle frequency selective fading and multi-path propagation, which are frequent problems in underwater settings.

Moreover, OFDM is specially well suited for Deep Water acoustic communication because its adaptability to various bandwidths and its effectiveness in making no use of the available spectrum. The results of the simulation demonstrated that, in contrast to other methods like FSK and PPM, which saw a considerable deterioration in signal quality, OFDM preserved its integrity as noise levels rise. This suggests that OFDM is more suited to maintain data integrity in the face of interference, which is essential for trustworthy communication underwater.

In conclusion, the findings of this study show that OFDM is the best modulation technique/method for Low Noise Acoustic Transducer of Deep Water Echo Sounder. Because of its ability to withstand noise and its effective utilization of the limited spectrum, it is the best option for establishing dependable and transparent underwater communication. The results highlight how crucial it is, to use the right modulation technique when creating communication systems for difficult situations, and OFDM is the recommended approach because of its proven benefits.

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