EE443 Introduction to Optical Fiber Communications
UART Optical Link System
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Abstract:
In this project, I designed and implemented a high-speed optical communication system consisting of a digital optical transmitter and receiver. The transmitter receives a digital signal from a microcontroller and uses a 74LS05 open-collector inverter to control a PNP transistor LED driver. This configuration enables efficient current switching to drive the transmitting LED using a single +5V supply. On the receiving end, an OP950 photodiode paired with a resistor converts the optical signal into a voltage, which is then fed into a comparator circuit. The comparator restores the digital logic level, which is subsequently cleaned up using a low-pass RC filter before reaching the RX pin of the microcontroller. The system is optimized to minimize insertion loss and maximize signal fidelity, accounting for fiber attenuation, photodiode response time, and component limitations. With careful design choices, including matching photodiode sensitivity and LED wavelength, the system achieves a reliable data rate of up to 2 MHz over a 1-meter fiber cable.

Introduction:
The goal of this project was to create a fully functional optical communication system that converts an analog audio signal into a digital format, transmits it through a plastic optical fiber, and reconstructs it on the receiving end. To achieve this, I designed both an optical transmitter and receiver, each tailored for speed, signal integrity, and compatibility with standard microcontroller I/O. The transmitter uses a 74LS05 logic IC and a PNP transistor (2N4403) driver circuit to deliver sufficient current to the LED, translating digital LOW signals into optical pulses. On the receiver side, I implemented a basic photodiode and resistor block to detect light, followed by a comparator to re-establish clean digital logic levels. To further enhance signal quality, I applied a low-pass filter to reduce noise introduced by comparator switching. Throughout the design, I accounted for key factors affecting performance, such as fiber attenuation, insertion loss, photodiode response time, and LED switching delay. The resulting system demonstrates strong potential for high-speed digital transmission with future opportunities for performance improvements through higher-power LEDs and faster-switching components.

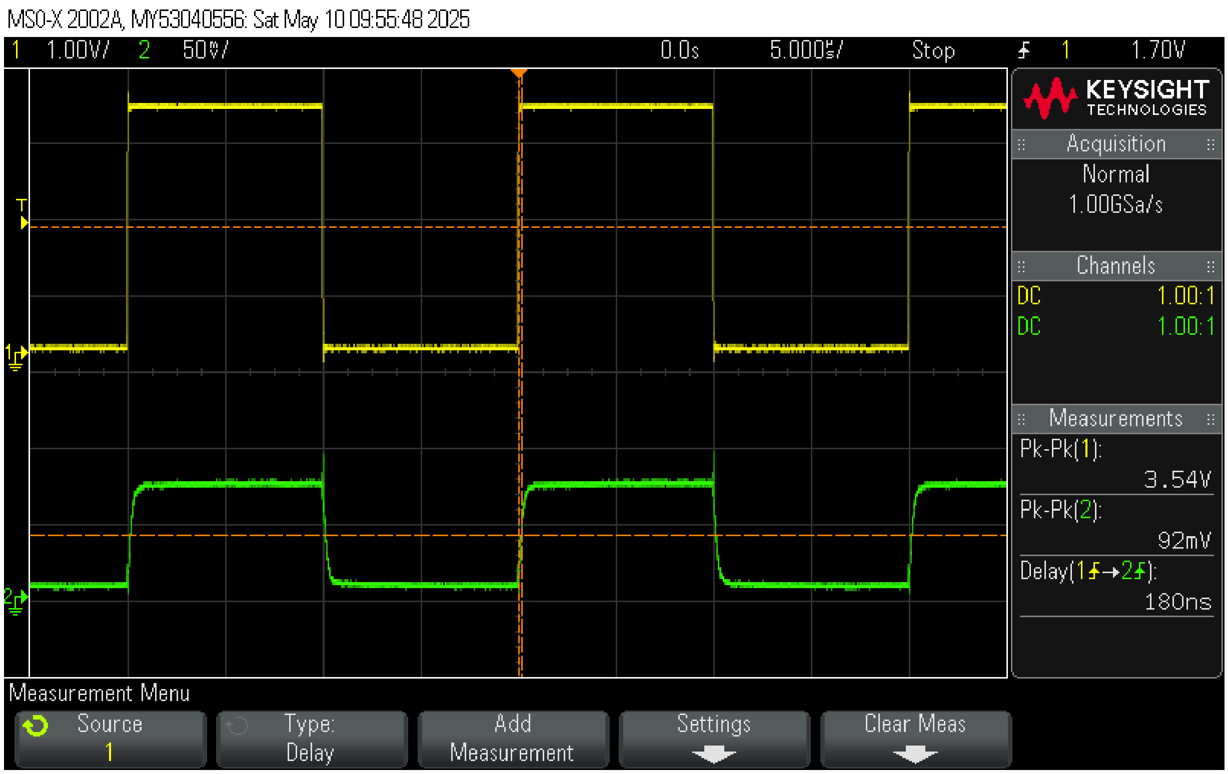
Fiber Length: 1 (meter)

Input square signal frequency: 50 (kHz)

Input square signal amplitude: 3.54 (V)

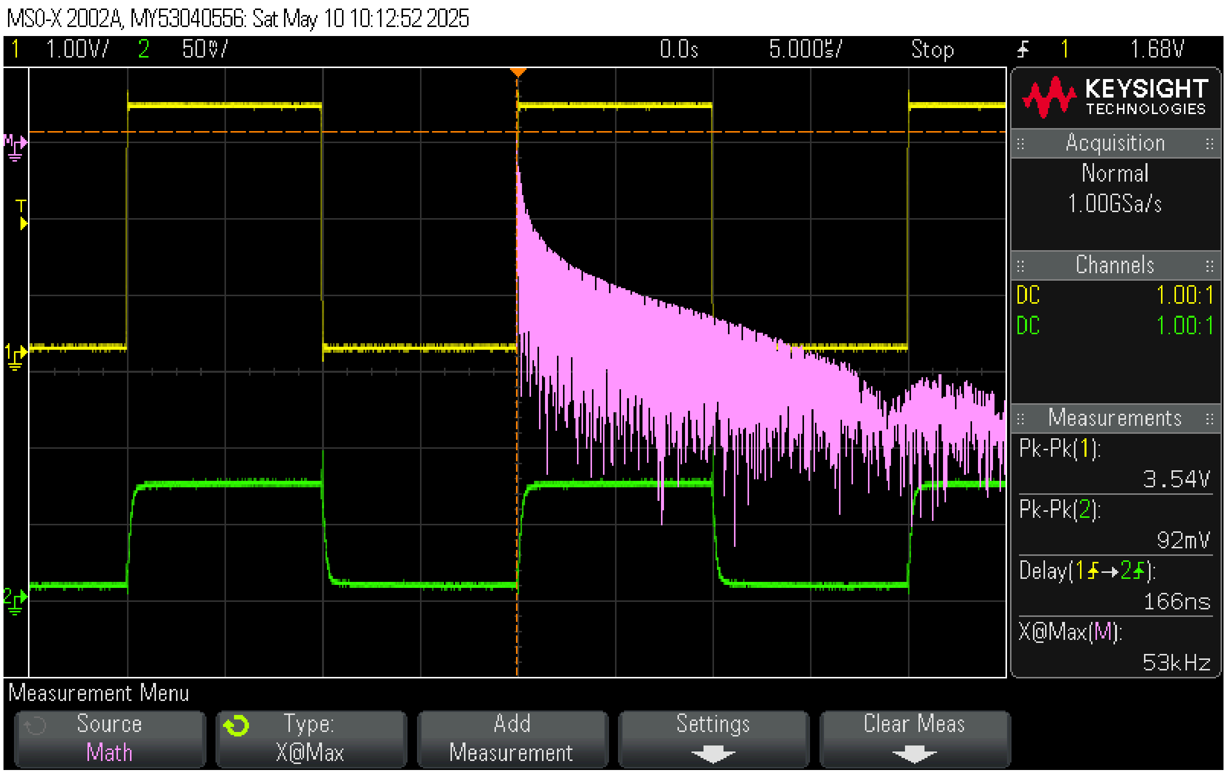
Delay between input to the OTX and output signal from the ORX: 180 (ns)

Amplitude difference between input and output signal: 3.54 - 0.092 = 3.448(V)

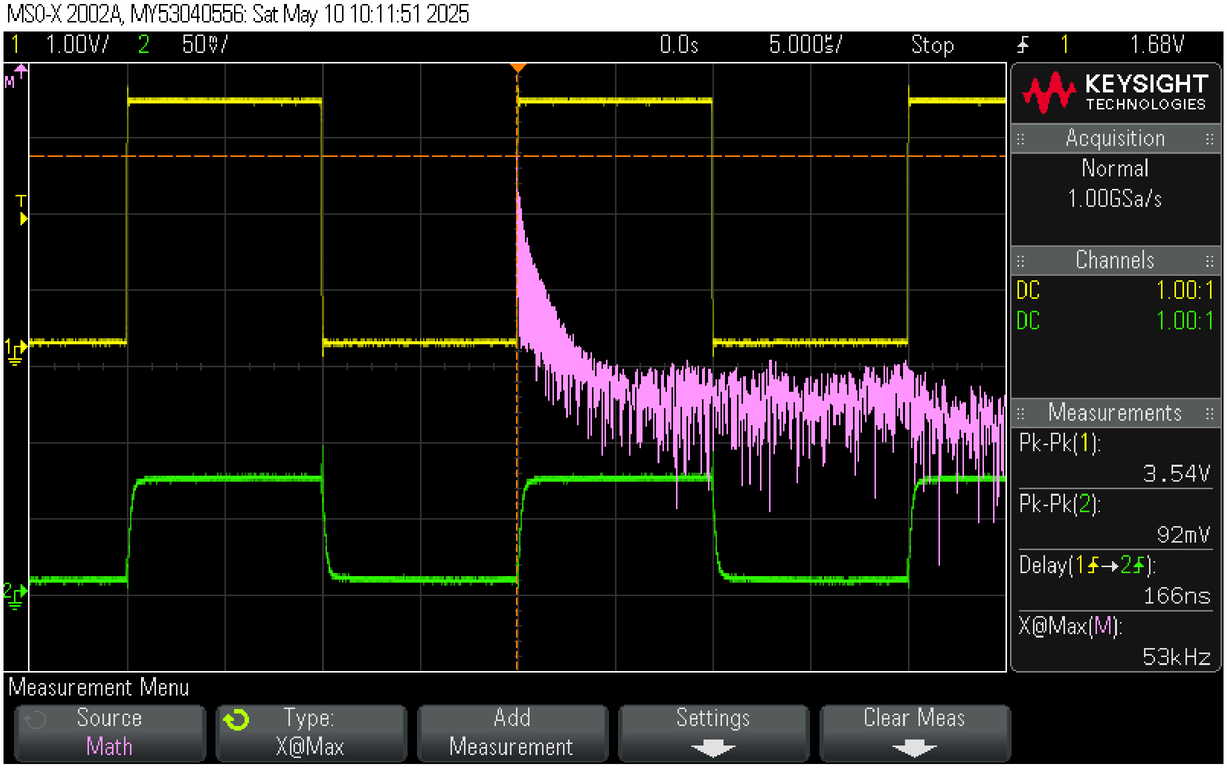


The yellow signal is the input signal applied to the LED. The green signal is the output signal measured at the photodiode/resistor node. The automeasure on the oscilloscope shows the P2P of the input and output signal. The measurement for the delay is also shown in nanoseconds.

Using a spectrum analyzer, compare the input and output signal in terms of harmonics and frequency distortions .

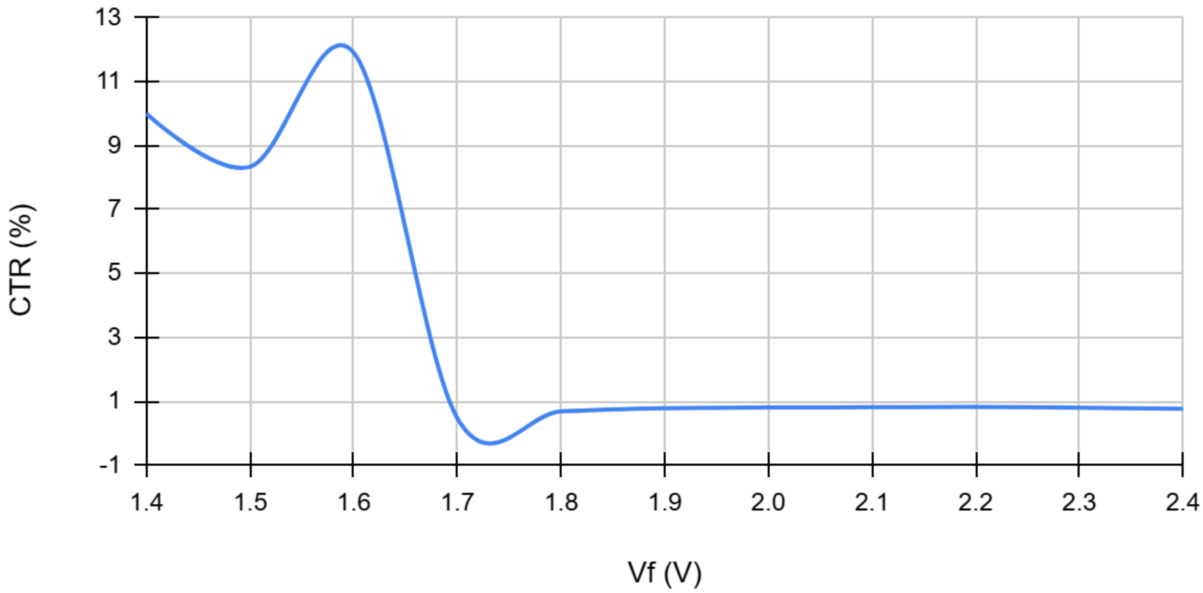


The signal shown in purple shows the frequency spectrum of the input signal (yellow). We can see through the frequency spectrum that the signal has a peak amplitude of around 50-100kHz. The spectrum has higher harmonics due to the high frequency transients in the square wave signal.

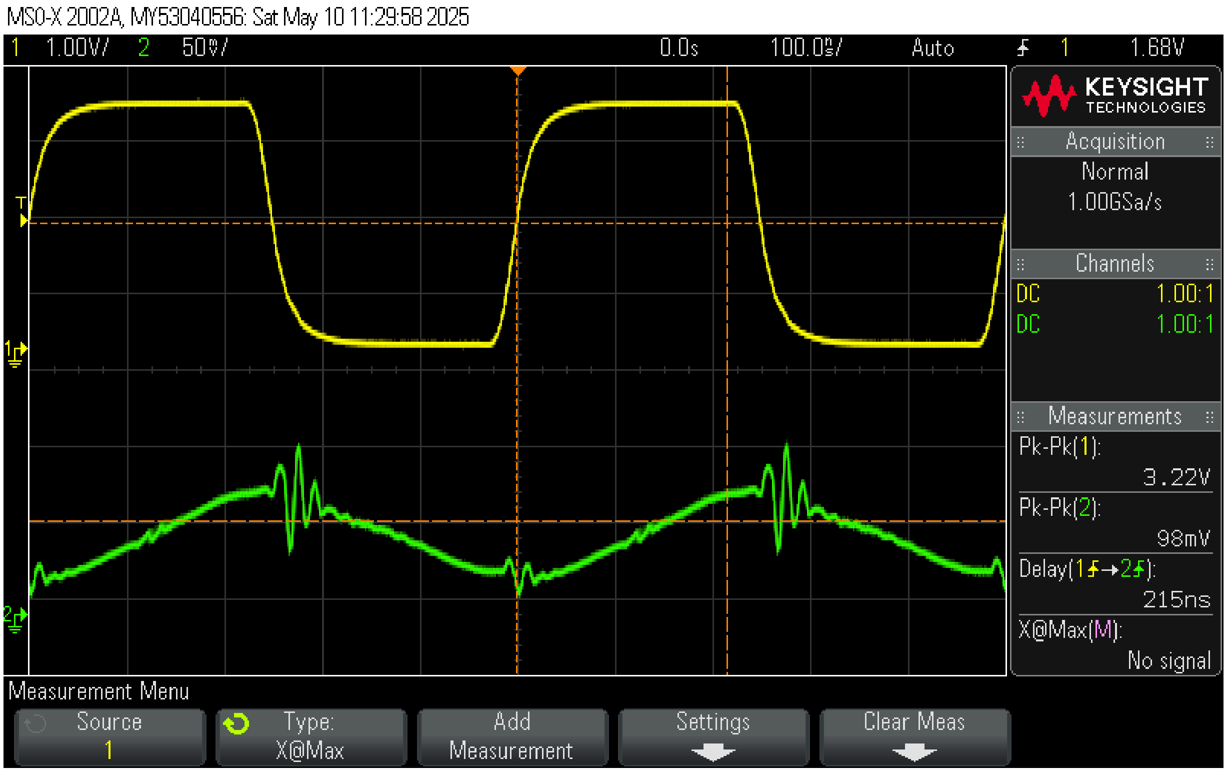


The graph of the frequency spectrum shows the combined frequencies that make up the output signal. Due to the slower transient response, we can see that the amplitude of the higher frequencies 'drop off' much faster than the input square wave.

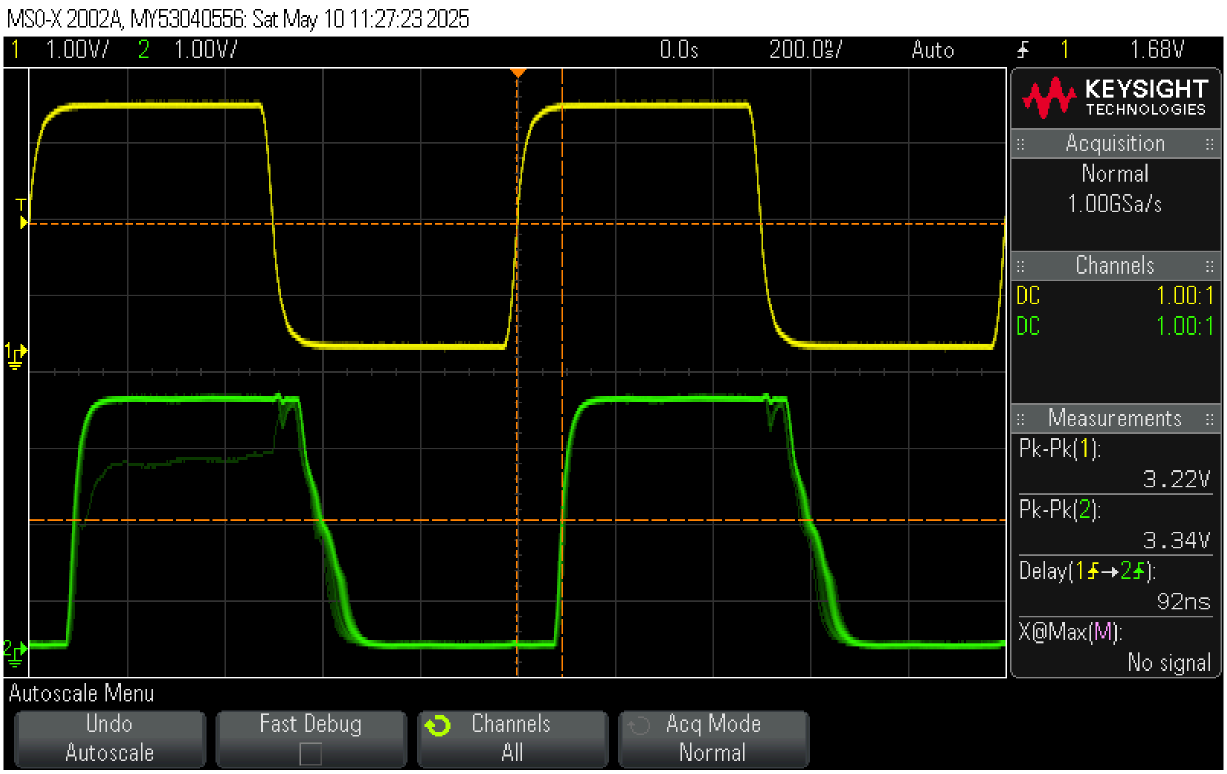
Current Transfer Ratio vs Voltage Across LED



The Current Transfer Ratio (CTR) is a key parameter in optical communication systems because it directly measures the efficiency of optical-to-electrical conversion at the receiver. A higher CTR indicates a more effective transmission of the signal through the optical link, helping us assess system performance and ensure reliable signal detection.



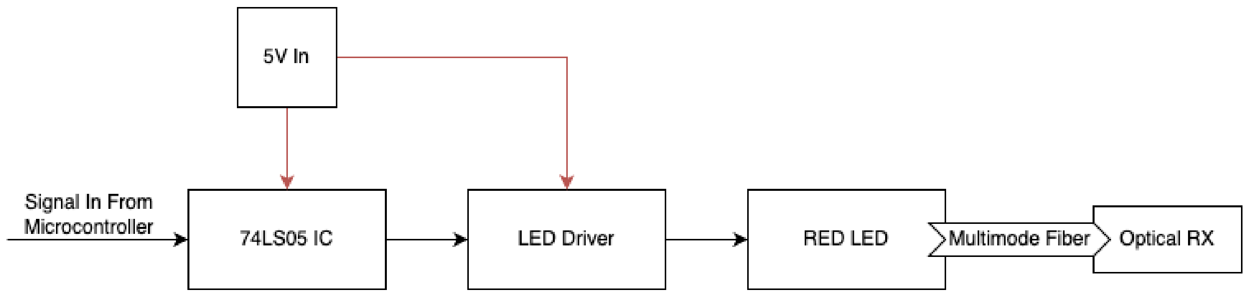
This figure shows the input waveform into the system. The frequency that was input was a 2MHz square wave. The green waveform is the direct output of the photodiode. We can see at this frequency, the waveform is very distorted, but not unfixable because the signal is able to reach above our reference voltage of ~30mV to the comparator +- hysteresis voltage (5mV).



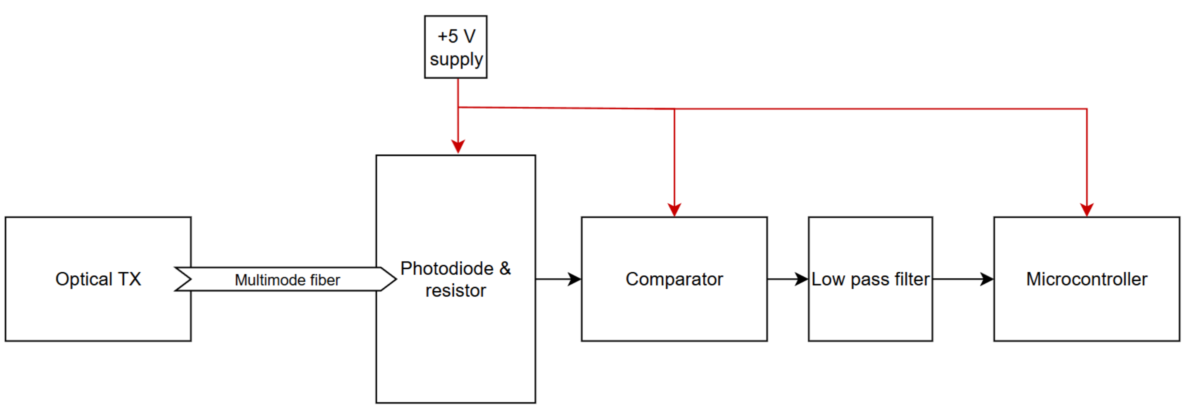
This image shows the same input frequency (2MHz) input in yellow and the output of the comparator in green. Connected to a microprocessor, it would be able to read these bits because it reaches the lower and upper threshold for the chip to read HIGH and LOW states. This is the highest input frequency that could be input into the system without seeing any major signal degradation.

Technical Design:

1. **Optical Transmitter Design:** The input signal is a digital signal that the previous microcontroller converted from an analog input (uses the ADC). This transmitter utilizes a 74LS05 Logic IC to output LOW logic that the PNP located in the LED driver can use to turn on, letting power flow to the LED turning it on, thus sending the signal out to the ORX. It uses one +5V supply



2. **Optical Receiver Design:** The raw receiving block consists of an OP950 photodiode and a 1kΩ resistor, this obtains our basic received signal from the transmitter. The comparator compares the voltage signal from the photodiode block and a reference voltage set by a voltage divider. After the signal is repaired by the comparator, it is filtered through an RC low pass filter to fix any noise caused by the comparator. The repaired and filtered signal is then fed into the RX pin of the microcontroller.



3. **Driver Operation in LED Switching**: We used a PNP Transistor Driver circuit. Specifically using a 2N4403. We used this device because when the 74LS05 outputs a LOW and the base of the PNP is pulled low by the diode and resistor network, it turns on the PNP, supplying current to the LED.
4. **Fiber Attenuation and Signal Loss:** There are losses in our plastic fiber due to a few reasons, one is that if the ends of the cable are not sanded and polished after making a splice, there can be massive insertion loss. Another piece of lost power is the interface between the fiber and the photodiode/LED, this could also be classified as insertion loss. Another form of loss comes from using a very cheap multimode cable which can have strong loss due to rayleigh backscattering.
5. **Photodiode Response Time:** The photodiode (OP950) detects the intensity of light signals and forces a response current. According to the datasheet, in reverse bias mode, with an applied signal with wavelength of 850 nm, and 50Ω resistor, the rise and fall time of the photodiode can be as fast as 5ns. This translates to a frequency of 200 MHz.
6. **Amplifier Gain and Output Power:** The built in gain of our comparator according to our datasheet is 6000 V/V [1]. As it is a dedicated IC comparator with no feedback loop, our gain is set by the hardware and cannot be changed.
7. **Amplifier Gain and Output Power:** In our complete system, increasing the gain of our comparator would not change the audio signal as it is transmitted in a digital format.
8. **Performance Improvements**: Overall, we believe we have made a very robust high speed system that can theoretically reach bit transfer rates as high as 2MHz through a 1 meter fiber cable. To increase this, we would need a proper transmitter laser or LED that has lower parasitic capacitance to switch faster. According to the LED datasheet, the propagation delay for the device is 25 ns [4], significantly slower than the 5 ns of the photodiode receiver. For the photodiode, we would need one that has a peak wavelength sensitivity that matches the transmitter LED. This would give us the best current transfer ratio to make a more defined voltage amplitude to feed into the comparator for repair. Another improvement would be to spec an LED that has a higher power rating, this would allow us to force more power through the optical cable to increase our signal amplitude at the photodiode receiver.

Circuit Schematic:

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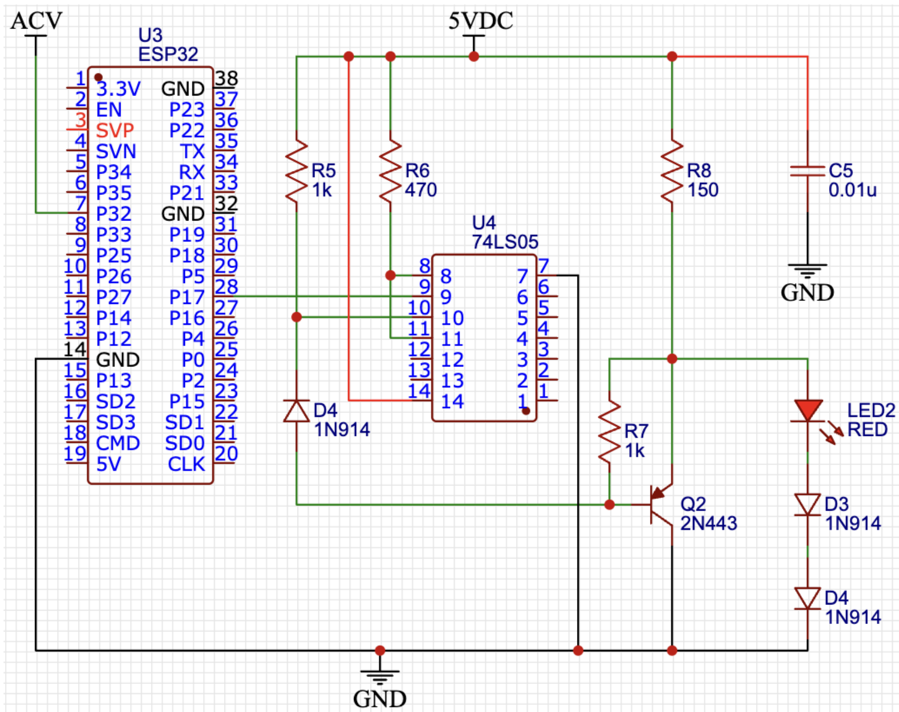
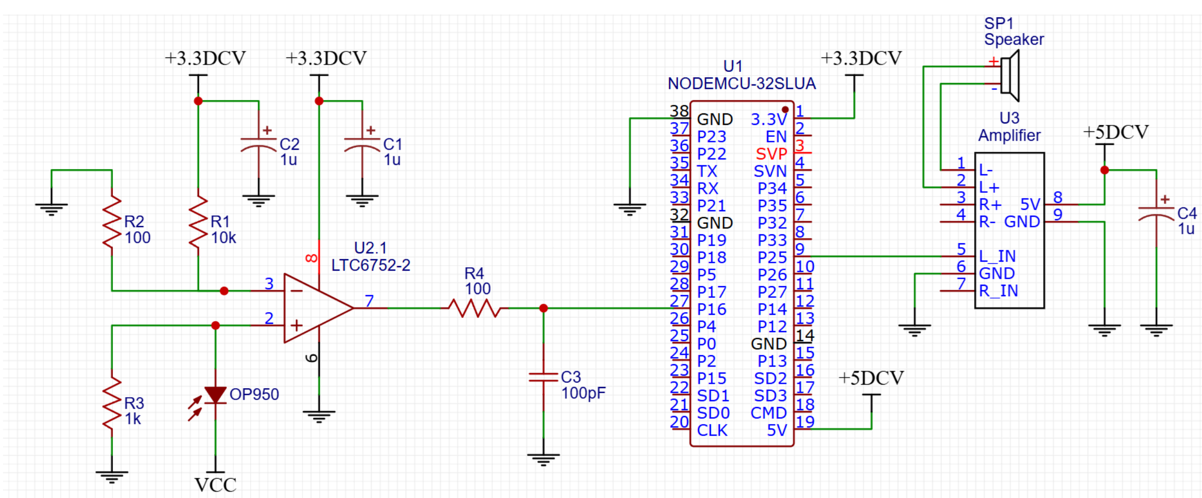


Optical TX



Optical RX

Table 1: List of Materials:

Component	Part number	Value
[2] ESP32	-	-
Red LED	IF E96E	-
Photodiode	OP950	-
NOT gate IC	74LS05	-
Comparator	LTC6752-2	-
Audio amplifier	-	-
PNP BJT Transistor	2N443	-
[3] Diode	1N914	-
Resistor	R1	10kΩ
Resistor	R2	100Ω
Resistor	R3	1kΩ
Resistor	R4	100Ω
Resistor	R5	1kΩ
Resistor	R6	470Ω
Resistor	R7	1kΩ
Resistor	R8	150Ω
Capacitor	C1	1uF
Capacitor	C2	1uF
Capacitor	C3	100pF
Capacitor	C4	1uF
Capacitor	C5	0.01uF

References:

- Fiber Optic kit - Voice kit
- Fiber Optics Lab Manual with Kit / Fiber Optic Lab Manual
- Fiber Optics Mini Course
- Kit Fiber Optics Tx&Rx Boards Voice/1Khz Signal Via Optical. / Manual
- [1] Analog Devices, LTC6752: Low Power, High Speed Rail-to-Rail Input Comparator with LVDS, PECL, or CMOS Output, Rev. C, Apr. 2023. [Online]. Available: https://www.analog.com/media/en/technical-documentation/data-sheets/6752fc.pdf
- [2] TT Electronics, OP950 Series PIN Silicon Photodiode, Rev. C, Apr. 2023. [Online]. Available: https://www.ttelectronics.com/TTElectronics/media/ProductFiles/Datasheet/OP950.pdf
- [3] Mitsubishi Chemical Corporation, SH-4001 Item Specification, Apr. 3, 2019. [Online]. Available: https://i-fiberoptics.com/pdf/sh4001.pdf
- [4] Industrial Fiber Optics, Inc., IF-E96E Fiber Optic Red LED, Rev. 2/20. [Online]. Available: https://i-fiberoptics.com/pdf/if-e96edatasheet.pdf