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A Highly Compatible Optical/Acoustic Modem based on MIMO-OFDM for Underwater Wireless Communication using FPGA

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ABSTRACT- This work is on Underwater Wireless Communication using optical/acoustic modem based on MIMO–OFDM method. Underwater Communication is a vast field where data analysis is performed on sea exploration, aquatic animals, aquatic species etc. But the current system is based on sound as medium for communication. This system faces many significant problems which plays a key role in affecting the performance of the entire system lost the data and resulting in efficiency of the system only for a few meters radius of transmission and reception. In this paper, the modem designed for both optical (light) and acoustic (ultrasound) signals using MATLAB Simulink and implemented on Xilinx System generator using FPGA. This helps in drastic reduction in the data loss. The communication of the proposed optical/acoustic modem is based on MIMO-OFDM multiplexing technique. The combination of MIMO-OFDM was very useful since MIMO does not use multiple generation i.e., it enhances the capacity by transmitting different signals over multiple antennas and OFDM reduces the need for signal equalization and increases the spectrum efficiency without adding additional bandwidth. The efficiency of the system is analyzed through the achieved data transmission and reception of data. The results prove the better performance of the proposed modem for underwater wireless communication.

Keywords: MIMO-OFDM, opto-acoustic modem, Underwater Communication, and efficiency.

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1. INTRODUCTION

As under water communication is a vast area with limited methods for its analysis. The first method of underwater communication was based on acoustic waves with huge data loss, high BER and noise interferences. Individual modems were used for transmitting and response of acoustical and optic signals intelligence were done individually. This has made the communication a time consuming and costly. Recently, a single modem was proposed for communication of both acoustic and optical signals with OFDM multiplexing technique. Delays caused by long propagation are used [1] in radio waves in free space and the difference in energy consumption for signal transmission and reception is caused by the submerged transducers. This introduces results for underwater acoustic signal propagation with less utilization of hardware energy. An underwater wireless optical communication shows a less absorption in visible spectrum range of 400 to 550nm. Current researches with advances resulted in communication of mid-range of about 200m with bandwidth of 1 Gbps in clear oceanic environment [2]. Characteristics governing transmission are outlined and trends are surveyed. Local particulate concentration with transmission signal wavelength selection is highlighted. A successful communication, the wavelength preferred is 430nm to 550nm and the range is beyond this when the particulate substances are high in the selected area. The physical fundamentals for an efficient data transformation in underwater communication are reviewed [3].

Underwater wireless Optical communication is found to be the most efficient and highly secured with high data rate for communications in submarines, ships, unmanned vehicles, buoys and divers and underwater sensors within a short range of less than 100m. Its applications extend for the study of oceanic and sea ecological, biochemical and climatic changes [4-5]. Despites all the favoring factors for underwater communication, underwater optical communication is found to be very challenging. The light propagation in water is greatly affected by its attenuation caused by the combination of scattering and absorption effects. In absorption, the energy of photon is lost due to the energy transfer when there is an interaction between the suspended particles and water molecules. practically the higher data rates are obtained by the combination of MIMO-OFDM. During the mid-1990s, the research conducted shows that the MIMO can be used with popular coming new technologies like 5G and 6G air interfaces. The exponentially ever-increasing need for bandwidth, performance of UWA and spatial diversity has made the way for the function of MIMO with OFDM multiplexing. This combination of multiplexing has proved its function as a

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promising solution in many scenarios in underwater wireless communication. On the other hand, the design challenges in implementing the scheme in order to achieve the bandwidth requirement is the contrary part of it. The underwater wireless communication has found its applications in pollution control monitoring, offshore exploration and data collection etc. Then, the changeable depths and dynamic variation of ocean causes the need for both acoustic and optical networking together in a single system. Thus, the various applications of opto-acoustic communication were also discussed in this paper. One of the most challenging transmission tasks is submerged acoustic/optical correspondence is the limited transfer speed, low data rate and bandwidth. limited data transmission is a major problem in underwater acoustic/optical channel and the changes in environment causes a greater effect on acoustic/optical communication. As a result, the transmission capacity that is supplied is stopped to kHz only [6].

Muhammad Tahir [7], explained the underwater wireless communication using EM waves. In this method, the transmitted data rate is increased but the propagation range is limited to deep and shallow sea water. The performance of EM waves is better in dirty and shallow waters. In paper [8], explored the different underwater communication channels like RF, acoustic and optical. In the application of water quality surveillance, UWSN is used. Evaluated the performance of multi-hop communication in comparison to direct transmission in terms of energy, transition rate, and propagation time.

The paper is organized as follows. In *section 2*, the design of a novel hybrid MIMO-OFDM based opto-acoustic modem and its implementation in Hardware is described in *section 3*. Then, in *section 4* explained about the results and discussion, and finally, concluded the design in *section 5*.

2. ARCHITECTURE OF A MIMO-OFDM BASED HYBRID OPTICAL/ACOUSTIC MODEM

A novel hybrid modem with MIMO-OFDM is proposed in this paper. The optical signals as well as acoustic signals are used the input. Separate channels are used for acoustic and optical source. Audio files are the input for acoustic channels and optical signals as input to optical channels. Both the inputs are sent to the MIMO-OFDM which is the most suited and efficient modulation technique for the proposed hybrid modem. using Fast Fourier Transform (FFT) as well as Inverse FFT (IFFT) MIMO-OFDM can be attained. single data stream (combination of acoustical and optic signals) at first and then it is split into multiple narrowband channels. It is done at different frequencies which reduces the reduces the interferences. In MIMO-OFDM transmitter, the capacity of the transmitter is multiplied over various unique signals through multiple antennas, and orthogonal frequency-division multiplexing (OFDM), divides a single radio channel into a large number of closely spaced sub-channels.

The modulated signal was sent through an additive white Gaussian noise before demultiplexing and then demodulated. Then error rate is calculated. At reception side, the signals were demultiplexed and then extracted based on the necessity. Signals are then differentiated as individual signals as acoustic (ultrasound) and optical (light) as found from their corresponding channels at the output side. In workplace, ultrasound module is used as the input source for generating acoustic signals and LED light is used as the input source for optical signal. Therefore, in the aimed MIMO-OFDM based hybrid opto-acoustic modem, both the acoustic and optical signals were transmitted and received successfully through a single modem.

2.1 An Overview of a MIMO-OFDM System

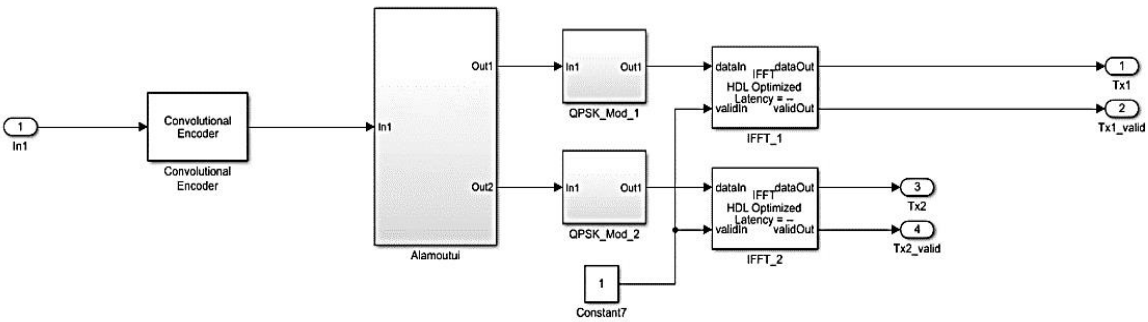

Figure 1: Design of a MIMO-OFDM Tx. Section using MATLAB Simulink

The dominant air interface for 4G and 5G broadband wireless communications is the Multiple-Input, Multiple-Output Orthogonal Frequency-Division Multiplexing (MIMO-OFDM). It combines the MIMO technology with OFDM, the combination of above increases the capacity of a channel by transmitting the distinct signals over multiple antennas is a MIMO technology and dividing an available channel into a huge number of closely spaced sub-channels and provides the high speed with secure reliable communication. At the transmitter side, when OFDM is implemented along with IFFT and OFDM with FFT at the receiver side, the conversion of wide band signal into N narrowband fading signals is done. Frequency selective fading is affecting this scenario. Thus, in the frequency domain itself, the equalization is performed by

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scalar division carrier with the co-efficient of sub-carrier channels. Thus, the knowledge of the channels at the receiver side is required before the implementation of the communication system. Thus, the combination of MIMO-OFDM is proved to be highly beneficial as OFDM technique facilitates the use of more antennas and obviously larger bandwidths too. Equalization is also simplified dramatically by MIMO. *Figure 1* and *figure 2* shows the design of a MIMO-OFDM transmitter & receiver section using MATLAB Simulink.

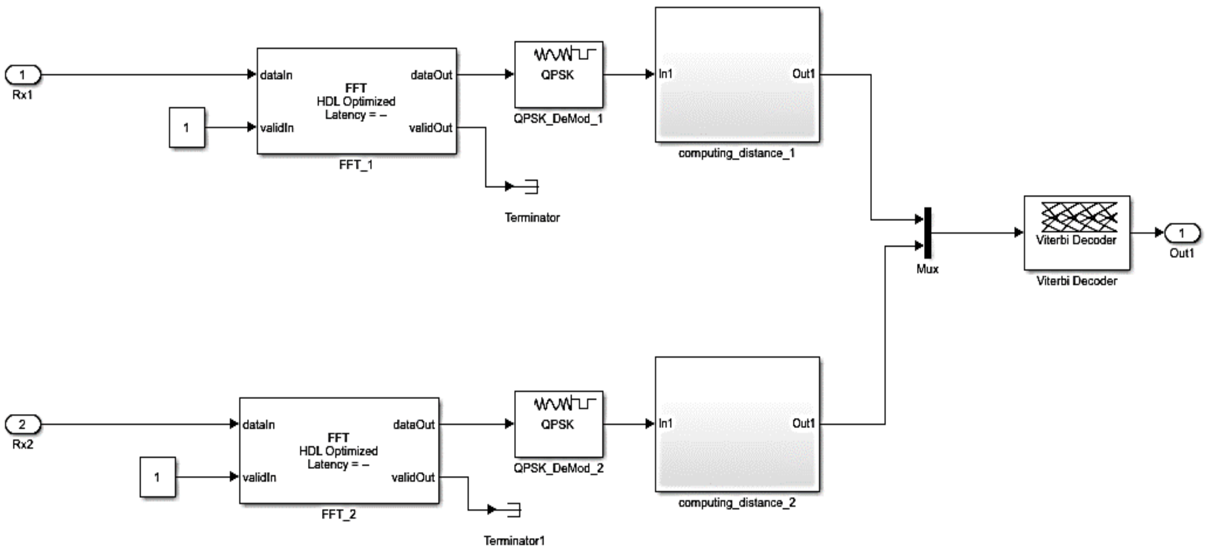

Figure 2: Design of a MIMO-OFDM Rx. Section using MATLAB Simulink

In this proposed modem, FFT and IFFT algorithm used for data transmission and reception. An FFT is an algorithm that computes the Discrete Fourier transform (DFT) of a sequence or its inverse (IDFT). Fourier analysis converts a signal from time domain to absolute frequency domain or vice versa. The decomposition of a succession of values into elements of various frequencies is called DFT. Such procedure has its application in various disciplines. IFFT is a fast algorithm and it performs reverse of FFT, that is converts a signal in frequency domain to time domain. 555 timer is used for the generation of square wave and is shown in *figure 3*.

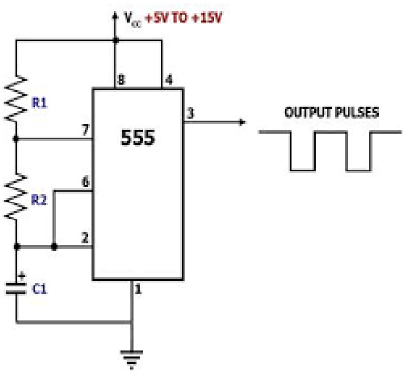

Figure 3: The Circuit of 555 timer

3. HARDWARE IMPLEMENTATION

Figure 4 shows the Hardware Experimental Block diagram representation of a MIMO-OFDM based hybrid Optical/Acoustic Modem for UWC system.

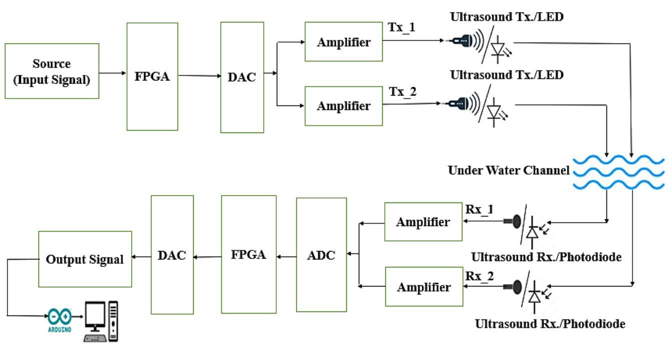

Figure 4: Experimental Block diagram of a MIMO-OFDM based Hybrid Optical/Acoustic Modem for UWC

This modem has the source of inputs is LED for optical signal and ultrasound module for acoustic signals. The input signals are simultaneously fed into FPGA and then it is sent to DAC where the conversion of digital to analog signals is done. Then the converted signals are fed into the amplifier where the input signals are amplified which is ready to be transmitted over the corresponding transmission channels as acoustic and optical signals. The transmitted signals are received separately through antennas and are fed into the amplifier again and are then sent into the ADC section. Here, the received analog signals are converted back into the digital signals. The converted signals are fed into FPGA at the receiver side and the output of FPGA is again fed into digital to analog converter. Here the signals are converted into analog signals which is then amplified again. Finally, the amplified signals are got as the output signals of the receiver side.

Research Article | Volume 11, Issue 4 | Pages 993-1000 | e-ISSN: 2347-470X

The circuit designed for the transmitter side of the defined hybrid modem was implemented with MIMO-OFDM and is shown in *figure 5*. *Figure 6* shows the real time design of the receiver side of the defined hybrid optical/acoustic modem with MIMO-OFDM.

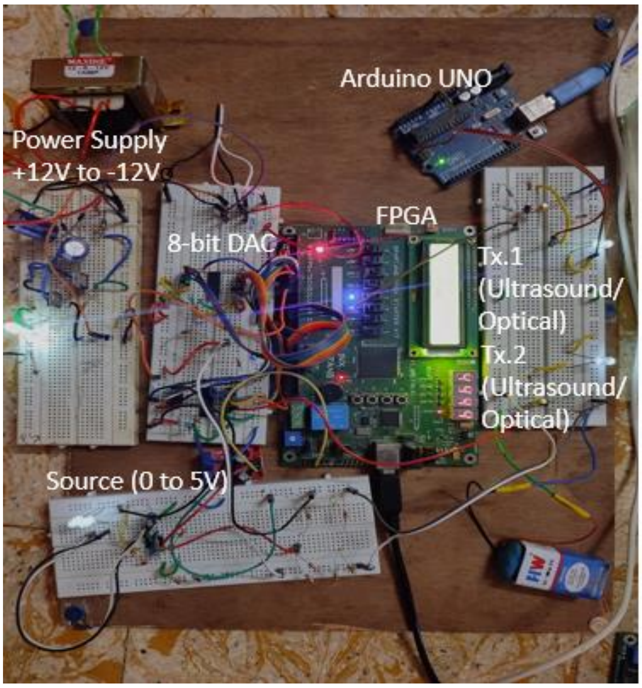

Figure 5: MIMO-OFDM based optical/acoustic Modem Transmitter Section

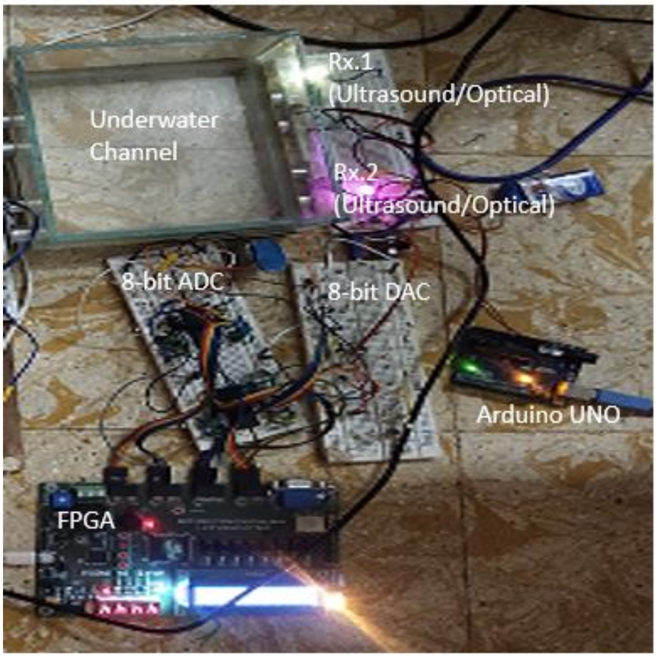

Figure 6: MIMO-OFDM based optical/acoustic Modem Receiver Section

The underwater communication channel setup for both the transmitter and the receiver of a MIMO-OFDM based hybrid optical/acoustic modem is shown in the *figure 7*.

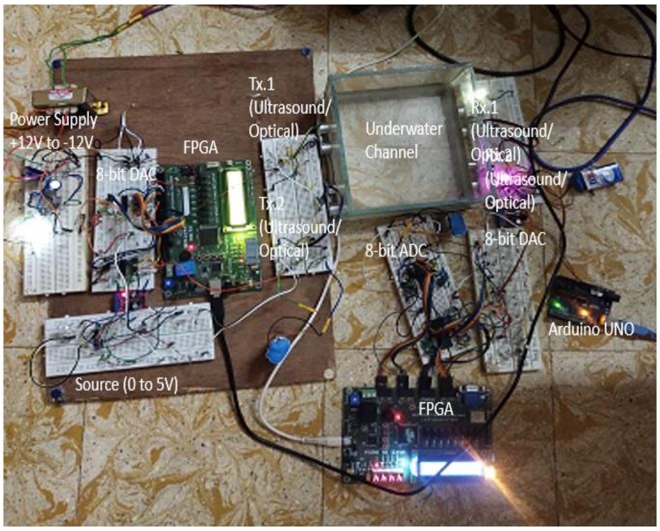

Figure 7: Tx, Rx and Underwater Channel set-up of a MIMO-OFDM based optical/acoustic Modem for UWC

3.1 Acoustic (Ultrasound) signal transmission and reception through Underwater Channel

Figure 8 shows the circuit for the transmission and reception of acoustic (ultrasound) signal through underwater channel. Source (0 to 5V) constructed for generating input pulse signals (0V as 0 and 5V as 1) for MIMO-OFDM. The source output of the circuit is given as input to the FPGA pins. MIMO-OFDM is implemented in FPGA. the transmitter end consists of ultrasound module for acoustic signal transmission. the transmitter sections (Tx.1 and Tx.2) are constructed using transistor (SL100) as an amplifier circuit with necessary circuit elements as shown in above. Similarly, the receiver section (Rx.1 and Rx.2) also constructed using transistor (SL100) as an amplifier with necessary circuit elements as shown in above. The Output is taken out from FPGA pins and is applied as input to Trigger pin of HC SR04 which is a transmitter that transmits ultrasound (acoustic) signal.

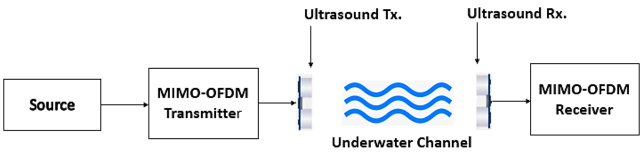

Figure 8: Schematic representation of transmission and reception of ultrasound signal through Underwater channel

Then the transmitted ultrasound signal is captured from Echo Pin of HC SR04 which acts as Receiver. The output of Echo Pin of HC SR04 is given as input to Arduino Uno Board to the A1 Analog In. This is aimed to capture the analog signal for processing in Computer. The python program intends to acquire signal for COM4 port of the computer and computes the spectrum.

3.2 Optical (Light) signal transmission and reception through Underwater Channel

Figure 9 shows the circuit for the transmission and reception of optical (light) signal through underwater channel. Source (0 to

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Research Article | Volume 11, Issue 4 | Pages 993-1000 | e-ISSN: 2347-470X

5V) constructed for generating input pulse signals (0V as 0 and 5V as 1) for MIMO-OFDM. The source output of the circuit is given as input to the FPGA pins. MIMO-OFDM is implemented in FPGA. the transmitter sections (Tx.1 and Tx.2) are constructed using transistor (SL100) as an amplifier circuit with necessary circuit elements as shown in above. Similarly, the receiver section (Rx.1 and Rx.2) also constructed using transistor (SL100) as an amplifier with necessary circuit elements as shown in above. The Output is taken out from FPGA pins and is applied as input to the transmitter that transmits light (as signal). Then capture the transmitted light (signal) using Receiver with photo diode or Light Dependent Resistor (LDR). Then the output of receiver is given as input to Arduino Uno Board to the A1 Analog In. This is aimed to capture the analog signal for processing in Computer. Then the python program intends to acquire signal for COM4 port of the computer and computes the spectrum.

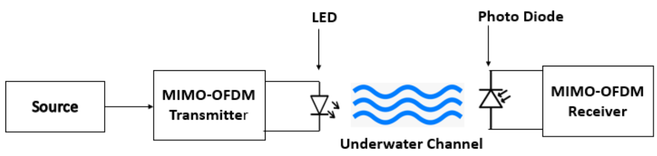

Figure 9: Schematic representation of transmission and reception of optical signals through Underwater channel

4. RESULTS AND DISCUSSION

The general power analysis for the transmitter and the receiver is shown in *figure 10* and *figure 11*. After simulation, the spectrum analysis for the result of the transmitted signal and the received signals through two transmitters and receivers is done. The bandwidth consumption of each MIMO-OFDM is found to be 234.47 MHz Hence, the total bandwidth required for the entire MIMO-OFDM system in the proposed hybrid modem is 938.28 MHz.

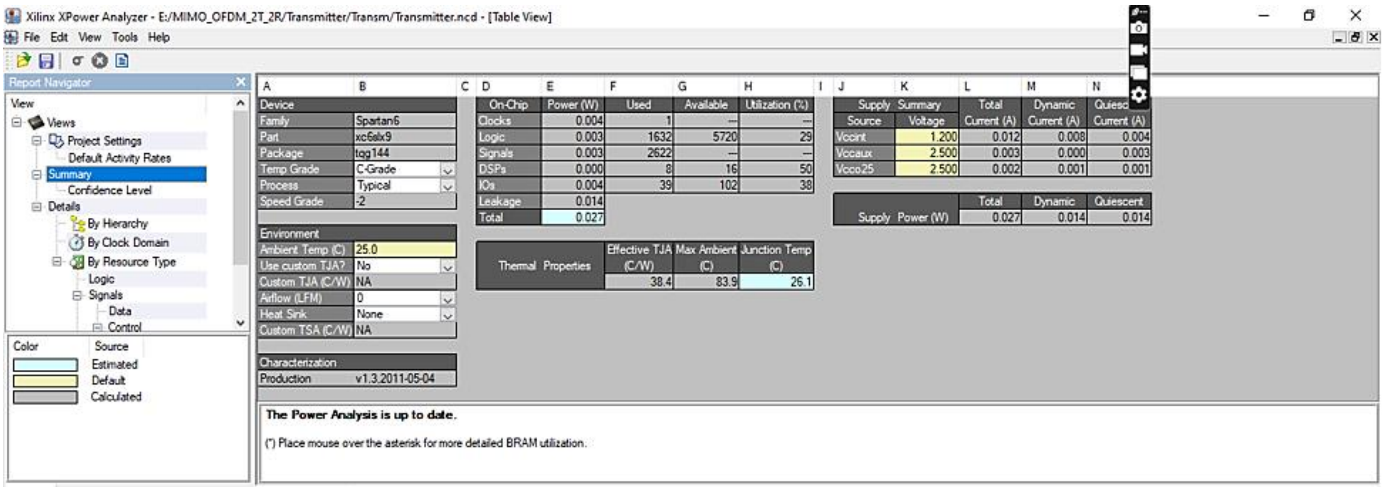

Figure 10: Transmitter power analyser

Figure 11: Receiver power analyser

The spectrum analysis of the transmitted and the received input optical and acoustic signals are done. *Figure 12* shows the FFT spectrum of the transmitted acoustic (ultrasound) signal through transmitter_1.

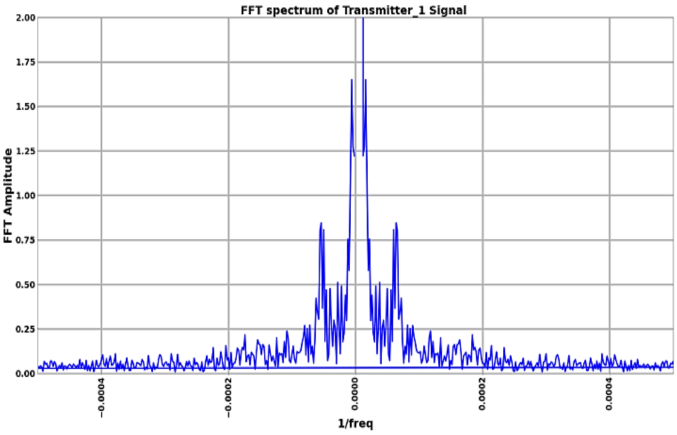

Figure 12: FFT Spectrum of acoustic (ultrasound) signal at Transmitter_1

The FFT spectrum of the received acoustic (ultrasound) signal through receiver_1 is shown in *figure 13*.

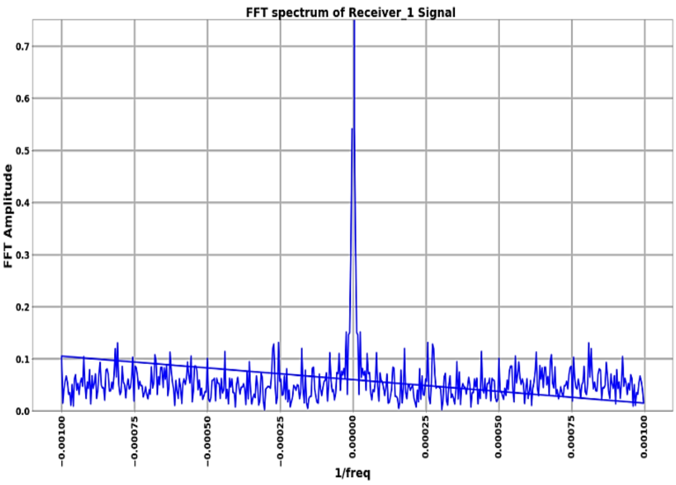

Figure 13: FFT Spectrum of acoustic (ultrasound) signal at Receiverer_1

The FFT spectrum of the transmitted acoustic (ultrasound) signal through transmitter_2 is shown in *figure 14*.

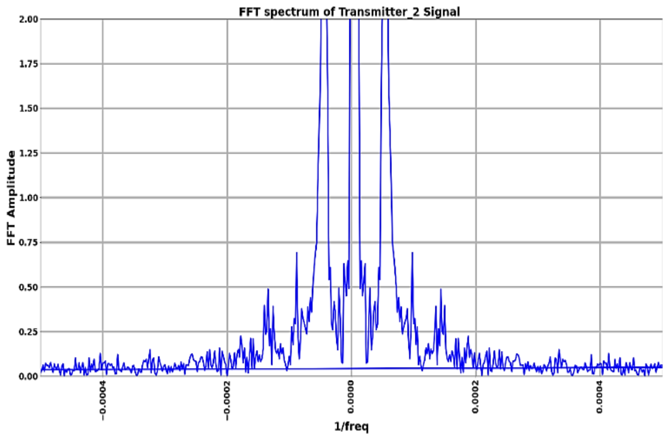

Figure 14: FFT Spectrum of acoustic (ultra sound) signal at Transmitter_2

The FFT spectrum of the received acoustic (ultra sound) signal through receiver_2 is shown in *figure 15*.

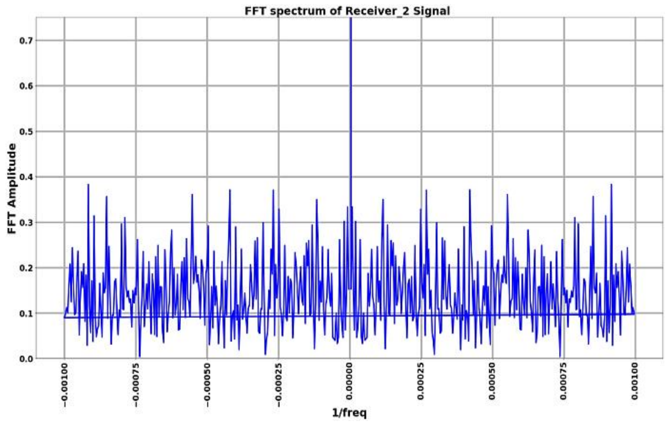

Figure 15: FFT Spectrum of acoustic (ultrasound) signal at Receiverer_2

The FFT spectrum of the transmitted (Input source) and received (output) acoustic (ultrasound) signal through MIMO-OFDM Tx. and Rx. sections were shown in *figure 16* and *figure 17*.

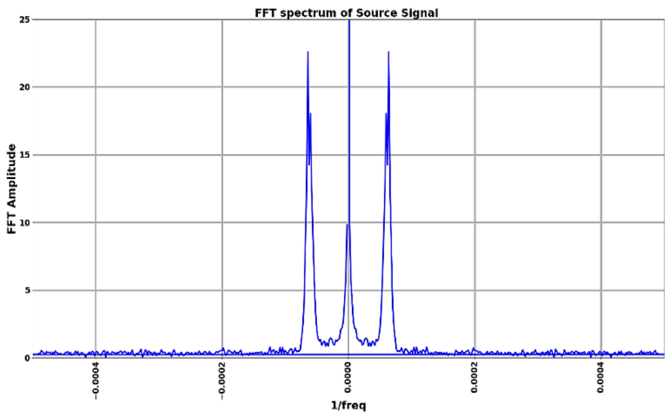

Figure 16: FFT Spectrum of input source acoustic (ultrasound) signal

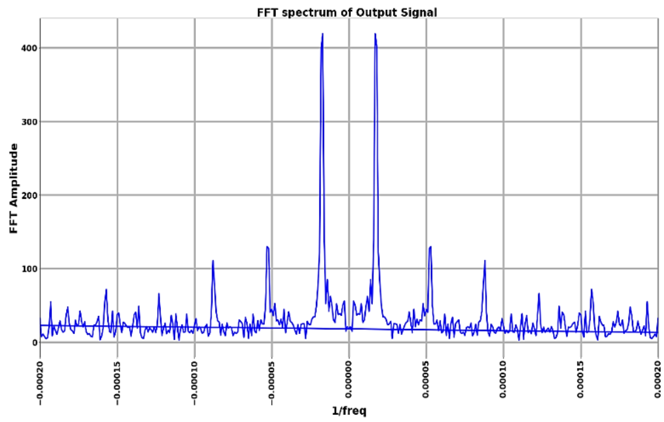

Figure 17: FFT Spectrum of Output acoustic (ultrasound) signal

The FFT spectrum of the transmitted optical (light) signal through Transmitter_1 is shown in *figure 18*.

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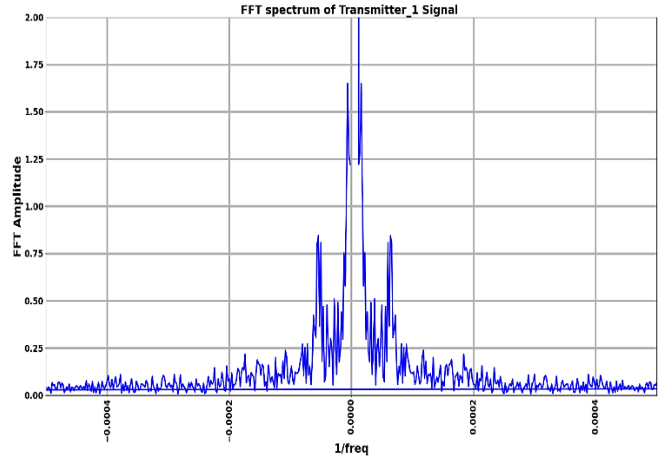

Figure 18: FFT Spectrum of Optical (light) signal at Transmitter_1

The FFT spectrum of the received optical (light) signal through Receiver_1 is shown in *figure 19*.

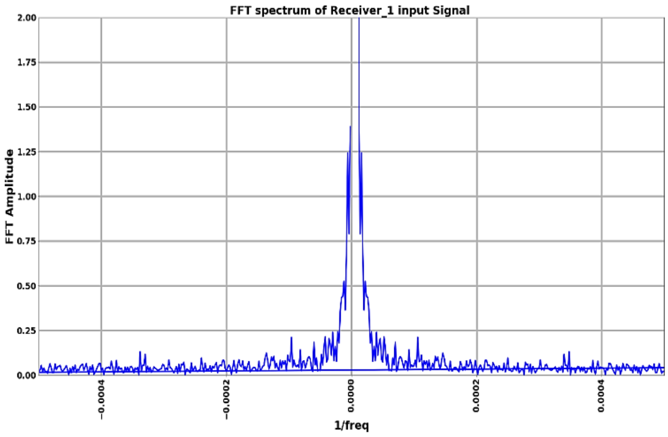

Figure 19: FFT Spectrum of Optical (light) signal at Receiver_1

The FFT spectrum of the transmitted and received optical (light) signal through transmitter_2 and receiver_2 is shown in *figure 20* and *figure 21*.

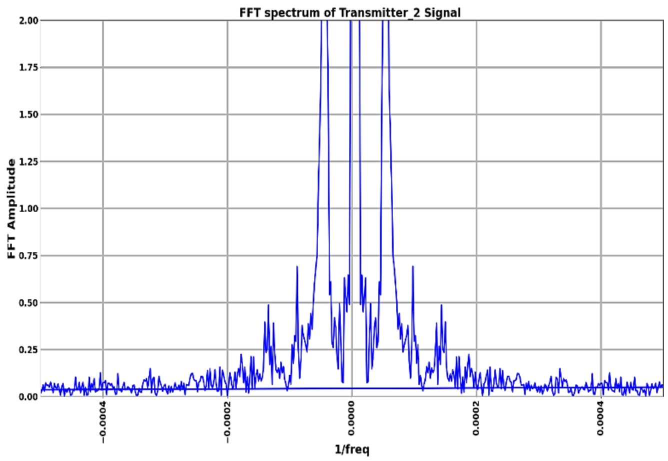

Figure 20: FFT Spectrum of Optical (light) signal at Transmitter_2

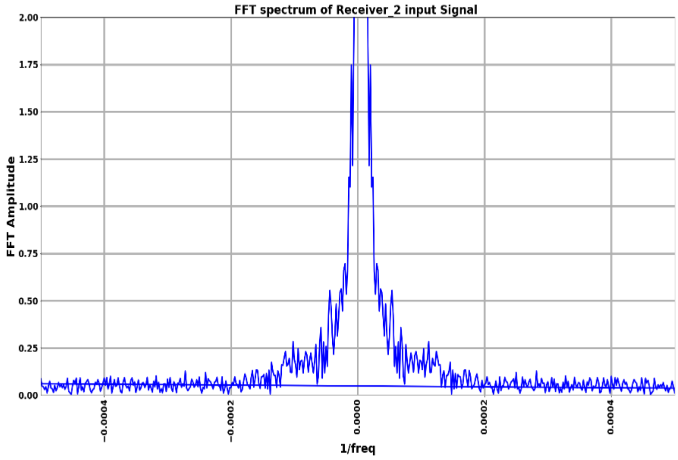

Figure 21: FFT Spectrum of Optical (light) signal at Receiver_2

The FFT spectrum of the transmitted (Input source) and received (output) optical (light) signal through MIMO-OFDM Tx. and Rx. sections were shown in *figure 22* and *figure 23*.

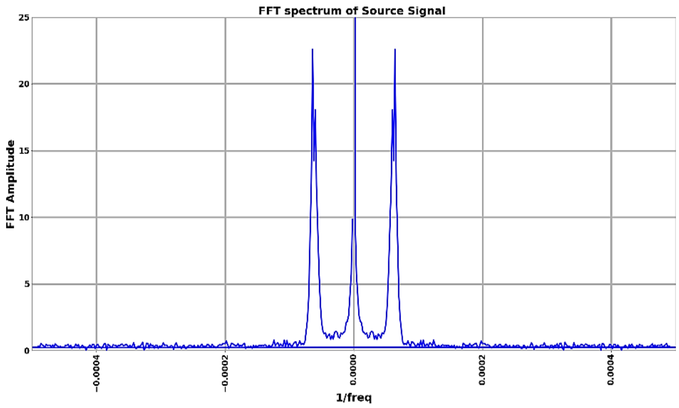

Figure 22: FFT Spectrum of Input source Optical (light) signal

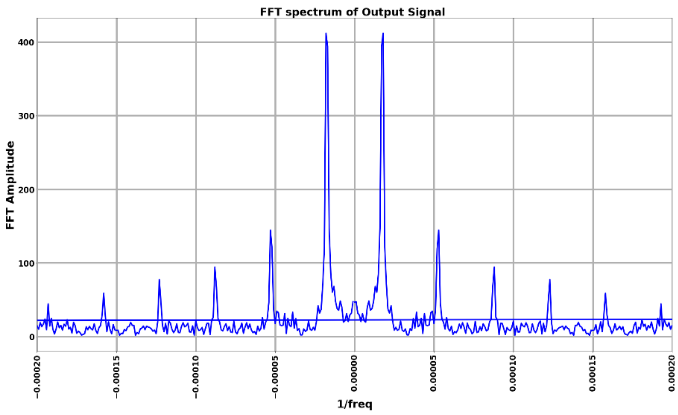

Figure 23: FFT Spectrum of Output source Optical (light) signal

From the spectrum analysis and the transmitted and received signal strength, the loss of the signal is found to be around 0.2dB between the receiver input and the transmitter output. Similarly, the signal loss is by 1.6 dB between the receiver output and the transmitter input. The speed of transmission and reception of acoustic signal is found to be 5Kbps. Similarly, the transmission and reception of optical signal is found to be 1.2Gbps. The comparison of the parameters like bandwidth, power, data rate, attenuation, BER and cost for different modems are listed in *table 1*.

Table 1: Comparison of Parameters for the Proposed MIMO-OFDM Based Optical/Acoustic Modem

Parameters	Modem			
	Acoustic	Optical	Opto-Acoustic	MIMO-OFDM based Optical/Acoustic
Band-width	1KHz-100KHz	<150MHz	18MHz-140MHz	234.57MHz-938.28MHz
Power	Few Tens of Watt	mW-Watt	1.585 W	0.027 W (Tx.) 0.018 W (Rx.)
Data Rate	In Kbps	Up to Gbps	9.6 Kbps	5 Kbps-1.2 Gbps
Attenuation (Signal Loss)	0.1 dB-4 dB	0.39 dB-11 dB	-	0.2 dB-1.6 dB
BER	-	-	-	0.49-0.51 %
Cost	High	Low	Economical	Economical

5. CONCLUSION

In this paper, Designed and Implemented a Hybrid model MIMO-OFDM based Optical/Acoustic Modem for Underwater Wireless Communication using FPGA. From the results, the signal intensity obtained for both acoustic and optical signals through different transmitters and receptors is found to be almost same. The achieved signal loss between Rx. input and Tx. output is 0.2dB and 1.6dB between the Rx. output and Tx input. The transmission and reception of optical (light) and acoustic (ultrasound) signals through an individual modem implemented with MIMO-OFDM is proved to be efficient for Underwater Wireless Communication. Practically the proposed hybrid modem with MIMO-OFDM serves as a simple solution for the upcoming generations of high speed underwater opto-acoustic communication which is bandwidth limited. The future scope of the work can be towards still more optimized bandwidth and operating conditions.

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Contributions: CH. Pallavi conducted the experiment and analyzed the data from the experimental results. Manuscript preparation, data collection and analysis were performed by CH. Pallavi. All authors read and approved the final manuscript.

Conflict of Interest: The authors of this research declare that they have no conflicts of interest.

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