Experimental Study Of Underwater Optical Wireless Communication Link

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***Abstract*—An experimental setup of underwater wireless optical communication link is presented in this article. The article presents the results of an experimental study of underwater wireless optical link. Operational distance length 4.6 m. Receiver is built on the basis of sofware defined radio. Underwater optical wireless link and free space optical link frequency response are obtained. Based on the results of calibration measurements, the dependence E_s / N_0 at the output of the matched filter from the transmission frequency was obtained.**

I. Introduction

In recent years, there has been noticeable interest in underwater wireless optical communications (UWOC). The advantages of these systems over traditional acoustic subsea systems are high transmission rates, low latency, and low power consumption.

One of the first experimental studies of UWOC systems was carried out in 1995, the results of this study are given in [1]. The system was built using light-emitting diode (LED) as optical source. The communication range was 30 m, the maximum speed was kbps. In 2008, the possibility of underwater communication at a distance of 50 m and a speed of 1 Gbit / s was demonstrated [2]. In this system, instead of LED, a laser diode (LD) was used. Further development of the element base (lasers, photodiodes) made it possible to increase the communication range and the transmission speed. In work [3] the achievable speed is 5 Gbit /s, the communication range declared in work [4] is 200 m. In recent works, special attention has been paid to digital signal processing. Error-correction coding, equalization, efficient modulation techniques, such as OFDM, increase the efficiency of UWOC. In work [5] the results of OFDM signal transmission at a distance of 2.4 m, with a speed of 5.36 Gbps are presented. In [6], the possibility of using NOMA technology is considered, which makes it possible to implement communication link on 2 m at a speed of 4.6 Gbps. In [7] underwater visible light communication system with a speed 3.2 Gbps with dual-branch multi-layer perceptron based post equalizer is presented. Commercial UWOC solutions are implemented by Sonardine [8] and AquaOptics. One of the Sonardine modules is capable of operating up to a depth of 4000 meters, providing transmission rates in the range of 2.5 ÷ 10 Mbit / s at a distance of up to 150 meters. Working length is 450 nm. The modules can contain a memory cell, information to which can be recorded (for example, from a built-in video camera) and then transmitted via an optical channel. In work [9], the analytical performance of an UWOC system employing on–off keying modulation and MIMO transmission scheme at a data-rate of 500 Mbps over a link-range of 30 m was investigated. Research in this direction provides an opportunity for organizing Internet of Underwater Things (IoUT).

The main task of this work is to implement an experimental setup for evaluating the characteristics of the UWOC for research and educational purposes. The main difference from previous works is that laser is modulated directly by a radio signal. In addition, the presence of separate 2 m sections in a pipe with water allows research for different types of water, simulating different layers of the hydrosphere.

II. Experimental setup

Experimental setup is based on underwater channel modeling presented in [10]. The use of this statistical model made it possible to determine the components for the implementation of the laboratory bench

Technical parameters are presented in Table I.

TABLE I. Technical parameters

Parameter	Value
Wavelength	450 nm
Photadetector type	APD
Optical source	Blue LD
Optical modulation	IM/DD
Operational distance	4.6 m
Power	150 mW
Photodetector operating bandwidth	150 MHz

Block scheme of the experimental setup is depicted on Fig.1.Photo of the experimental setup is presented on the Fig.2.

Transmitter part of the setup is designed using AUCD blue LD (wavelength 450nm) with a spectral width of 2nm and an optical output power of 150 mW. Electrical-to-optical conversion produced by laser emitting module Elecdemo. On the receiver side, avalanche photodiode (APD) with an operating bandwidth of 150 MHz is used and the optical-to-electrical conversion is accomplished by APD driver board Elecdemo. For flexible signal processing at reception, the receiver is implemented as a software-defined radio, with specially developed software modules in the Spectr-2 environment developed by MTUCI

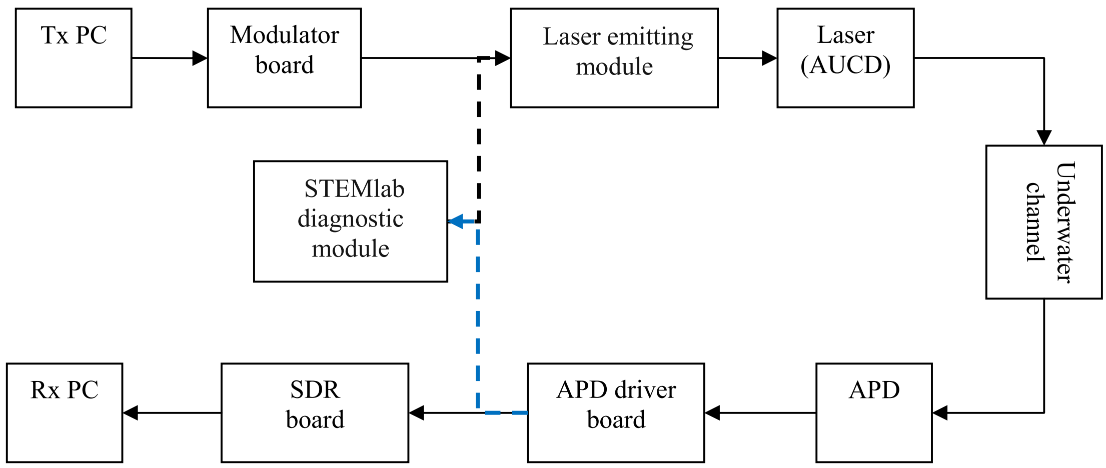

Fig. 1. Block scheme of the experimental setup

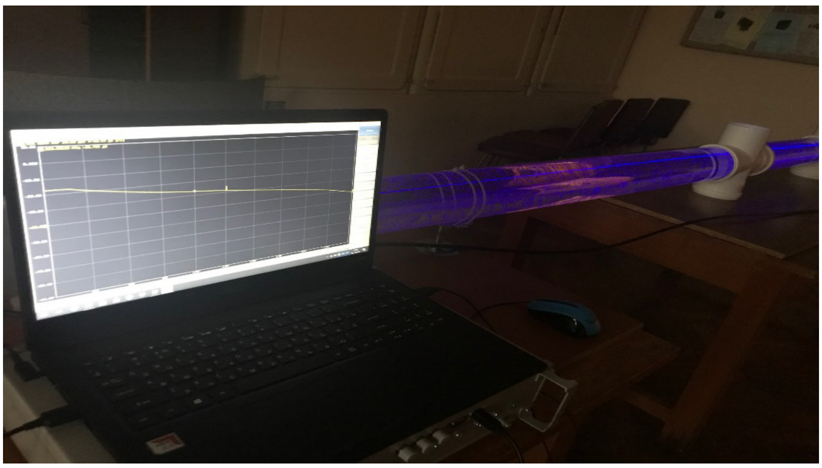

Fig. 2. Photo of the experimental setup

Calibration signal was used to observe the optical channel. The transmission and reception of the calibration signal was carried out by means of the STEMLab 125-14 diagnostic module manufactured by Red Pitaya on the base of Xilinx Zynq7010.

III. Results

Two experiments were carried out on the setup shown in Fig. 2. First, the frequency response of the underwater optical channel and free space optical channel was analyzed. The results are presented in Fig. 3.

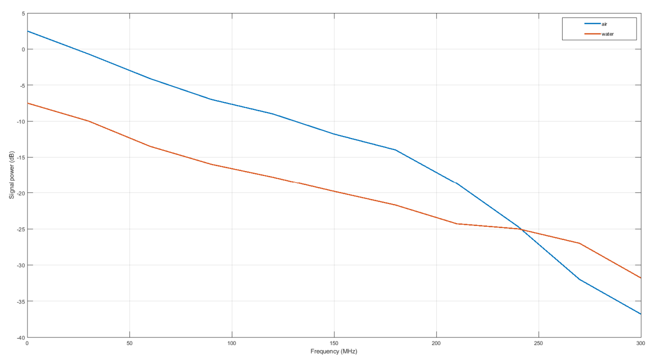

Fig. 3. Underwater optical channel and and free space optical channel frequency response

Measured values of frequency response for underwater optical channel and free space channel are presented in the Table II.

TABLE II. MEASURED VALUES OF FREQUENCY RESPONSE FOR UNDERWATER OPTICAL CHANNEL AND FREE SPACE CHANNEL

Frequency, MHz	Signal power n air, dB	Signal power in water, dB
0.3	2.5	-7.5
30	-0.7	-10
60	-4.1	-13.5
90	-7	-16
120	-9	-17.5
150	-11.8	-19.8
180	-14	-21.7
210	-18.7	-24.3
240	-24.7	-25
270	-32	-27
300	-36.8	-31.7

From the data presented in the table, it can be seen that, starting from a frequency of 240 MHz and higher, the signal attenuation in air is stronger than when transmitted in water.

The second experiment was done with STEMlab board. The calibration signal was generated from Gold codes with $N = 2047$ length. When calibrating the path, a signal consisting of M=86 Gold codes was used. Each code is padded with a parity bit to the N+1 length. The total duration of the calibration signal is $L = M \cdot (N+1)$ pseudo-random symbols. Symbol rate $R = 25000$. Sampling frequency 100 kHz . Based on the results of calibration measurements, the dependence E_s / N_0 at the output of the matched filter from the transmission frequency was obtained, shown in Fig. 4. The unevenness in the 70 MHz frequency band does not exceed 9 dB.

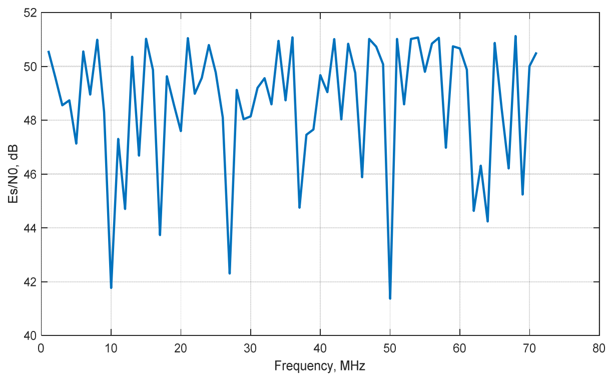

Fig. 4. UOWC and free space optical communications frequency response

The obtained SNR values of the signals make it possible to transmit radio signals over long distances when they modulate the laser.

IV. CONCLUSION AND FUTURE WORK

An experimental setup of underwater wireless optical communication link (UWOCL) is presented in this paper. The article presents the results of an experimental study of underwater wireless optical link. Operational distance length 4 m. Receiver and transmitter are built on the basis of sofware defined radio. An assessment of the noise immunity of the system is carried out.

An increase in the transmission range is possible through the use of low-noise amplifiers, as in satellite communications. It is necessary to create a transmitter and receiver for wideband signals with various types of modulation and coding and to determine the optimal modulation and coding parameters for underwater laser communication. Proposed solution allows using this implementation both in underwater and free space communication line. To study the possibilities of developing this setup, it is necessary to carry out similar measurements at various displacements of the laser beam from the receiving element.

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