Group 12 – VLC
Visible Light communication

Developing a
laser Ethernet transceiver
to a final
prototype assembly

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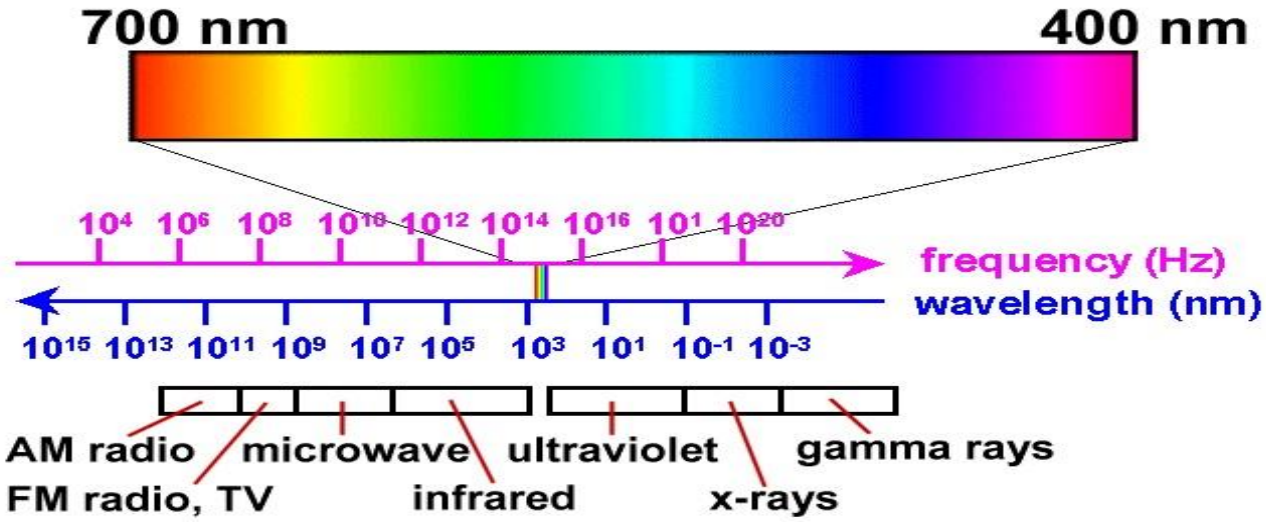
Introduction

Motivation

- Currently more than 15 billion Wi-Fi and cellular devices, estimated to be 100+ billion by 2020 causing a congested network (bandwidth is limited)
- Some areas are sensitive to electromagnetic interference
- Radio signals can easily be intercepted reducing their security
- VLC using lasers is fiber optic ready
- The visible spectrum is 100x larger than maximum radio spectrum

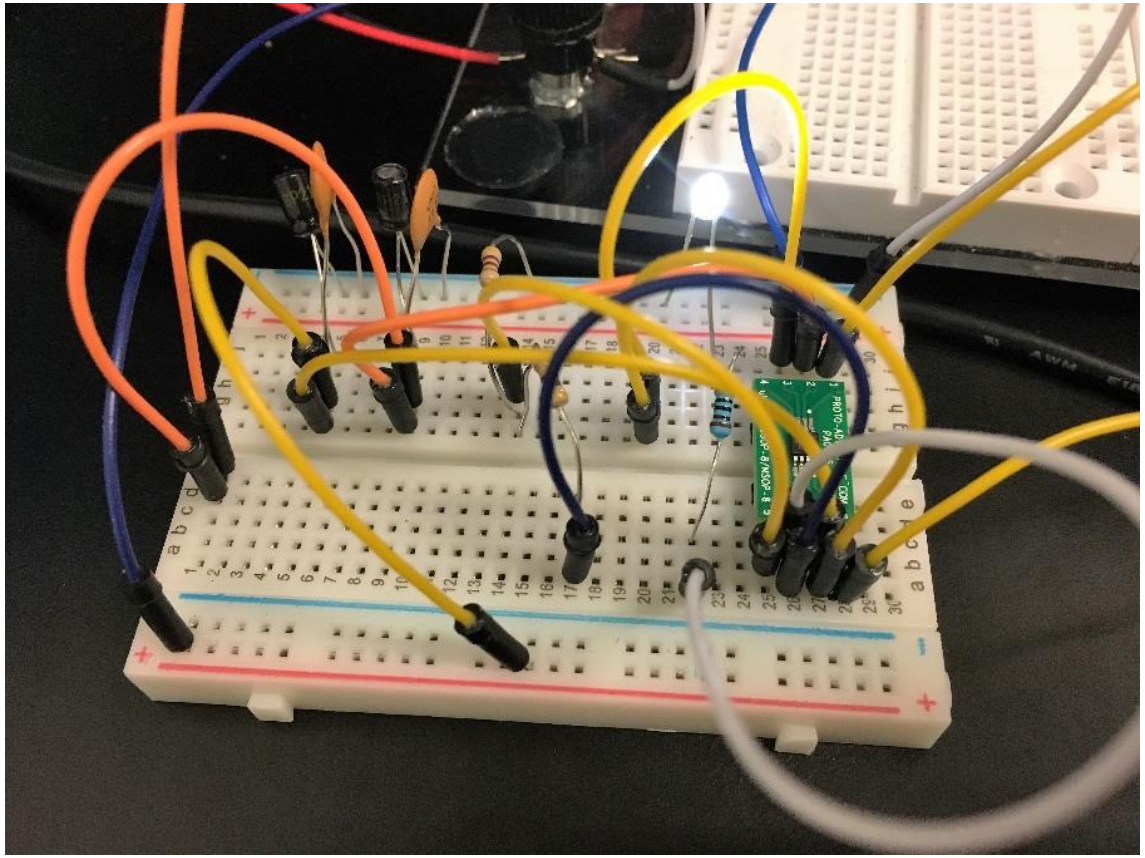
i.e. The radio spectrum is 3 Hz - 3 THz whereas VL is 400 - 800 THz (



Issues to execution

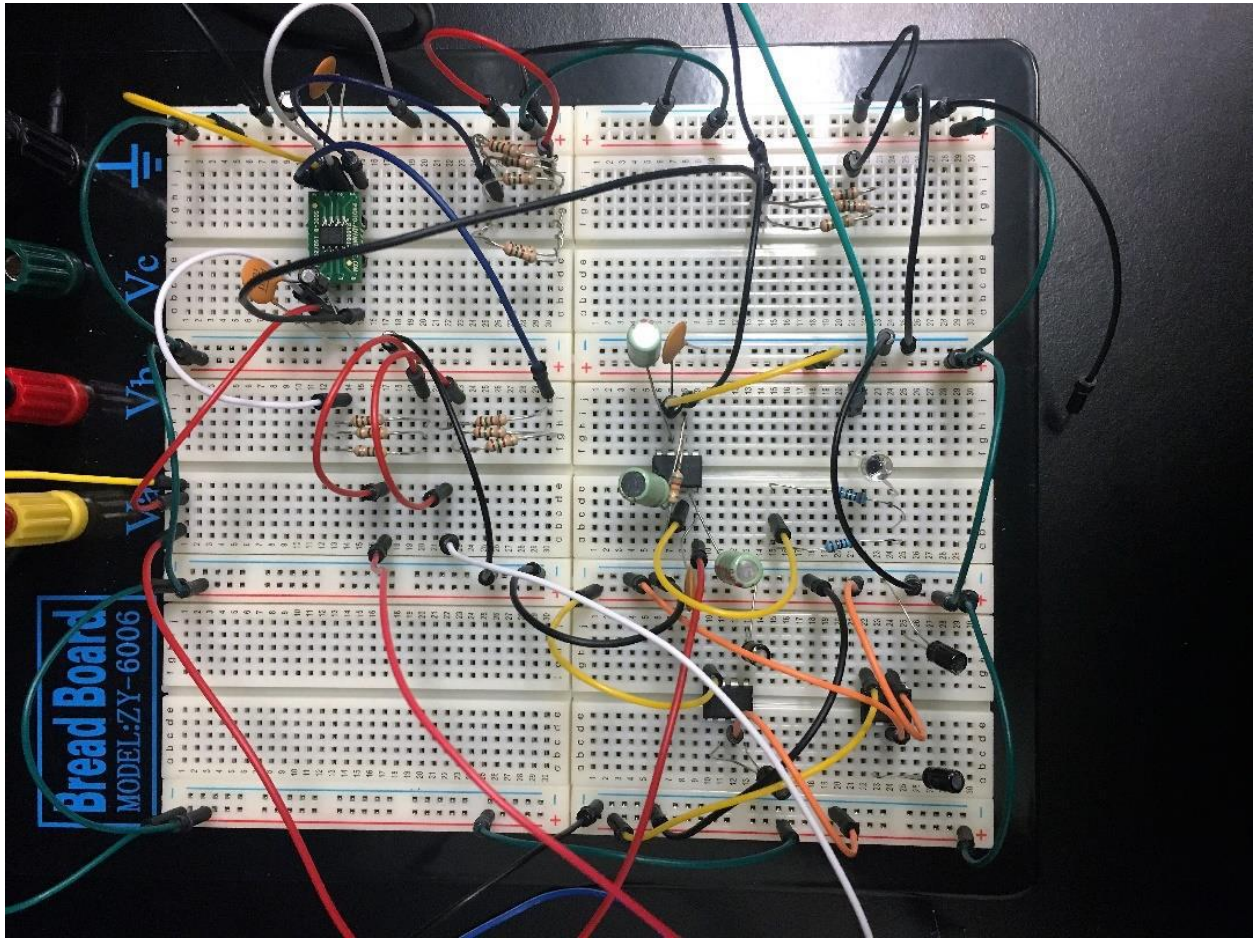
- First thoughts were to make a Li-Fi system, full duplex, and 100 Mbps speed meaning LEDs transmitting data.
- Originally we attempted to make a 100Base-T system using white LEDs as the data carrier
- Then we attempted to make a 10Base-T version also using white light as the data carrier.
- Each proved to be extremely costly in order to be effective as well as time consuming because of the advanced digital signal processing required.
- There were other factors such as non-linear light to current curves
- Final solution was to make a 10Base-T system using laser diodes

LiFi Prototyping and Initial Design



- The transmitter on the breadboard for the 10 Base-T VLC via white LED light.
- Problems include high SNR
- Range of frequency input limited at 10 kHz
- Testing required integration from a surface mounted IC into DIP packaging
- Non-linearity of the light to current curves

Prototyping for receiver



The breadboard build of the receiver.

Real World Implementation

- We've essentially created a small scale model with the idea that it could be scaled using different equipment, keeping the same concept, to be used in real world applications
- A company called Koruza currently sells optical transceivers capable of 1-10Gbps speeds.
- In data centers companies are now transitioning to free space optics to connect server racks instead of fiber links

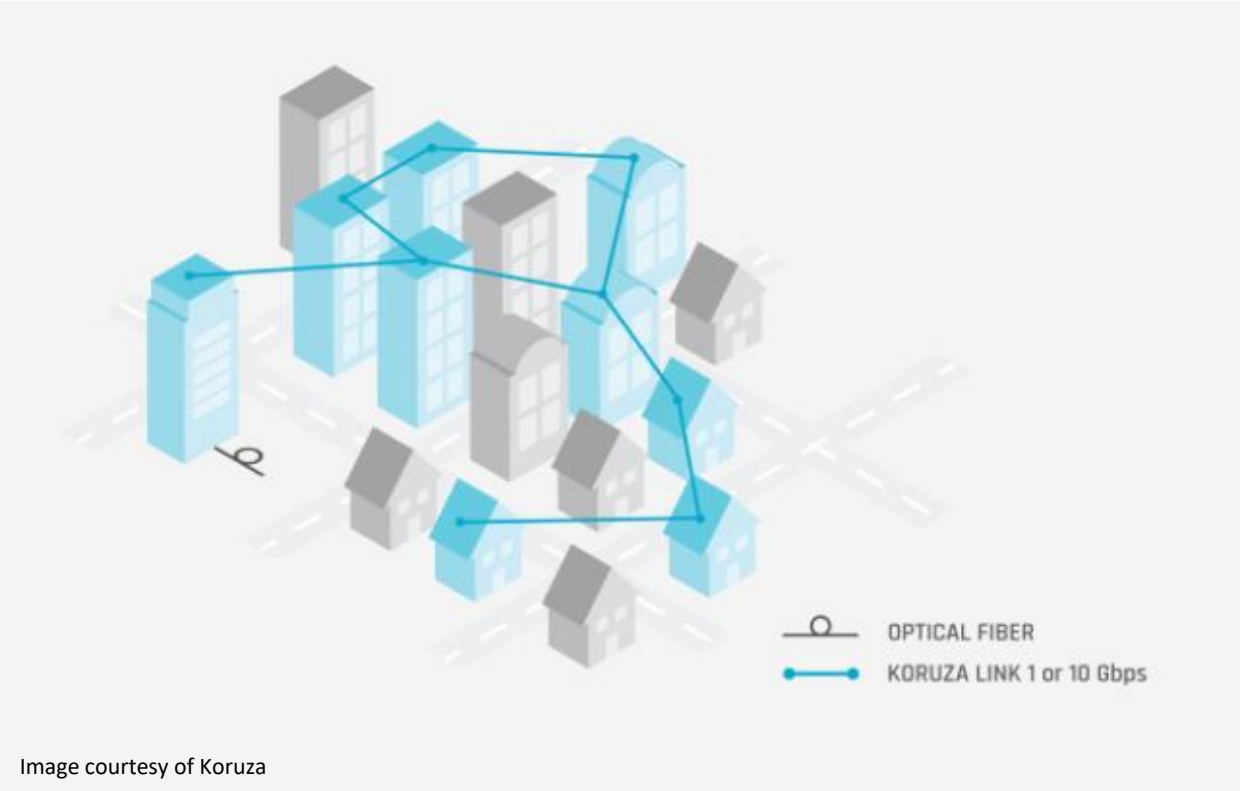


Image courtesy of Koruza

Introduction

Goals and Objectives

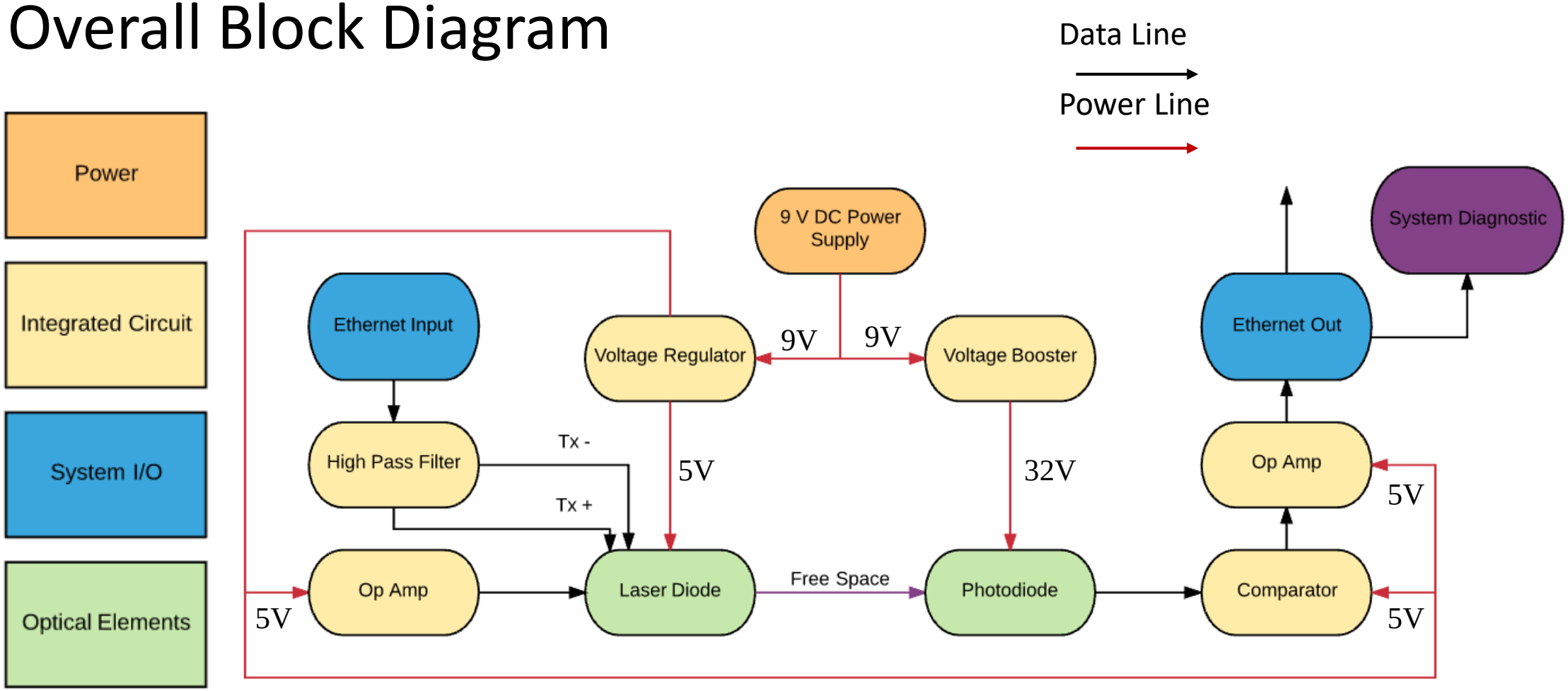
- Create a scale-able wireless Ethernet link using visible light as the carrier and free space as the medium
- Provide a system ready to be integrated into existing infrastructure
- Show that our system can wirelessly connect two routers without using radios
- Show that basic VLC systems have comparable speeds to Wi-Fi
- Keep the design small and sleek, with low power consumption and affordable price

Specification and Requirements

Component	Parameter	Design Specification
System	Usage	Full Duplex
System	Power consumption	< 15 Watts
System	Compatibility	Ethernet
Optical link	Speed	5 – 10 Mbps
Software	Diagnostic return time	< 10 seconds
Laser Diode	Transmission distance	>1m
Photodiode	Directional Tolerance	>5 degrees

Principle of Operation

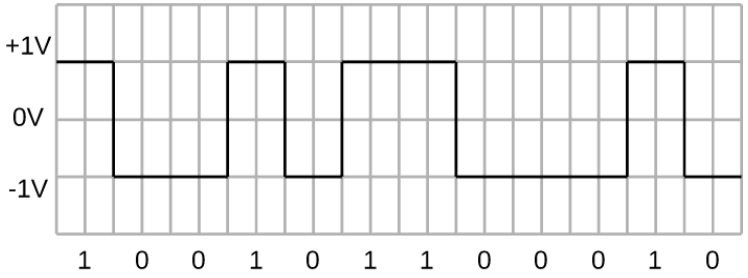
Overall Block Diagram



Principle of Operation

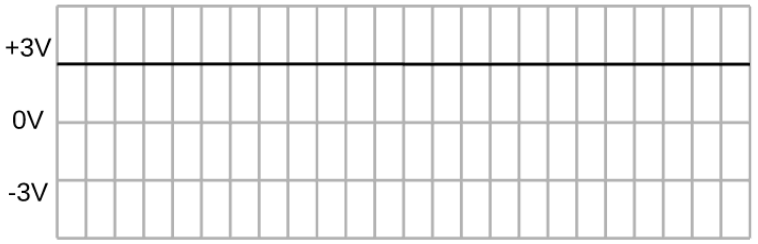
Input

- 10Base-T signal takes values of -1 or +1
- Simplest form of OOK modulation
- Sum DC bias of laser diode, with data signal creates modulation
- When signal is -1 laser diode is dimmed
- When signal is +1 laser diode is brighter



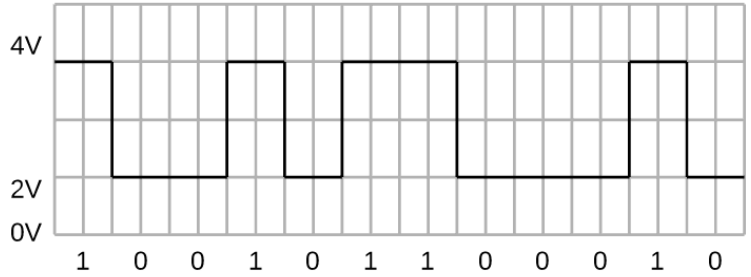
Sample data signal

+



DC bias of LD

=



Signal going into LD

Principle of Operation

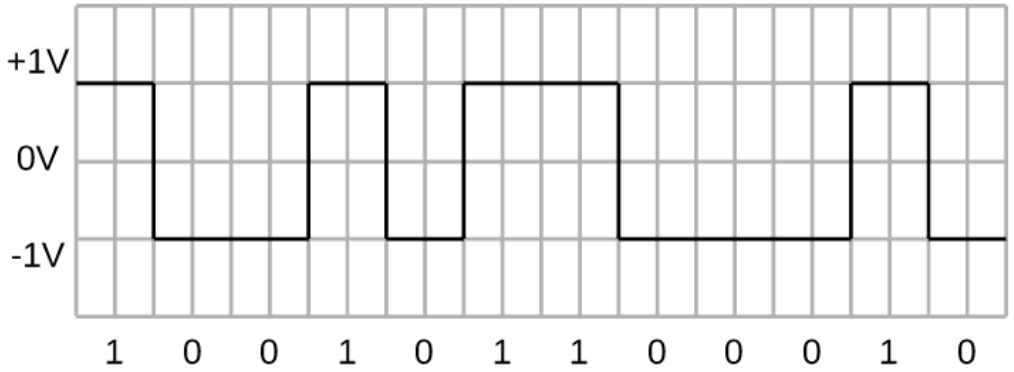
Transmission & Collection

- Signal travels through free space to be collected by the photodiode
- Photodiodes produce current relative to the incident light (intensity)
- With the use of a transimpedance amplifier we convert the current based signal into a voltage based signal

Principle of Operation

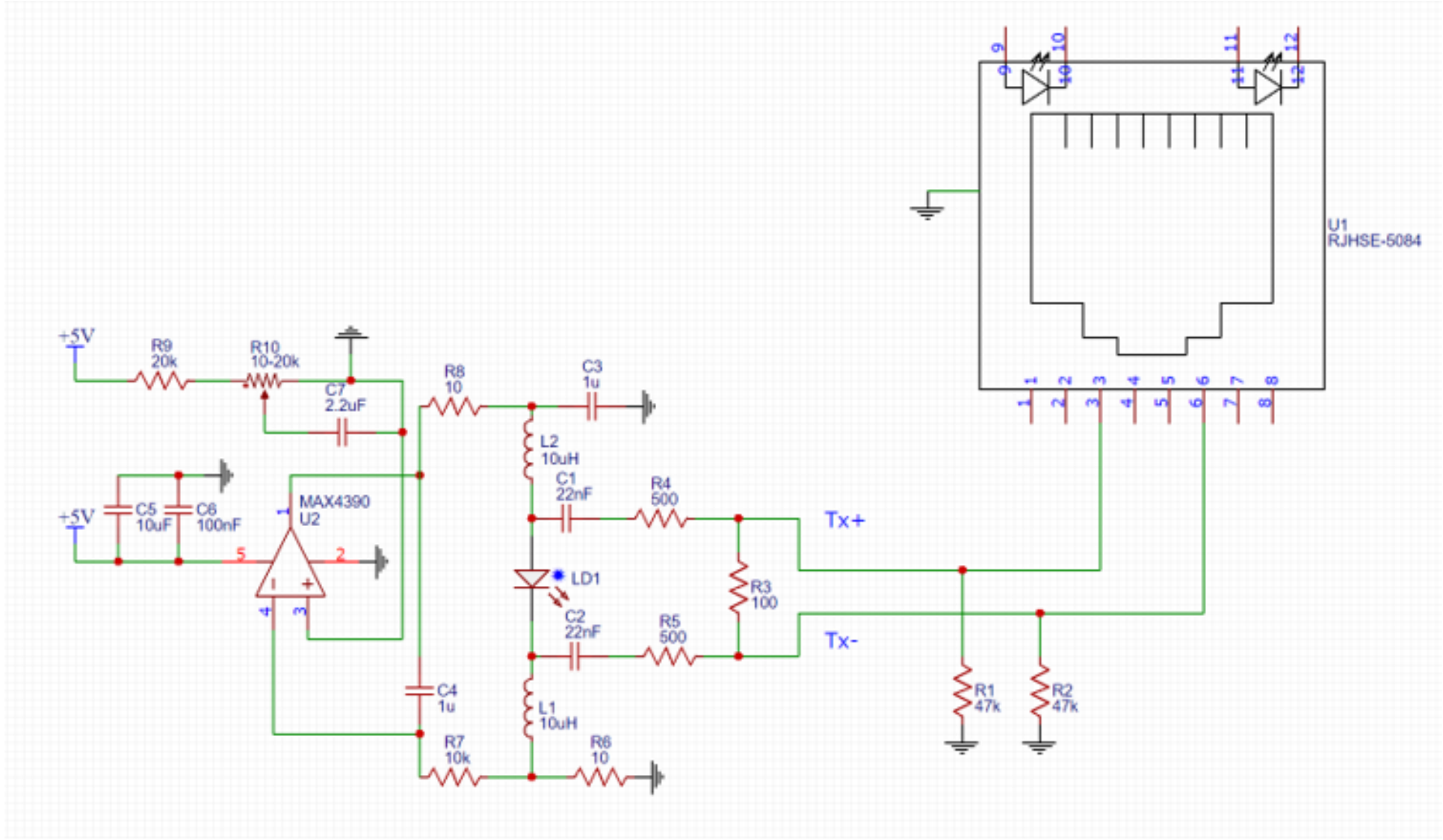
Output

- After receiving the signal from the transimpedance amp it is sent through one final op amp
- The signal is then sent to the Rx lines of the Ethernet cable in the form of a differential



Ideal signal going into the receiving end of and Ethernet cable

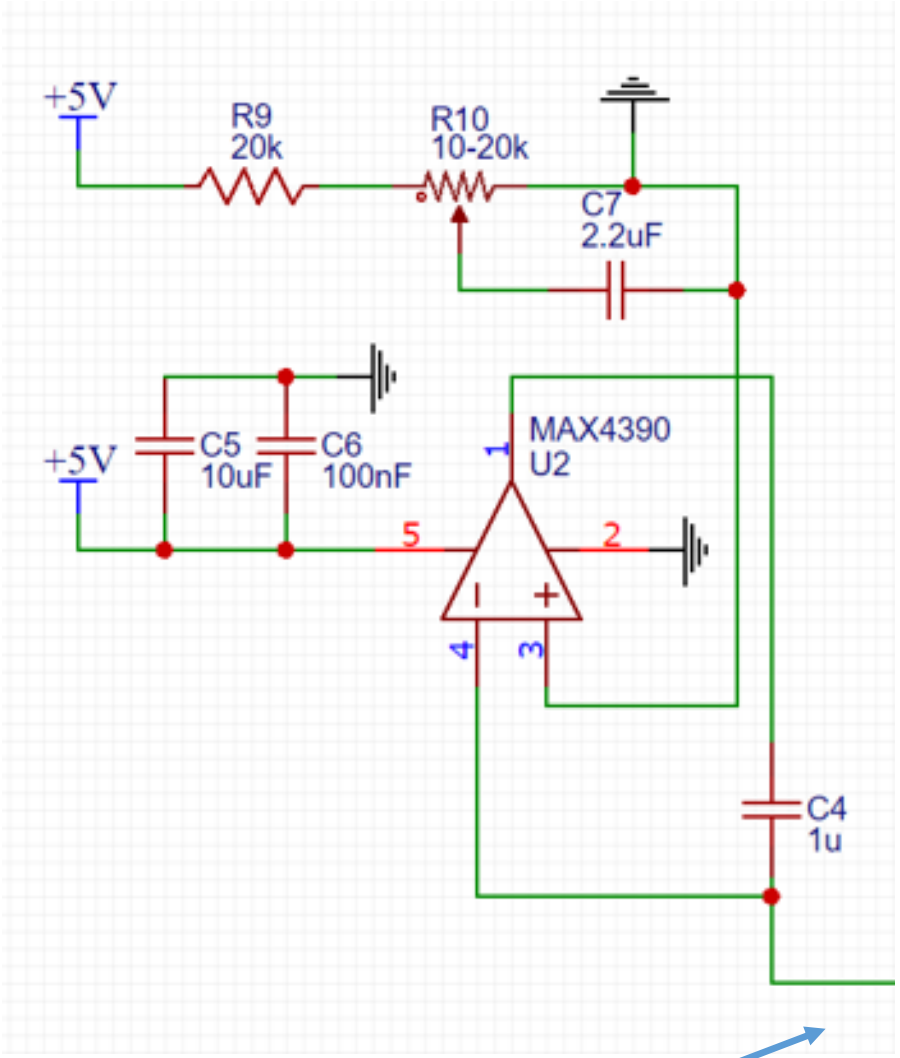
Transmitter Design



Transmitter Design

Op Amp configuration

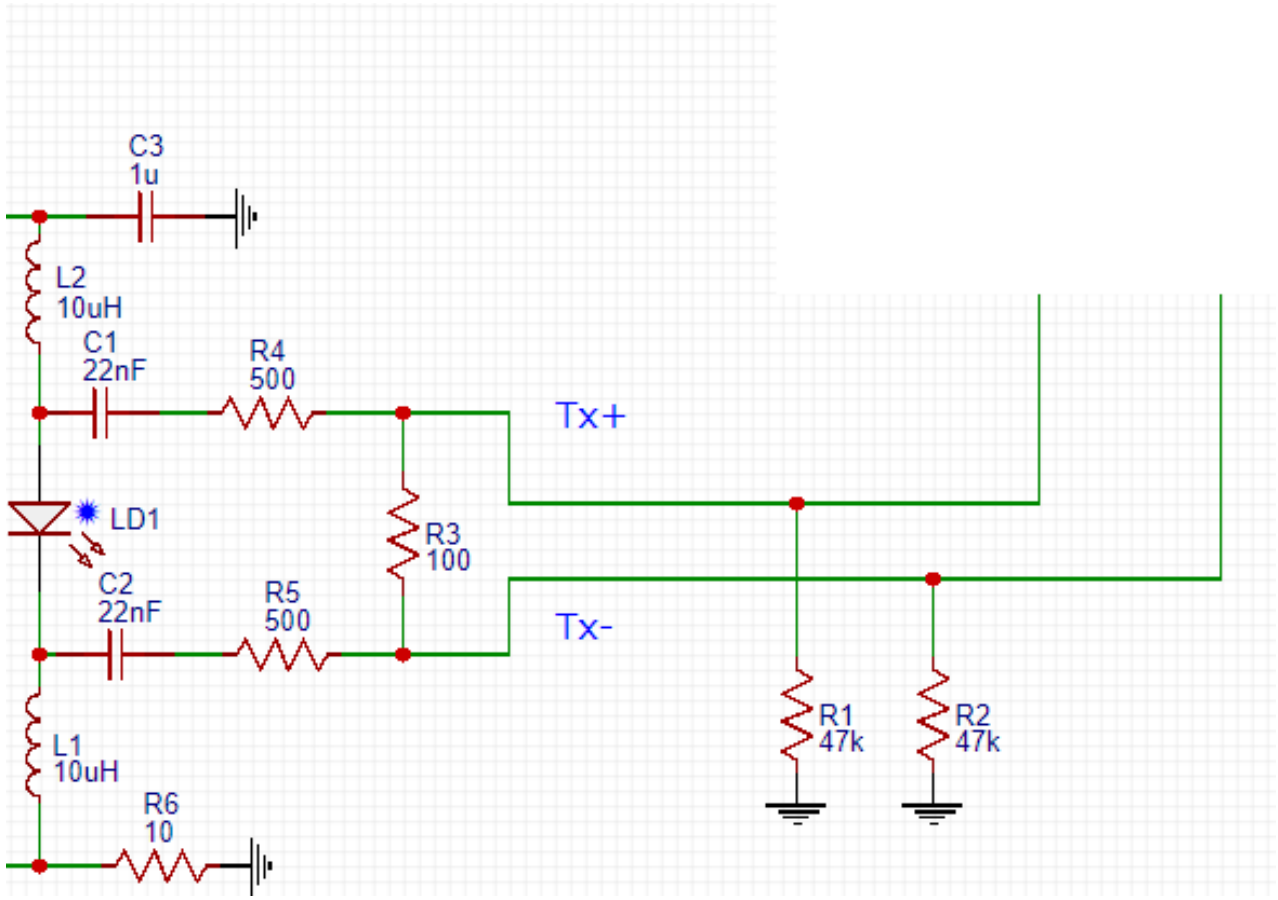
- The MAX 4390 is used as a constant current source, by making one of the resistors a potentiometer we can actively adjust the output current.
- This directly powers the laser diode with a DC signal set to about 20 mA



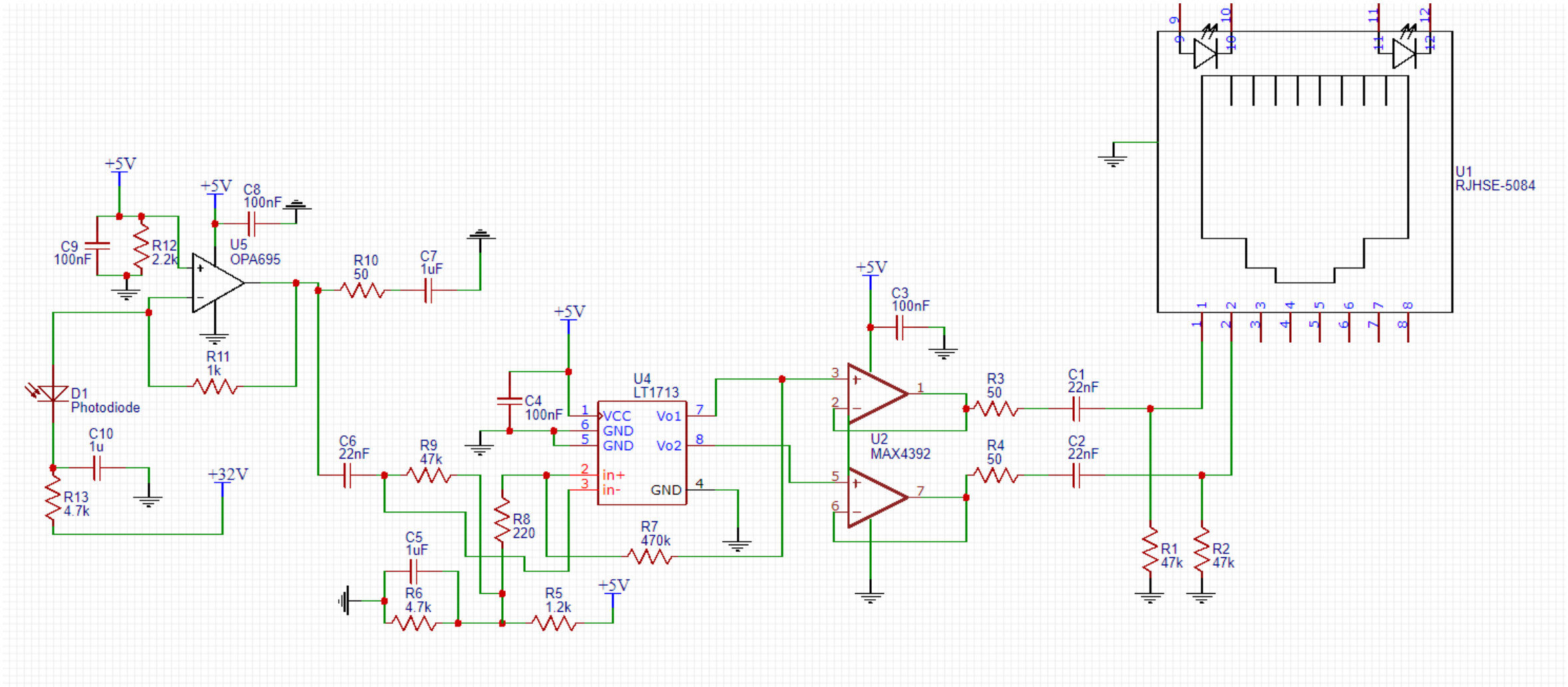
Transmitter Design

Laser Diode configuration

- The laser diode has a threshold current which creates the stimulated emission process.
- Setting the resistor value we can control the modulation amplitude while above the current threshold.
- We use capacitors to block any kind of DC signal
- We use inductors to prevent the AC signal from reaching any other part of the circuit



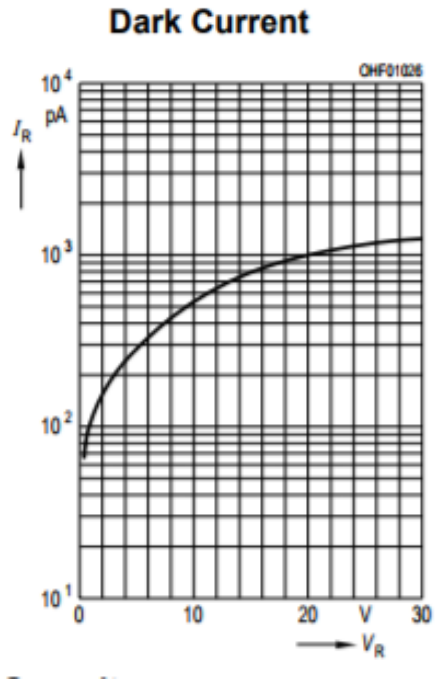
Receiver Design

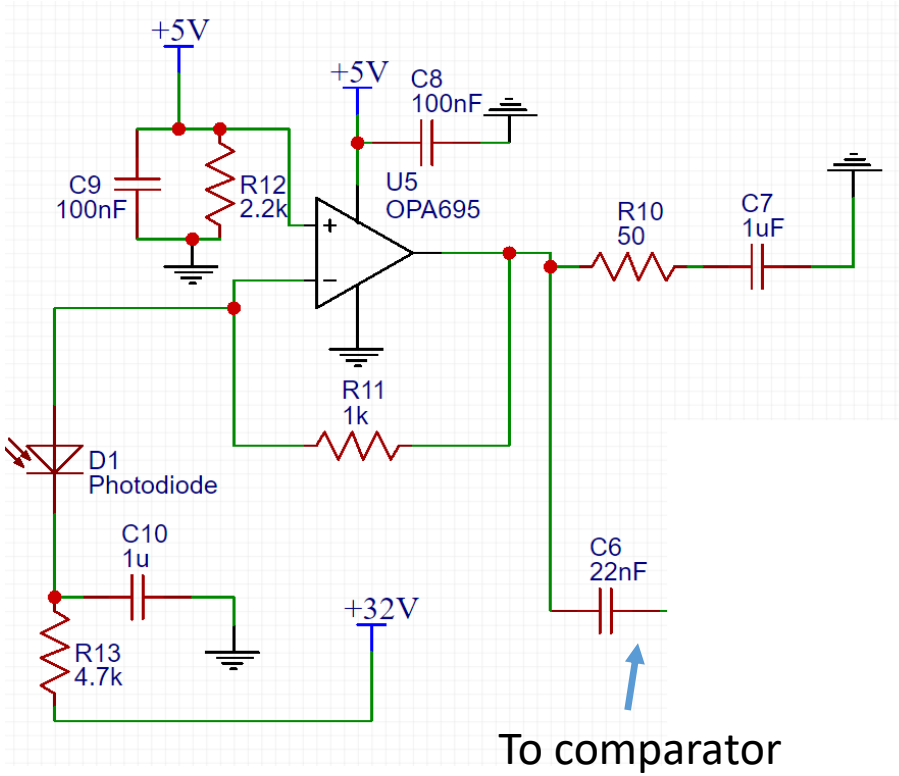


Receiver Design

Photo Diode configuration

- We reverse bias the photodiode (photoconductive mode), as we increase the bias voltage we decrease the capacitance of the diode and achieve a better response time
- The larger the reverse voltage the greater the dark current
- Passing the output of the photodiode to a transimpedance amplifier makes it ready to be processed

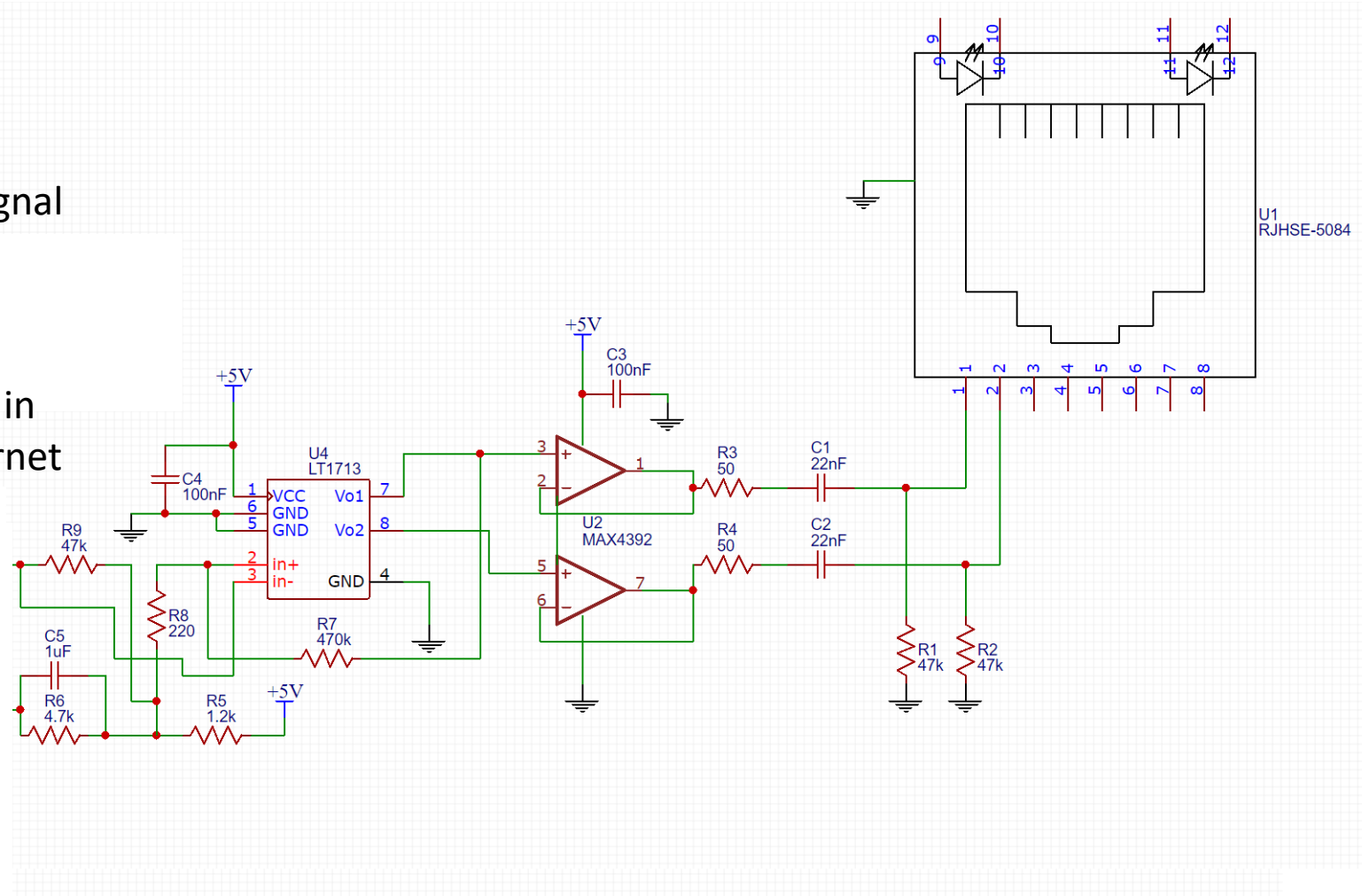




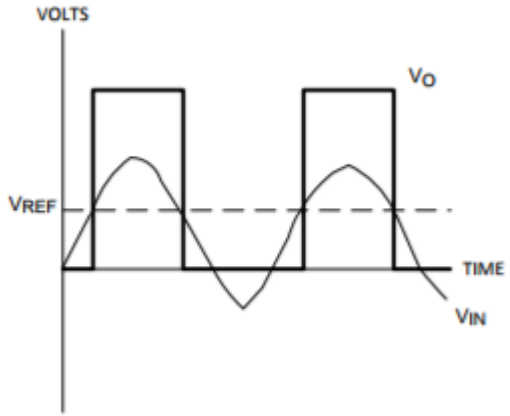
Receiver Design

Output configuration

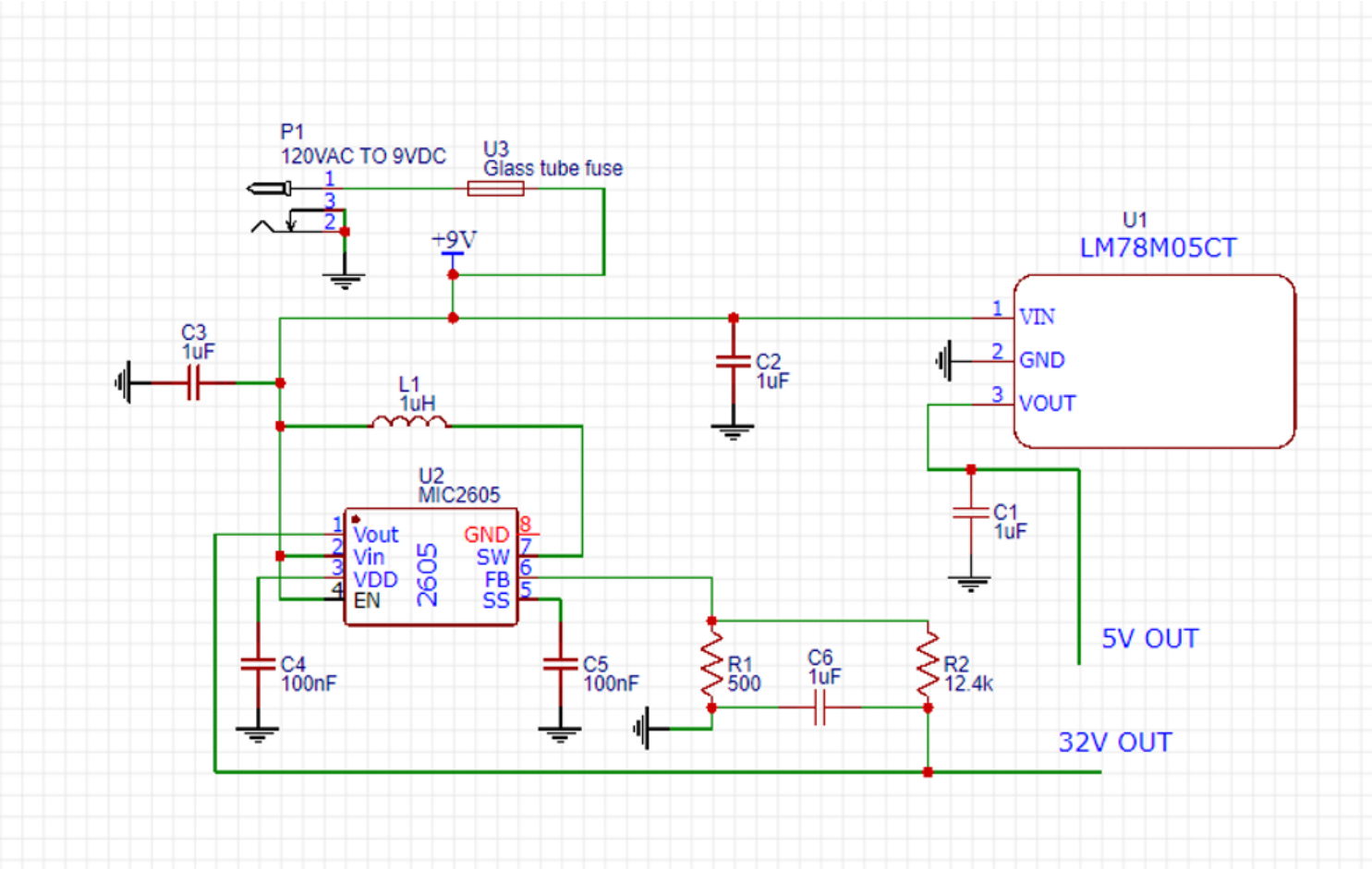
- A comparator converts the continuous signal received by the photodiode into discrete values
- The data signal is amplified one last time in order to be properly resolved by an Ethernet device



A sample signal and its output after passing a comparator



Power Supply Circuit



- The power supply system consists of a barrel jack, to be connected to a wall outlet, a fuse, a voltage regulator LM78M05CT, and a voltage booster the MIC2605.
- The fuse will break if the voltage regulator or booster is shorted, or overloaded, since these supply the power to the rest of the components they will be protected in this instance.

Strategic Components and Part Selections

1. Operational Amplifiers - MAX4390 and MAX4392
2. Transimpedance Amplifier - OPA695
3. Comparator - LT1713
4. Voltage Converter - MIC2605
5. Voltage Regulator - LM78M05CT
6. Photodiode - SFH203
7. Laser Diode - Jameco Valuepro 154145

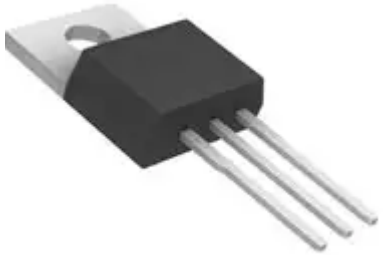
Operational Amplifiers

Specifications	MAX4390	THS4051	MAX4392	THS4052	OPA695
Operating Temperature	- 40 °C to 85 °C	- 40 °C to 85 °C	- 40 °C to 85 °C	- 40 °C to 85 °C	- 40 °C to 85 °C
Cost	$1.84	$2.98	$1.20	$5.26	$4.37
Operation Bandwidth	85 MHz	38 MHz	85 MHz	38MHz	450 MHz
Supply Voltage	4.5 – 11 v	9 - 33 V	4.5 - 11 V	9 – 33 V	5 – 12 V
Mounting type	SMT	SMT	SMT	SMT	SMT
Channels	1	1	2	2	1

Comparator-LT1713

- Cost –$2.55
- Propagation delay time- 7ns
- Power Supply Range is 2.4 V-12 V
- Purpose: The comparator allows for the reshaping of a the output coming out of this device which should look like a perfect square excluding the ripple effect of the Fourier components.

Voltage Regulator-LM78M05CT



- Cost :$0.69
- Output current 500mA
- Output Voltage 5V and 15V

Voltage Booster-MIC2605

- Low Cost: $1.18
- Voltage conversion efficiency: 99%
- Power Supply Range: 4.5V-20V
- Output voltage: ≤ 40V

Photodiode- SFH203

Specifications	BPV10	SFH 203	SXUV5
Operating Temperature	- 10 ºC – 40 ºC	- 10 ºC – 40 ºC	- 10 ºC – 40 ºC
Cost	$1.11	$0.29	$363.95
Response, Peak in nm	400 – 1100 nm, 950 peak	400 – 1000 nm, 900 peak	Near IR, 800 nm
Reverse Voltage	5 – 60 v	5 - 50 V	20 V
Mounting type	Through hole	Through hole	Through hole
Forward Current	70 uA	9.5 uA	10 uA
Frequency Response	250 MHz	270 Mhz	1 GHz

- Purpose: To collect the data signal being emitted from the laser diode

Photodiode	Advantage	Disadvantage
BPV10	Large response range, good output current	High reverse voltage to be effective
SFH 203	Cheapest, with good range	Low output current
SXUV5	Low reverse voltage, very fast response	Extreme price

Laser-Jameco Valuepro 154145

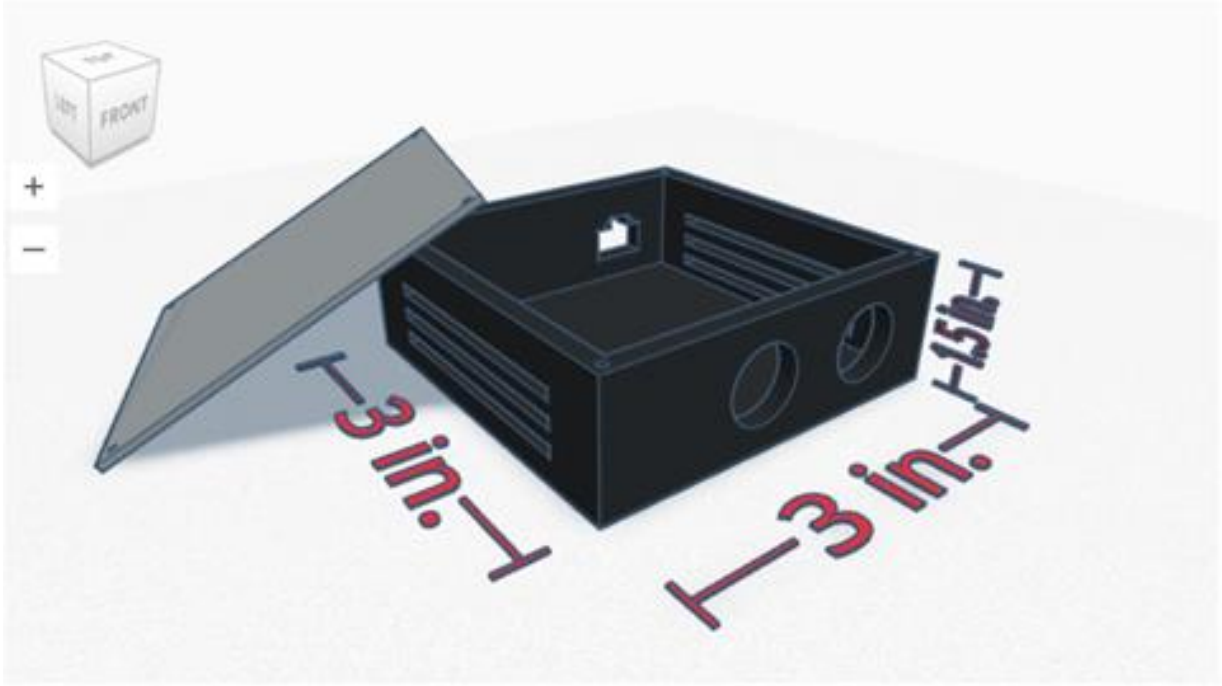
Laser Specifications	Jameco Valuepro 154145	Lilly Electronics 532MD-30-5V-TTL	Thorlabs ML925B45F
Operating Temperature	-32.8°C to 149°C	＋15 ℃ - 35 ℃	-32.8°C to 85°C
Cost	$3.49	$25.80	$48.50
Operating Voltage	3 V	5 V	1.5 V
Working Current	< 40 mA	> 265 mA	< 50 mA
Wavelength	650 nm	532 nm	1550 nm
Output Power	< 5 mW	30 mW	5 mW
Mounting Type	Wires, through hole 2 pins	Through hole 3 pins	Through hole 3 pins

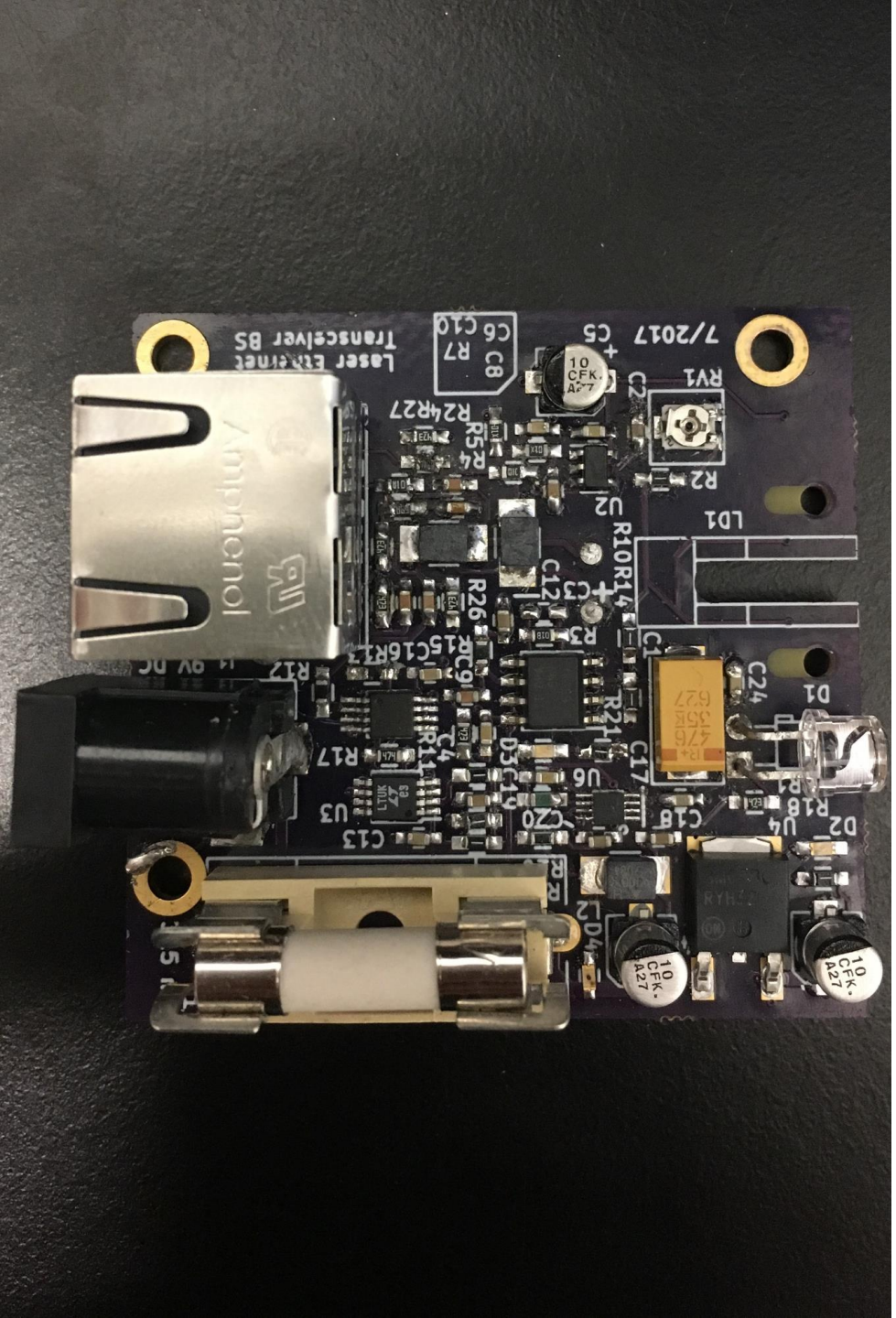
- Purpose: The laser diode is the modulator for the data, its output acts as the carrier and its modulation is the data

Photodiode	Advantage	Disadvantage
Jameco Valuepro 154145	Operating voltage and current value, low price, 2 pins	Low output power
Lilly Electronics 532MD-30-5V-TTL	High output power	High price, high current required
Thorlabs ML925B45F	Low current and low voltage	High price

Device Housing

- The box itself is quite small at only 3" x 3" x 1.5" in the order of length, width, then height.
- The front of the box contains two holes cut out for future lens placement
- The two sides are lined with vents to help keep the electronics cool while in operation.
- There is also a barrel jack opening for the power supply that is not shown in this rendering.
- A lid that is secured by 4 screws to keep the contents safe and locked inside.





Testing and Construction

- The PCB schematics were modeled in KiCAD
- OSH Park manufactured the boards
- The smallest chip is the voltage booster only, 2x2 mm
- All passive components are 0603 form factor
- The boards themselves measure 55.9 x 55.9 mm
- Hot air and a fine-tip soldering pen was used to solder the components.

Software

Proposed System & Requirements

- Desktop-based system for file transfer and network information
- Can establish and terminate connection
- Can estimate transfer speed
- Can estimate the file size being sent
- Can check the status of the computers involved
- Can display the network information

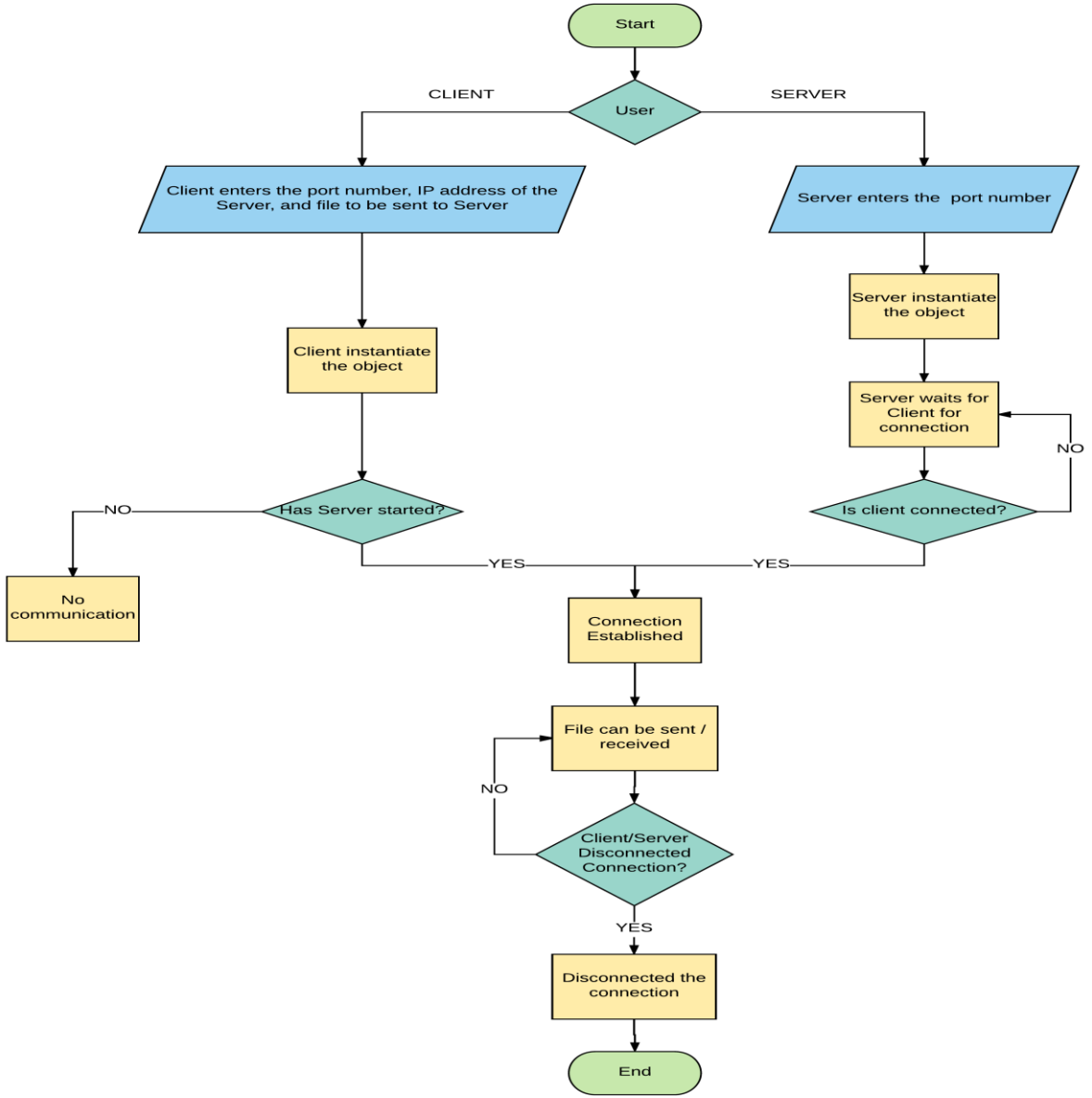
Software Development Tools

- IDE : Visual Studio
- Language: C#
- Connection: .NET Framework
- OS: Windows
- GUI : Windows Forms

Why TCP Protocol?

- TCP vs UDP
- UDP was connectionless, sockets did not need connection.
- TCP needs connections, which it will only function if hardware connects
- FTP is the a layer working on top of the TCP through the application layer, we use a subset of the FTP in our interface
- Also we decided to work with the concept of TCP/IP protocol stack since it is simpler and standardized compared to ISO.

Flowchart Diagram

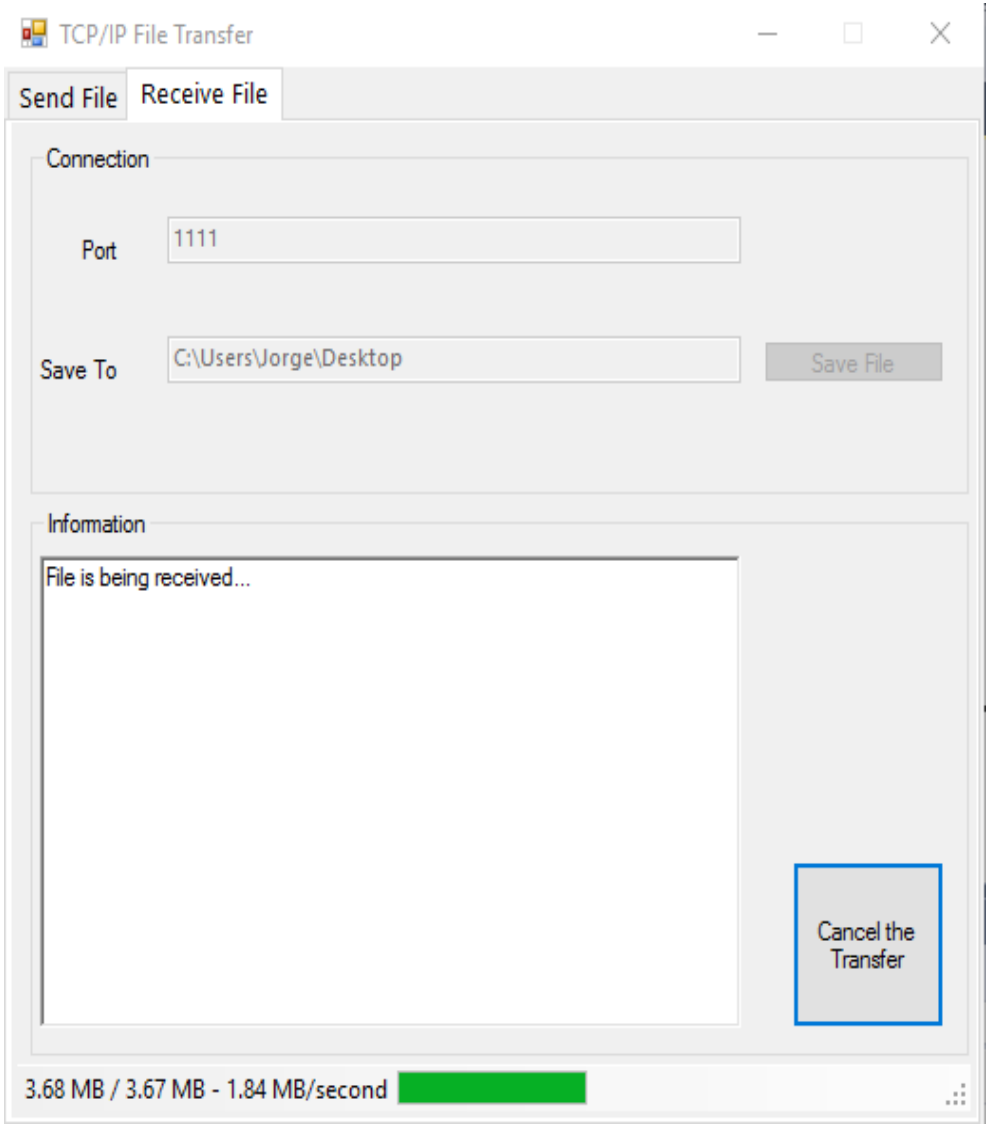


Design of the "TCP/IP Receiver" Side

- The Server GUI will function as the receiver from the Client.

Functionality:

- Start Connection
- Select port number
- Selected location where the file will be saved

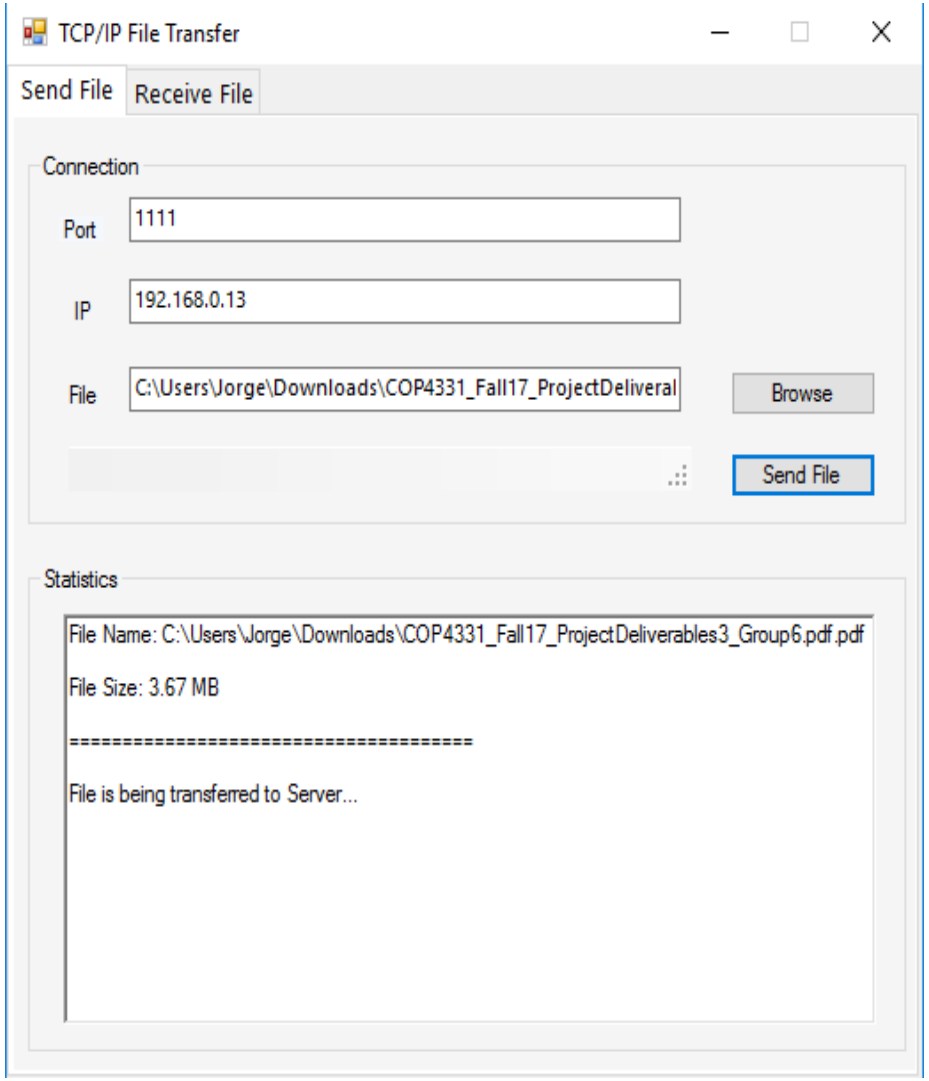


Design of “TCP/IP Sender” side

- The Client GUI is on one side of the data transmission
- This GUI will provide us with the estimated information of the link communication when data is being transferred

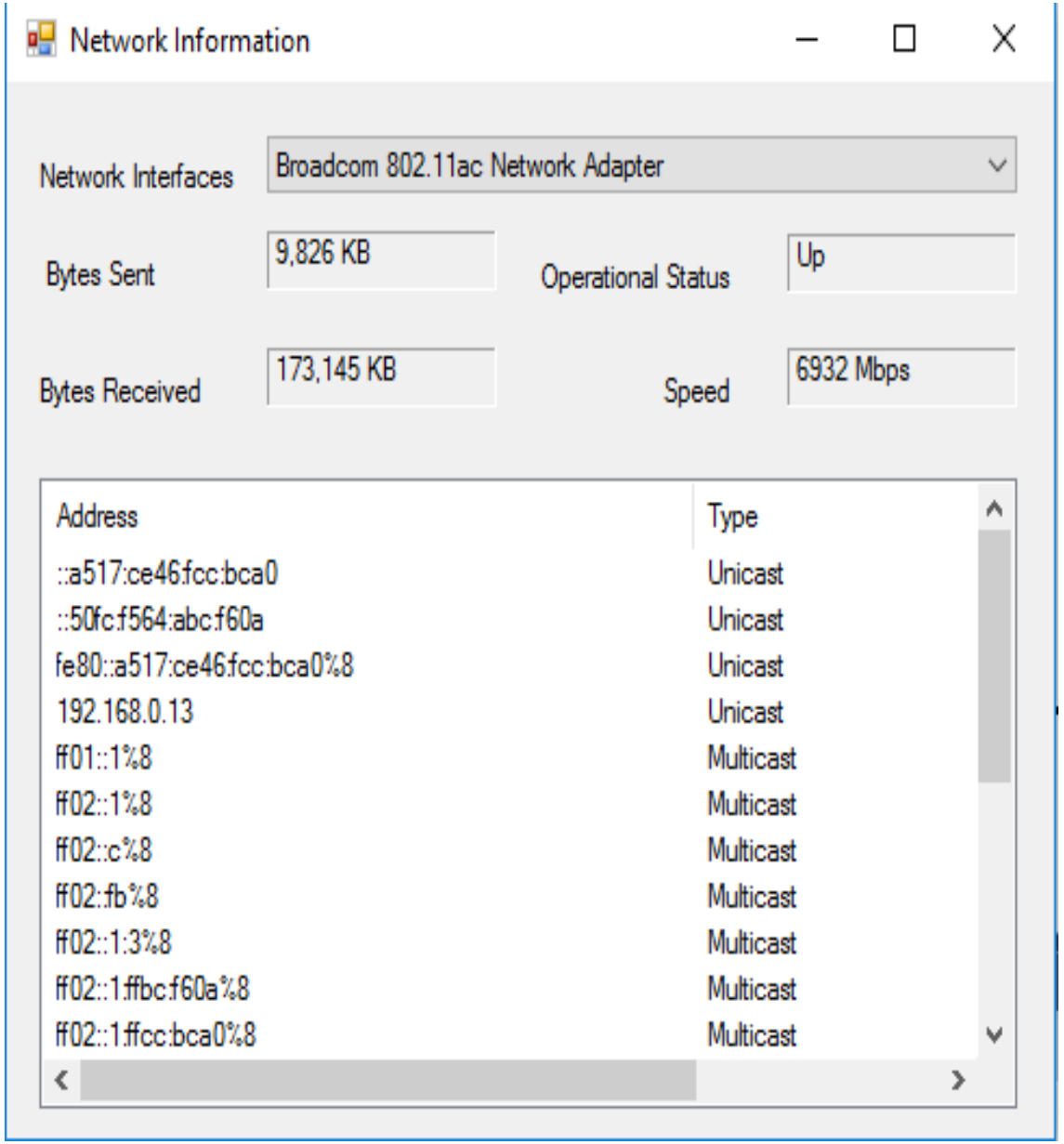
Functionality:

- Select port number
- Select Server's IP address



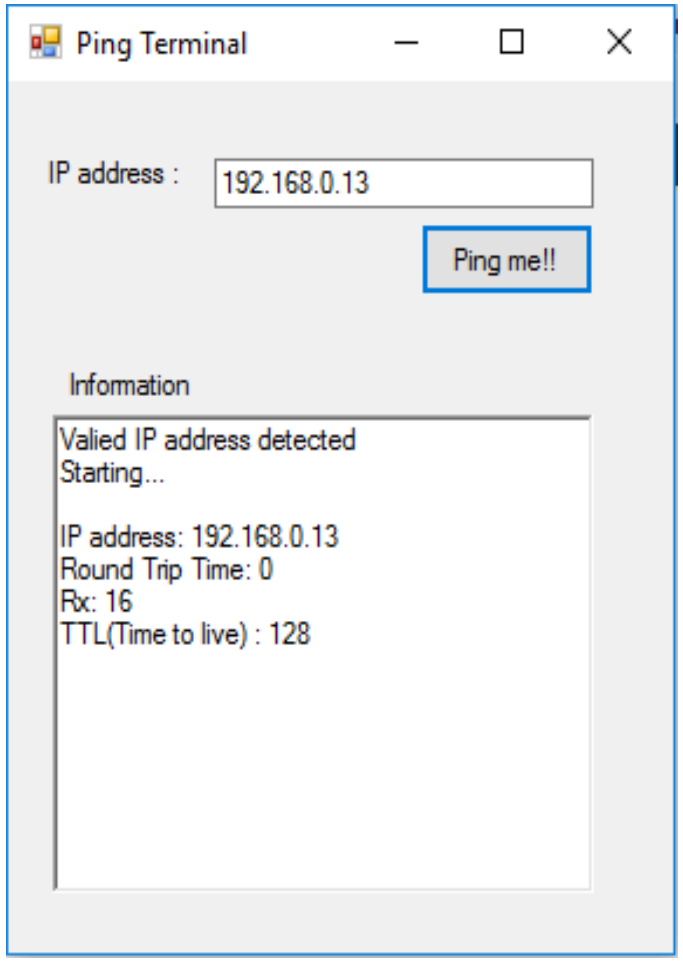
Design of the Network Information “Terminal”

- Provides us with the information of the status of whatever network interface we are running on.
- **Functionality:**
- On the 'Network Interfaces' drop-down menu, select the type of network you want to check during the transmission of data that is executed.



Design of the Ping Testing

- The Ping Testing GUI is essential because it would verify if the specific laser Ethernet transceiver will function, essentially if it responds.
- **Functionality:**
- By writing the user's name on top blank space, we would get the IPv6 address and the time it took to reach the machine.



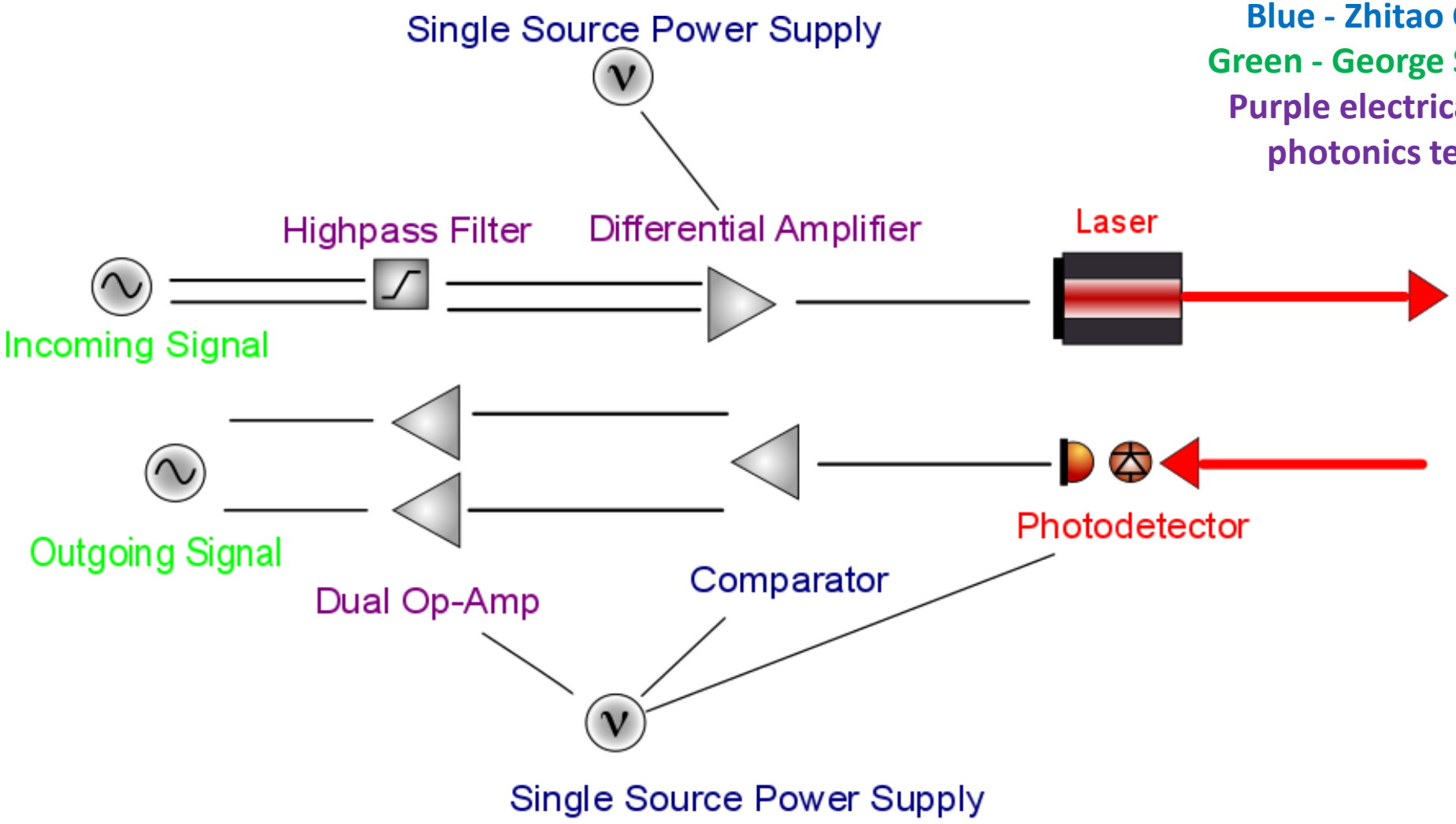
Software Conclusion

- The expectations of the software is that it will work over any network interface even where Visual Light Communication mean is NOT involved.
- This design of the system was made in a simple way so users can visualize the whole purpose of the software.
- GUI is lacking polish, but doesn't affect the goals of the software.
- The system is limited just to a LAN network
- The system is limited to Windows.

Administrative Content

Work Distribution

Red - Benjamin Stuart and Garrett Bennett
Blue - Zhitao Chen
Green - George Salinas
Purple electrical and photonics team



Work Distribution

	Benjamin	Garrett	George	Zhitao
Power Distribution	2nd	3rd	4th	1st
Comparator and Op Amps	2nd	3rd	4th	1st
Data Analytics	2nd	3rd	1st	3rd
Photodiode	1st	2nd	4th	3rd
Receiver Amplification	1st	2nd	4th	3rd
Laser	2nd	1st	4th	3rd
Transmitter Bias	2nd	1st	4th	3rd
Testing	2	1st	3rd	1st
Construction and PCB	3rd	1st	3rd	1st

Administrative Content

Budget

- Overall the cost of the design is $49.69 per board.
- Each component was ordered for the fact that we have six PCB’s and that there would be some initial mistakes in creating such a device for the first time.
- Of course, if there was more of a reason to pursue this product professionally, there are companies which can manufacture every one of the components on to the PCB via machine vision and assembly technology such as smallbatchassembly.com.
- The 500 Ω specialty resistors cost $5.33 each.

Budgeting

Part Name	Company	Purpose	QTY	Price Each	Price Total
SMD 0603 Resitors	Various		139		$72.71
SMD Capacitors and Inductors	Various		35		$30.61
RJHSE-5380	Amphenol	RJ45 SHEILDED 8 CONT NO LEDS	6	$1.45	$8.70
MC78M05BDTRKG	ON SEMICONDUCTC	MC78M05BDTRKG	10	$0.40	$3.95
LT1713IMS8#PBF	LINEAR TECHNOLOG	LT1713IMS8#PBF	8	$4.38	$35.04
MIC2605YML-TR	MICROCHIP	MIC2605YML-TR	8	$1.13	$9.04
OPA695ID	Texas Instruments	High Speed Operational Amplifiers Ultra-Wideband Current Feedback	6	$4.37	$26.22
MAX4390EUK+T	Maxim Integrated	High Speed Operational Amplifiers 85MHz w/Rail-Rail Output	6	$1.84	$11.04
SFH 203 P	Osram Opto Semicor	Photodiodes PHOTODIODE	10	$0.66	$6.61
LT Q39E-Q1OO-25-1	Osram Opto Semicor	Standard LEDs - SMD True Green	10	$0.26	$2.64
HT-193UY-5591	Inolux	Standard LEDs - SMD Yellow 589nm 45mcd 20mA	10	$0.12	$1.18
PCB	OHS	PCB Order	6	$12.97	$77.80
Laser	Amazon	Laser Head Diode Dot Module WL Red mini 650nm 6mm 3V 5mW 10PCS	10	$0.60	$5.99
Total					**$291.53**

Questions?