A Design of Novel Hybrid Opto-acoustic Modem for Underwater Communication

M.Lenin Kumar, M.Janaki Rani

Abstract: ***Underwater communication has become one of the most interesting and rapid growing field with its broad areas of water based applications in military and also in commercial systems. Its communication channels undergo severe attenuation, frequency dispersion, multipath effect and limited power resources which has made it one of the most challenging communications. Of these key challenges, optical and acoustic are the most predominantly compelling underwater communication with complexities for long range and high bandwidth requirement especially power constrained modems. In this paper, integration of both optical and acoustic signals through a single hybrid opto-acoustic modem is proposed for underwater communication. The proposed modem has been simulated for transmission and reception of both optical and acoustic signals. The output signals are verified with respect to the input signal. The proposed design has been simulated and the simulation results prove the success and efficiency of the proposed hybrid modem design. Achieving high bandwidth for long distance transmission with low power consumption and high speed on terrestrial and subsequently in underwater can be carried out as the future work.***

Keywords: ***underwater communication, optical communication, acoustic communication, opto-acoustic signals, Orthogonal frequency-division multiplexing (OFDM).***

I. INTRODUCTION

The underwater application has gained increasing and interestingly wider scope and range from simple telemetry application like movement detection and pipeline surveillance in coastal areas to the more complicated mission applications involving submarine which also needs to track moving objects. All the communication techniques are originally designed and developed for terrestrial communication channels and these are modified to suit for the underwater communication channels. Acoustic communication has been proved to be best suited for long distance underwater communication despite their low bandwidth constraint which is considered as the commanding challenge. The ranges of the distance are from a few hundred meters to a few kilometers. Some of the other challenges in acoustic communication are Multipath, refractive properties, rapid time variation, fading and Doppler shifts[8]. For a very short distance, uses short range and high frequency acoustic modems and one or more kilometers are meant for high frequency acoustic modems.

Revised Manuscript Received on June 05, 2019

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To overcome this short come, Optical underwater communication is being considered as the best possible solution. Over thirty years, the use of visible light was considered as the best viable technology for underwater communication since the reduced attenuation caused by the absorption of the electromagnetic waves by the sea water. Figure 1 represents the underwater communication.

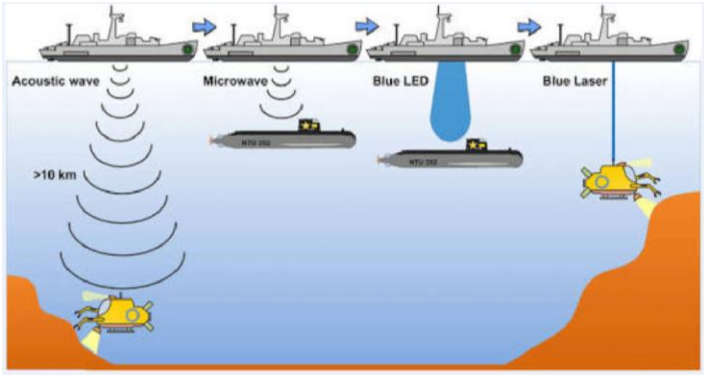

Fig. 1 Schematic representations of underwater communication

II. LITERATURE SURVEY

Long propagation delays are made use of in [1] with respect to the radio waves in the free space and the difference between the transmitted and the received energy consumption produced by the underwater transducers, to introduce solutions for underwater sound propagation and minimization of hardware energy. The protocols are developed for efficient transmission scheduling in a 3D deployment to optimize the energy consumption by adopting the best suited topology management. Paper [2] proposes an optical wireless communication for underwater since sea water exhibits a reduced absorption in visible spectrum specifically between 400-550nm. Recent researches and developments have paved the way for mid-range communication 200m at high bandwidth of 1Gbps in clear ocean. The importance of local particulate concentration and the selection of transmission signal wavelength have been highlighted.

The physical fundamentals and the engineering implementations for an efficient information transmission for underwater communication has been reviewed in paper[3]. The physical waves under consideration includes, radio, light and sound. The fundamental physics of various waves have been studied first.

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Later the pros and cons of adopting the different communication carriers for acoustic, radio and optical which are based on the fundamental engineering practice. Paper [4] focuses on the feasibility and reliability of underwater optical communication based on the physio-chemical systems with the effects of various phenomena which has impact on the system performance. An exhaustive overview has been presented of ultra optical underwater communication. A hybrid approach of both acoustic and optical communication has been tried in the existing acoustic system which has resulted in high data rates, less energy consumption along with low latency. paper

A low cost and low power acoustic modem has been designed in paper[5] to have better short range communication. The tests are performed with transducers for an in- air communication. The efficient functioning of the proposed new design modem has been proved by the successful transmission and reception of data with low latency. [21] provides a comparative study of three dispersion comparison fiber model as pre, post and symmetrical which involves the concept of compensation fiber of Bragg grating under 40Gbps single channel optical fiber transmission system. Three modulation schemes duo-binary coding, modified duo-binary and carrier suppressed return to zero are simulated and analyzed in terms of Q-factor and bit error rate for each set up by range of CW laser power. The simulation of optical system based on optisystem-10. In paper [22], a DC-biased optical OFDM and asymmetrically clipped OFDM are considered for underwater optical wireless communication. This produces a half-way symmetry time signal at the output modulator by assigning the subcarriers. This assigns data. This DC based OFDM assigns data evenly to all possible subcarriers in order to increase the data rate. This paper considers a practical LED model to study the performance in terms of average electrical OFDM signal power versus bit error ratio in the presence of AWGN.

III. COMPARISON OF ACOUSTIC AND OPTICAL COMMUNICATION

A Modem converts digital signals into analog signals and are transmitted over a medium. At the transmitter side, the signals are modulated with the required modulation schemes like FSK, PSK, BPSK and QPSK. At the receiver end, the MODEM demodulates the received analog signals and is reconstructed into its corresponding digital signals. Designing a low cost and low power modem is a key challenge in underwater communication. In this section, basic underwater optical and acoustic communication and its modem design is discussed.

Optical communication

Present underwater communication involves the information transmission in the form of optical and acoustic waves. All these techniques have their own advantages and limitations. Optical waves are also the electromagnetic waves having the wavelength range between 400nm and 700nm[14]. Due to their high frequency, short wavelength and high speed, it paves the way for high speed communication upto 1Gbps[6],[7]. The most significantly used inherent property is the attenuation co-efficient(c), which is used to find out the loss of optical power meter and is measured in m^{-1}[15],[17]. Both scattering and absorption gives rise to attenuation. Based on Beer's law, the optical power (I_o) for a distance (d) with a transmitted power (I_t) is given by equation 1. Figure 2 shows the schematic representation of optical communication system

$\mathbf{I_o = I_t\, e^{-cd}}$…………..(1)

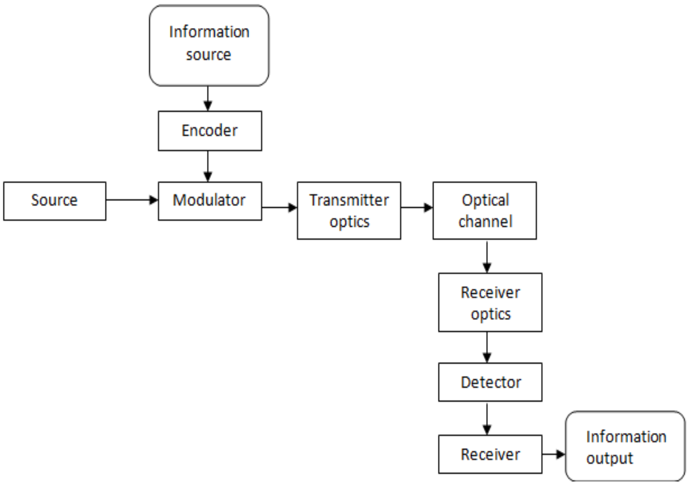

Fig. 2 Schematic representation of optical communication system

Refractive index(n) is defined as the ratio of speed of light in vacuum to the speed of light in a medium. The refractive index can be related to attenuation coefficient through the below mentioned equation 2 [16],[18].

Complex refractive index, $m = n + i_k$…………..(2)

Where k – imaginary electrodynamic absorption coefficient. It is related to the absorption through the factor 4Π/λ where, λ is the wavelength of the transmitted signal.

Acoustic Communication

In water, sound waves are propagated at very low speed say approximately 1500m/s. The propagation of waves occurs at multiple paths. In addition to path loss, spreading loss also incurred which is directly proportional to the transmission distance. Hence the overall path loss is given by equation 3

$\mathbf{A(l,f) = (l/l_r)^k a(f)^{l-lr}}$…………..(3)

Where f- frequency of signal, l – transmission distance (considered with reference to a distance l_r)k- path loss exponent, a(f) – absorption coefficient

Design of Underwater Acoustic Modem

The components of underwater communication are Power unit, it consists of battery and DC/AC converters and a processing unit holds a small memory and a processor. Sometimes external memory can also be added. Loudspeaker or a hydrophone is a source. The Circuitry adapts the signals to the processor for processing. However, RS-232 is being used by the commercial modems or USB port to program it or to download the stored data. Figure 3 shows the block diagram of the underwater acoustic communication modem.

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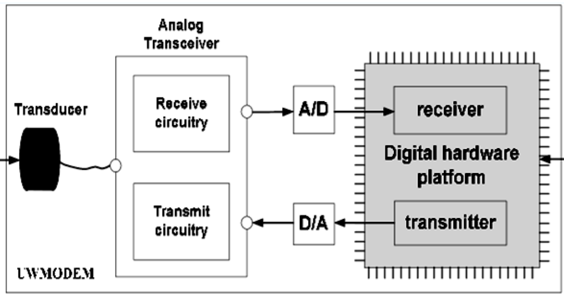

Fig. 3 Block diagram of underwater acoustic modem

The performance comparison of acoustic and optical underwater communication in telemetry method is done. The optical communication range is 100m with the data rate of 1Mbps and its performance efficiency is measured as 30,000bits/joule. In acoustic communication, the coverage distance is of several kilometers and the data rate is 1Kbps with the performance efficiency achieved as 100bits/joule. Table 1 shows the comparison of underwater communication systems [9], [19].

Table. 1 Comparison of underwater communication systems

Parameter	Acoustic	Optical
Transmission distance	Upto 20Km	10-30 m
Attenuation	Distance and frequency dependent	Distance
Speed	1500 m/s	2.255×10^8 m/s
Transmission power	Few tens of watts	Few watts
Cost	High	Low
Data rate	In Kbps	Upto Gbps
Antenna size	0.1m	0.1m
Latency	High	Low

IV. EXISTING METHODS

In [23], several techniques have been established to accomplish a low-power underwater communication application with increased monitoring life and all- analog wakeup tone receiver which triggers the data receiver which is more expensive. The modem hardware has three main portions, a wakeup receiver, a single transmitter and a data receiver. There are three output frequencies which corresponds to the data space, data mark and a wakeup tone. It is impossible to transmit simultaneously data and the wakeup tone. The figure 4 shows the modem hardware and the circuit operating power is 5 volt. The software control of the power distribution is carried on by the power control block so that both the receivers and the transmitter can be turned on or off. Shifters are used for compatibility.

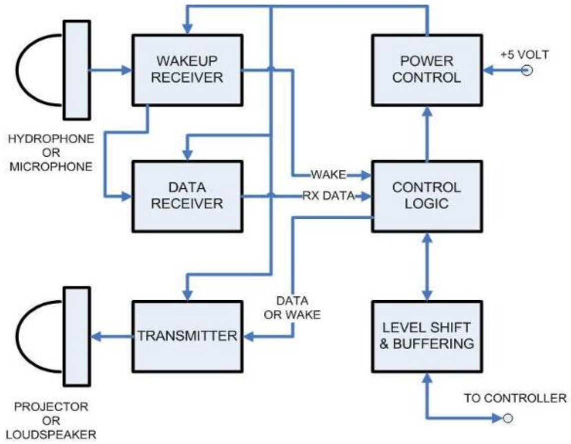

Fig. 4 Block diagram of modem

The major hardware portion is implemented in TinyOs to support the packet level communication. The design moto is to promote modularity and clear layering. [24],[12],[13] presents a system design for wireless underwater optical communication. Figure 5 shows the block diagram of underwater optical communication system .It consists of the source which generates information which has to be transmitted. The information generated is then modulated according to the carrier.

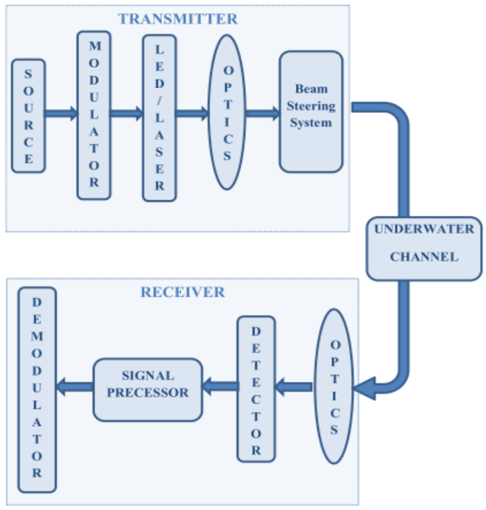

Fig. 5 Block diagram of underwater optical communication system

The projection optics and the beam steering elements are in the transmitter which focuses and steers the optical beam towards the direction of the receiver. The signal which bears the information is then propagated through the underwater communication channel. At the receiver side, the incoming signal is collected and is passed to the detector which converts the optical to electrical signals [11]. The converted electrical signal is then passed through a Signal Processing Unit (SPU) and finally through a demodulator to recover the original transmitted signal. In [20], a soft acoustic modem test bed has been designed and constructed for transmission of image.

The modem is intended for testing the designed algorithms. Figure 6 depicts the acoustic modem test bed. There is a PC in the transmitter section which serves as the transmitter. The process of transmission starts with the image information processing. The image information is converted into binary sequences and error correction is done through coding. FSK, QPSK or BPSK can be adopted with OFDM. The carrier frequency is 7 to 15 KHz. The Digital to Analog conversion is performed by external DAC to receive a better audio output. Voice Activity Detector (VAD) is used for sound detection. It determines the start time of the recording process. By adopting the coherent detection, synchronization for determining the initiation of transmission signal and the demodulation process is achieved.

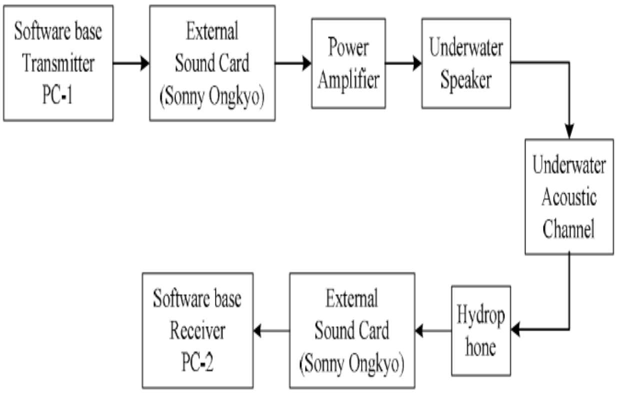

Fig. 6 Design of underwater communication test bed [20]

V. PROPOSED HYBRID OPTO-ACOUSTIC MODEM

In this paper, a novel hybrid modem has been proposed which can take both the optical signals and acoustic signals as the input. The there are separate channels for acoustic source or transmission and for optical source and transmission. Audio files are given as input to the acoustic channels and optical signals are fed as input to the optical channels. Both these inputs are fed to the Orthogonal Frequency Division Multiplexing(OFDM) which is the most suited modulation technique for our proposed modem. OFDM has been achieved by using Fast Fourier Transform(FFT). Here, the single data stream (combined optical and acoustic signals) is split as several narrowband channels at various different frequencies inorder to reduce the interferences.

OFDM system

The Figure 7 shows the OFDM signal generated by the system at baseband. figure 8 shows the proposed OFDM transmitter and figure 9shows the OFDM receiver. Figure 10 shows the proposed OFDM receiver. OFDM allows a high spectral efficiency as its modulation scheme and carrier power can be controlled individually for each carrier. The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams which are transmitted simultaneously over a number of subcarriers.

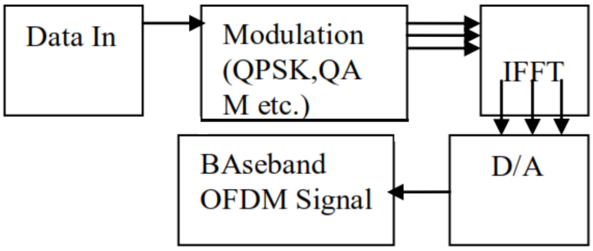

Fig. 7 OFDM Transmitter

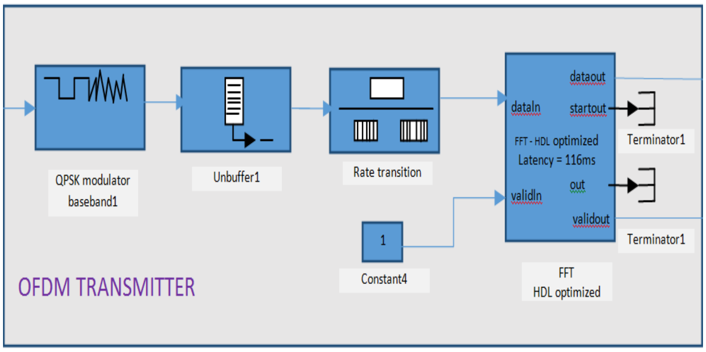

Fig. 8 Proposed OFDM Transmitter

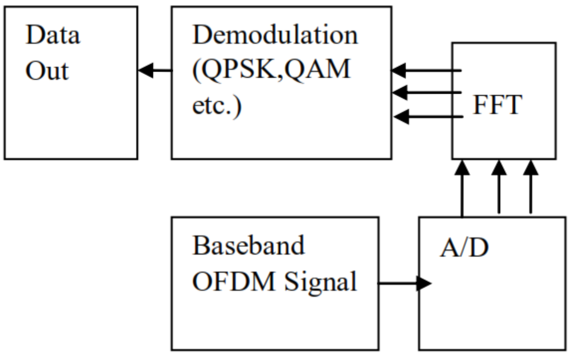

Fig. 9 OFDM Receiver

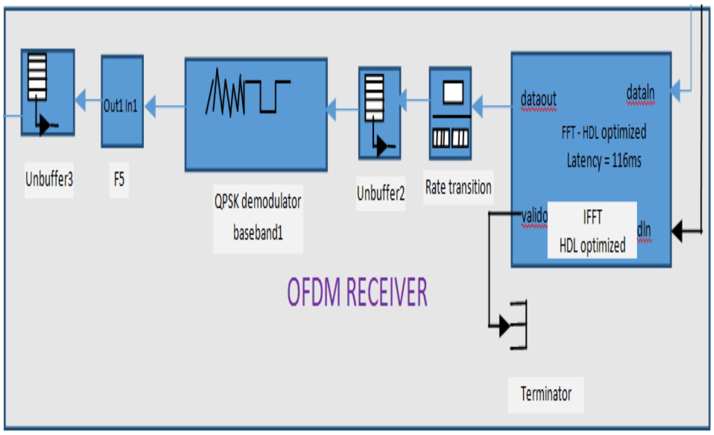

Fig. 10 Proposed OFDM Receiver

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Figure 11 shows the simulation circuit of the proposed hybrid Opto-acoustic modem. The variant source and variant sink are called as the variant regions which are based on the block connectivity. The computing process of variant choice regions is called as variant condition propagation. The variation on the signal source is provided by the Variant source. Similarly, the variation on the destination or the output signal is provided by the Variant sink. The variant conditions are implanted at both the inports and outports of its Variant Source and sink. An AWGN channel is added which adds white Gaussian Noise to the real input signal which passes through it after being transmitted by OFDM. This produces a real output signal. Similarly, when the given input signal is complex this adds a complex white Gaussian noise to produce a complex output signal. AWGN block inherits the sample time from the given input signal. Random source of DSP is used to generate the noise. The noise generator is initialized by the initial seed parameter. Priority encoder can be used to activate the switch.

In OFDM transmitter, the input signals are first Quadrature Phase Shift Keying(QPSK) modulated and then subjected to generate and analyze the received OFDM signals. The modulated signal is then passed through an additive white Gaussian noise prior to demultiplexing and demodulating. Then the number of bit errors is calculated. In the receiver part, the signals are demultiplexed and demodulated and according to the requirement, the signals are separated as optical and acoustic signals and are received through their respective channels at the output devices. In test bed, mike and LED are used as the source for acoustic and optical signal generations. The acoustic sensors are used as the output device. The proposed hybrid opto-acoustic modem has successfully transmitted both the acoustic and optical signals through a single modem and the signals are effectively received at the respective output devices.

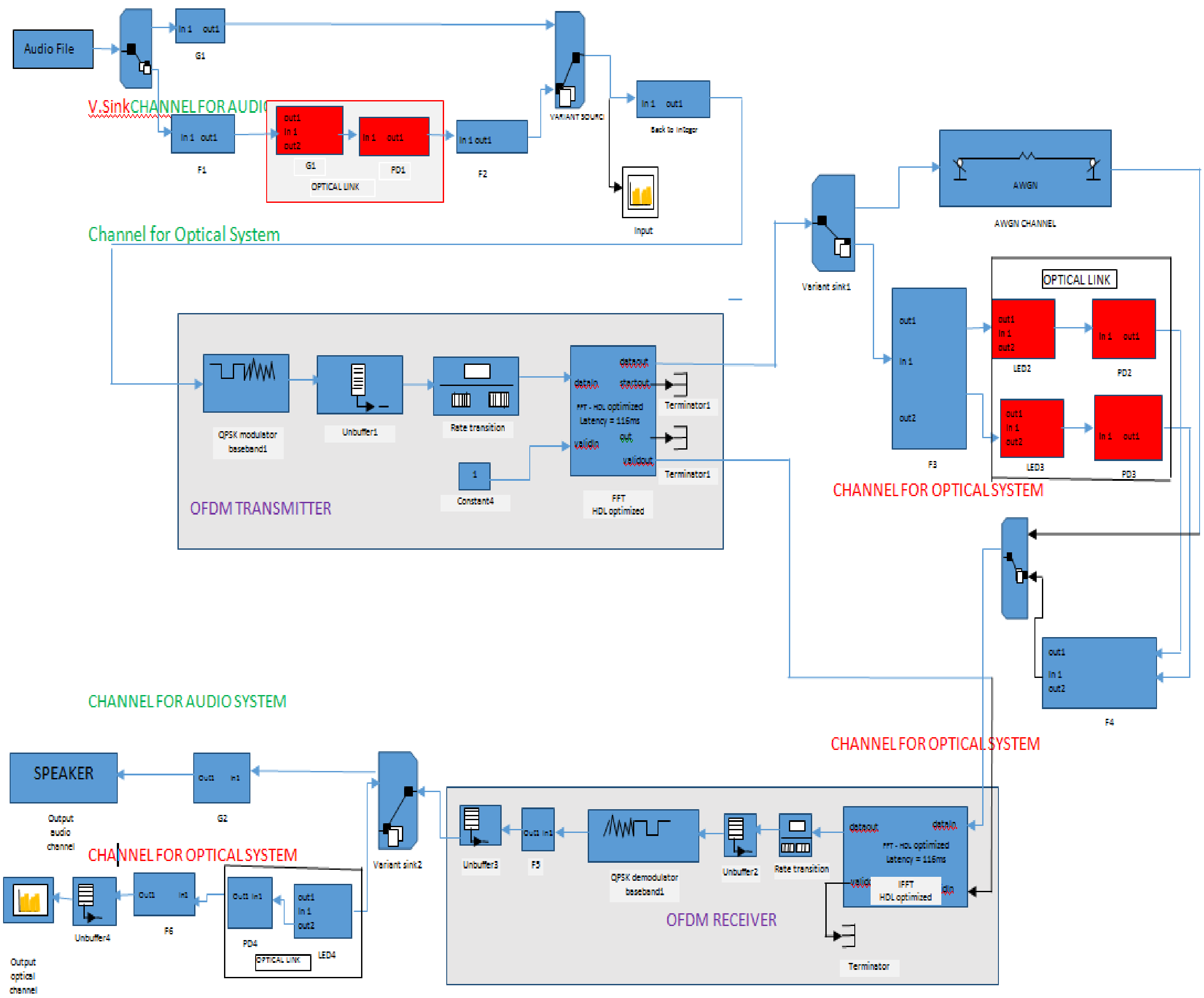

Fig. 11 Proposed hybrid Opto-Acoustic modem

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VI. RESULTS AND DISCUSSIONS

MATLAB version R2017a is used for simulating the signals. Three iterative sets of input files of acoustic and optical signals are transmitted and received. Figure 12 and 13 shows the received first set of output acoustic signal and optical signals with the given below audio input file 1 through the novel hybrid modem. Similarly, figure 14 and 15 are the second set of received audio and optical output files with the given below audio input file 2. Also, figures 16 and 17 are the third set of received acoustic and optical output files for the given audio input file 3. Priority encoder and decoder can be implemented to assign the required priority for receiving the outputs.

Audio input 1: “INDIA IS A BEAUTIFUL COUNTRY TO LIVE”

Audio input 2: “INDIA IS A LOVELY PLACE TO LIVE”

Audio input 3: “I LOVE MY FAMILY”

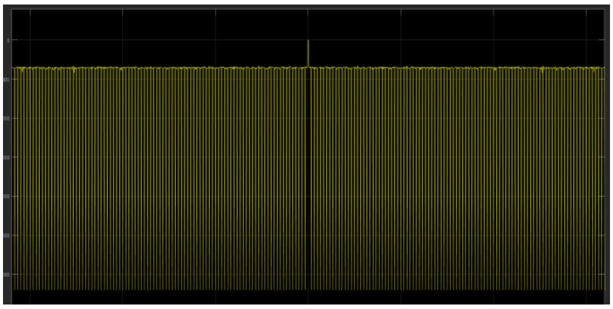

Fig. 12 Audio output1

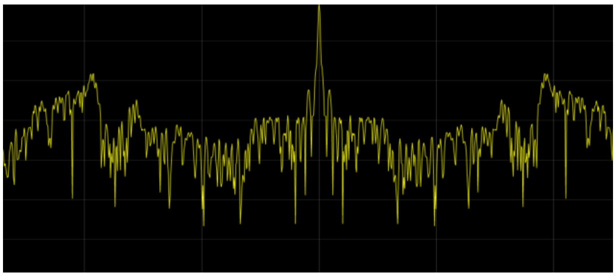

Fig. 13 Optical output1

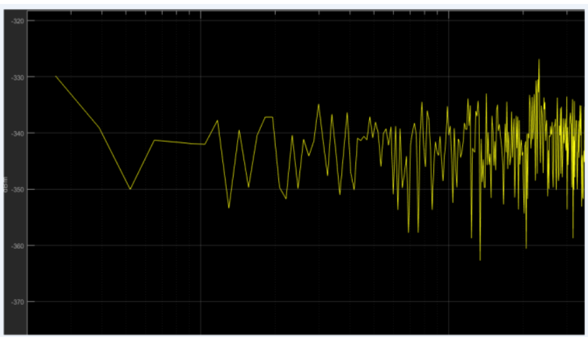

Fig. 14 Audio output2

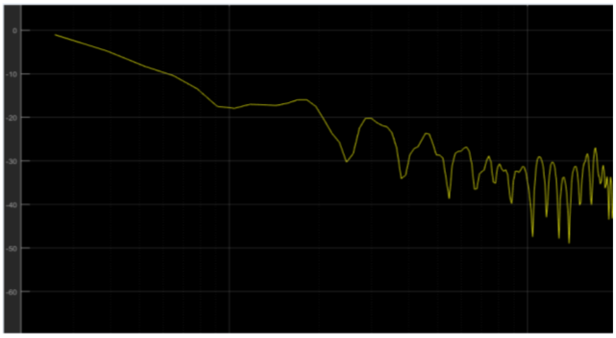

Fig. 15 Optical output2

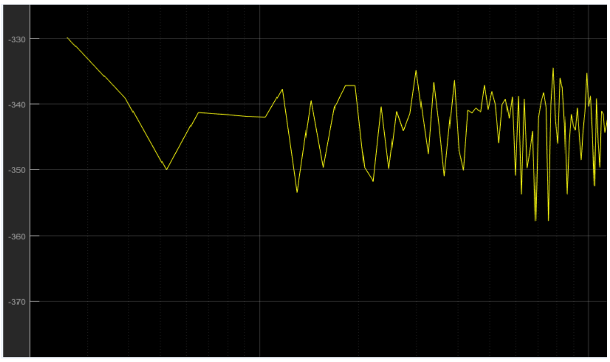

Fig. 16 Audio output3

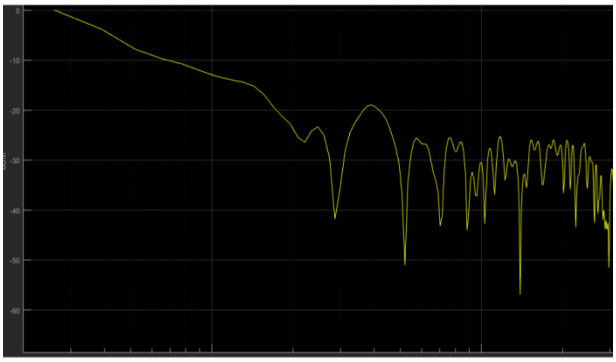

Fig. 17 Optical output3

VII. CONCLUSION AND FUTURE WORK

In this paper, a novel hybrid opto-acoustic modem which has the capacity of transmitting and receiving both the acoustic and optical signals as input through a single modem has been proposed. The functionality of the proposed modem design is tested through simulation. The rationale of our design is to achieve long distance communication with reduced power consumption and efficient data transmission. The simulation tools and its hardware design details with the preliminary tested results are presented. The successful transmission and reception of both the acoustic and optical signals are shown through the simulation results which prove the efficiency of the proposed hybrid modem.

However, the future work can be implementing the proposed hybrid Opto-acoustic modem on both terrestrial and underwater to achieve a successful underwater communication.

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