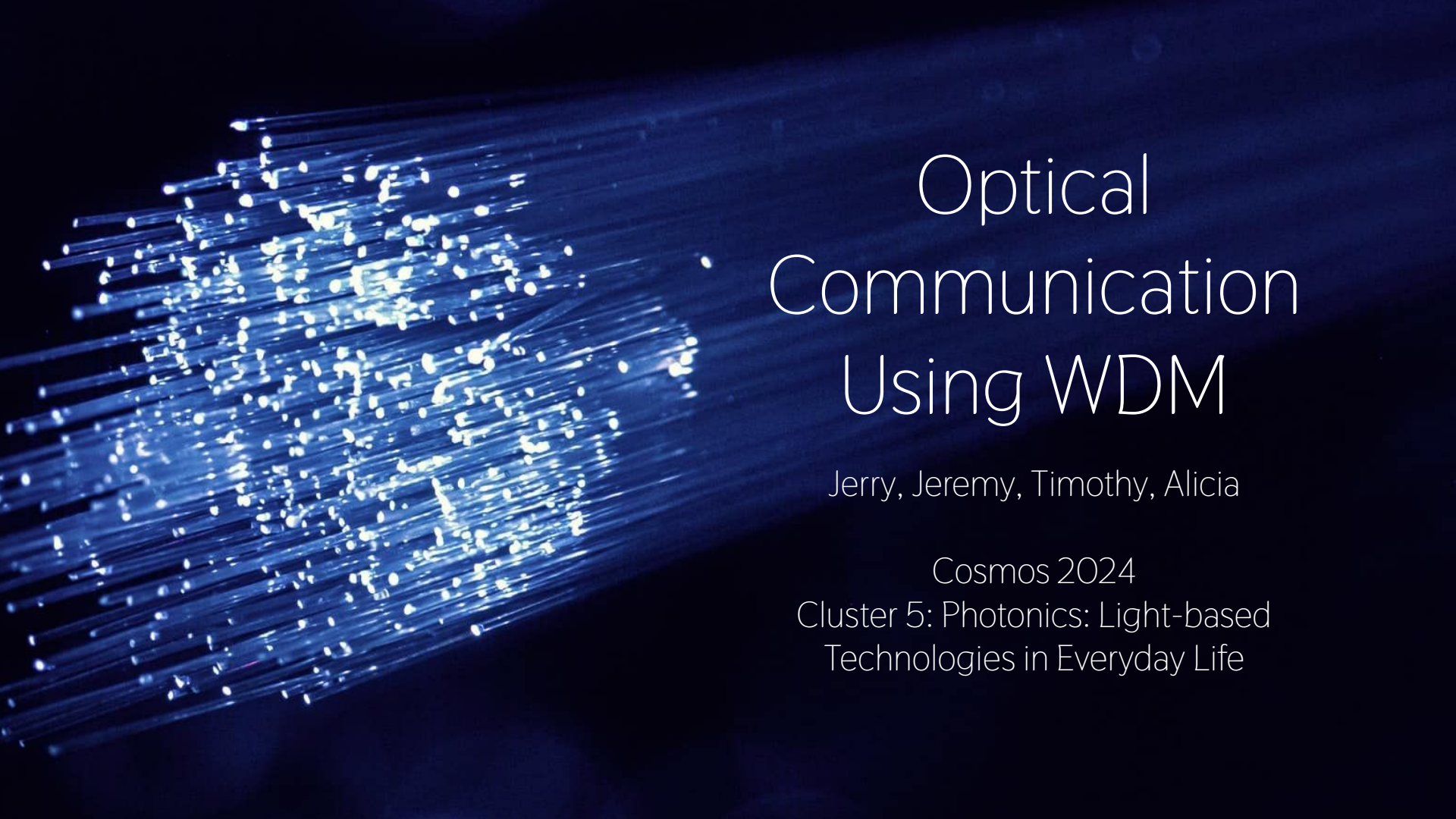

Optical Communication Using WDM

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Cosmos 2024
Cluster 5: Photonics: Light-based Technologies in Everyday Life

Cosmos Life

Introduction

Have you wondered how you can send and receive texts from someone miles away from you?

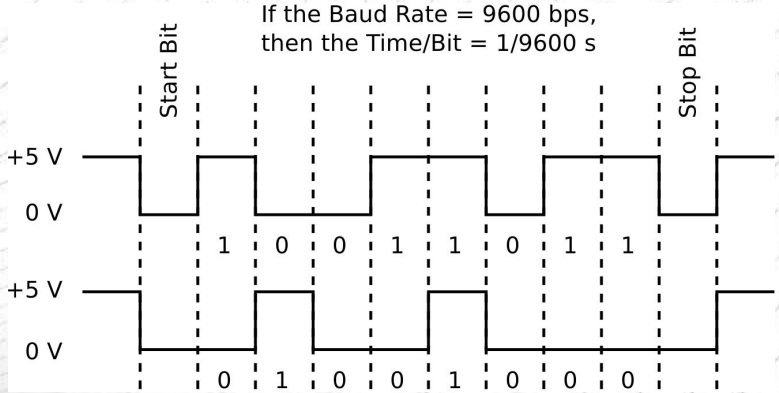
- Optical communication serves as the basis for quick transmissions of data
- Nearly all forms of modern communications involve Wavelength Division Multiplexing (WDM)
  - Combines different colors of light into white light and splits it back up
  - Allows large amounts of data to be transmitted at once

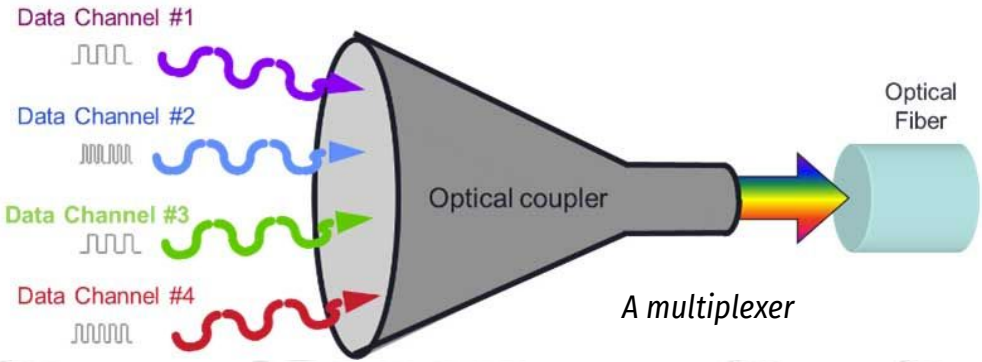
Main Goal

Test the efficiency of a free-space Wavelength Division Multiplexing system and the impact the length of a message has on the accuracy and speed of transmission.

Key Concepts

Multiplexer/Demultiplexer: Component of WDM system that combines or separates different wavelengths of optical signals to be sent and received through a single channel, usually optical fiber





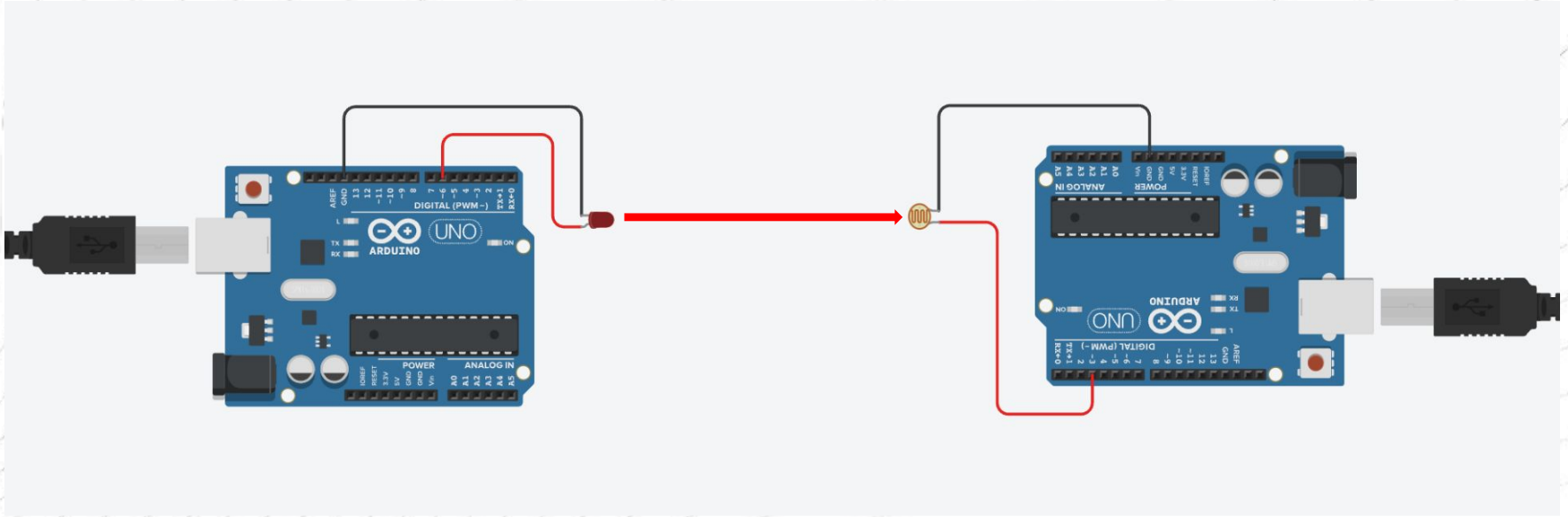
A multiplexer

Wavelength: Determines color and energy of a light wave

Modulation: The way waves are manipulated

Photoresistor: Sensor whose resistance varies with the amount of light on its surface

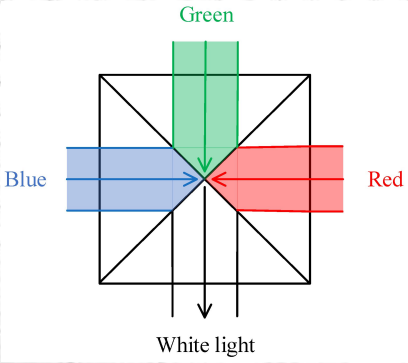
Basic Principle: One-Beam System

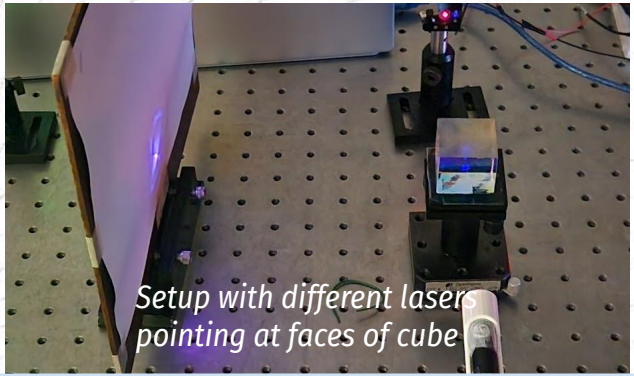


- Instead of a wired connection, our setup uses pulses from a laser diode
- Received by light sensor
- Challenges: alignment, signal interpretation, obstruction

Methodology: Beam Splitting

- Used **trichroic prism**
  - Combines and splits beams of different colors
- Red, green, and blue combine to make **white** light
- Prism has coatings/materials to split beam at right angles

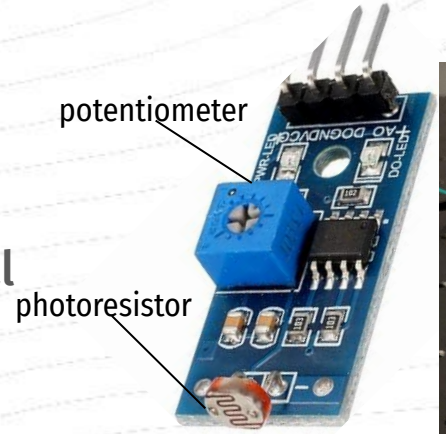


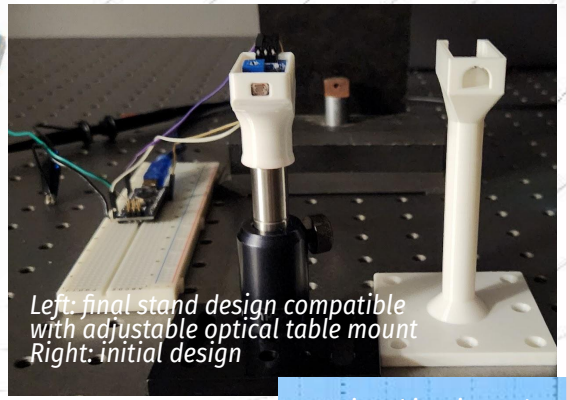

Setup with different lasers pointing at faces of cube


Three colors of light combining into a white spot on the screen

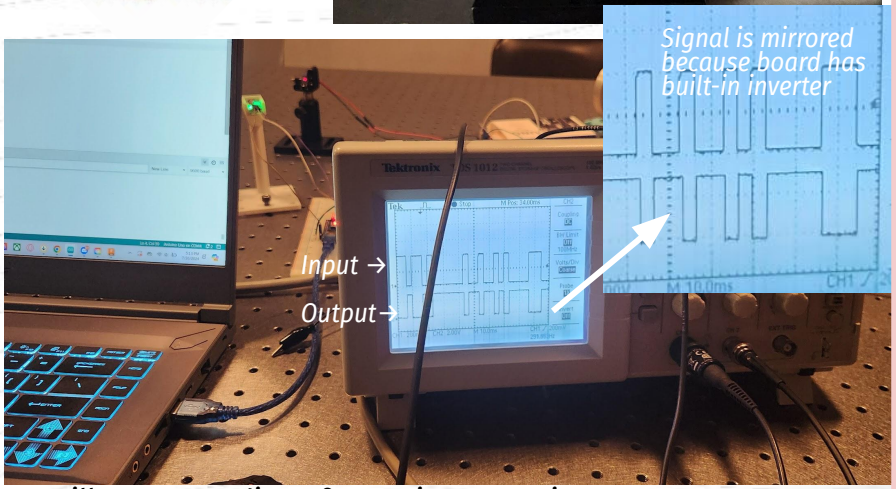
Methodology: Receiving

- Used **digital photoresistor** board to convert optical pulses to digital signal (on/off)
- Sensor contains **potentiometer** to adjust *on* threshold
  - Can tune for different wavelengths and intensities
- Designed + 3D printed stands to hold sensors steadily
- Viewed sensor output on **oscilloscope**



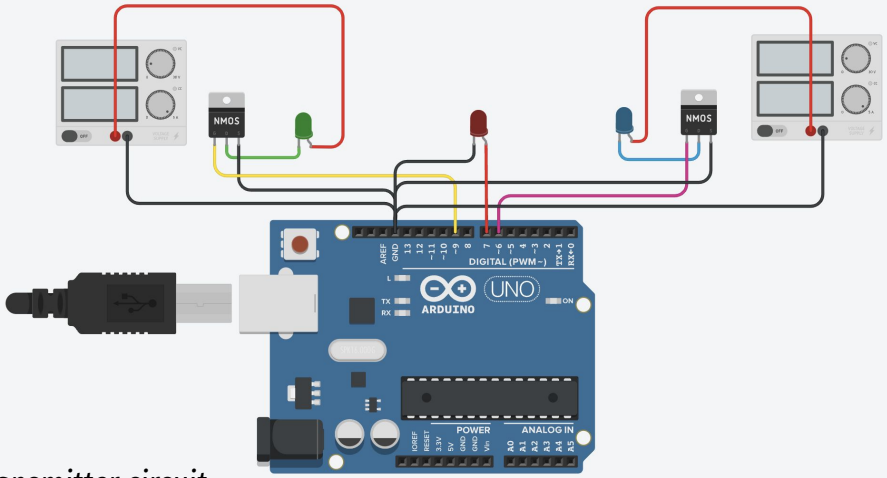


Left: final stand design compatible with adjustable optical table mount
Right: initial design

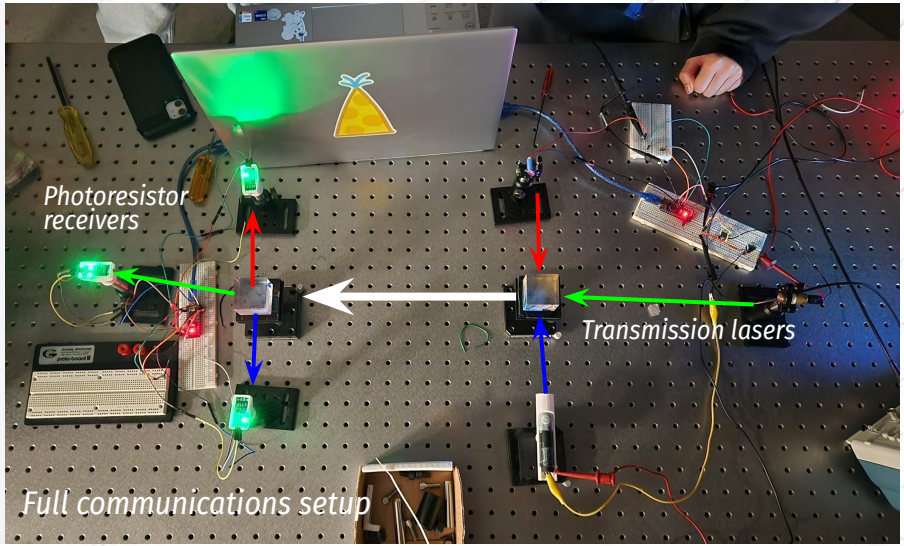


Oscilloscope reading after tuning potentiometer

Setup: Three-Beam System



Transmitter circuit



Full communications setup

- Needed power supply and MOSFET to control green and blue lasers because of Arduino current limit
- Challenges: leveling the lasers and combining them into one beam of white light, ensuring that the blue and green laser diodes don't receive too much power

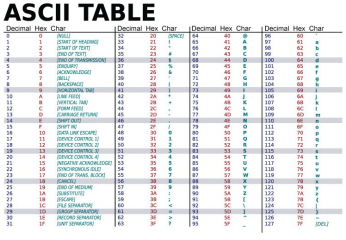
Communication Protocol

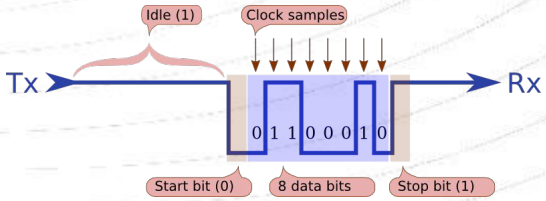
<u>Time-Based:</u> Each character is mapped to its ASCII code, and a pulse of a certain time is given to this character. We add a delay of 50 milliseconds for each character to ensure that even if there is a delay, it accurately reads in the time.

- Example: The character ‘A’ has an ASCII code of 65. Through processing: (65 - 32 + 1) * 50 = 1700 ms. Thus to transmit the character A, we send a laser pulse of 1700 ms

<u>Serial-Based:</u> We used the built in serial communication on Arduino. This data is read at a rate of 1/(baud rate) per second on the other Arduino. In our case we use a 300 baud rate.

- Asynchronous vs Synchronous Serial Communication





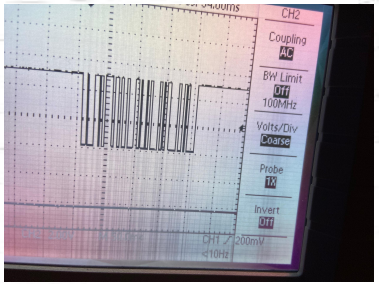
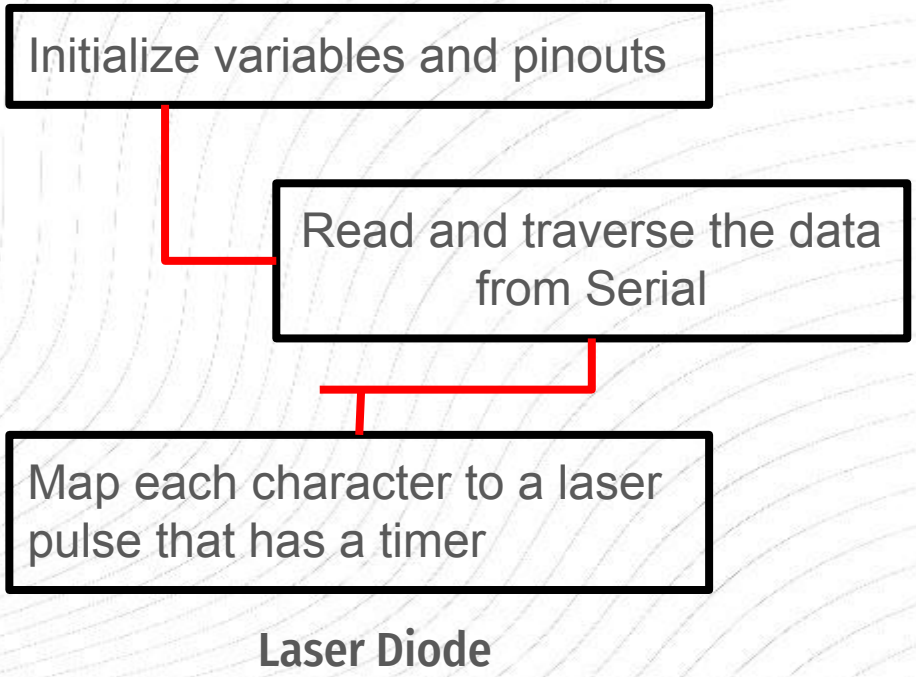
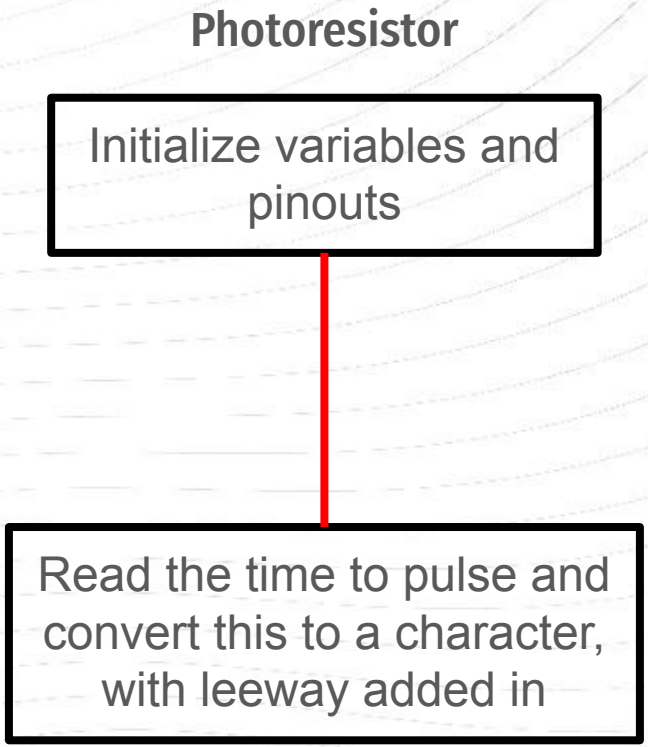


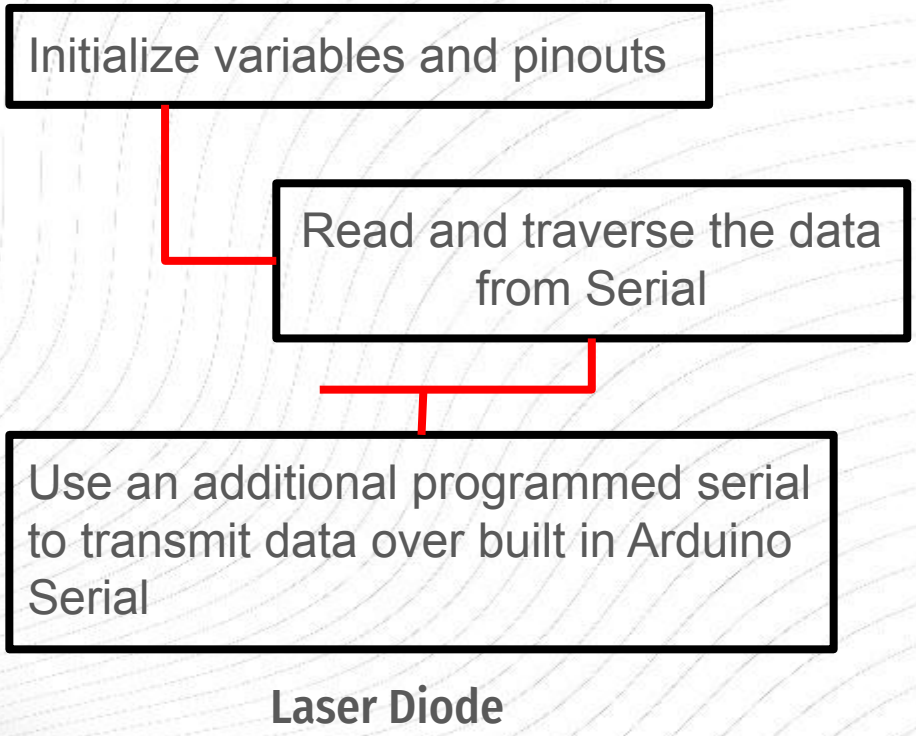
Image of Serial-Based Pulsing for “bob”

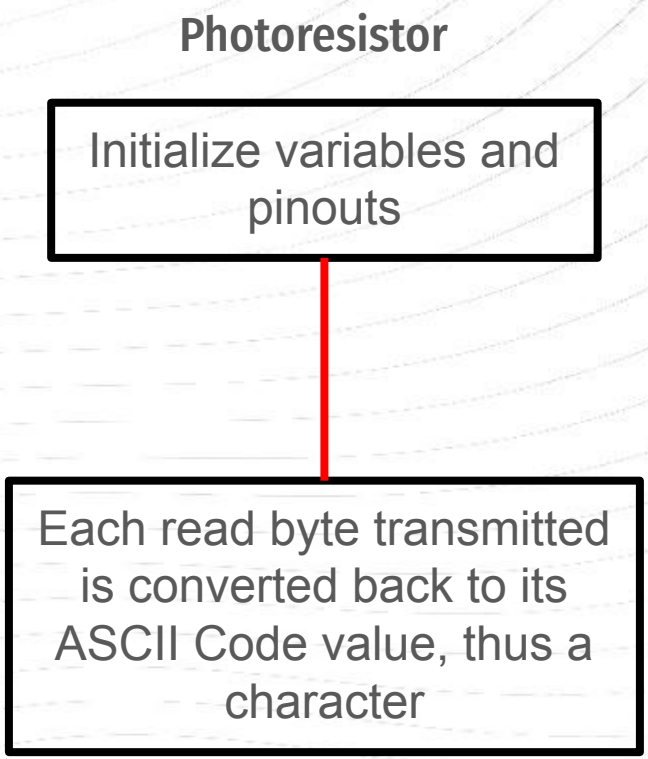
Single Beam System - Code for Time-Based Pulsing:



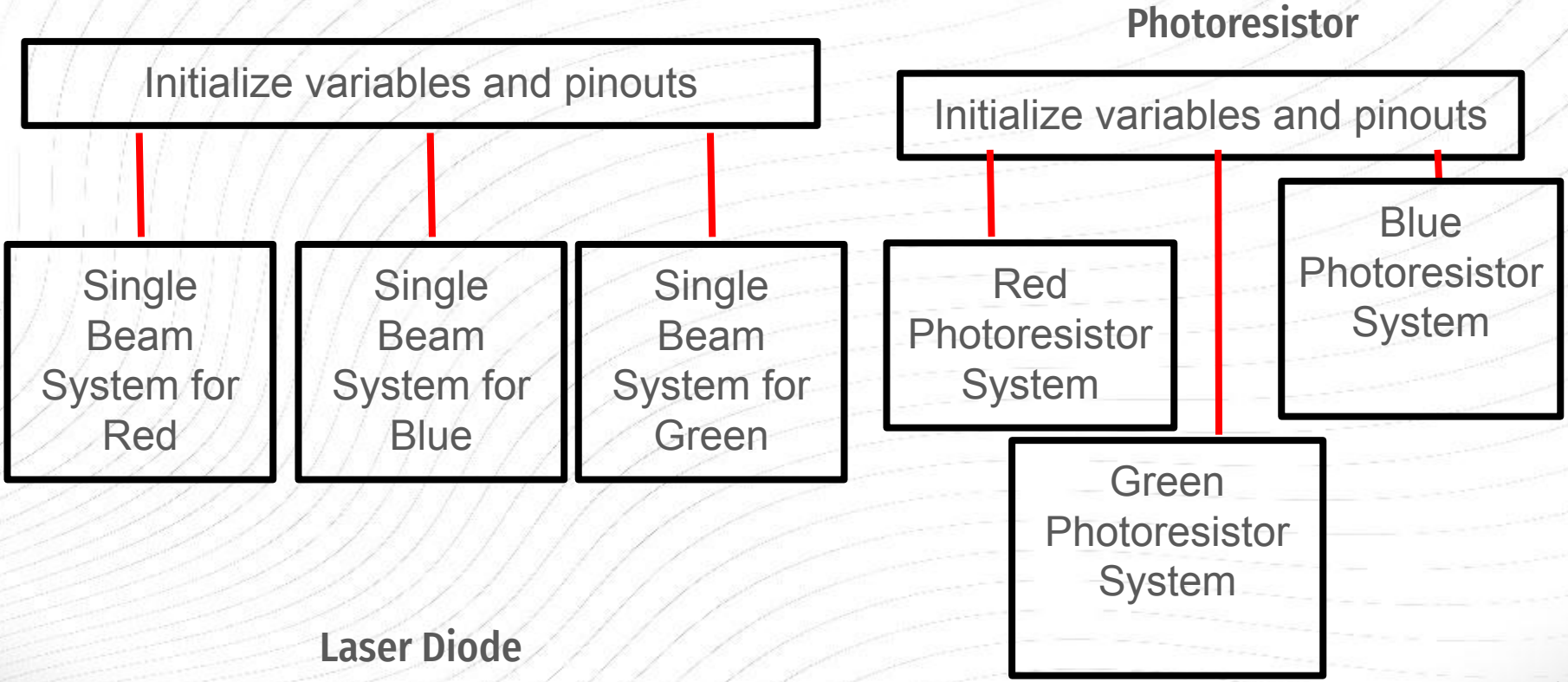


Single Beam System - Code for Serial-Based Pulsing:





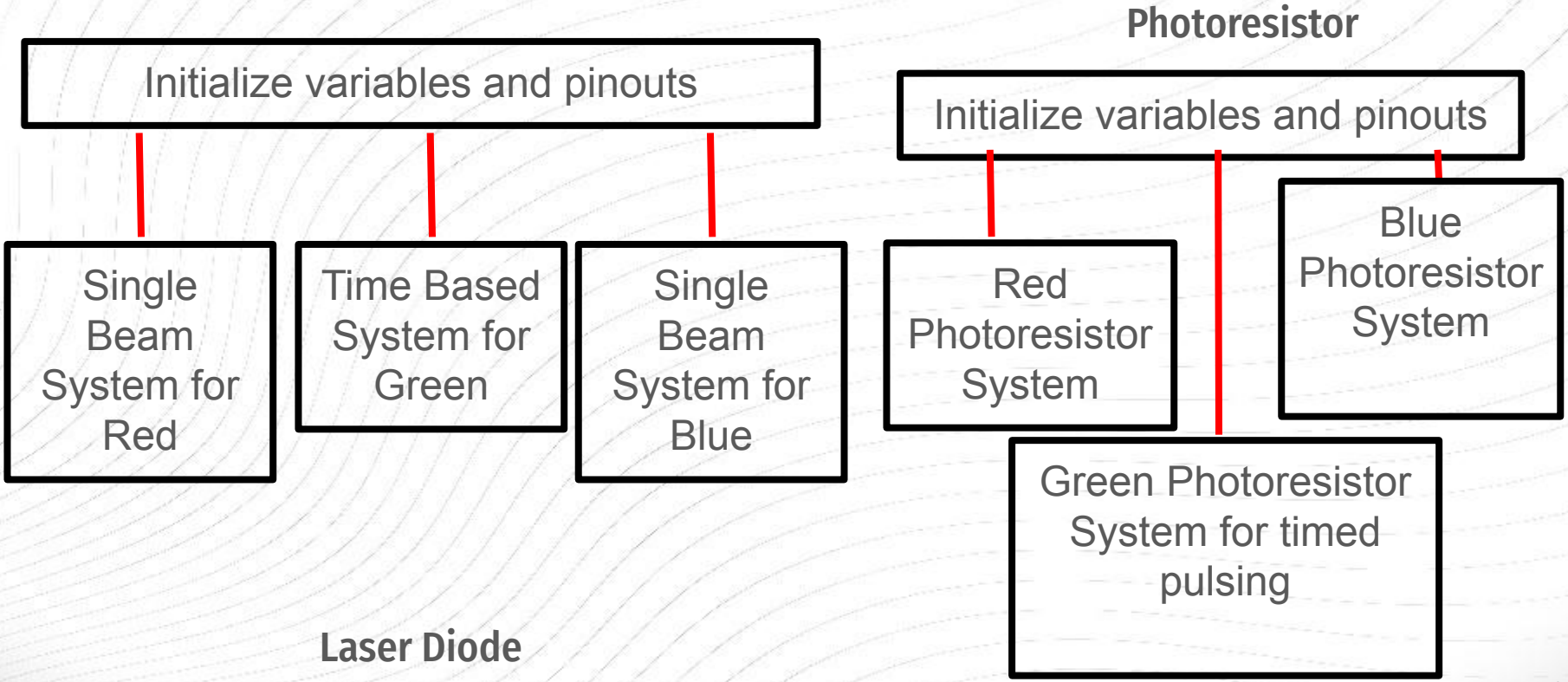
Three Beam System - Code for Serial-Based Pulsing:



Challenges

- **Precision**
  - Varies with calibration, power supplied to laser, small changes to position of equipment
- **Communication Protocol**
  - Unable to implement serial on green laser
  - Created own time-based protocol at cost of speed
- **Hardware limitations**
  - Arduino can only send one serial signal at a time
  - Not “true” WDM, but would be if using multiple arduinos for simultaneous serial transmission

Three Beam System - Corrected Version:

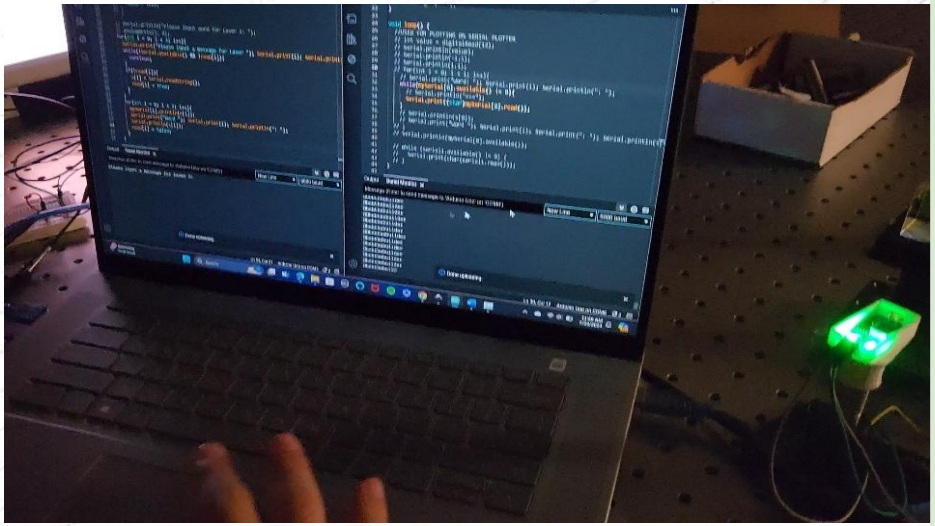


Testing: Transmission Speed

- Timed the duration from sending message to completely receiving

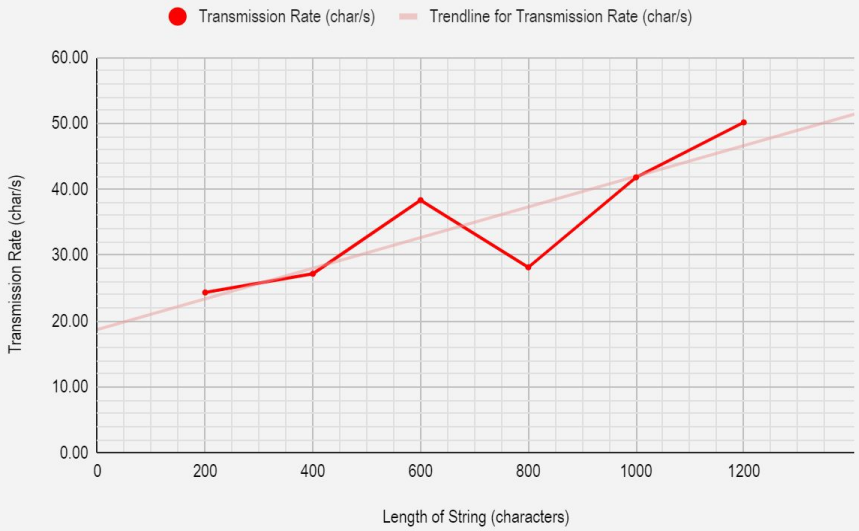
- Calculated transmission rate
- (number of characters/total time)

- Sent messages from 200-1000 characters (200 char intervals)



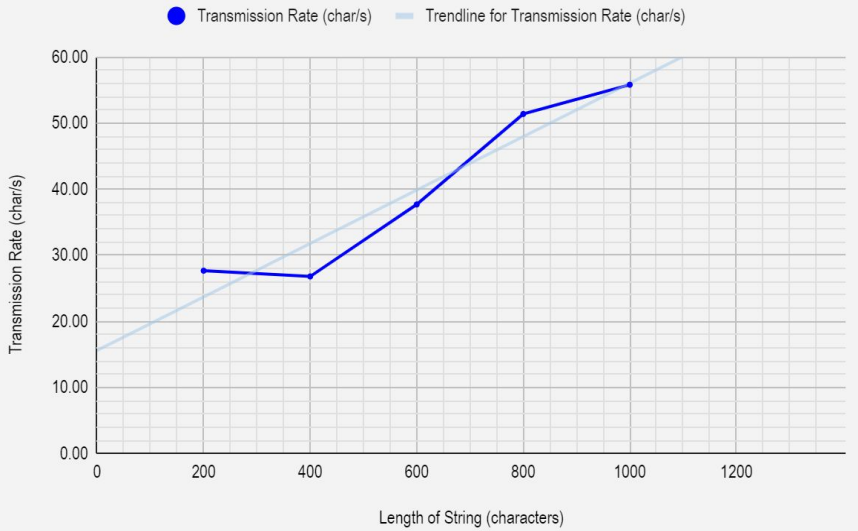
Effect of String Length on Transmission Speed

Red Laser Channel



Effect of String Length on Transmission Speed

Blue Laser Channel



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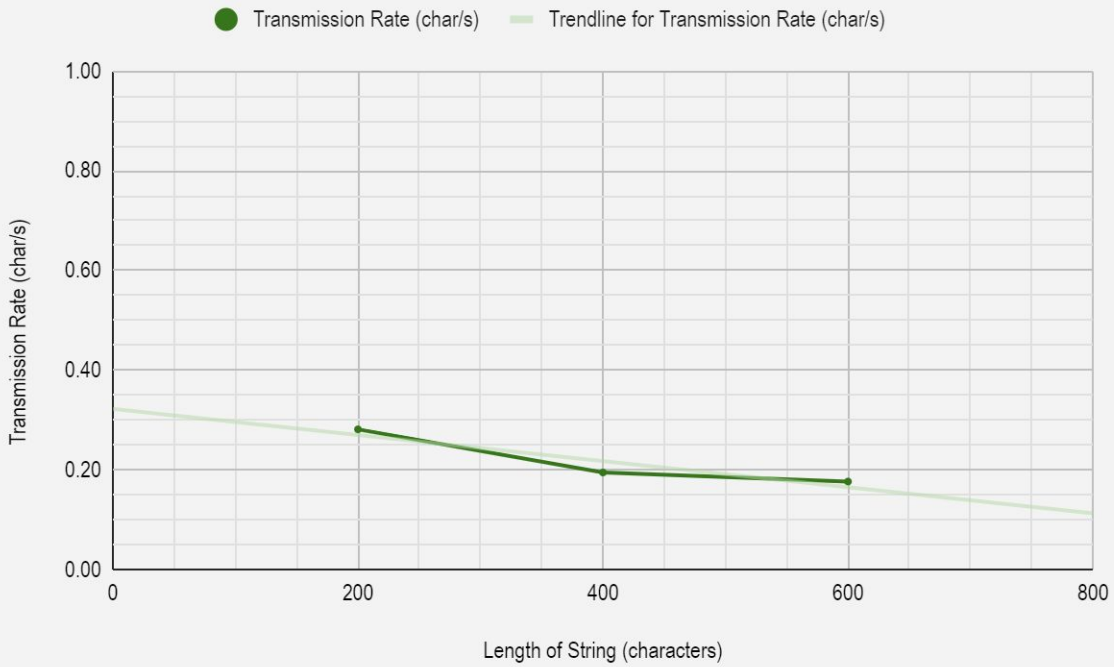
Effect of String Length on Transmission Speed

Green Laser Channel



Analysis: Transmission Speed

- Red and blue channels increased in rate as character count increased
  - Implies large fixed delay
  - Each additional character has less effect on duration
  - Hardware considerations: arduino, diode
  - Rate of change of characters per second per character was higher for blue

- Green channel remained slow
  - Since each character is a unique pulse length, transmission is slow
  - Very small rate of change

Average transmission speed (characters per second): Red - 34.99, Green - 0.22, Blue - 39.87

Testing: Accuracy

- Generated text with recognizable words
- Found number of changes from received text compared to original string
- Counts mutations, additions, subtractions
- Calculated accuracy rate: (length of original string - # of errors)/length

```
1 Jayden was a creature of habit, his days a predictable rhythm of coffee, code,
and the occasional video game. Winter was a whirlwind, her laughter a contagio
us melody that disrupted the quietude of his existence. They met in the most m
undane of places - the office coffee machine. A spilled cup and a shared laugh
later, they found themselves drawn to each other like two magnets. Winter's wo
rld was a kaleidoscope of colors, her spirit as vibrant as the sunsets she ado
red. Jayden, in his grayscale world, found himself drawn to her warmth. Slowl
y, he began to see the world through her eyes, discovering hidden beauty in th
e ordinary. With Winter, every day was an adventure, a departure from the fami
liar. Their connection deepened with each shared moment. They explored hidden
city corners, discove
```

```
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y. With Winter,  day as an Adventure,A departure from the familiar. Pheir
connection deepened ith each shared moment. They explored `idden city corner
s, iscove
```

COSMOS

Effect of String Length on Message Accuracy

All Channels

Analysis: Accuracy

- Text intelligible
  - Always above 92% accuracy
  - Red channel tended to get more accurate over time, avg. **95%**

- Green and Blue channels
  - Green and blue tended to stay consistent, green was always **100%**, and blue averaged at **99%**

- Very little disturbance in open air
- Likely would not vary with distance; subject of further investigation
- Error correction not implemented, but existing performance sufficient to be corrected

Conclusion

- WDM optical communication is a very complex and precise method
  - We needed to make work arounds because certain lasers were not precise enough
  - Spent a lot of time aligning and combining lasers
- Different communication protocols have their own benefits
  - Blue and Red lasers implemented serial based pulsing which is very fast but also has more errors
  - Green laser implemented time based pulsing which gave 100% accurate but was very very slow
- Our system is not perfect and has a lot of flaws and limitations
  - The lasers were not made to do optical communication
  - Made the most of what we had and implemented many work arounds
- Other things we hope to test: how disturbances like water and dust affect the transmission

Acknowledgements

Thank you to our...

Professors: Dr. Sahar, Dr. Tu, and Dr. Ilinykh

Teacher Fellow: Mr. Barrows

TAs: Karl, Daniel, and Jay

And all of our classmates!

Optical Communications

By: Jerry, Jeremy, Timothy, Alicia

Arduino Code

Transmission Code

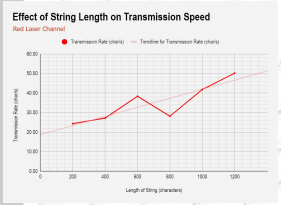
```
#include <SoftwareSerial.h>

SoftwareSerial mySerial[3] = {SoftwareSerial(2, 3), SoftwareSerial(4, 5), SoftwareSerial(6, 7)};

int p = 0;
bool read[3] = {false, false, false};

String s[3];

void setup() {
  Serial.begin(9600);
  for(int i = 0; i < 3; i ++){
    mySerial[i].begin(300);
  }
}

void loop() {
  for(int i = 0; i < 3; i++){
    Serial.print("Please input a message for Laser "); Serial.print(i); Serial.println(":");
    while(!Serial.available() && !read[i]){
      continue;
    }
    if(!read[i]){
      s[i] = Serial.readString();
      read[i] = true;
    }
  }
  for(int i = 0; i < 3; i++){
    mySerial[i].println(s[i]);
    Serial.print("Word "); Serial.print(i); Serial.println(": ");
    Serial.println(s[i]);
    read[i] = false;
  }
}
```

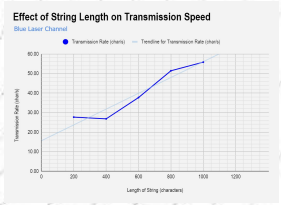
Receiver Code

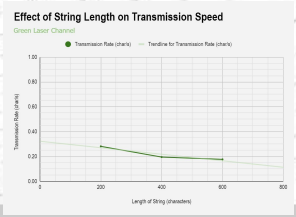
```
#include <SoftwareSerial.h>

SoftwareSerial mySerial = SoftwareSerial(11, 3, true);

void setup() {
  // put your setup code here, to run once:
  mySerial.begin(300);
  // mySerial.begin(300);
  Serial.begin(9600);
}

void loop() {
  //USED FOR PLOTTING ON SERIAL PLOTTER
  // int value = digitalRead(12);
  // Serial.println(value);
  // Serial.println(-1.1);
  // Serial.println(1.1);

  while (mySerial.available() != 0) {
    Serial.print(char(mySerial.read()));
  }
}
```

*Receiver code is the same for the 3 different Arduinos, only pin number changes.

Data





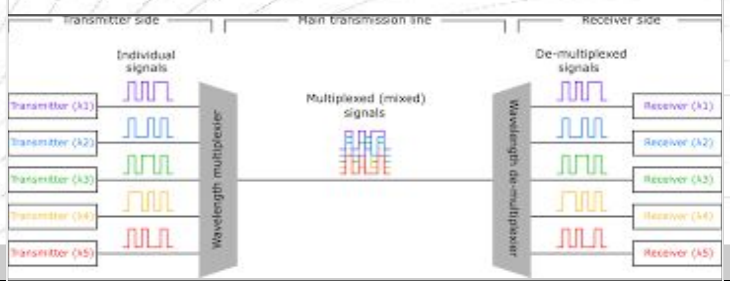


Goal

Test the efficiency of a free-space Wavelength Division Multiplexing system and the impact the length of a message has on the accuracy and speed of transmission.

Background

Optical communication serves as the basis for quick transmissions of data like texting. Currently, almost all optical communications involve Wavelength Division Multiplexing (WDM) which allows large amounts of data to be sent through a single optical beam by splitting and combining different wavelengths of light.



System Setup

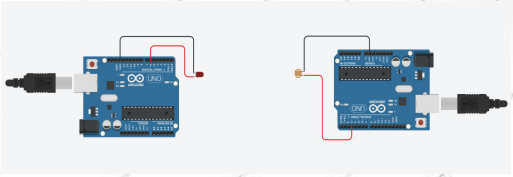


Diagram of one laser test system.
Left is the laser connected to Arduino.
Right is a photoresistor connected to arduino.

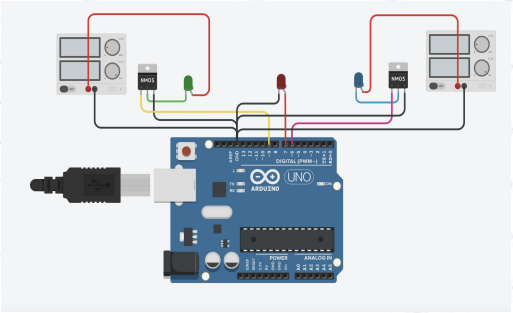
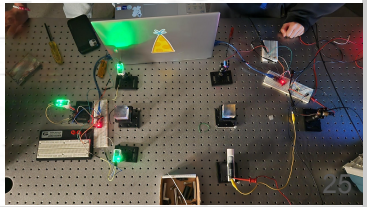


Diagram 3 laser transmission system.
Receiver system is same as before.

Picture of final setup: laser diode on right, photoresistors on left.



Code:

jerry-zh0u/COSMOSCommProject (github.com)

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