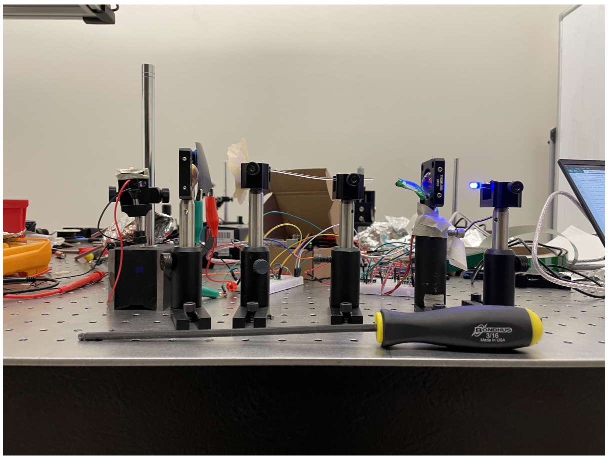
Introduction to Photonics

Final Project Report



Dual-Wavelength UART Communication on a Single Optical Fiber

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Abstract

Fiber optic communication has many advantages in areas where standard electrical signal transmission falls short. Optical fibers allow for increased transmission speed, lower transmission power, increased reliability over long distances, and immunity to electromagnetic interference. This project explores a dual-wavelength fiber optic communication system which utilizes bidirectional communication, transmitting, and receiving signal through a single optical fiber, to establish a UART connection between two Arduino. By using different wavelengths of light we achieve increased bandwidth per fiber and analyze the possible benefits and drawbacks of this approach such as signal integrity, transmission speed, transmission interference, and error rates.

Our system utilizes specialized photo-diodes and analog-to-binary signal converters to separate and convert the optical signals to electrical and vise-versa in order to establish UART communication over fiber optic cables. We determine the success of this system by analyzing the bit error rates of serial communication. This research applies principles of ray optics, wave optics, and signal processing in order to demonstrate the feasibility of optical application in embedded systems

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Background and Introduction

As Pat Gelsinger observes, "we're no longer in the golden era of Moore's Law, it's much, much harder now... we've definitely seen a slowing"('Moore's law'), a new method to increase computation power and speed is necessary to keep pushing the dial of human progress forward. Politics, economics, and science are all largely dependent on the capabilities of computing and the speed of data transmission. Military drone operations depend on latencies of less than 20 ms while keeping their operators as far from the battlefield as possible. Finance firms' success depends on receiving data even just a few milliseconds before their competitors. Scientists depend on the computational speed and data transmission capabilities of their computers to convert large scores of data into meaningful hypotheses. The milliseconds matter, and lightspeed communication can take us one step closer to cutting down these transmissive times.
Traditional electrical signal transmission is subject to electromagnetic interference, power consumption and signal loss over long distances and transmission speed limitations dictated by their copper medium. With the increasing number of electrical devices and dependencies established every year, these issues compound and interfere to a higher degree. Fiber optic communication presents a compelling solution to this problem, as optical communication has resistance to EM interference, high bandwidth, low latency, and can transmit signals over long distances.

Methods

Equipment:

- IR emitter
- IR photodiode
- Blue LED
- Amorphous silicon solar cell (for blue light detection)
- Two 25 mm lenses
- Two comparator circuits (transimpedance amplifier + comparator)
- Two Arduino Uno boards
- Fiber optic cable
- Oscilloscope and basic shielding (paper pieces)

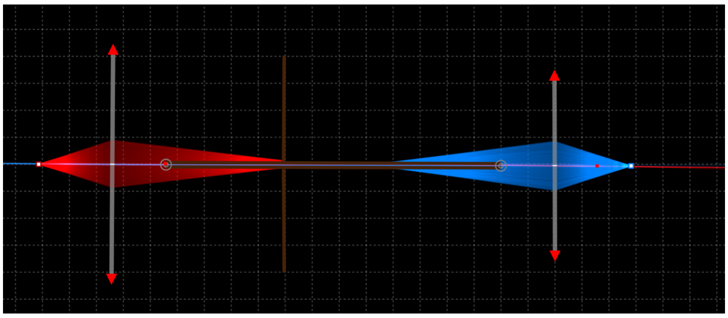

Figure 1: Optical Setup Design.

Optical Setup:

- Each emitter (blue LED or IR LED) was placed at the focal length of a 25 mm lens.

- A single mode fiber optic cable was aligned at the focal length of each lens so that light would be within the acceptance cone and transmit into the fiber.
- The receiving end for blue light used an amorphous silicon solar cell as the photodiode to filter out IR interference, while the IR side used a dedicated IR sensor which had peak sensitivity in the IR wavelength and attenuated blue light("LTR-3208 IR Phototransistor Datasheet").
- Pieces of paper were used attenuate incident light from the LEDs outside the Optic Fiber.

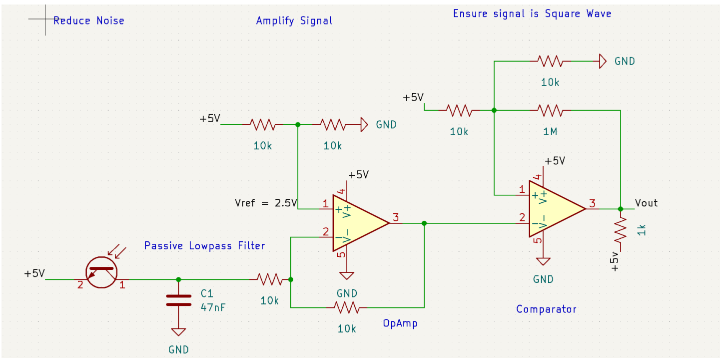

Figure 2: Analog to Digital Converter Circuit Diagram.

Electronic Setup:

- Both IR phototransistor and the solar cell photo-diode outputs were connected to a signal amplifying and circuit then into comparators to output a digital signal.
  - First, a transimpedance amplifier converted the photodiodes current output into an amplified voltage.
  - Then, a comparator converted this analog signal into a digital output readable by the Arduino.
- Each Arduino was programmed to transmit UART signals by blinking its respective LED (blue or IR) and to receive data via the corresponding photodiode or solar cell.
- An oscilloscope was used to validate the integrity of the signal and measure signal noise.

Software:

- Arduino code was written to establish a connection and send characters at a known baud rate over UART.
- Testing was done initially one wavelength at a time. Upon success, the dual-wavelength system was tested with both directions simultaneously.

Results

Part 1a: Blue Wavelength Transmission

By pulsing the blue LED and viewing the comparator output on the oscilloscope, we confirmed a stable signal aligned with our transmit pulses. The amorphous silicon solar cell successfully filtered out all affects from the IR signal, giving us a nearly 100 % data accuracy for the one-way link.

Part 1b: IR Wavelength Transmission

Figure 3: Electrical Noise.

For the IR transmitter-receiver pair, alignment was more difficult, as this light is invisible to the naked eye. We used a phone camera to help us align the IR emitter. Despite meticulous alignment, the IR channel was more susceptible to noise due to reflections of the blue light off the surroundings. Due to the gain of the op-amp system, even the attenuated blue light was enough to affect the signal output from the comparator. This contributed to occasional bit errors, but we were able to achieve reliable data transfer after tuning the comparator thresholds.

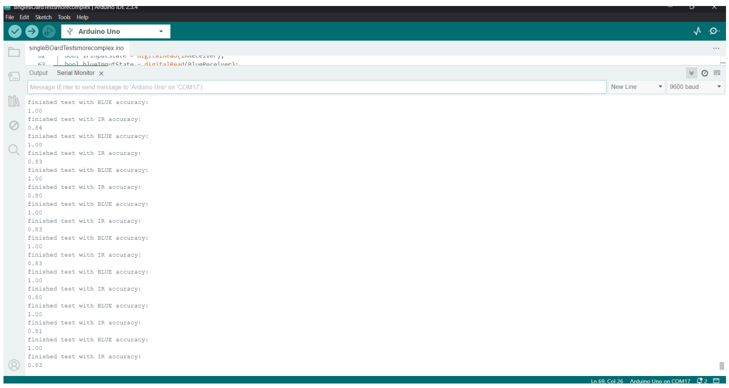

Figure 4: Bit Error Rate.

Part 2: Dual-Wavelength Bidirectional Link

Once both individual paths were confirmed to be near 100 percent functional individually, the LEDs were each coupled into opposite ends of the same fiber. The Arduinos attempted to transmit and receive concurrently via the single optical fiber:

- The blue channel maintained a high accuracy (close to 100 %).
- The IR channel exhibited more fluctuations, with measured accuracy typically between 80 % and 84 %(see Figure 4).

These results highlight that multi-wavelength transmission in a single fiber can work, but photo-diodes with more refined wavelength acceptance spectrums are necessary.

Discussion

While the optical setup was relatively straightforward, implementing the bidirectional communication created some unexpected challenges. One recurring issue was the interference of the Blue LED with the IR receiver. Our initial experiment had wavelengths that were even closer(Red and Blue) which had even more issues with separating the signals. Switching to receivers which attenuated one signal and accepted the other greatly reduced this issue.

Another challenge was the ambient electrical noise. Since our IR receivers responsivity was lower, we used a greater gain in the op amp which resulted in a recurring electrical interference around 120hz. Our attempts to apply a simple RC filter were only partially effective.
Overall, the experiments revealed that:

- Precies alignment and filtering are essential for optical serial communication.
- Amorphous silicon sensors are effective for visible light while naturally rejecting IR.
- Full-duplex optical communication is possible over a single fiber using distinct wavelengths, but it requires careful alignment and photodiode selection.

Conclusion

This project successfully establishes a dual-wavelength fiber optic UART link between two Arduinos, allowing simultaneous bidirectional transmission via a single fiber. While the IR channel experienced periodic noise and slightly elevated bit-error rates, the blue channel remained largely resistant to interference. These results highlight both the promise and the complexity of optical communication for embedded systems, where factors like alignment, noise management, and optimal sensor/emitter choices are critical. Building on these findings, future work could incorporate advanced modulation techniques, refined optical filtering, or error-correction methods to further mitigate crosstalk and ambient interference. Comparing fiber optic UART performance against wired UART would also help quantify the potential gains in speed and reliability. Overall, this research lays a foundation for more robust and faster fiber optic communication solutions tailored to resource-constrained environments.

References

B. E. A. Saleh and M. C. Teich, *Fundamentals of Photonics*. 2nd ed., Wiley-Interscience, 2007.

E. Hecht, *Optics*. 5th ed., Pearson, 2017.

“Fiber Optic Basics,” in *Optical Society of America* (OSA) Reference, 2021.

”Ray Optics Simulator.” Phydemo, https://phydemo.app/ray-optics/simulator/. Accessed 21 Mar. 2025.

”Moore’s law.” Wikipedia, The Free Encyclopedia, Wikimedia Foundation, 16 Mar. 2023, en.wikipedia.org/wiki/Moore

”LTR-3208 IR Phototransistor Datasheet.” Lite-On Technology Corporation, n.d., https://www.liteon.com/datasheets/LTR-3208.pdf. Accessed 21 Mar. 2025.

Report (75 points total)	
Title/Abstract (10 Points)	
(2) Clear, concise title	2
(3) 150-200 word abstract, clearly describes report	3
(5) Well-written and clear	5
Background/Introduction (15 Points)	
(5) Describes the large-scale challenges the field is facing	5
(5) Clearly describes the state-of-the-art	5
(5) Clear description of the problem to be addressed	5
Results/Discussion/Conclusion (20 Points)	
(10) 2-3 Professional figures with a clear takeaway	10
(5) Project results described in a clear way	5
(5) Forward-looking conclusion	5
References (5 Points)	
(5) 5-10 Correctly cited references	5
Methods (10 Points)	
(10) A clear description of what was done, such that the average scientist could reproduce it	10
Writing (15 Points)	
(10) Clear, concise writing that communicates results in a straightforward way	10
(5) Free of typos and errors	5
Presentation (25 points total)	
Slides (5) Clean, professional slides	 5
(5) Communicate message without over-use of text	5
(5) Cover information at an appropriate scale within the time limit	5
Presentation (5) Speak clearly, confidently, and concisely (5) Handle questions appropriately	 5 5

Table 1: Rubric for Project Report and Presentation.