Team 2117 - Underwater Data Transfer
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ECE 4902 Spring 2021

Spring 2021 Final Report

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Abstract

This senior design project is sponsored by General Dynamics Electric Boat. They are an enterprise specializing in the design, development, and construction of nuclear submarine technology, located in Groton, Connecticut. GDEB has tasked us with investigating and identifying various wireless technologies that can be used underwater for a lossless transmission of data. The theoretical use case for this system is communication of information between a relatively small UUV and a submarine. This project is a multi-year endeavor to have the goal of ultimately improving the transfer bandwidth between two or more moving underwater platforms within 30 feet of one another. Our preliminary investigation has shown the most merit in pursuing the design of an optical communication system, as it holds the highest power efficiency and data rate possible achievable with modern technology.

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Nomenclature/Glossary

UWOC: Underwater Optical Wireless Communication.
Optical Communication: A form of wireless communication utilizing lasers and photoreceivers to transmit data.
Photodiode: A semiconductor circuit component that is able to receive emitted photons and transfers that energy into an electrical current.
Laser: Light amplification by stimulated emission of radiation.
Microcontroller: An integrated circuit computer that is programmable to fit the input/output needs of the user.
Optical Modulation: A process and/or device that is able to cipher information onto a stream of light. Modulation requires demodulation for the information to be understandable.
Encoding: The general process of adding redundancy into an information system so no data can be lost.

I. Introduction

Transmission of data underwater is a task that has not advanced in . Communication and data transmission underwater is important because it is used in a variety of industries. The Navy and its contractors such as Electric Boat use it all the time in many of their submarines and ships. There are environmental agencies that make use of data transmission to monitor ocean pollution or marine wildlife. This can also be extended simply to oceanography or the effect of climate change on the ocean. As mentioned previously, the most common way of accomplishing this goal is the use of acoustic waves. The benefit of acoustic communication is the distance at which data can be transmitted, usually between 10kHz - 100kHz for anything less than 10km. However, they have diminishing data rates with distance (below our goal for 10m) and low power efficiency, about 100 bits/J. Electromagnetic waves in the Radio Frequency range is another option, with higher data rates and lower power consumption. However, this technology suffers from a strong attenuation with water, limiting the usable distance significantly. We decided to halt investigations into this technology after this, as it was not suitable for a 10 meter range given the attenuation. There are research groups currently who have taken strides to make use of RF waves in data transmission over longer distances. Often, these systems communicate on or near the surface of the water, which is not an option we can consider. The last and most promising option considered is that of optical communication. Optical or Laser data transfer has higher speeds, higher possible data rates, and can work in different environments in water. Therefore, our team will be further investigating the specifications and design of an optical communication system to tackle this project.

II. Problem Statement

This project will consist of ECE Senior Design Team 2117 designing a system of wireless data transfer that is optimized for an open ocean environment. Mr. Eric Hultgren, our contact at Electric Boat, has helped us with any questions regarding the scope and specifications of this project. This system would be designed for the specific theoretical use case between an unmanned underwater vehicle and a submarine or ship that can send instructions and receive data from the UUV. This project will also be a collaboration between the University of Connecticut's ECE, CSE, and MechE departments within the School of Engineering. The ideal system would require a transfer rate between 100KBps and 1GBps, with a goal of no lost packets. It was specifically important to our sponsor that our project implementation has as little signal error as possible, as most real-world use cases for any data transfer system would never desire information to be lost. Due to the specifications of the UUV, we are limited to using 30V DC Voltage and 3A current for our system. Another relevant part of the project is the fact that we want to avoid using any materials that could be considered harmful to aquatic life (lead, arsenic, etc.). The device we would use has to be able to transmit between 30 ft of distance, as well as have the ability to function at a depth of at most 650ft, which is the approximate depth of the UUV. According to Electric Boat, this project is intended to be handled through mainly theory and simulations, as hardware deliverables on a large scale would be difficult to accomplish given the circumstances of this academic year. This means that a hardware implementation of our design is not necessary or preferred. Our goal has been to present simulations across the three departments in our group, with ECE specifically focusing on our research into optical communications & alternatives, a MATLAB/Simulink simulation, and a proof of concept hardware implementation of a scaled down optical communication system. Our investigation has been primarily spent on looking for a specific solution or method of underwater data transmission, and we have been looking at the current and popular methods used and weighing the benefits and detriments of using a newer technology compared to what has already been established in the data transmission field. It is also important to note that there have been completed optical communications systems fabricated that are of a design similar to what Electric Boat is looking for in a finalized product.

III. Approach & Design

1- Background

The current landscape of underwater data transfer systems is dominated by acoustic communication. Acoustic communication consists of using a medium of a solid or water to transmit sound waves which can be sent and received as data. Acoustic data transfer is also a very thoroughly researched field with lots of commercially available products that can be used to design and build your own system. Another big benefit of Acoustic communication is the effectiveness between distances in the km range. Despite this, Acoustic communication suffers from a low data transmission rate and efficiency relative to emerging competitors. This is why a part of this project was the research of potential alternatives to acoustic communication. The two major emerging technologies that can theoretically replace acoustic underwater data transfer are optical and RF communications. RF or Radio Frequency communication is one of the alternatives becoming available currently. In this technology, RF waves are sent from the transmitter to the receiver, usually using a modulator and demodulator on the transmitter and receiver respectively. RF technology often ends up being altered due to interference of other RF signals around. The medium of open ocean is desirable in this case, as it can minimize the potential for RF interference. Despite this, RF communication systems have a strong attenuation by water (3.5-5 dB/m), which severely limits the distance RF waves can travel underwater. Currently, the papers our team has looked at suggests that it would be difficult to create a lossless RF communication system for our theoretical requirement of 30 ft of distance, as that specification is just barely within the recommended distance underwater RF communication should be used in. Even within that range, a 10 meter range would not support the data rate of 100 MBps.

2- Optical Communication & Design Considerations

The alternative we are pursuing is optical communication. Underwater optical data transfer systems have similar steps to the previously mentioned RF systems. Optical communication systems generally have a type of LED or Laser to send the necessary data while using a phototransistor or photodiode of some kind to receive the information. One of the biggest benefits of optical communication underwater is the fact that it generally operates at a significantly higher data rate in the Gbps range. Optical communication also has low attenuation by water (0.39 dB/m in Ocean), while being significantly more energy efficient than acoustic communication (30,000 bits/J vs 100 bits/J of acoustic). Laser based communication has a speed that is on the same magnitude as the speed of light, which is described as ~2.225e8 m/s in an underwater medium. Optical communication is not perfect however, any optical communication system made this way will fail to operate or operate less efficiently when line of sight has been lost between the transmitter and the receiver. As this is an emerging technology there are no clear industry standards for an optical data transmission platform as well as the fact that there is no consumer off the shelf systems that would help in popularizing the use of optical wireless communication. The current landscape of underwater optical communication generally is populated by test setups of researchers that utilize computers/microcontrollers that modulate a laser of some sort that hits any type of photoreceiver, being demodulated and decoded by a second microcontroller and ultimately data shows up on a second computer.

There are several elements of design for optical communication that are important to realize a complete system. On the transmitter end, the primary consideration should be for the type of emitter that will be used. The two general types are LEDs and Laser based systems. LEDs hold the benefit of a wider line of sight, but generally this means the luminescence is spread through that wider area. While this can minimize error due to line-of-sight mismatching for these systems, the effective working distance is lowered. Lasers can also have a faster slew rate and generally support higher power transmissions. LEDs on the other hand are cheaper and are simpler to implement for systems with higher levels of complexity. They are also seen to be more reliable, even if their lifetime is not necessarily longer than that of lasers. There are also examples of laser/LED arrays used as transmitters. This solution attempts to create systems that work at longer ranges while providing a wider field of view for the receiver. Generally it would make sense that there is a cost increase with the use of these systems, and more electronic components may need to be used. Examples of this include transistor switching circuits or a current mirror to prevent thermal runaway for high power systems.

The desired characteristics of an ideal optical receiver is one that is capable of receiving photons from a wide angle view, and has a high signal to noise ratio accompanied by an appropriately high gain to identify the transmission in an environment with marine life, UV sun radiation, and other unexpected factors. There are also factors of modulation and error correction that will be expanded upon later on.

3- Ideal Design Choices

Within the realm of optical communication, there are a few choices that designers have to make regarding how they want their system to look and function. The primary decision we had to make once we decided to work towards simulating this type of system was choice of the wavelength of the light. Even underwater, different wavelengths of light perform better in different environments. The studies that we reviewed made the point that the main factors in determining the wavelength of light that should be used for an optical communication system is by consulting the absorption and scattering coefficients of light for different water environments. For our purposes, we ideally want our system to be used in a more clear open ocean environment. This is conducive to using a wavelength of about 450nm to 500nm, resulting in blue-green light.

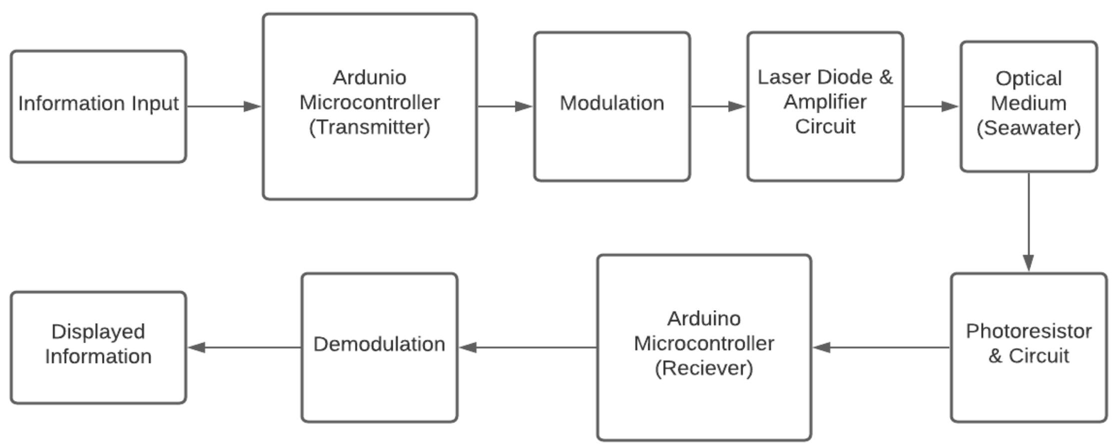
The LED or Laser would be given between 10mW and 5W of power as this is a large range that would be able to transmit at the required data rate over the required distance underwater. The temperature range that a laser or LED would need to operate in is -5°C to 40°C, which is a good range for a controlled open ocean environment. For the purpose of a real laser, we would want to use a semiconductor laser, which has a wavelength of 450nm to 470nm.

We also need a receiver, and for any theoretical hardware implementation would like to use a semiconductor photodiode. We would specifically want to look into the PIN photoreceiver because it is fairly cheap while having a solid light tolerance and fast response time relative to the main competitor in the space, the avalanche photodiode (APD). According to the papers we have read as research, there are also quantum photosensor devices being tested that are inspired by biological organisms that exist underwater. These sensors are trying to mimic the process of photosynthesis as an information gathering technique.

For an optical data transfer system, a reliable modulation and demodulation source and scheme are necessary. Intensity modulation is the preferred method of modulation that is currently being used in optical systems due to the fact that they are relatively inexpensive and easier to implement than coherent modulation. As the name suggests, intensity modulation only tracks the intensity of the emitted light, which changes based upon the desired data for transmission. For the purposes of this project, an intensity modulated and demodulated signal would be optimal, and could be done either by having the driving current of the light source modulated, or modulating the light source after generation. This can be done utilizing the microprocessor that would be transmitting the signal, as a form of on-board modulation. An alternate method would be to utilize an external and dedicated optical modulator device to modulate the signal. This method is far more expensive for our purposes and would not necessarily guarantee a better result both in hardware or through simulation. As far as a modulation scheme is concerned, we have seen a number of popular styles such as On-off keying, phase shift keying, and pulse position modulation. For a detailed simulation of this system we are looking towards using on-off keying as it is conceptually simplistic and has significant documentation regarding implementation in Simulink. This is also the modulation technique that we would look to implement in an ideal hardware environment, as there are some examples of systems built this way that can meet or exceed the goal data rate.

A microprocessor or computer device is necessary to send the signal to the laser and optical modulator, which then can transmit the signal to the receiver. Our photosensor would be connected to a demodulator device that would be able to decode the data being transmitted which would get sent to a second microprocessor device to be able to display the data and/or manipulate it. If we were to do any proof of concept hardware implementation, we would want to use Arduino Uno microcontrollers to perform this, as it has the capability to modulate and demodulate the signal using Pulse Width Modulation without any additional external equipment. Of course these devices would require a power source as well, and a proof of concept design would use a simple 5V power source which we have not included in the part list as it is intended for testing purposes as of the writing of this report.

Once all of the electronics and software are together and operational we would need a theoretical housing for these devices to operate underwater. In this, we would look to our partners in Mechanical Engineering who would develop a waterproof housing for both the transmission and receiving ends, while performing a thermal analysis of the device at different stages of load. This investigation into the components and steps necessary to create an optical communication system as well as our Simulink model of the system are our deliverables, as previously mentioned. We also provided a proof of concept hardware implementation as we deemed it was possible based upon available Arduino libraries and documentation.



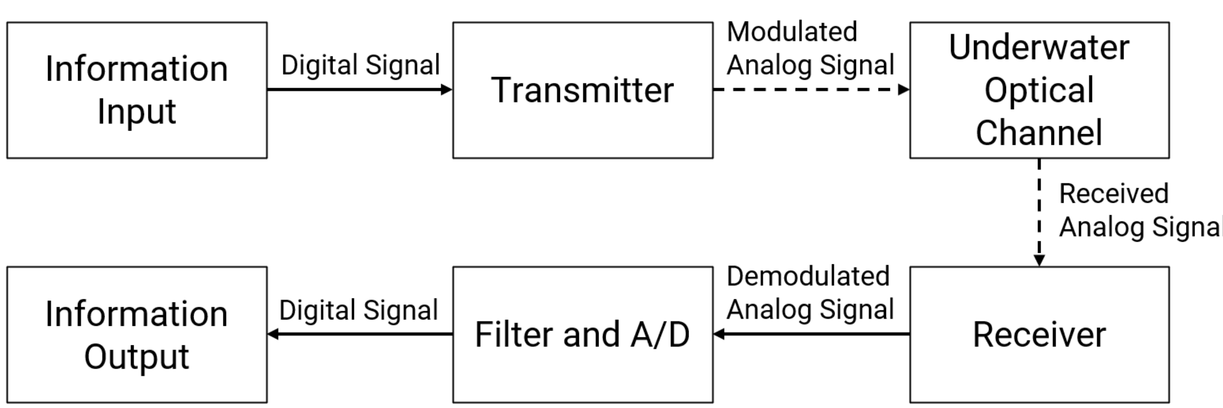


Figure 1&2: Specialized & Generalized block diagram of an UOWC. Our hardware and simulation of a system like this will primarily look to be closely related to the first diagram but the second is provided for understanding.

4- Hardware PoC

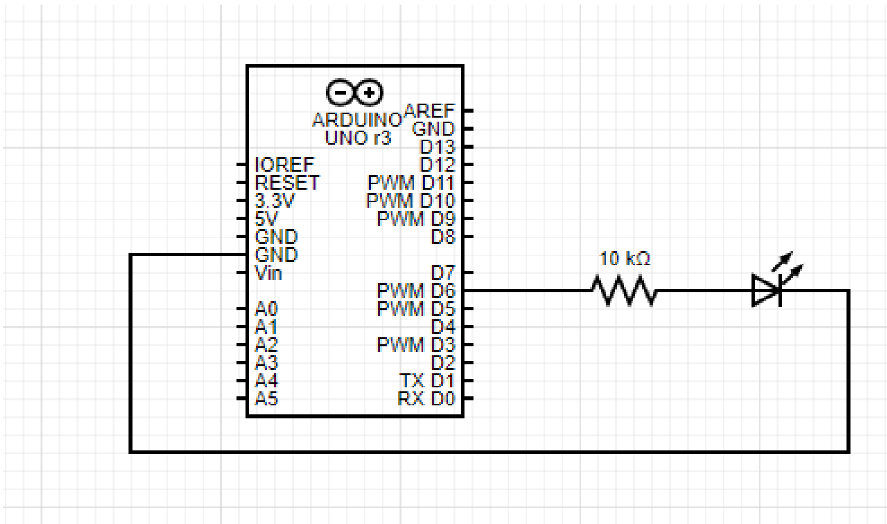


Figure 3: Diagram of Transmitter Circuit

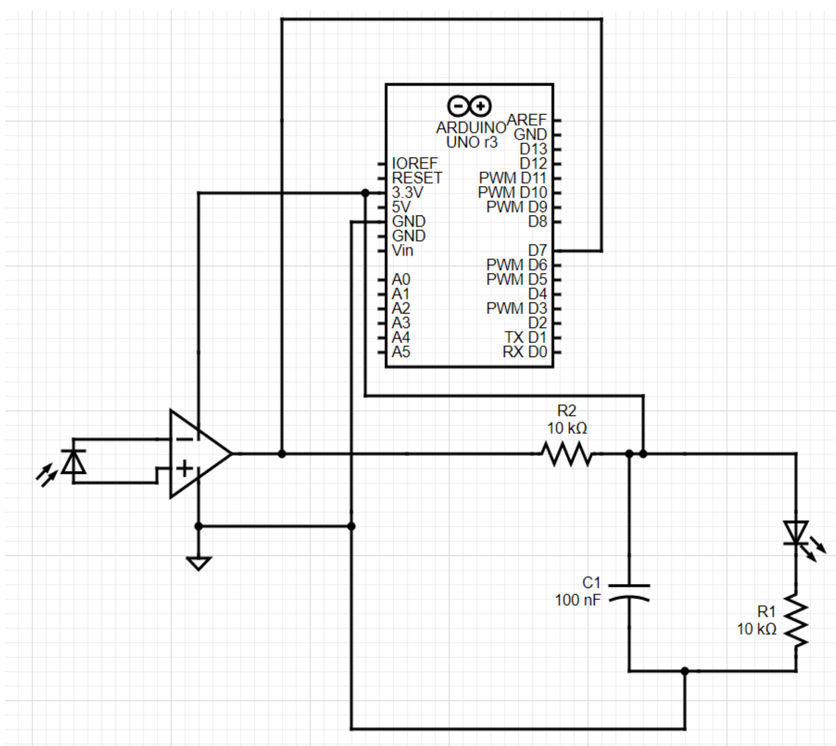


Figure 4: Diagram of Receiver Circuit

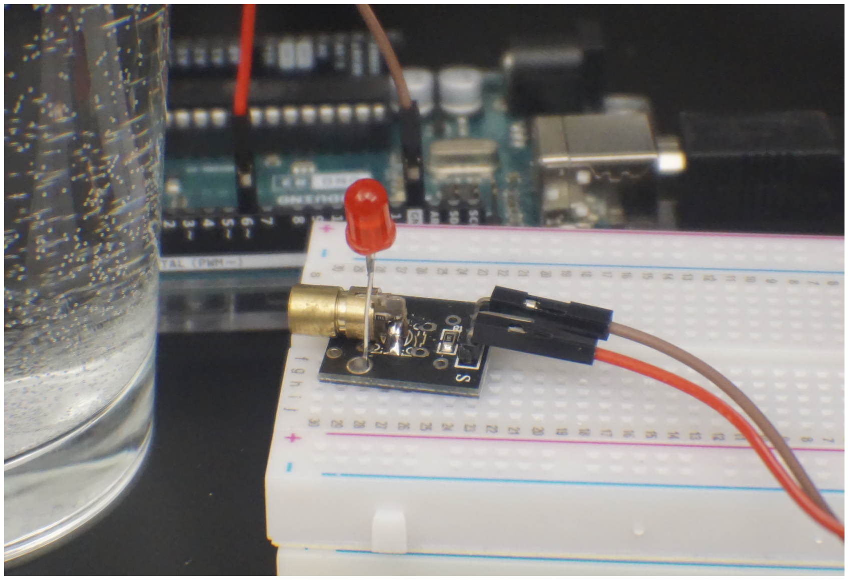


Figure 5: Picture of Transmitter Circuit

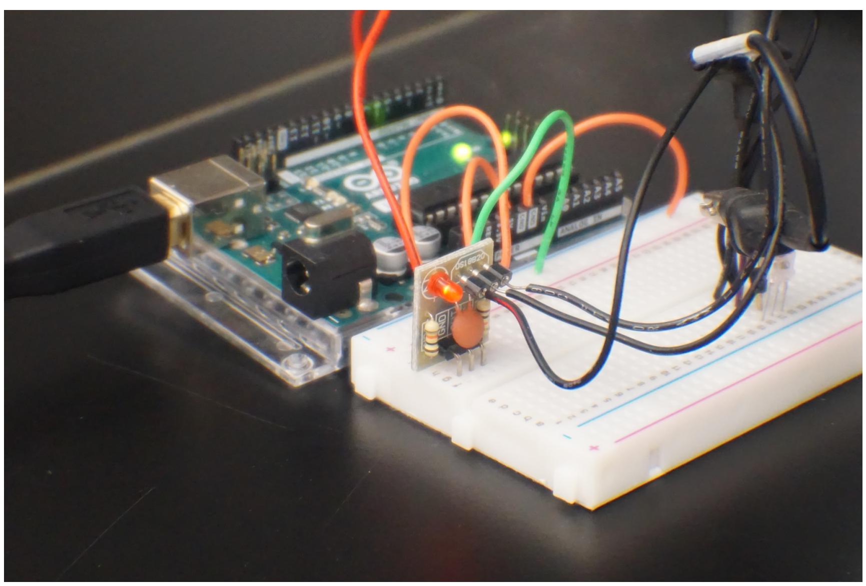


Figure 6: Picture of Receiver Circuit

While the transmitter is fairly straightforward as it is just a laser and a limiting resistor, the receiver design depends significantly on the type of photoreceiver used. The receiver includes a filter circuit as well. The physical design choices for the hardware were intended to be intentionally low cost, as we were unsure about the ability of any hardware implementation to remove error in the signal due to various reasons. Because of this we used Arduino UNO R3 microcontrollers as they have a significant amount of documentation and library data for various applications. Despite this choice however, we were aware that these specific microcontrollers have a relatively low clock rate, which would theoretically limit the data rate. The transmitter utilized is a KY-008 650nm laser diode. We decided to use a 650nm laser diode primarily because this specific laser diode is commonly used with Arduino-based projects, with significant information about other uses. The 450nm laser diode we initially purchased for this project also did not have a high enough slew rate to modulate the laser in a way that could be received by our initial choice of photodiode. It is relevant to mention that in another iteration of a hardware design for this project, we would want to pursue using a 450nm laser diode as it would provide the least attenuation by water. Regarding the receiver, we initially wanted to use the TSL257-LF laser diode but as the version of this receiver we purchased was not optimized for blue light, we saw merit in using the optical receiver circuit listed on the parts list. This optical receiver is similar to the KY-008 laser diode because it is used in a variety of other applications and Arduino projects with positive reviews in this regard. There are also other optical communication projects that utilize these components, albeit not to the same extent or situation. This receiver was convenient because the PCB includes the filter circuit with the same resistor and capacitor values that we would have had to manually construct on the breadboard.

As for the modulation and error correction, we utilized a publicly released Arduino IDE library designed for optical communication. As none of our group members in both our ECE & CSE teams had extensive experience in this field, we thought this would be the best solution for what is essentially a practical demonstration of a miniature UOWC system. Manchester code is supported by this library, so this signal will be modulated in this way. This library also makes use of Hamming(7, 4) encoding, which is one of the simplest forms of a Low Density Parity Check Code. LDPC codes are currently used in modern day for implementations of UOWC systems as mentioned previously. This system is able to transmit short strings at a maximum of about a foot through a medium of air and through a glass of water, about 7cm lengthwise at the LOS. There was minimal error throughout the tests, but for strings longer than approximately 250 characters there were errors encountered consistently. This would make sense as this error correction scheme as it is implemented in the library is not designed for longer strings.

5- Simulink Model

Beyond the physical proof of concept, a system model will be designed via Simulink such that some of the differences between a future implementation and the proof of concept can be analyzed. Ideally this system model will incorporate many of the empirical parameters associated with a future UUV implementation and can provide a skeleton for future development of the system. The Simulink model will very closely follow the block diagram, and will ultimately serve as a mathematical framework for analyzing potential design changes against.

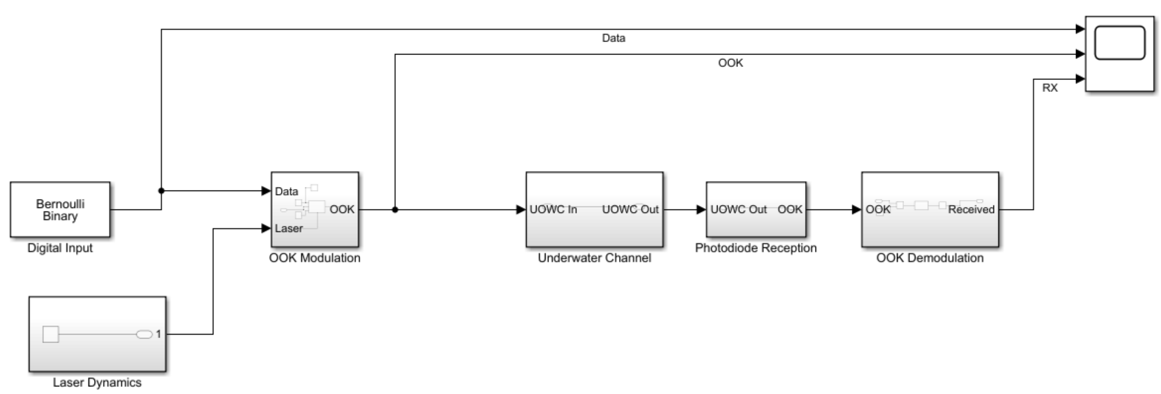


Figure 7: Overall Simulink Model for UOWC system. Notice that each subsystem will contain multiple subcomponents as well, which can be altered to determine the effect of varying design choices on outcomes.

The model will consist of four primary components, with each component containing various subsystems. Firstly, the signal must be generated. This Signal Generation process involves a Bernoulli Binary digital input (representing whatever encoded data message) as well as an OOK Modulation process. The Signal Generation process contains three subsystems, the Bernoulli Binary input, the OOK Modulation Scheme and the Laser Dynamics block (currently set as ideal). Through the combination of these three elements, we can attempt to accurately model the process of generation and initial transmission of the data to be transferred via the optical wireless system.

The OOK Modulation Scheme was based on a publicly available digital communications library for via Mathworks and ultimately took the form of:

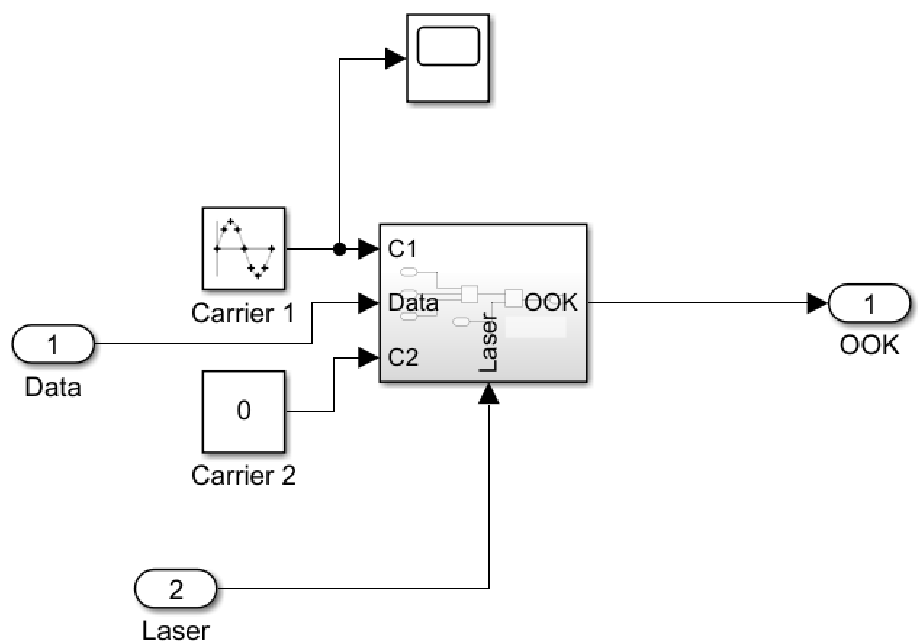


Figure 8: OOK Scheme with Carrier 1 as a constant sampled high frequency sinusoid and carrier 2 as the “Off” constant reference of zero. Laser Dynamics represent a phase shift and actuation delay, though are assumed ideal to begin with.

Secondly will be the model for the Undersea Channel itself. There are two general system types for Underwater Optical communication channels, Line-Of-Sight (LOS) models which assume a direct line of sight between the original laser transmitter and the photodiode receiver, and Non-Line-Of-Sight (NLOS) models, which assume that the optical signal will be picked up indirectly via reflection effects and the system geometry through which the message will be passed(Spagnolo 2020). LOS link systems are significantly easier to model and will be our primary focus given that NLOS models incorporate a larger degree of complexity than will be manageable given our restrictions.

LOS configuration models also are fairly difficult to model and rely heavily on both using empirical data from field research and sophisticated numerical methods to solve the radiative transfer equation (RTE) for the system(Spagnolo 2020). Most commonly this is done via the Gauss-Seidel iterative method, and ultimately results in an approximated state-space approach used to calculate the received, reflected and absorbed power of signals passed through the channel. Ultimately the model produced relied on a constant attenuation factor based upon Beer-Lambert's Law.

$$P(z, \lambda) = P_0 e^{-(\alpha(\lambda)+\beta(\lambda))z}$$

Figure 9: Beer Lambert's Law As a Function of Wavelength and Distance through a constant medium in 1D

Ultimately this produces a medium with a constant model.

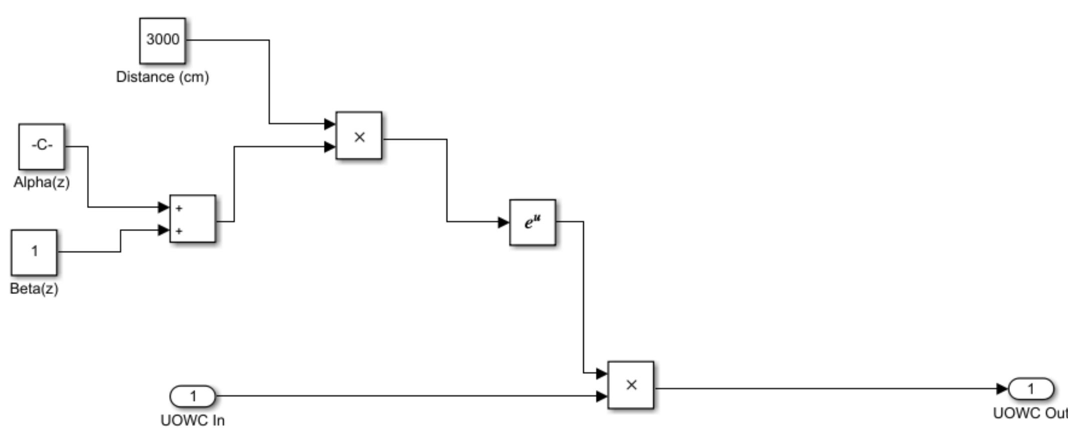


Figure 10: Undersea Channel Model with Constant Attenuation and Factor control for distance, absorption and scattering. Scattering assumed constant and Absorption set to 4*10^(-5)

Finally, there is the signal reception system. This system will be fairly similar to the Signal Generation process in that it will contain 4 independent components. Firstly the dynamics of the photodiode receiver need to be modeled. This information can be empirically derived from the photodiode used in the final design but is assumed constant for now. After the photodiode model the signal will need to be demodulated and decoded. This would have been the best way to incorporate the CSE team, however there were breakdowns in communication so a simple OOK demodulation scheme was also chosen.

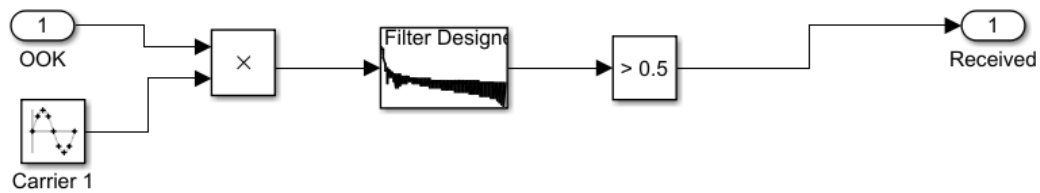


Figure 11: OOK Demodulation with FIR Digital Filter and Comparator Reconstruction

This model was planned to make up a significant portion of the final deliverable however a lack of available empirical data on both Undersea Channel modeling and laser diode actuation and reception dynamics for these systems prevented this from becoming something that would be accurate enough to apply. The system does work fairly well, with one significant issue of dropping longer strings of 1's which would require a more finely tuned reconstruction and filter process.

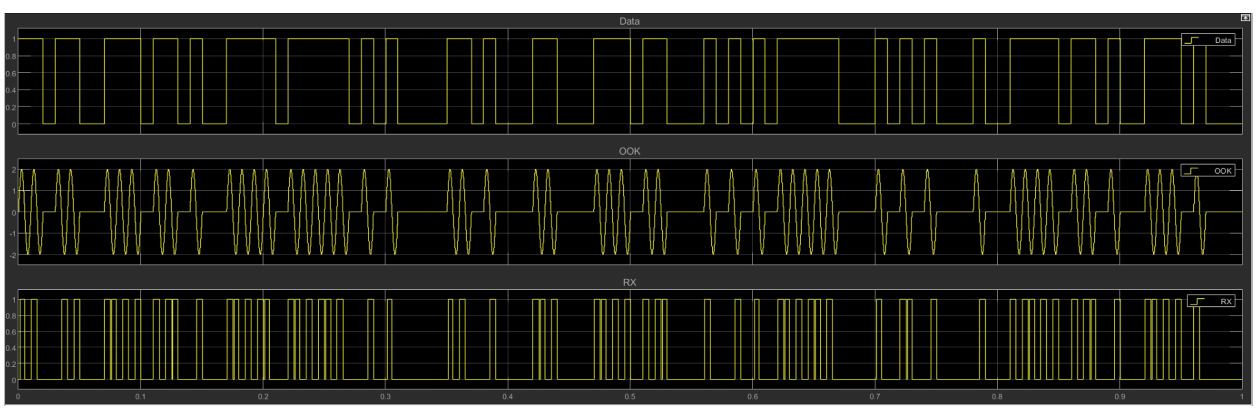


Figure 12: Final Received Signal. Note the gaps in reconstructed signal where long strings of 1 should be.

6- Constraints

While virtual designs and simulations would not have any monetary impact on this project, any scaled down hardware implementation would require a budget from our sponsor which our proposed hardware implementation is within. Our main constraint for this project would be the lack of in-person communication we are able to have within such a large group for this project, but all deliverables will be able to be completed regardless of this. There is also the time constraint of only being able to work on a hardware design for this project during the academic semesters, which should not be a problem as well, since the simulation and software aspect of this project is able to be completed remotely, which has been established to be the main concern for the Spring semester.

7- Alternate Designs Considered & Standards

As covered previously, we had considered the possibility of using RF or Acoustic communication for this project as these are more common methods of underwater data transfer, especially for the purposes of a military contractor. Despite this, we have seen optical communication as the most unique of the three options due to the potential for an incredibly high data rate at the required distance between transmission and reception. Underwater optical wireless communication is still an active research area with no clear industry platform or standard as mentioned previously. As this project is a multi-year endeavor with multidisciplinary involvement, there is significant room and time to conduct research on larger models in both simulation and hardware. A further partnership between Electric Boat and the University of Connecticut for funding and testing on a project involving fabrication of one of these devices on a larger scale would also be beneficial, as academic research labs are at the forefront of investigation into the long-term feasibility of this technology.

Our hardware concept for this project has utilized the standards of the Arduino microcontroller platform and Arduino IDE & language, as well as Universal Serial Bus 2.0 as this connection will allow us to send/receive serial data and power the Arduino devices.

8- Functioning UOWC Systems

During our research and investigation, we noticed that there were a few notable UOWC systems that were made public by companies or research groups. The most promising system we have seen, constructed by Sonardyne, is called the BLUECOMM 100. This system was rated at transferring data at between 1 - 5 Mbps for a range of approximately 15 meters. The system is slightly larger than Electric Boat's theoretical use case however, being 254mm by 128 mm & weighing 2.4 kg. This system also uses the same 450 nm wavelength blue light for presumably the same reason we wanted to.

Another implementation of UOWC that we have seen is the results of MIT Lincoln Lab's research. Their team has worked on a relatively but high power optical communication system that takes the form of two UUVs that are able to find each other's locations while submerged in an olympic swimming pool. This is due to the fact that the systems will spin around until their transmission lasers hit and then further lock on to the optical receiver module of the other UUV. After this process, data transmission can begin. This system makes use of photodiode array technology, to increase the surface area of the receiver. While they have not revealed the data rate of this system, it is estimated to be similar to the BLUECOMM 100 at about a 10 meter range.

IV. Project Management

RACI Chart:

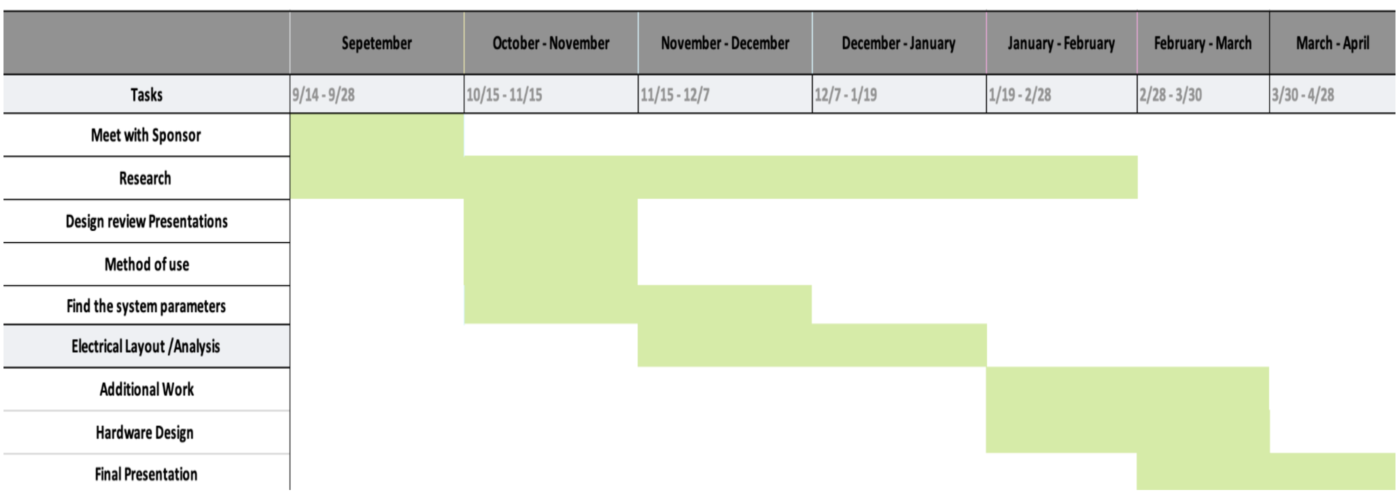
TEAM 2117

RACI CHART

Project task or deliverable	Kiran	Ryan	Harris	Sponsor	Advisor
Initial Research					
wireless underwater data transfer techniques and technologies	R	R	R	C	I
Identification of Notional Parameters	R	R	R	C	I
Design					
POC Hardware Construction	R	A	A	C	I
Reasearch Report	R	R	R	C	I
Simulation Deliverables	A	R	A	C	I
Logistical					
Sponsor/ Advisor contact	R	A	A	A	A
Ordering Supplies	R	A	A	I	I
Updating Website	R	A	A	I	I

Responsible = R
Accountable = A
Consulted = C
Informed = I

GANTT Chart:



Hardware Component List:

Table 1

Part	Price	QTY	Net Price	Web Link
ARDUINO UNO REV3	$23.00	2	$46.00	https://store.arduino.c
TSL257-LF (Optical Sensor)	$9.99	1	$9.99	https://www.amazon.c
Youliang 2PCS KY-008 Laser Transmitter (2 PCS)	$5.99	1	$5.99	https://www.amazon.c
5V Laser Receiver Sensor Detection Module for Arduino (5 PCS)	$7.99	1	$7.99	https://www.amazon.c
Qiaoba Laser Diode 450nm	$18.89	1	$18.89	https://www.amazon.c
10kΩ Resistor	$0.10	10	$1.00	https://www.digikey.c
100nF Capacitor	$0.57	4	$2.28	https://www.digikey.c
Total Price			$92.14	

This is the list of parts we will be ordering for this project. We want to order multiple laser diodes to test the changes of different wattages on the data transfer rate of the laser.

V. Summary

Our team has considered the positives and negatives of a variety of wireless data transfer and communication systems based upon research by leaders in this technology. We have decided based upon the constraints, requirements, and practicality that an optical system would be an ambitious yet suitable design. This is because typical UOWC systems obtain high data rates (low gbps range) while maintaining better power efficiency compared to alternative solutions. Although the current common method of underwater wireless communication is to utilize acoustic waves, as opposed to electromagnetic waves in RF or Optical systems. Acoustic waves have many disadvantages, such as their low data and bandwidth. Our design for a basic optical communication system contains a high power laser or LED to send the data through the underwater channel. A PIN photodiode will be waiting on the other end to receive the data, which will usually be connected to an amplifier circuit leading to the microcontroller in charge of demodulating and decoding the data. With our team using a blue-violet light, the device will have the capability of working 100 meters below water. An ideal system will provide a laser power source of up to 5W, and will be able to work between -5°C to 40°C due to the semiconductor-based laser. One last note is regarding the fact that we would want future hardware to make use of a different microcontroller option, as the Arduino clock rate could be seen as a limiting factor for a system with more power transmitter/receiver or array based solutions. A more specialized microcontroller designed for this process would be ideal.

VI. References

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[3] Tarek A. Eldallal, Heba A. Fayed, Moustafa H. Aly, “Data transmission prototypes through wireless optical communication link using Arduino microcontroller”, Journal of Optoelectronics and Advanced Materials Vol. 21, Iss. 7-8, pp. 459-469, Jul. 2019.

VII. Appendices

Senior Design Project Checklist

Project name: ECE Team 20117: Underwater Data Transfer

Sponsor: General Dynamics Electric Boat

Contact: Eric Hultgren – ehultgre@gdeb.com

Team members (majors/programs):

Kiran Nadkarni - ECE

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Brendan Taylor- ME

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Ryan Young- CSE

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Gus Marx- CSE

Faculty advisor(s):

Dr. Necmi Biyikli- ECE

Dr. Chih-Jen Sung- ME

Dr. Jacob Scoggin- CSE

Skills, Constraints, and Standards: (*Please check (√) all those that apply to your project.*)

Skills:	**(√)**
Analog circuit design and troubleshooting	
Digital circuit design and troubleshooting	√
Software development/programming	√
Embedded Systems/Microcontrollers	√
Web design	
RF/wireless hardware	
Control systems	√
Communication systems	√
Power systems	
Signal processing	√
Machine shop/mechanical design	√
Other (please specify):	
Constraints:	
Economic (budget)	
Health/safety	√

Manufacturability	√
Environmental (e.g., toxic materials, fossil fuels)	√
Social/legal (e.g., privacy)	
Standards:	
List standards/electric codes that you used (e.g., IEEE 802.11, Bluetooth, RS-232, VHDL, etc.)	**If applicable, list the name or # here:** **Arduino Microcontroller Platform and Software, Universal Serial Bus 3.0,**

Table 2: These are all of the skills and standards, mentioned previously, as a part of the project checklist.