Underwater Optical Wireless Communication

A Project Report

submitted by

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in partial fulfilment of the requirements
for the award of the degree of

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THESIS CERTIFICATE

This is to certify that the thesis entitled **Underwater Optical Wireless Communication**, submitted by **VANDANA SOMI BABU**, to the Indian Institute of Technology Madras, for the award of the degree of **Master of Technology** (Photonics) in Electrical Engineering, is a bonafide record of the research work carried out by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: Underwater optical Communication, Driver Circuit, PPM

The purpose of this report was to understand optical communications between a transmitter and a receiver in two different environments viz. free-space and underwater using green light laser pointers. To drive and modulate the laser within the linear region of L-I characteristic curve, we proposed and build a current driver circuit. The driver circuit has been developed using LF347 (Op-AMP), TIP-41C transistor.

In this report, the L-PPM has been employed in free-space and underwater optical communication system. The system performance has been analyzed based on BER performance along with the channel length. We focused on optical communication with laser sources and PPM signals. The performance of an underwater optical communication system with 4-PPM has been numerically analyzed in terms of effect in BER with respect to the channel length. By using the GNU Radio software, a laser-based link was demonstrated to show the performance of such a system. The results show that with the increase of transmission distance the bit-error rate performance degrades

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ABBREVIATIONS

SHG	Second Harmonic Generation
PPM	Pulse Position Modulation
USRP	Universal Software Radio Peripheral
UOWC	Underwater Optical Wireless Communication

NOTATION

α	Attenuation
σ	Flight path in degrees
ρ	Volume charge density

CHAPTER 1

INTRODUCTION

Optical communication uses light to carry information from one place to the other. In recent years, demand for optical communication has increased rapidly due to its capability of carrying information at high data rates (~ Gbps) with low power. Specifically, Optical wireless communication has a huge demand in fields of space, terrestrial and underwater environments. The need for underwater wireless communications exists in applications such as remote control in the off-shore oil industry, pollution monitoring in environmental systems, disaster detection and early warning, national security and defence (intrusion detection and underwater surveillance), as well as new resource discovery [1]. Among many others, acoustic and RF based wireless communications are widely used in the underwater environment. Visible light wireless communication had been less explored and recently interest has grown among researchers on this.

Acoustic communication is the widely used technique in underwater environments due to the low attenuation (signal degradation) of sound in water. This is especially true in thermally stable, deep water settings. On the other hand, the use of acoustic waves in shallow water can be badly affected by temperature gradients and multi-path propagation due to reflection and refraction. The much slower speed of acoustic propagation in water, about 1500 m/s, compared with that of electromagnetic and optical waves, is another limiting factor for efficient communication and networking.

Secondly, using electromagnetic (EM) waves in radio frequencies does not work well in an underwater environment due to the conducting nature of the medium, especially in the case of seawater which is having high conductivity. The speed of EM waves mainly depends upon permeability μ, permittivity ε, conductivity σ and volume charge density ρ which varies according to the type of underwater conditions and frequency being used. It has been observed that attenuation of RF waves increases with the increase in frequency and are heavily attenuated by sea water.

Optical waves, on the other hand, have high bandwidth but they are affected by other propagation effects due to temperature changes, scattering, dispersion and beam wandering. Optical wireless underwater communication is limited to short distances due to severe water absorption at optical frequency band and strong back-scatter from suspended particles. However, there is a relatively low attenuation optical band of blue-green wavelengths of EM spectrum underwater [3]. The table below shows the comparison between different wireless communication techniques in terms of data rates and range.

Communication Type	Propagation Speed.	Data Rates	Range	Channel control
Acoustic	1500 m/s	~Kb/s	~Km	Multi path, Doppler, temperature, pressure, salinity, environmental sound noise
RF	3.33×10^7m/s	~Mb/s	≤ 10m	Conductivity, Multiple
Optical	3.33×10^7m/s	~Mb/s	10-100 m	Light scattering, line of sight communication, ambient light noise

Table 1.1: Comparison between underwater Acoustic, RF and Optical Communications.

The rest of the report is organized as follows. Chapter 1 introduces the basic concepts of regarding "optical communication". The model of underwater channel is presented in chapter 2. And the performance of an L-PPM system is assessed in free-space and the underwater scattering channel in section 3. Finally, some conclusions and future aspects are drawn in section 4.

1.1 Background

A signal (either acoustic, RF or optical) when passed through any channel experiences attenuation. The two main physical processes that cause attenuation of a signal are Absorption and Scattering [5,6]. It is evident from the absorption spectra of Electromagnetic radiation in water shown in that the region between 440 nm - 540 nm (Blue-Green) has the least absorption.

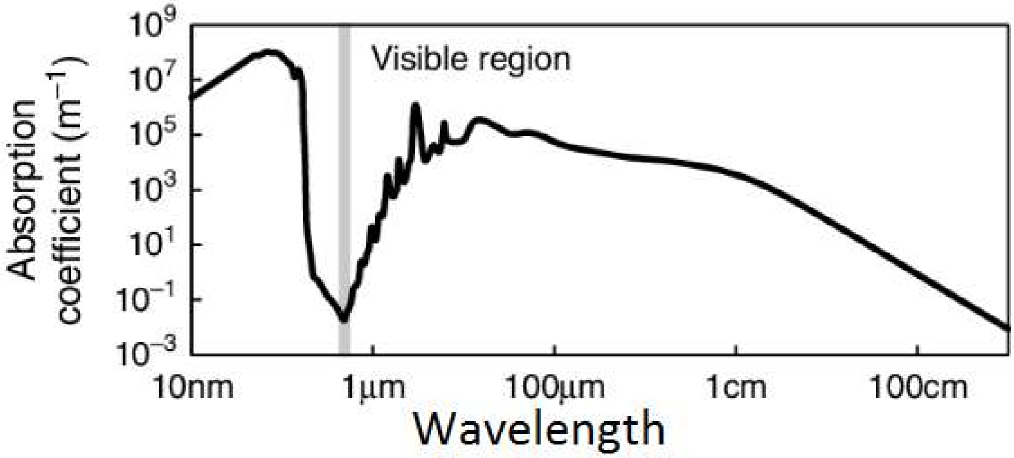


Figure 1.1: Absorption coefficient of pure sea water at different transmission wavelengths [7]

Researchers have reported theoretically and experimentally that blue-green light is capable of carrying information up over a few meters [3].

1.2 The underwater channel characteristics

As the underwater realm has experienced a great increase in human activity over the past few years, so also has interest grown in developing high-speed wireless communication links that are viable underwater. Furthermore, the acoustic systems that have formed the backbone of underwater communication for over 70 years are becoming increasingly out-of-date as time goes on due to their limited bandwidths and inherent lack of stealth. To confront the widening gap between the demands for high-speed communication and the limitations of acoustic solutions, this work proposes an optical alternative [4].

It is important to know the factor that reduces light intensity in water. The important factors are (i) absorption, (ii) scattering, (iii) turbulence, (iv) alignment, (v) multi-path interference, (vi) physical obstruction and (vii) background noise.

1.2.1 Absorption

Absorption is the process in which the water molecules and other particulates absorb a photon, and then transform the photon into thermal energy and chemical energy. Water contains a lot of particulate matter in different sizes and composed of dissolved salts. A typical absorption spectrum is shown in Fig.1.2 below. Generally, absorption by sea water is considered as four parts.

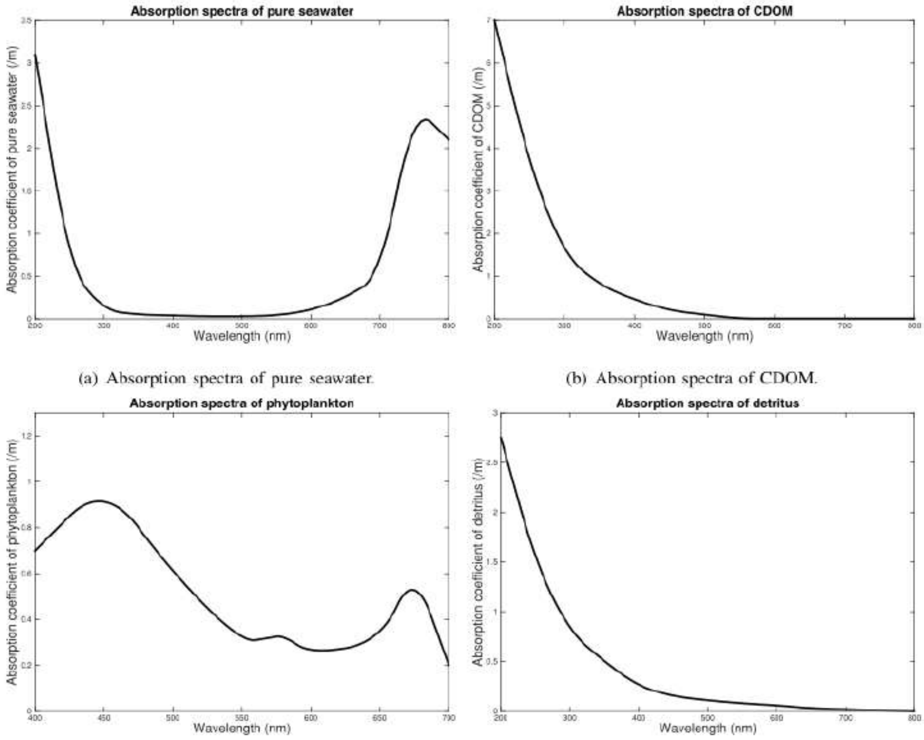
$$a(\lambda) = a_w(\lambda) + a_{CDOM}(\lambda) + a_{phy}(\lambda) + a_{det}(\lambda)$$

$a_w(\lambda)$ = absorption due to pure seawater

$a_{CDOM}(\lambda)$ = absorption due to CDOM (colored dissolved organic material)

$a_{phy}(\lambda)$= absorption due to phytoplankton is caused by chlorophyll

$a_{det}(\lambda)$ = absorption due to detritus.(living/non living organism) [8].



(a) Absorption spectra of pure seawater.

(b) Absorption spectra of CDOM.

(c) Absorption spectra of phytoplankton.

(d) Absorption spectra of detritus.

Figure 1.2: Absorption spectra of water in visible region

1.2.2 Scattering

Scattering is the deviation of the light beam from its path due to the suspended particles in the propagation medium. Scattering happens due to the change in refractive index of the medium by change in temperature, salinity and the flow of variation in water. Scattering depends on the size of particles in the medium and light wavelength as well. Due to scattering, energy is not lost but the number of photons reaching the photo detector decreases. If the particle size is smaller than incident wavelength, Rayleigh scattering occurs and if the particle size is comparable or larger than incident wavelength, Mie scattering occurs as depicted in Fig.1.3. Mie scattering is forward directional while Rayleigh scattering happens in all directions.

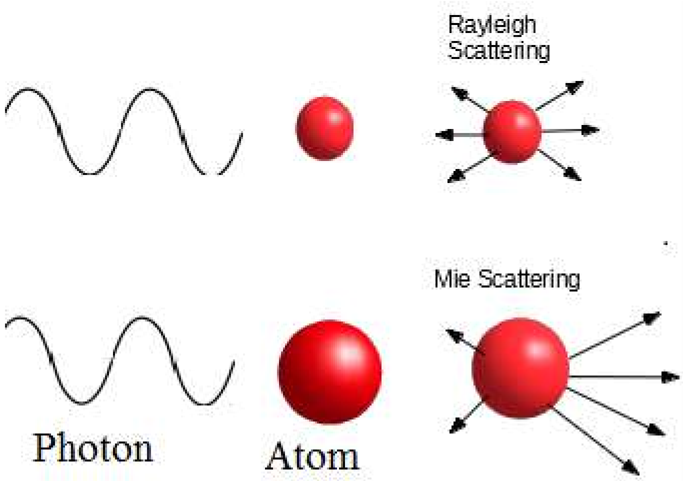


Figure 1.3: Rayleigh scattering and Mie Scattering

Even scattering plays a significant role in lower wavelengths but, the overall absorption dominates where less particulate and organic matter.If particulate and organic matters more scattering will take place and minimum attenuation takes place at 470 nm to 550 nm.[3].

Absorption and Scattering, these are the two main phenomena that cause loss of intensity or change in direction of optical signal in underwater.

If light, with some power P_i passing through the medium within that some amount of power could be absorbed , scattered and remaining power transmitted to the receiver.

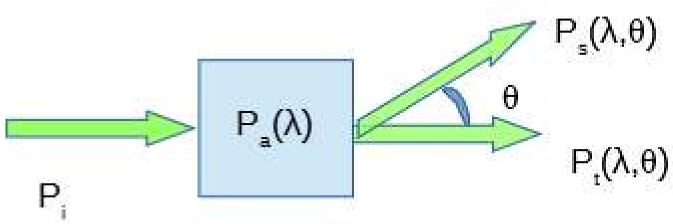


Figure 1.4: Optical property of medium

So we can write absorption coefficient a(λ), scattering coefficient b(λ) as a function of attenuation coefficient c(λ).

$$\boldsymbol{c(\lambda) = a(\lambda) + b(\lambda)}$$

The propagation loss

$$\boldsymbol{Lp(\lambda, x) = \exp(-c(\lambda)x)}$$

1.2.3 Turbulence

Turbidity is an event where refractive index of water changes rapidly.The change of refractive index creates optical boundary leads to light get refract and reflect. Change in refractive index due to the variations in salinity, pressure and density of suspended particle see below figure. This leads to large fluctuations in the intensity of the signal at the receiver. A sharp change in refractive index in water due to turbulence is known as scintillation.[7]

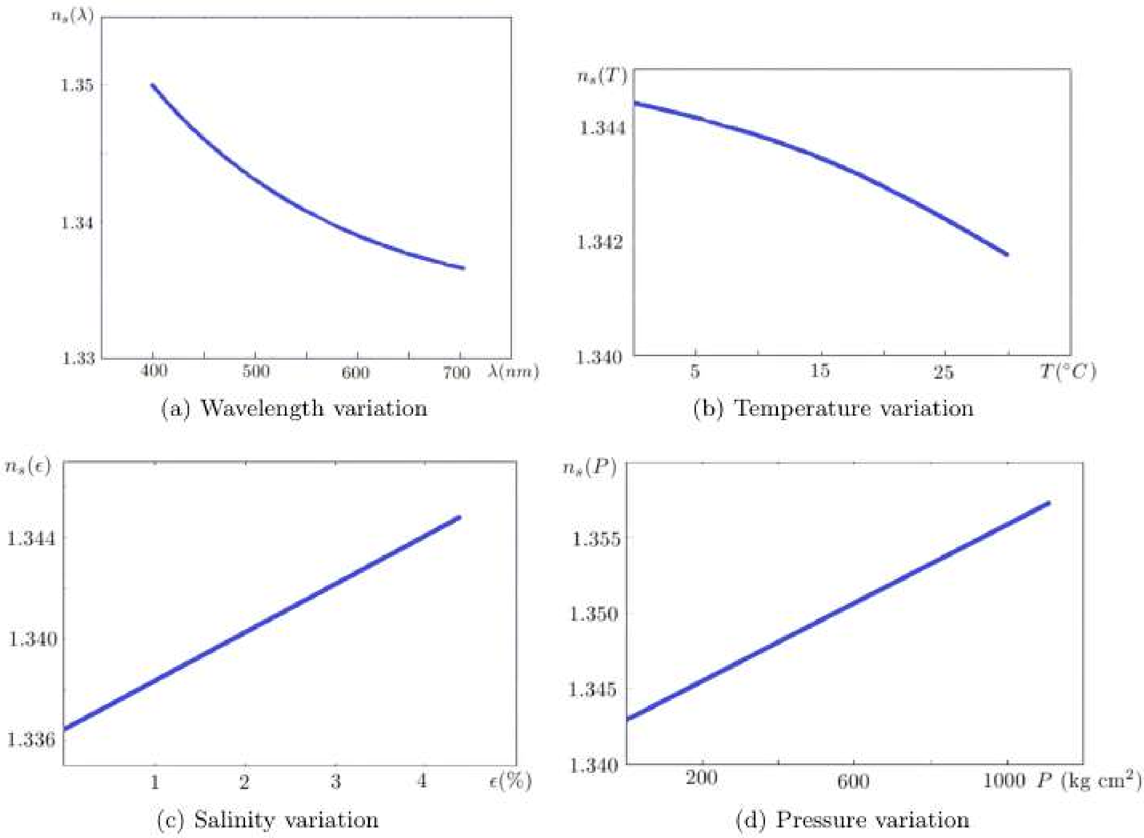


Figure 1.5: Change of refractive index with some parameters[6]

1.2.4 Alignment

Optical beam is very narrow, maintaining the LOS for a reliable optical link is very critical in UOWC. Due to the movement caused by underwater vehicles, ocean current or other turbulent sources, a constant tracking between transceivers is essential to maintain an uninterrupted reliable link.

1.2.5 Multi path interference

If a photon is scattered away and then later scattered back and detected, it has traveled a longer path than a photon moving a straight line. The longer path takes more time to travel and the time delay between receiving the two photons can cause inter-symbol interference if the bit rate of the system is not suitably lowered to accommodate for the temporal scattering. Because of this temporal broadening data rate is limited.

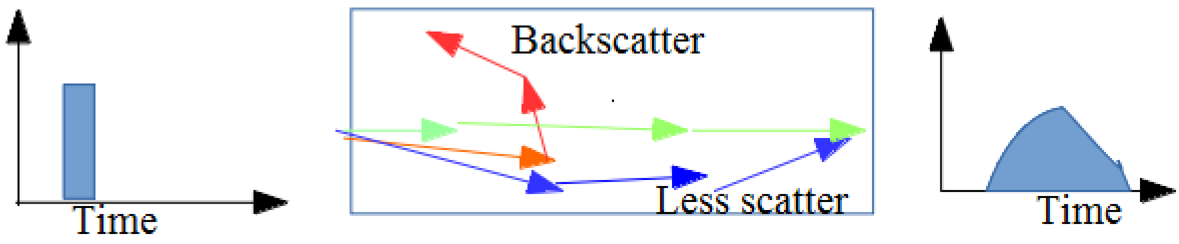


Figure 1.6: Multi path Interference

1.2.6 Background noise

Back ground noise must be taken into account while designing UOWC link. Noise is strongly dependent upon operating wavelength and geographical location. The main sources of background noise are:

(i) Background noise from the Sun

(ii) Scattered light collected by the receiver.

1.2.7 Physical obstruction

Optical signal or light is very narrow, so any marine animals will cause loss of signal at any instance at the receiver. This requires a lot of techniques for error corrections , signal processing and for resend the data which we lost.

CHAPTER 2

Experimental setup Characterization

For any communication, we need three important things which are i) Transmitter ii) Medium iii) Receiver

2.1 Transmitter Setup

The transmitter converts the source information into optical signals which are transmitted to the receiver through the medium. The essential components of the transmitter are (i) modulator, (ii) driver circuit (iii) optical source.

2.1.1 Source

Optical sources presently using are LEDs and Lasers. LEDs have high beam divergence but lasers are less divergence and coherent sources. For good optical transmitter, the choice of laser power and wavelength has to be made very carefully. So we chose Green Laser (532nm, 100mW) as an optical source. Laser diodes, because of their nature, need to be powered by a current source. Direct emission of 532 nm lasers is not available. Commercially available lasers are 1064 nm, are used to generate 532 nm by the process of SHG (Precaution: IR leakage happens so it may damage detector). So, to eliminate the IR, we need to use Filters.

Beam Divergence angle

Laser has less divergence. Due to this property, lasers are used for long range communication. The optical signal from the laser will travel more distance than LEDs light signals. Green laser divergence angle measured as

Distance of screen (cm)	Beam Diameter(mm)
90	3
150	4
450	5
600	7
750	8
900	9

Table 2.1: Measurement of Beam Divergence angle

Beam Divergence

$$\frac{(D2 - D1)mm}{(d2 - d1)cm}$$

$$= \frac{(9 - 7)mm}{(900 - 600)cm}$$

$$= 6.66 \times 10^{-4} rad$$

$$= 6.66 \times 10^{-4} rad \times \frac{180deg}{3.14rad}$$

$$\theta_{div} = 0.03821\, degrees$$

2.1.2 Driver circuit

Due to the highly nonlinear voltage–current characteristics of laser diodes with a low differential impedance (high dI/dV) which also significantly depend on the junction temperature, it is usually not sufficient to apply a certain constant voltage; instead, the electric current needs to be stabilized by automatically adjusting the applied voltage. The drive current and not the voltage determines the rate with which electrical carriers are injected into the junction of the laser diode. Therefore, the optical output power is strongly linked to the drive current and less directly to the drive voltage. We can see in fig.2.3 L-I characteristics of the Red laser diode. Similarly Green laser diode with driver circuit. Fig-2.1 shows the green or red laser diode with a driver circuit based on the L-I characteristic curve for corresponding lasers pointers.

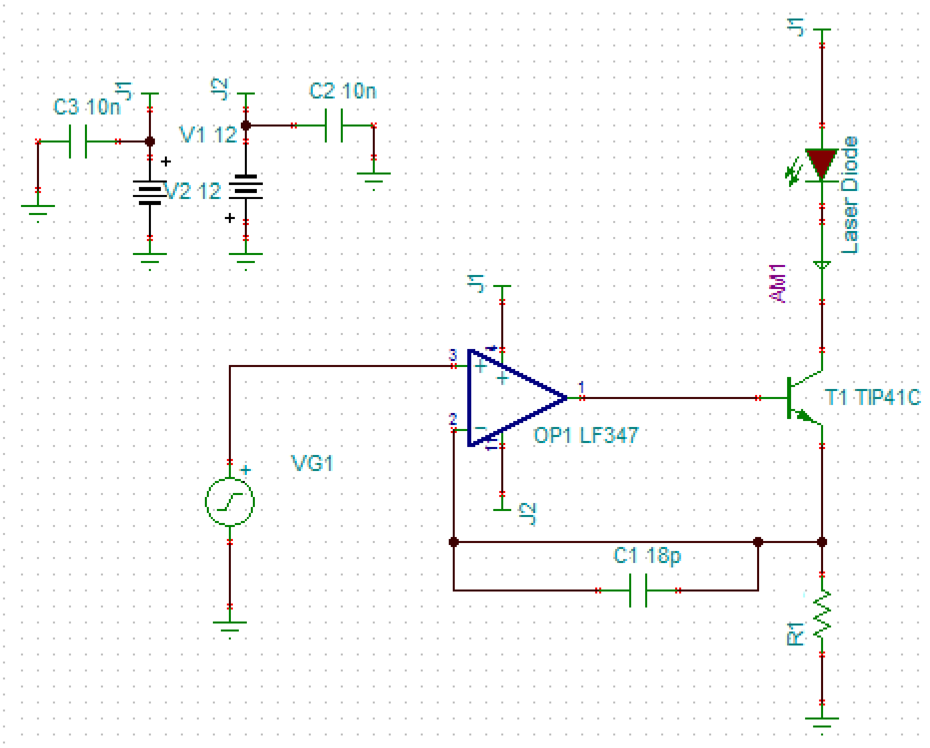


Figure 2.1: Laser Diode Driver Circuit Schematic

Above driver circuit used for both sources Red (<5 mW) and Green(<100 mW). only R1 value change for drawing required current. Lasers has nonlinear V-I and L-I characteristics. So above the threshold current/ voltage region only stimulated emission will start. That means linearity condition will hold. So it is necessary to operate laser diode in the linear region of V-I or L-I curve.. Power Transistor TIP41C is used because of high power dissipation by the transistor. For the cooling purpose we need to attach one heat sink to the transistor. 5W size 20 ohm resistor is used to sustain for high current values in for green laser and 178Ω for red laser. Here, the combination of Op-Amp and transistor acts as a voltage to current converter. Feedback loop is used to maintain the voltage across the resistor. The same voltage is seen by the input +ve pin of the op amp. We chose $R_L$value such that for a range of varying offset voltages output current will be in a particular range to manage the output power of laser within the linear region of the L-I characteristic curve. We used bias-tee for varying offset voltages. If we provide constant offset voltage within the circuit, we need to vary R_L. But, if the value of R_L is kept fixed, we can vary the output current by changing the offset voltage accordingly, which is more robust technique than that of previous approach.Thus, the laser diode can be operated in the linear region.

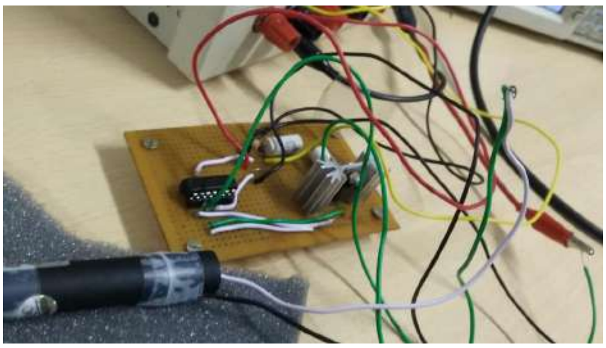


Figure 2.2: Driver Circuit

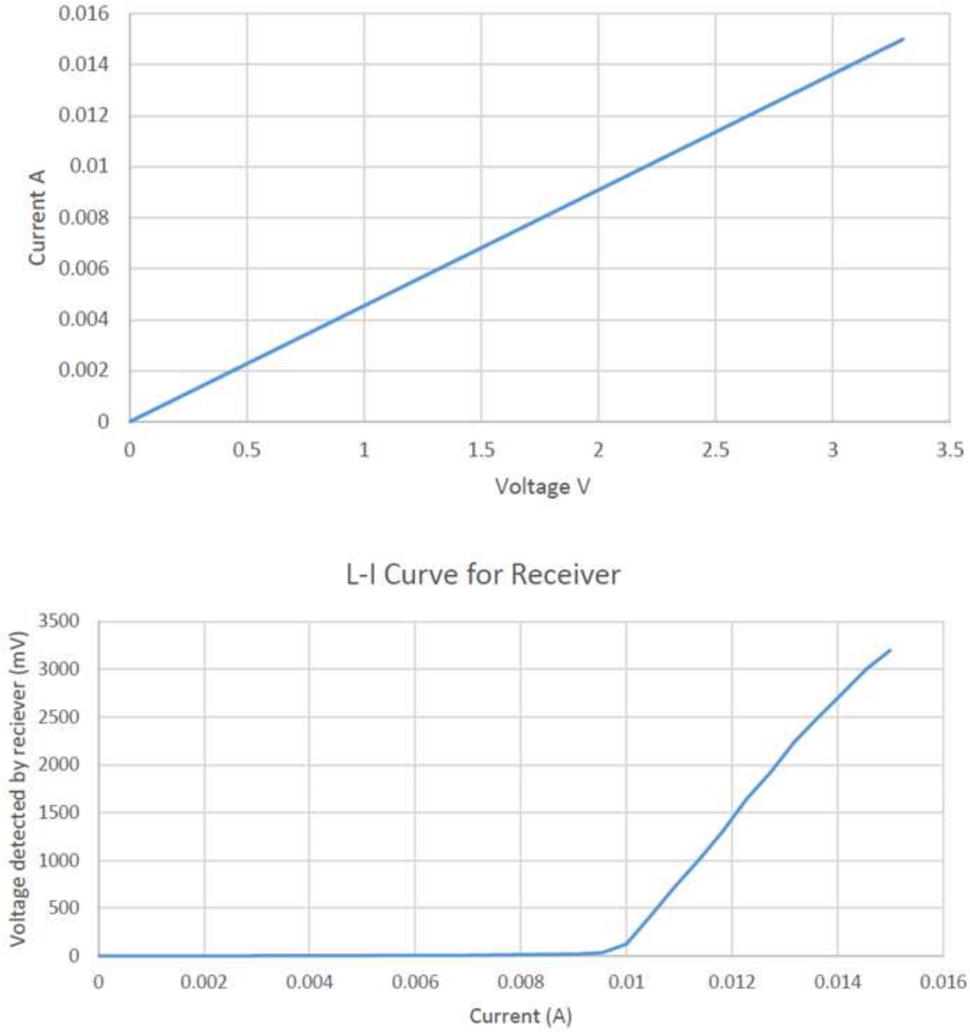


Figure 2.3: V-I and L-I characteristics of Red Laser

For Red laser diode, threshold current is 12 mA.So, we operated laser above the threshold value to maintain the linear region of the L-I curve.

Frequency response of the driver circuit

We tested driver circuit frequency response with red laser. This circuit can respond to the frequency up to the f_{3dB} = 20MHz.

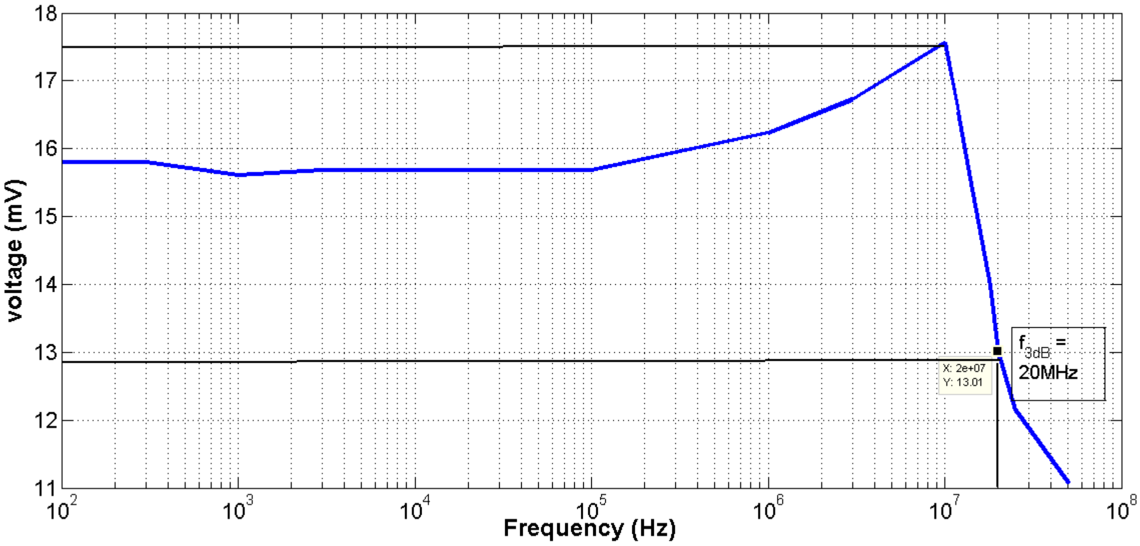


Figure 2.4: Frequency response of the Driver circuit with Red laser

Green light is generated through SHG Process. The laser pointer being used contains IR along with green radiation. In order to measure power at 532 nm, a dichroic filter is used to remove IR. As depicted in figure 2.5, Si visible power meter is used to measure the filtered light. Thorlabs' Dichroic Mirrors/Beamsplitters spectrally separate light by transmitting and reflecting light as a function of wavelength. Longpass Dichroic mirrors are highly reflective below the cutoff wavelength and highly transmissive above it. The Dichroic Mirrors/Beamsplitter we have used for our experiment has the specifications as below:

Cutoff wavelength (DMLP950)	950 nm
Transmission Band(Tabs>85%, Tavg>90%)	990-1600 nm
Reflection Band (Rabs>90%,Ravg>95%)	420-900 nm

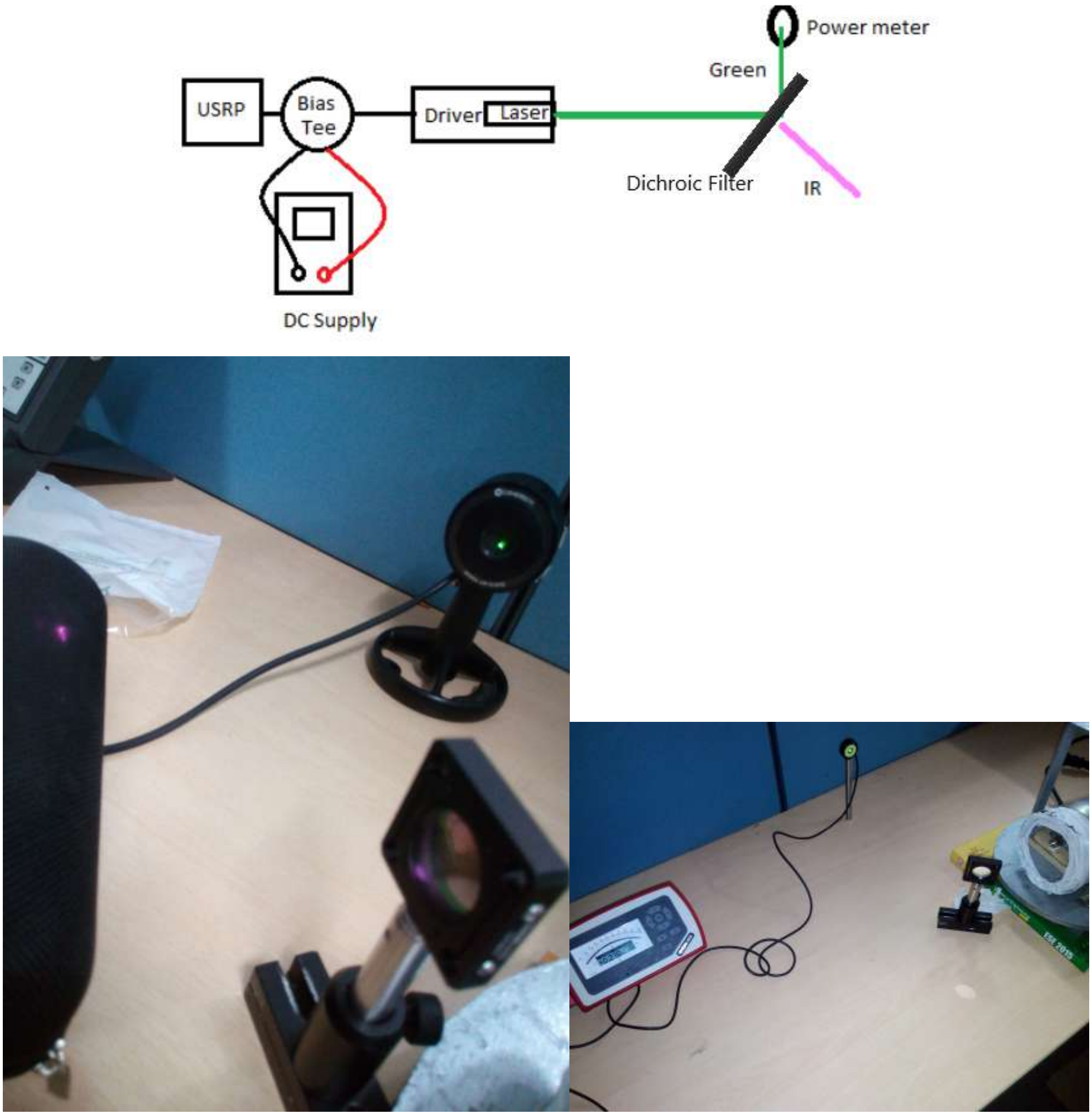
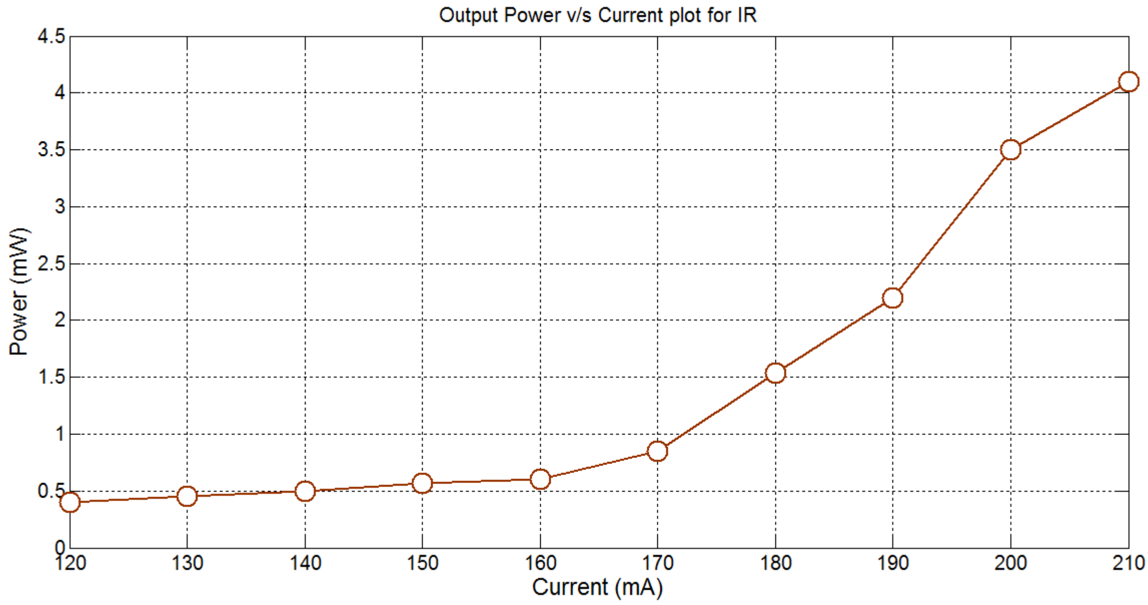


Figure 2.5: Green Light power measurement setup



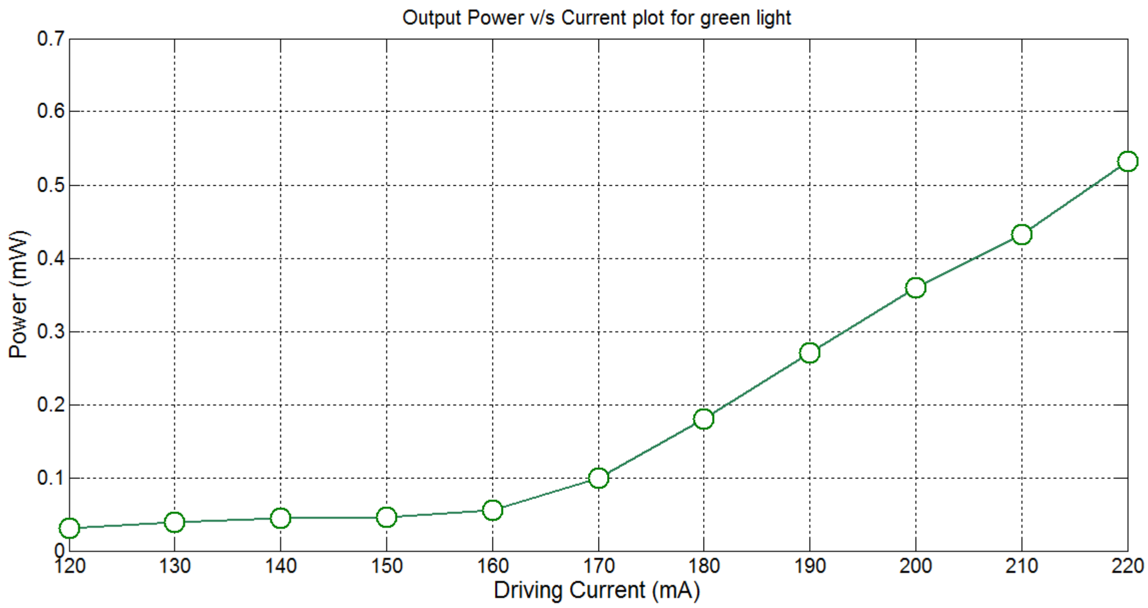


Figure 2.6: V-I and L-I characteristics of green laser diode with driver circuit

We can see from the graphs Fig: 2.6, Green power is only 10% of the IR. So our receiver will detect IR mostly comparable to green. Both are shows same characteristics curves.

2.1.3 Receiver

Optical Receiver is converts optical signal to electrical signal.

Figure 2.7: Photo detector

Fig: 2.7 shows photo detector is used to receive optical signal.We used Thor labs PDA100A detector as receiver which has a switchable gain.

Responsivity

The responsivity of a photo diode can be defined as a ratio of generated photo current (I_{PD}) to the incident light power (P) at a given wavelength:

$$R(\lambda) = \frac{I_{PD}}{P}$$

Receiver module is constituted by trans impedance amplifier OPA656, AGC (auto gain control) circuit and PIN photo diode.

Trans impedance amplifier is a current to voltage converter, it can be used amplify the current output of Geiger-Müller tubes, photo multiplier tubes, accelerometers, photo detectors and other types of sensors to a usable voltage.

The responsivity for 532 nm is 0.34 A/W. Receiver is working on the principle of photo electric effect. when light incident on the photo detector, electrons are generated and causes the current..

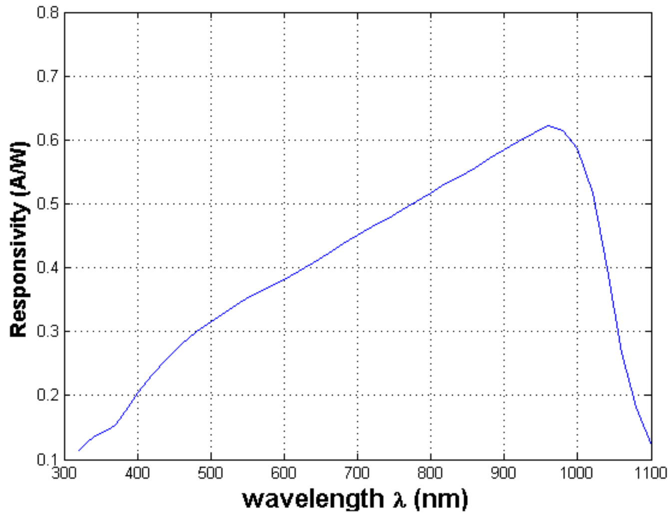


Figure 2.8: Si Photo detector Responsivity curve

According to the responsivity curve, responsivity is very high for IR.

Trans-impedance amplifier circuit schematic is showed in Fig.2.7. It consists of a feedback resistor and an op amp chip. It amplify the current from photo diode and covert to voltage .

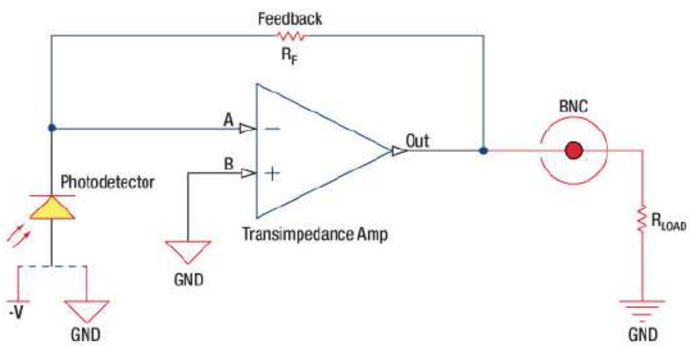


Figure 2.9: Trans Impedance Amplifier Circuit

The value of the resistor determines the gain of the trans-impedance amplifier and it optimizes the response of the trans-impedance amplifier. Maximum input optical power can be incident on detector can be calculated as

$$Optical\,Power = \frac{Maximum\,Output\,Voltage\,(V)}{Responsivity\,(\frac{A}{W}) \times Scalefactor \times TIA\,Gain(\frac{V}{A})}$$

$$Scalefactor = \frac{R_L}{R_L + 50\Omega}$$

So in case of IR Maximum optical power is 22 mW ,Green 60 mW. Should not cross this limit otherwise leads to damage the detector.

2.1.4 Modulators

This optical source doesn't have any information but it acts as carrier for the signal. Modulators help in converting low-frequency information signal onto optical carrier for long distance communication. The parameters that characterize optical modulators are bandwidth, insertion loss, modulation depth, drive power, and maximum optical throughput power [8]. Modulation can be applied to any one parameter, i.e., intensity, phase, frequency, or the polarization of the optical carrier. The most commonly used modulation is intensity modulation (IM) in direct detection where the intensity of the optical source is modulated in accordance with the source information. This can be achieved either by varying the direct current of the optical source or by making use of an external modulator.

2.1.4.1 Introduction to PPM

The information in visible light communication system can be transmitted by using both the baseband signals and the passband modulation schemes providing a novel implementation platform for matured wireless communication technology. A selection of the modulation scheme should be made by considering the need for data rates, signal strength and the cost of the communication equipment for example.

This section contains the Pulse Position Modulation scheme for free-space and underwater optical communication. Pulse position modulation (PPM) signalling is a means of transmitting multiple bits per symbol in an intensity modulated/direct detection (IM/DD) system. In order to implement this, a direct modulated laser is used along with direct detection. The modulation maps a sequence of bits to a PPM chip signal. The transmitted signal is a sequence of pulses. Each pulse has the same amplitude and width, but depending on the bit sequence, the delay between the pulses is changed.

This section provides an overview of the system design of the system using lasers operating in the visible wavelengths. The "blue-green window" has been identified as the carrier of information for the underwater communication link.

2.1.4.2 Block Diagram of the system design:

A transmitter consisted of an optical source, either an LED or a diode laser, and the receiver was a Thorlabs PDA100A amplified Si photodiode detector. The receiver output was passed through a DC-block and into an Ettus Research USRP signal acquisition board. This performed digitization/sampling, demodulation, and basic filtering before streaming the digital samples to the PC for software processing in GNU Radio. The key feature that has to be taken care is component features and its design. As in every communication system, it has the transmitter which gets the data either from the computer or microprocessor and this electrical signal is converted into optical signal by the suitable photon source. Every state in the electrical signal must be switched properly during transmission so that the receiver can decode the data without any error. On the receiver side, these optical signals are converted back to electrical signals and the data that has been transmitted will be recovered back and displayed either on the computer or any display.

The key feature in design is the selection of suitable photon source as the rest of the system drives the photon source. The coherent laser beam provides a good quality output which however, is rapidly degraded by underwater scattering and turbulence. Moreover, lasers are capable of supporting high data rates due to large modulation bandwidth (>1 GHz) as compare to LEDs whose modulation bandwidth is almost less than 200 MHz.

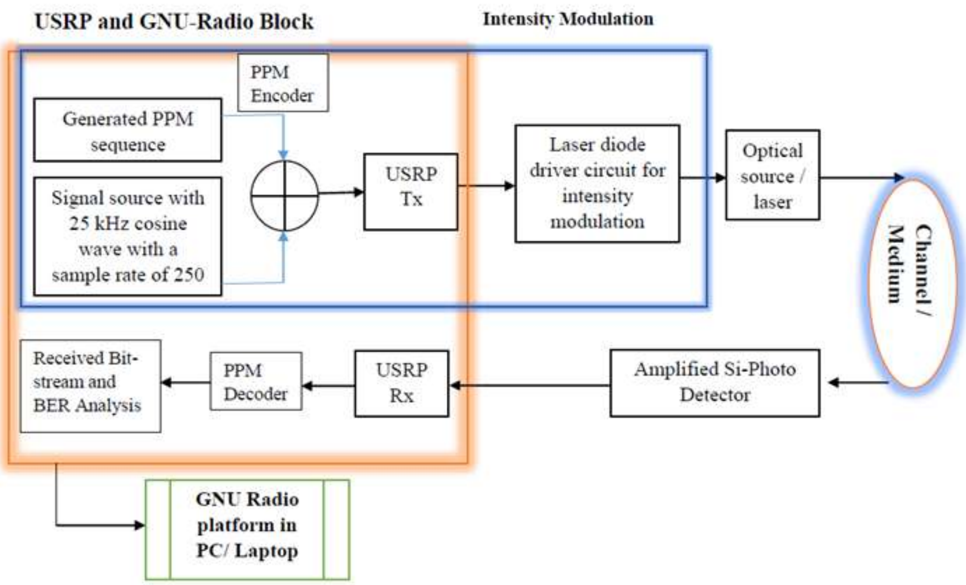


Figure 2.10: Block Diagram of the system design

The system is described as follows:

• The RF transmitter and receiver used is the USRP N210 baseband board.

• The USRP is interfaced with the computer using the GNU-Radio software module.

• The data to be transmitted is stored in a binary file, read by the GNU-Radio and then transmitted by the USRP.

• In L-PPM encoder, each symbol is represented as a PPM chip, which can take one of two possible values. A sequence of L PPM chips corresponds to a PPM symbol. Each PPM symbol is mapped by (log2 L) bits.

• In order to decode the time domain signal to get the bit stream, we use the orthogonality of the L-dimensional PPM symbol.

• A visible laser diode or transmitter is basically a light intensity modulated light source, whose purpose is to transform the information data to the light signal using an applicable modulation method. The transformation from the electrical signal to the light should be as linear as possible in order to achieve the optimal conditions for the transmission.

• The channel can be either free-space or water.

CHAPTER 3

Experimental work and Results

Our experimental work done in two parts; one in free space and second one in underwater with two laser source Red(635nm), Green(532nm). We are aimed to do direct modulation with analog signal. so we tested driver circuit with red laser for analog modulation compatibility.

3.0.1 Free space optical communication

• System parameters: -

Transmitted data:

o L: 4

o Bits transmitted or length of the bit-stream: 16

o Number of L-PPM symbols: 8

o Oversampling factor: 32

o Number of samples transmitted: 32 * 8 = 256

Synchronization: The data is continuously transmitted and received by the USRP; in order to process this data, a time window of the total transmitted symbols is taken and passed to the offline post processing. Since an arbitrary chunk of the repeated data is captured, it is important to synchronize the received samples with the start index.

- **Results and Discussion:** The Figure (3.1(a)) and Figure (3.1(b)) show the output of the transmitted and received sequence after synchronization and before down-sampling, for L-PPM, for different values of Channel length. The open source software defined radio project, GNU Radio, was used for the experiments to perform the various radio transmission tasks on the data. Sample code included in the project was modified and used to perform bit-error rate measurements. The free-space link has been established upto 15 meters and we observed that the received sequences were perfectly synchronized with the transmitted sequences. Thus, the BER value along with the length is very less in this case.

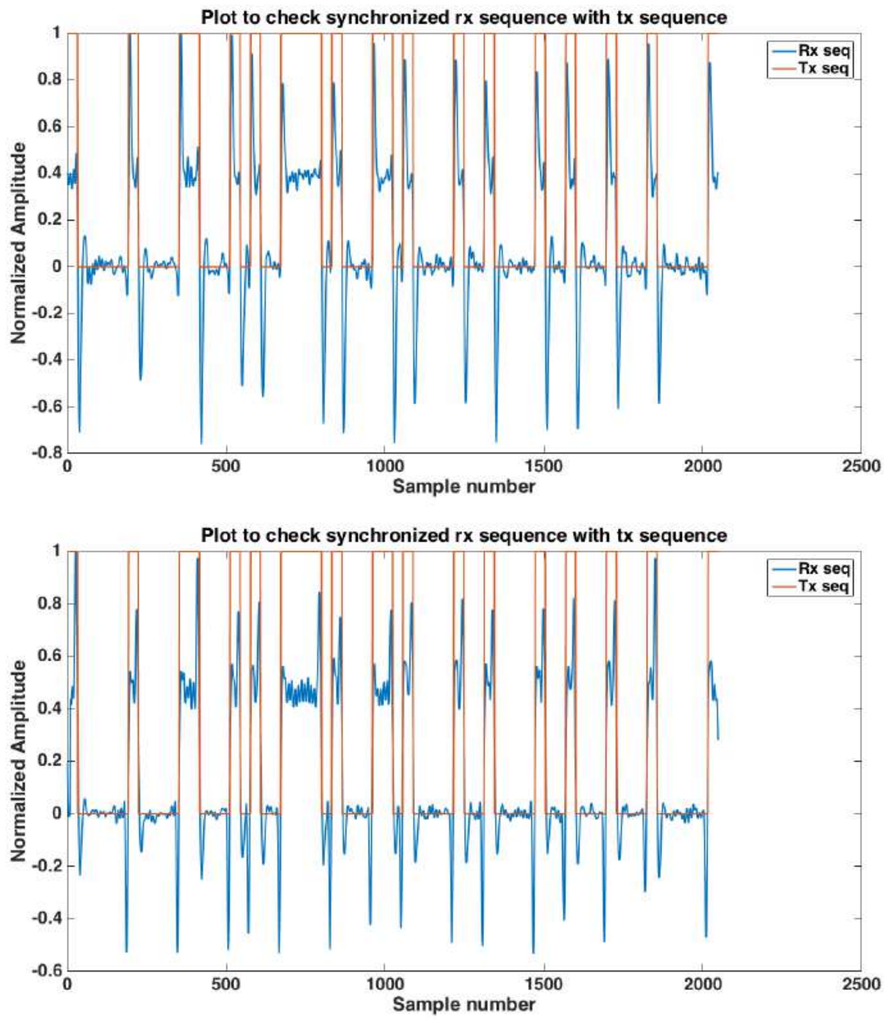


Figure 3.1: Received Signal: L-PPM at a distance of 1 meter(a) and 15 meters(b)

BER Degradation

Effect on transmitted signal is been analysed in the following BER v/s channel length curve, where we increased the length of transmitted bit-stream. We can see here, as we increased the transmitted bits from 16 (2^4) to 8192 (2^{13}), the BER value is getting increased with respect to length of the channel.

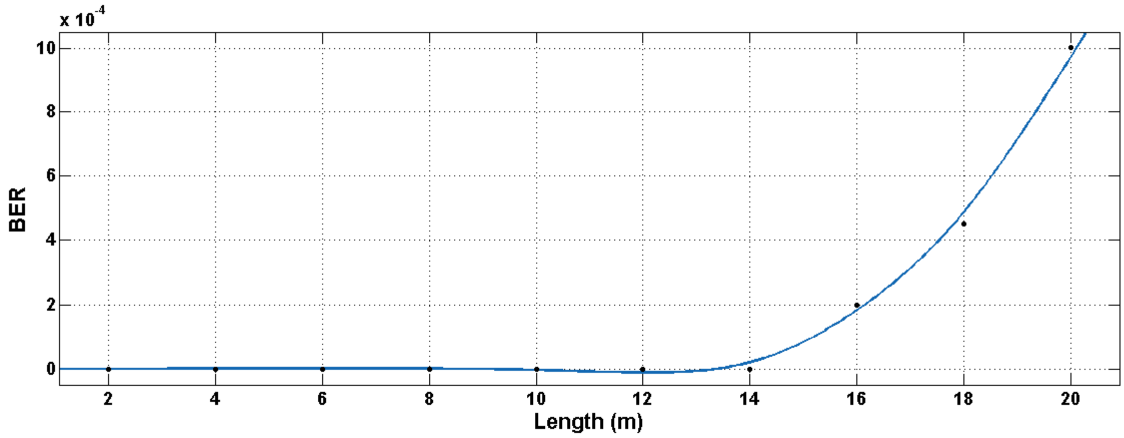


Figure 3.2: Length Vs BER of L -PPM signal in Free Space

3.0.2 Underwater Optical Communication

One of the first challenges in the project was to locate a suitable experimental area for conducting the experiments. A suitable water tank with enough space to work in was a primary criterion. A survey was done of the tanks within the campus. This included certain water tanks in the Mechanical Engineering Department and a few tanks in the Ocean Engg Department. Finally, the Wave Flume Lab in the Ocean Engineering Department was chosen. The lab houses a glass walled fresh water tank with dimensions of 20 m x 0.5 m x 0.7 m. This particular lab was chosen for the following reasons:-

(a) The lab had sufficient area to work around the water tank where the associated accessories of the link would be kept.

(b) The water tank was easily accessible from all sides to allow for easy setup of the waterproof modules in the tank.

(c) Since the walls of the tank were made of glass, it was convenient to observe the optical beam and make necessary alignments.

(d) The tank had a wave maker installed which could be used to generate turbulence externally thereby simulating real time conditions.

we decided to make the laser setup waterproof so as to be able to keep the transmitter inside the water tank For the purpose of waterproofing, a cylindrical PVC pipe was picked from a hardware store. The advantage of using a PVC pipe was that the associated accessories, like end caps and metallic clamps to secure the pipe were easily available in varying sizes. The challenge was to keep one end of the pipe transparent and yet waterproof. An acrylic sheet was placed on one end of the pipe. The water proofing was further reinforced by using a commercially available sealant silicon gel. Before installing the laser inside the pipe, the water-tight integrity of the pipe was checked by keeping the pipe immersed in water for a period of sixty minutes. The laser pointer was disassembled from its packaging and was mounted on a board which was cut to a size so as to snugly fit into the PVC pipe. The other end of the pipe connected to another PVC pipe with L clamp of an appropriate size. Other side of hole was used to allow the power supply to the laser to pass through. The connector was also sealed waterproof by using sealant.

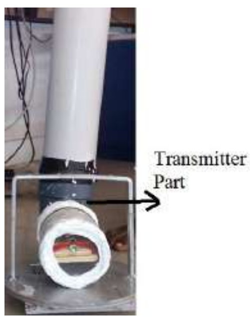
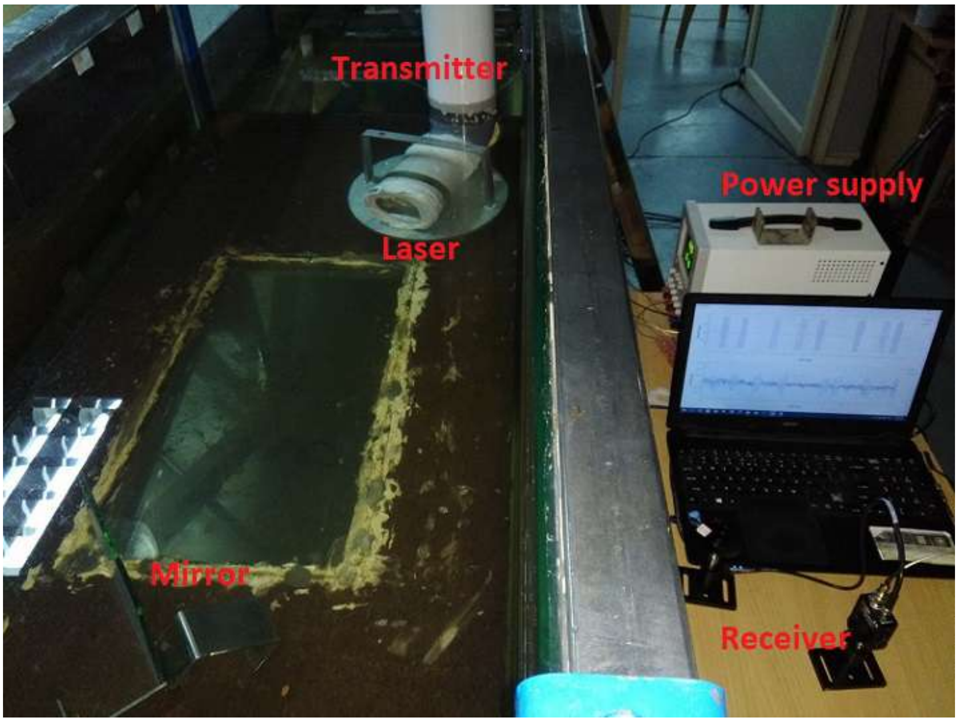


Figure 3.3: Transmitter Package

The entire assembly was then secured on an Aluminum plate using metallic clamps to keep it steady. The assembly was then taken to the water tank in the

Wave Flume lab and was checked for its functioning.



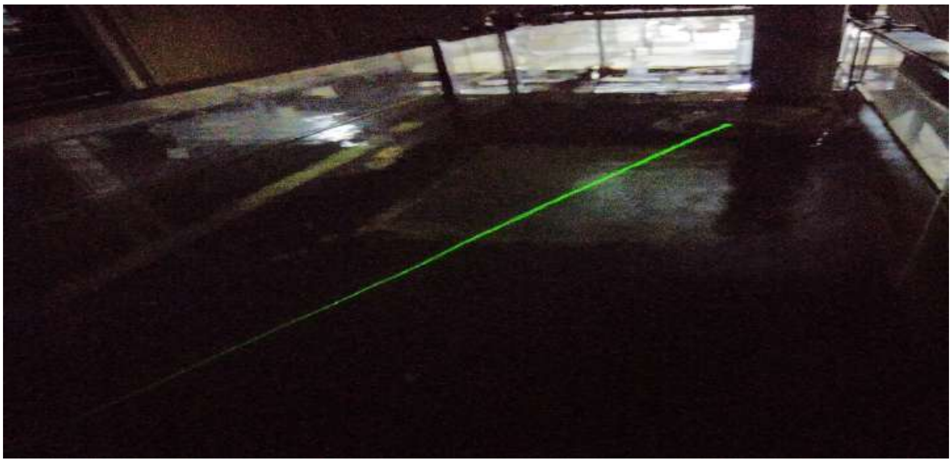


Figure 3.4: Experimental setup in underwater

System parameters: -

Transmitted L-PPM data:

o L: 4

o Bits transmitted or length of the bit-stream: 8192

o Length of PPM sequence = L*bit length / log2(L) = 2* 8192 = 16384

o USRP Sampling rate = 1/(250e3)

o Oversampling factor: 32

o Length of synchronization sequence = 64

o Length of up-sampled sequence with synchronization sequence = 526336

Results and Discussions

Even in clear water condition, the scattering level is still appreciable, the tank-water was not that much of clean. At very high concentration of Maalox the laser beam is scattered away from the optical axis and the diameter increases, resulting in a reduced contrast between the centre of the beam and the wings. The result is a reduced optical intensity at the receiver end, down to the limit at which the tracking system ceased to operate.

In Figure.3.6, we find that with the increase of distance the BER performance degrades. It explains that the signal to noise ratio decreases and the distortion due to scattering increases as the distance increases [11].

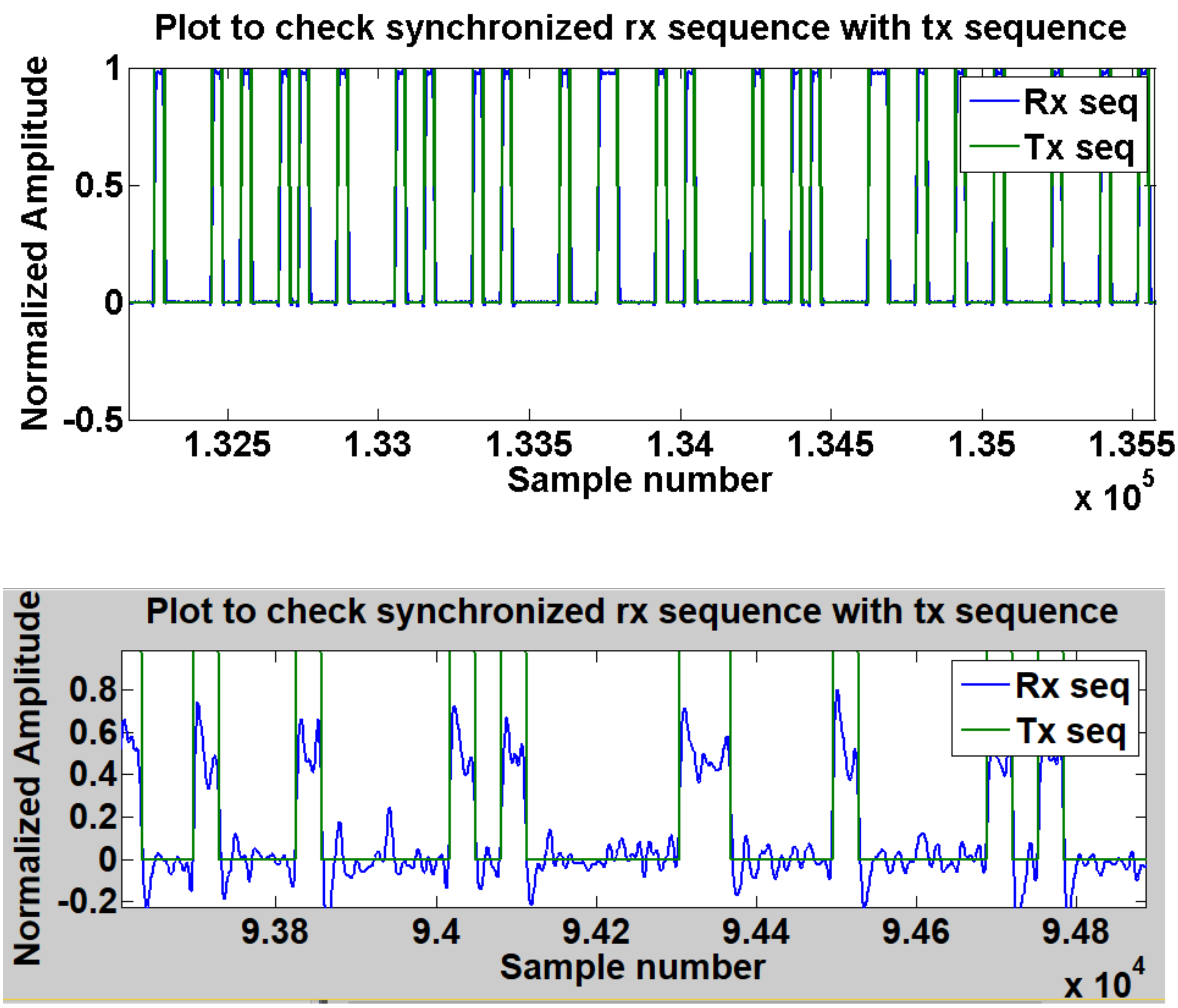


Figure 3.5: Received L-PPM signal at1 meter and 3 meter

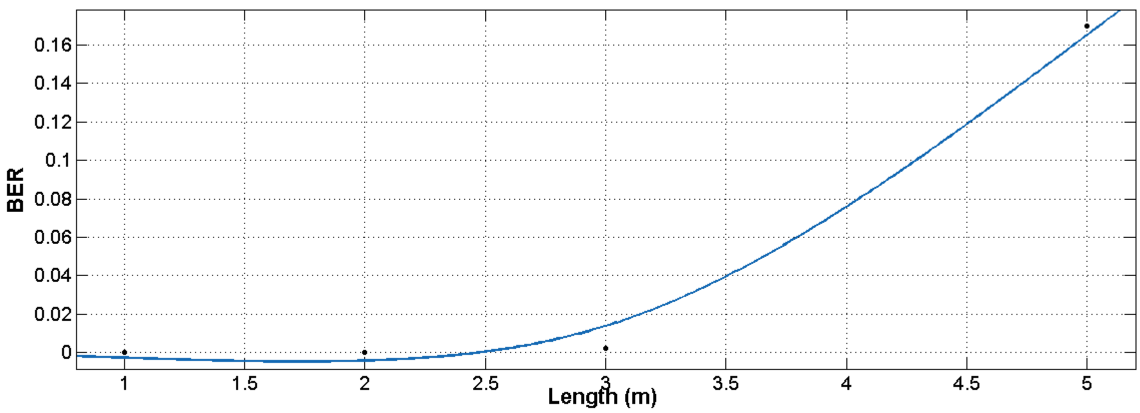


Figure 3.6: Length Vs BER of PPM signal in underwater

CHAPTER 4

Conclusion and Future Scope

4.0.1 Conclusion

Optical communication appears to be a promising method for supplementing existing acoustic communication schemes, especially in situations in which a direct optical link can be established between the source node and the target. Our novel low cost system appears to be a useful way of exploring these applications, and has several novel aspects which make it useful as a model for further development. This research is primary step for Underwater Free Space Optics. The research has mainly focused on using suitable optical elements to transfer data from transmitter to receiver and observed when an optical beam interacts with the Air - Water interface. By using the GNU Radio software, a laser-based link was demonstrated to show the performance of such a system.

The results show that with the increase of transmission distance the bit-error-rate performance degrades. The pulse position modulation (PPM) has been widely used in freespace optical communication systems for its high power efficiency. In this paper, the L-PPM is employed in free-space and underwater optical communication system, and the system performance is analysed based on BER performance along with the channel length.

4.0.2 Future Scope

As potential for future work, we plan to investigate modulation techniques that yield a higher degree of bandwidth efficiency. By using a software defined radio system, future improvements can be easy made in software to test various modulation formats or digital filtering.

The requirements of an underwater to free space wireless link would arise in a wide array of scenarios.

Some of these are :-

(a) High speed communication

(b) Security and harbor inspections

(c) Maintenance and surveying of underwater pipelines and oil rigs

(d) Underwater sensor network and observatories

(e) Remotely operated vehicle telemetry Most of these applications benefit from standout features of optical communications which include High data rates, Wireless operation, Conservative power budget, Low cost and reproducibility, High Fidelity of data transmission.Thus to give an impetus to the research in Underwater Optics, the following is recommended as a future scope:-

(a) Careful experimentation of signal attenuation in natural sea waters.

(b) Power measurements for seawater with different quantities of phytoplankton.

(d) Addressing the issue of pointing and tracking. Exploring options like beam steering and adaptive optics as possible solutions.

(e) Experimenting with multiple laser sources as a means to nullify large scale turbulence effects. Acoustical communications will still stand as the primary source of underwater communications, but the research has shown the optics may have a place in the underwater environment as well in the times to come. In applications which require the beam to interact with the sea surface, optical communication holds strong advantages over acoustic communications.

(f) 8-PPM or 16-PPM can be used to get more improvement in bit-error-rate performance and higher power efficiency.

CHAPTER 5

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