# Impact of Water Turbidity on Laser Light Transmission


## Midshipman 4/C Cheshire, Viswanathan, Engl, and Hobson

### Professor Svetlana-Avramov Zamurovic



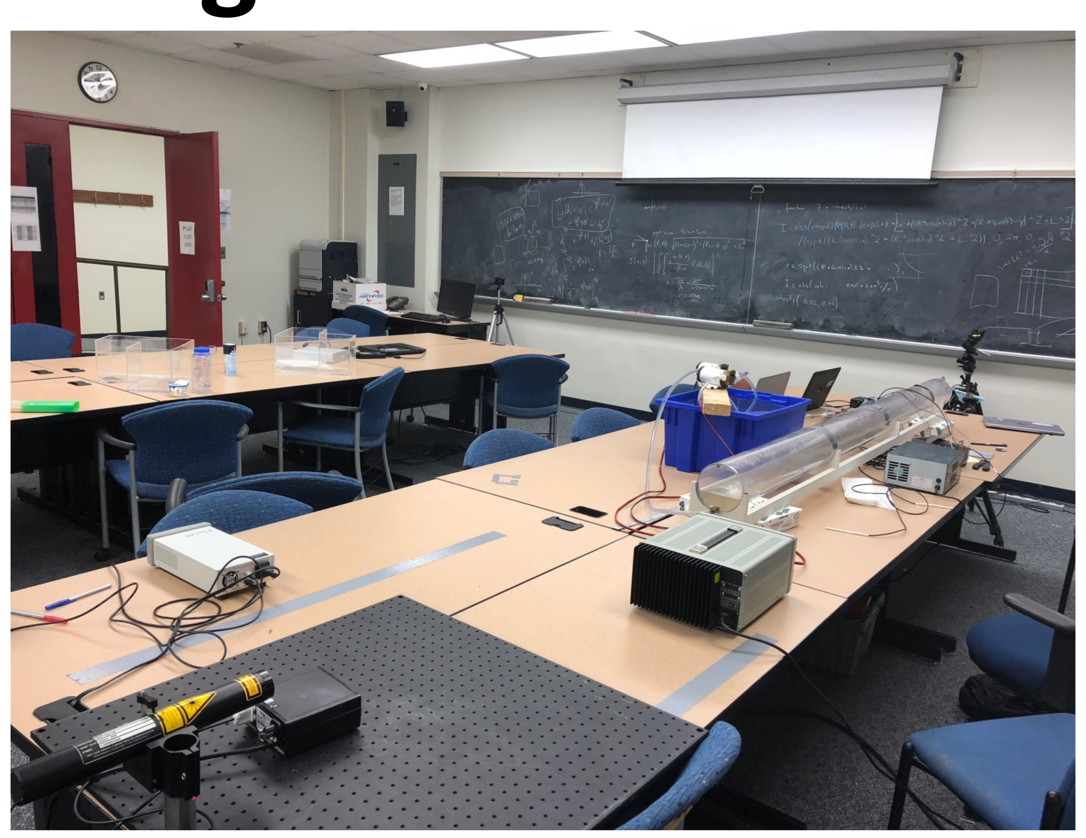
## Abstract

The purpose of this experiment is to observe the extent to which turbid flow of a fluid in the path of a laser beam affects its nature and predictability. Laser communication is gaining traction in the Navy due to its efficiency in line-of-sight applications, but needs to be modified to meet the needs of underwater environment for application in sub-waterline surface and submarine communications. Our goal is to determine if there are any macroscopic trends when considering the integrity of information, transmitted by beam, passing through mechanically disturbed (or turbid) water that are not necessarily intuitive.


## Background

Lasers eliminate many of weaknesses in communication with tradition signals (e.g. mass transmission and interception). Despite the potential for lasers, turbidity in a medium inhibits the ability of a optics to transmit a constant stream of data. In order to quantify this interaction, the effect of turbidity on Bit Error Rate of lasers was studied. Lasers emit a Relative Intensity Noise (RIN) based upon the energy intensity of the laser (Rudger). The spectral density of the laser emitted is described as the power as a function of frequency. With increased medium turbidity, the spectral density decreases over the distance traveled. Therefore, less power per evolution of light is present the further you engage the turbid medium. Lasers are only efficient based on two things: how much data they can transfer, and data reconfiguration. Data reconfiguration on the receiver end is determined by how little the spectral density of the wave will diverge in turbid conditions. How much data that can be transferred is also dependent on the stability of the spectral density.

## Images



## Methods

1. Align 633nm laser, water tank, and amplified detector in a manner such that the laser will shine through the water tank, the turbidity created from the stream of water produced by the pump, and hit the amplified detector on the other side of the tank.
2. Attach water pump to water tank
3. Take an initial control measurement
   a. Shine 633nm laser through calm water tank with pump at 0V
   b. Measure light intensity at 24000 Hz measurements over a period of 1 second
4. Take experimental measurements
   a. Increase pump voltage to 3V, 6V, 9V, 12V to simulate an increasingly turbid environment
   b. Record intensities at 24000 Hz over a period of 1 second
5. Use recorded data to attain average intensity for each trial
6. Use average intensity to analyze difference between intensity in calm water versus turbulent water
7. Graph difference between beam spread in calm versus turbid water
8. Graph Bit Error Rate by using average intensity as a baseline and treating all data above the average as a "1" and data below the average as a "0" (this relative index is an appropriate indication of overall signal quality).

## Experimental Setup

__Current:__

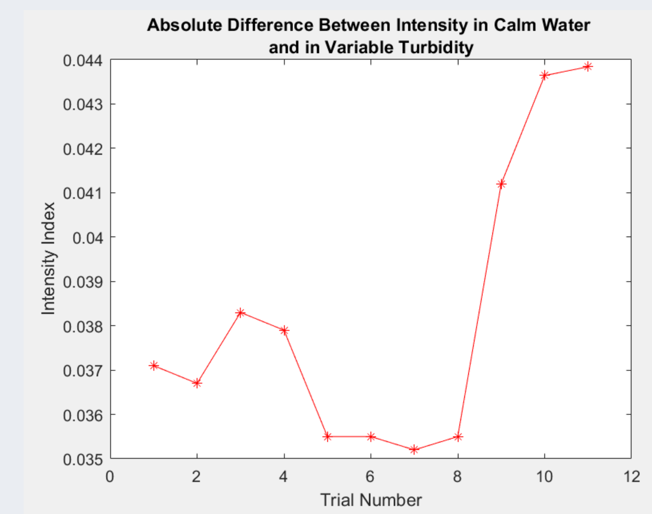
- **Supplies**
  - Pump
  - 633 nm Helium Neon Laser
  - Tube of Water
  - Amplified Detector
- **Objective**
  - Flow rate into tank will be changed by voltage applied to the pump at 3V increments up to 12V to determine the relationship between laser intensity fluctuations and turbidity in water.
  - Qualify the rate at which intensity fluctuations become so great as to obscure Bit Error Rate of laser based communication.

**NOTE:**
**3V used in trials 1,2**
**6V used in trials 3-5**
**9V used in trials 6-8**
**12V used in trials 9-11**

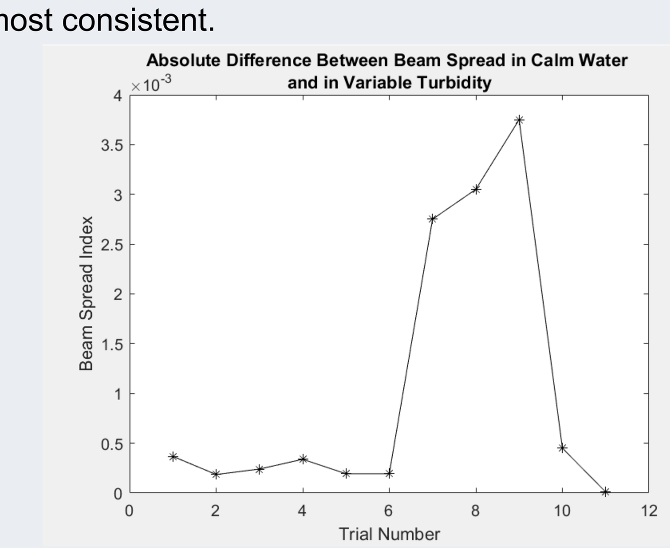
***Original first trial at 3V was scrapped as an outlier, and thus was not included in analysis.**

## Results

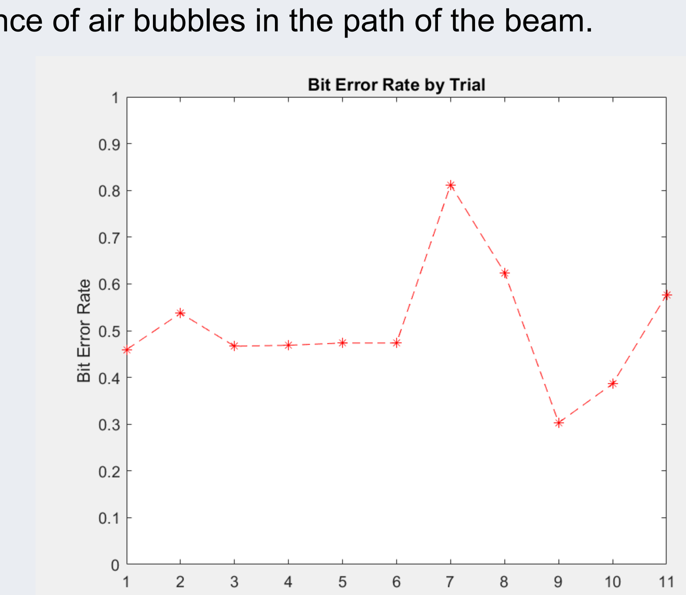
For the following graphs, the points were created by subtracting the average value for each trial (each of which consisted of 22000 subvalues) and took its absolute difference from the average of three trials taken in calm water.




The above plot shows that increasing the turbid flow of the water caused a generally divergent trend from a calm water baseline. This is expected, as turbidity will have increasingly chaotic effects on the beam. However, it is important to note that trials conducted in 9V (6-8) appear to be the most consistent.




The above plot demonstrates that the transmission of optical data through water would become increasingly inconsistent when approaching higher levels of disturbance by modeling the difference between the standard deviation of beam intensity in calm water and that of each trial. For our purposes, this data can be used to approximate the "beam spread" (a general indication of beam centroid wander). The sudden increase at trial 8 is largely due to the sudden appearance of air bubbles in the path of the beam.




Rather unexpectedly, it appears that the least consistent signals originated from the turbidity in trials 6-8, which was produced by 9V, and that the minimum signal interruption occurred in trial 10, which was produced by 12V. This is contrary to the observations drawn from the first graph Below is the relationship between BER and signal-to-noise ratio.

$$\frac{C}{N} = \frac{Eb}{No} \bullet \frac{fb}{Bw}$$

Where C/N is the Carrier-to-Noise ratio (analogous to quality of signal), E is BER measured in energy, N is Spectral Noise, and f/B is a ratio of transmission vs. reception rate. It can be used to translate BER to quality of signal (Pearce).

## Conclusion

Based on the graphs of our laser intensity in a turbid medium, there is a noticeable trend of decreased laser intensity with increased turbidity [as indicated by divergence from the control variable (calm water intensity)]. There was a notable plateau of low difference from the control in the intensity values derived from the 9V trials, which at first was interpreted as improved communications. However, upon inspection of the fluctuating trend in Bit Error Rate (BER), the 9V trials were noted to have the least reliable communications (in accord with the proportionality of signal quality and BER, as outlined in the included equation). Furthermore, the 6V trials had a very consistent BER, and the 12V trials had an unexpectedly low average BER. These observations support the conclusion that decreased intensity and increased turbidity does not lead to lowered signal quality. Potential for higher-speed communications is thus revealed by our graphs' shared plateau regions (possibly a product of laminar flow caused by some threshold of resonance in the water). However, it is important to note the marked increase in our beam spread index's magnitude and inconsistency around the 12V trials. If upon further experimentation this trend of beam spread can be quantified in more specificity (i.e. controlled), in addition to whether certain thresholds of turbidity can improve communications due to resonance, there is significant potential for a future in laser beam line-of-sight communications on fast moving, underwater platforms.

## References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## Acknowledgements

MSC Graphics

3-5857, mscgraphics@usna.edu

Mon-Thur 0730-2245
Friday 0730-1700