End-Of-Project Report: Free-Space Optical Communication

EEE193B/CPE191 – Senior Design Project II
California State University, Sacramento

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Elevator Pitch

We're building a free-space optical communication system to illustrate how optical communications can be used to address a societal problem that is referred to as the digital divide.

Executive Summary

Certain locations of the world are left with no or a limited internet connection to the entire world. The world has a hierarchy when it comes to internet connections. The hierarchy mentioned is referred to as the digital divide. People without an internet connection are not experienced with the internet. The inexperience of the internet can lead individuals to trust sources which are not credible. The digital divide is causing the spread of misinformation that leads to people getting harmed. Not to mention that the cost to set up and repair the internet in places that use optic fiber cables is expensive. Also, the time to fix the optic fiber cables takes a long time too. The loss of internet could also rob the place of some economic growth because some people use the internet for trading goods. The COVID-19 pandemic has increased the need for more bandwidth to meet the consumer demand. The pandemic has made the Digital Divide a bigger issue than what it was before. The proposed idea to help the communication problem "The Digital Divide" is this free space optic communication (FSOC) device. The FSOC device is an optical transceiver with the intentions of meeting the consumer demands that is affordable and has a fast connection speed. The features of our FSOC device include fast deployment, wireless ethernet connection, a cost-effective device, and a local web database. Now looking at the optical transceiver itself there are different aspects to the device that are explained in detail. First. the hardware of the device is examined through schematics. The schematics included will demonstrate the optical transceiver, transmitter and receiver. The hardware in our FSOC device will include a class 3a laser, so we will follow safety guidelines when performing tests to achieve our goal of transmitting 10MB per sec. Then we plan to use some software to record data transmitted through the laser. The data will be transferred through the usage of the TCP/IP protocols. When trying to implement our FSOC device we observed different solutions currently out in the market and justified the use of our approach.

Now that we have a project with features that we want to meet planning was done to accomplish the project. A work breakdown structure was made to display all the tasks accomplished to finish the project and the individuals assigned to the task. A timeline was even created to make sure we do not fall behind in the project. The timeline shows how the team met deadlines in the project. The planning shows how we finished the project from August 2020 to May 2020. With every project there is a risk that we must be prepared for. The FSOC device has a good amount of risk attached to it. The smaller risks are software crash, a fuse blowing out, or misalignment of the laser. To address all the risks with our project we have made a risk matrix. Along with stating our potential risks we will talk about how we plan to approach these risks. At this point you may be asking how profitable this project is.

Free space communication (FSO) devices are a new trend in technology. Companies have been focusing on making FSO devices because the benefits from these devices have out weighted the cost. Research has shown how we can connect people in rural areas to high-speed internet. Then we look at our other devices in the market and compare our devices to them. Our device is cheaper but does not perform at the same rate as other devices in the market. The market of FSO devices has been going up and expected to grow exponentially in the next couple of years. We can conclude that our device has the potential to become a device that people want in the market. To guarantee the performance of our device tests were made to make sure our device works properly.

During the device test plan, our group comes to a consensus on how to test our FSOC device. Each member is assigned different experiments that they will perform and document. Our main goal with the device test plan is to stress test the device to determine its limitations. All of this is for the sake of making sure that our device continues to meet the feature set "punch list" that our project is committed to. After several months of testing, our device was successful in meeting our desired feature set and measurable metrics. However, we also encountered some of the limitations with the system. When we encountered a problem, we did more tests and gathered more data. The data, as it would turn, does suggest that FSOC systems can be used in lieu of coaxial cables. Furthermore, our experiment is a showcase in how FSOC systems, if managed correctly, can be a great tool against our growing digital divide.

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***Introduction Abstract* — Increasingly, the internet is becoming a more integral part of human civilization and, because of this, it is becoming more integrally important that societies have access to it. Furthermore, the societies that do have access to internet, have an increasing demand for faster and more affordable internet. Free-Space Optical Communication (FSOC) is rapidly becoming a multi-facetted solution to this multi-facetted problem. Since FSOC's use light waves to transmit data, as opposed to cables, its implementation costs and bandwidth capabilities make it an attractive modern solution to an ever increasingly important societal problem**.

Index Terms — Free Space Optical Communication, Internet Service Provider, Transmission Control Protocol, Internet Protocol, Free Space Optics, Light Amplification by Stimulated Emission of Radiation.

I. INTRODUCTION

There is no doubt that communication has been an important part of human history and its evolution. Time and again our ancestors have found innovative and ingenious ways of being able to communicate with one another over a range of distances. First with the creation of writing. Fire and metal plates were ingeniously used together to reflect light in order to communicate across relatively large distances quickly. Fast forward to the 20th century and we've evolved with the invention of the telephone, the radio, and the most recent communication marvel: the internet.

Today, the internet has connected most of the planet in a way where we can practically receive messages and video data instantly. It is no wonder why fortunate societies with access to it tend to have more opportunities available to them than those who don't. Unfortunately, however, there is a large disparity when it comes to internet access. According to Opensignal, a global standard in mobile network analytics, there are regions of the world where the internet is seven-times less than those regions with the fastest internet [2]. Because of this digital divide, these regions are further isolated and robbed of the same opportunities that we have come to take for granted. Furthermore, there are projections estimating that the consumer demand for internet will only increase. Estimates guess about 24% annually [3]. So, not only do we need to find a way to make the internet more easily accessible, we need a solution that can support this huge increase in consumer demand.

This digital divide, an issue that we'll return to throughout the report, is caused by the expenses and complications that come with large cable or fiber networks. It is important to understand that for service providers trenching and laying out potentially hundreds of kilometers of cabling is very expensive. Especially for remote regions of the world where it's either financially insensible or flat out impossible. Some service providers launch satellites which can reach these isolated regions. Satellites, however, are also very expensive. Not to mention that they come packaged with a slew of international governmental regulation and coordination.

So, the question becomes: how can we construct a broadband network cheaply that's able to access these remote regions more easily? While also being capable of meeting the increasing growth of consumer demand.

A. Free-Space Optical Systems (FSOC)

Free-space optics communications, or FSOC, can provide a potential solution. FSOC is a form of ultra-wideband communication. For now, it's best to visualize it as high frequency electro-magnetic waves (light) to transmit high frequency signals. The benefits are akin to fiber-optic communication but without the need of cables. By being wireless FSOC is a far more versatile system in terms of installation. This would drastically reduce industrial costs. Also, since FSOC is an optics (light) system, it's bandwidth capabilities can meet the consumer demand needs of the foreseeable future. Another benefit to using FSOC systems is that they operate outside of regulated frequencies. Further reducing costs and decreasing complexity.

Large scale FSOC systems, of course, are still expensive and are large industry-scaled projects. However, compared to the previously mentioned alternatives, it is a preferable choice in comparison to other communication systems with a faster data rate transmission as shown in Table.1 [4]. This is why, for a senior design project, we chose to build a small and rudimentary system. Albeit a robust system which can even be modified for a larger scale project.

With more of a proof-of-concept approach, our proposal is that we use Twibright Lab's RONJA [5] and Sven Brauch's [6] transceiver/receiver when considering a FSOC design. Both sources claim that their devices are capable of full-duplex wireless communication with a bandwidth of 10Mbps. The distance of transmission we aim to achieve is approximately 92 meters (~100 yards) or less. The distance of transmission, however, will likely be reduced to the size of an average room. Distance, as well as line of sight, are just a couple of major hurdles that will be addressed later in the report.

B. It's Not So Basic

Ironically enough, even though the internet is a major cornerstone of human civilization and a communicational ingenuity, the average user may not know how the internet arrives to their home. That's really not much of a surprise, since there can be hundreds of parties involved which muddles what came from where. Also, with buzz words like "Wi-Fi" or "4G/5G" the topic can be confused even further.

That's why in order to have a better understanding of our goals with this project, it's important to have a firm understanding of what part in this "internet chain" it is we are targeting. Below is a figure found from the website HowStuffWorks [7]. The figure illustrates, for the most part, how internet goes from the ISP (an internet service provider like AT&T or Google Fiber) to the user.

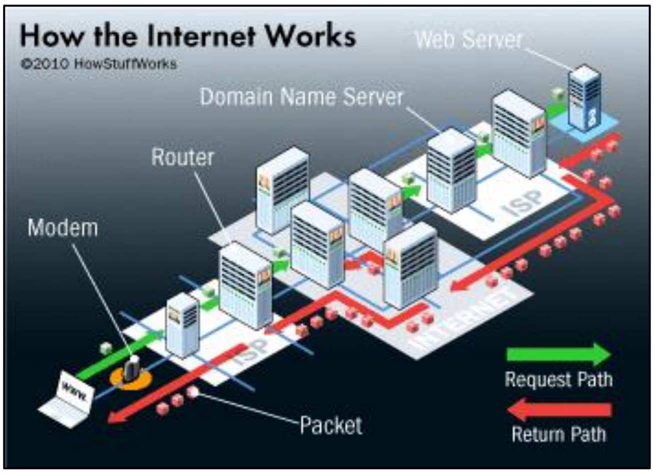


Figure A-1. How the Internet Works.

Our project primarily focuses on the connections between the ISP's domain name server and internet. These connections are illustrated as blue lines in the figure. They represent cabled networks that are physically connecting ISP to internet then back to a local ISP network and then to a user. As an aside, this is a gross oversimplification. We'll discuss this later in the report when addressing satellites but for now it will do. Anyway, these blue lines are the cables we would like to remove from the equation.

Note that the internet can be accessed by users a multitude of ways once the signal reaches a local network area. Although, usually, it's accessed as Fig. A-1. depicts. That is, the user is accessing the internet from a modem that is transmitting the signal wirelessly via Wi-Fi. Of course, if the cabled network access point is at the user's home, they may access it directly with their computer if they want. With mobile devices, wireless communication can be done through Wi-Fi, 4G, and more recently 5G.

C. The Difference: Security

And this is where we think the confusion lies. Wireless communication channels like Wi-Fi or 5G are broadcasted publicly through microwaves or radio waves. This means that other users can see the channel. When someone accesses a Wi-Fi network, there is typically a domain name, and the user may also need to input a password. In other words, other users can still see the channel, they even see your Wi-Fi domain name, but they can't necessarily access it because they may not know your password.

5G works the same way. The difference between 5G and Wi-Fi is that 5G is a dedicated mobile service. It has security features like a SIM card in order for it to work. Whereas Wi-Fi can be accessed by mobile or any other wireless capable device.

In any case, this is a very stark difference compared it to the type of FSOC system we're proposing. Just like cables, FSOC system do not broadcast any data or access point. Also, intercepting messages from these optical channels is, again, akin to intercepting messages from regular cables. Arguably harder to intercept.

Security in this format is absolutely necessary. This is especially true for ISP's and it is for us as well. The intent of our system is to be able to deploy large broadband networks without having to trench physical cables or optical fibers. So, we expect lots of private, valuable, and sensitive data to be transmitted through these cables. Any access point to these types of networks will undoubtedly be targeted by malicious actors. Table 1 shows how FSOC communication systems differs from other types of communication systems [4]. As we've discussed, when compared to other communication systems, FSOC has a lot going for it with not many trade-offs.

TABLE 1.
FSOC VERSUS OTHER COMMUNICATION SYSTEMS

Comparison of FSO With Different Communication Systems				
Parameters:	FSO	Optical Fiber	Microwave Radio	Coaxial Cable
Installation:	Moderate	Difficult	Difficult	Moderate
Data Rate:	Gbps	Independent	Mbps	Mbps
Security:	Good	Very Good	Poor	Good
Connectivity:	P2P, P2MP short and long reach	P2P, P2MP short and long reach	P2P short reach	Multi-drop short reach
Maintenance:	Low	Low	Low	Moderate
Spectrum License:	Not Required	Required	Required	Required

***Societal Problem Abstract* — The internet has become an integral tool for our civilization. Particularly in today's environment where the pandemic COVID-19 has essentially forced us all into self-quarantine. The situation has made the internet the primary way for us to communicate with one another as well as get the information we need in order to live are lives. Unfortunately, however, the internet is still not accessible to everyone. Moreover, those that do have internet are experiencing a greater need for better internet service i.e. speeds. This disparity in access to information, due to lack of good quality internet, is referred to as a digital divide. Our hopes are that this project can help others understand the issue as well as provide a potential solution.**

II. Societal Problem

Information – it's thought that only blackholes are capable of destroying it. Well, that's if you're willing to believe in Stephen Hawking's theories.

On earth, information has become an incredibly valuable commodity. Large corporations and companies pay millions upon millions of dollars to get as much of it as they can. They then sell that data to advertisers making potentially billions in return. For example, the business models of companies like Google and Facebook rely almost entirely on gathering data and selling it to advertisers. In fact, recently, former presidential-runner Andrew Yang has been advocating for policies where companies like Google and Facebook would have to pay users royalties if they profited from those users' data.

But information isn't just valuable to the ultra-rich, it's valuable to the ultra-poor. Arguably, more valuable because the potential for information, by virtue of technology, increasing their standard of living is more compared to those in a higher economic bracket [8]. It turns out that this disparity is referred to as the digital divide and it is a very real and a very large problem.

A. *The Digital Divide*

Digital divide is a terminology that was first coined by a man named Lloyd Morrisett [9]. He was an American psychologist with many careers. However, most may know him as one of the founders of Sesame Workshop. It's the same organization that created Sesame Street for which he was a co-creator.

Digital divide is described in a survey project report by the US Department of Commerce [[*10*]. It's called Falling Through the Net: A Survey Of the "Have Nots" In Rural and Urban America. It was published in 1995. Table 2 shows some of the data that was taken during the survey. The table shows the percentages of households with a modem compared to their economic status. As the data shows, low economic rural areas suffer the most in terms of internet access.

Table 2.
Percentage of US Households with A Modem

Income Versus Rural, Urban, and Central City Areas			
Income	Rural	Urban	Central City
< $10,000	23.6	44.1	43.9
$10,000 - $14,999	28.9	40.6	44.8
$15,000 - $19,999	32.4	30.7	28.3
$20,000 - $24,999	28.5	38.2	36.8
$25,000 - $34,999	32.6	41.1	43.3
$35,000 - $49,999	34.4	45.6	48.0
$50,000 - $74,999	46.7	49.8	49.2
$75,000 <	52.2	58.1	56.4

The definition of a digital divide is rapidly changing though. Increasingly it's becoming a general term for the inequality in distribution of internet access, quality, or speed. In any case, it's becoming blatantly clear that there is a correlation between a societies social, economic prosperity and its ability to access information.

B. *It's Not Just an Inconvenience*

It can be easy to forget how dependent we, as a civilization, have become to internet connectivity. This dependency has only been emphasized by the recent pandemic COVID-19. To say that it has put a light on how critical internet access has become would be an understatement. Most of the world has been forced into self-quarantine making the internet the primary source of communication for practically all of us.

All sectors of a nation's economy have been impacted. Medical services, for example, have all been converted to no-contact where possible. This, for the most part, makes internet access a necessity for those with medical conditions.

Table 3, which was obtained from *Impact of The Digital Divide in The Age of COVID-19*, is a table on why small health clinics may not engage in the conversation of COVID-19 [[*11*]. It suggests that it may be due to the digital divide. The limitation of internet connection prevents people from attending some online webinars. Some communities may not know how to access the right locations to be informed of important and reliable information. Another comment made by a doctor explains the need for a special location where people can go to get information about the pandemic. The government websites are not always good resources either because the doctor mentions "For instance, in some communities these sources could be the traditional healers, and in others they could be the general practitioners or pharmacists" [[*11*]. The doctor recommends this need for a risk communication channel to help sort out the misinformation which can harm or kill people. The solution of having a special risk communication channel specifically for medical information. The medical experts are not the only people facing the digital divide.

TABLE 3.
CONTRIBUTIONS TO THE DIGITAL DIVIDE IN HEALTHCARE

	Built Environment	**Social and Community Context**	**Education**	**Economic Stability**	**Health and Healthcare Access**
Contributions to the digital divide in health care	Lack of broadband internet availability region-wise; limited access to free public internet in community buildings such as libraries; absence of structural support/housing insecurity.	Shared or cultural expectations regarding use of digital devices, telehealth, and telemonitoring, mistrust of technology and/or medical community.	Literacy; varying degrees of digital literacy; inconsistent or unavailable education regarding changes in technology.	Inability to purchase devices or upgrades; affordable devices may not have capability to work with proposed programs; inconsistent access to devices due to economic instability	Choices of technology/programs heavily tied to reimbursement; healthcare systems likely to pursue advanced technology that may outpace patient capability; patient comorbidities may affect ability to effectively use technology

Since the internet has become a big thing here during the pandemic. People are looking for information related to pandemic. The internet does not always have correct information which can lead to more issues. Some of the misinformation on the internet has made people wary of what to believe from the internet. A journalist interviewed a health professional named Dr. Sylvie Briand [[12]. The journal is titled *A Voice From the Frontline: The Role of Risk Communication In Managing The COVID-19 Infodemic And Engaging Communities In Pandemic Response*. In it the journalist listens to the doctor's opinion on communication during a pandemic. The doctor deals with the information on the internet to see what information is reliable and not for health care professionals. The doctor told the reporter of an incident where he said "there were fake reports that methanol could cure COVID-19, and there were over 300 deaths linked to people ingesting methanol [[12]. The internet has vast amounts of information which has not been sorted. The invalid information has led to the deaths of many individuals. The doctor continued to tell the journalist the importance of having people engaged in the talk about the pandemic to prevent incidents like the one in Iran. The organization the doctor works for has webinars and the organization goes to religious groups to inform them properly about covid-19.

Up to this point, we've assumed that there even is an ISP broadband network to access. We've also been assuming that access is relatively stable and fast. Unfortunately, this is not the case for a large portion of the world. In fact, if one digs a little bit deeper, they'll discover some shocking truths about the inequality between the haves and the have nots.

The reality is, that today, even here in America, there is a large disparity when it comes to internet access. According to 2015 US Census Bureau data, just less than half of households that earn $20,000 a year have access to internet [[13]. Let this sink in. Children, statistically Hispanic and African American children, are likely to not have access to internet during a period of time where schools, in some parts of the country, are mandatorily online. According to a different study, done by UNICEF in 2017, about 29% of youth worldwide - around 346 million individuals- do not have internet access [13]. It's hard for us to imagine going just a single day without internet. And yet, there are millions of families doing just that. Families and children that could benefit the most from having cheap reliable internet.

No doubt, as time goes on, more of these regions will eventually get some form of internet access. Yet, if we assume that the entire planet was to have internet access, the issue would change from having access to disparity in the quality of that access. In other words, even if the world has internet the issue of unequal internet speeds can still put others at a disadvantage. This means that we need a solution that can provide fast, reliable internet to everyone equally.

C. *Costs of Communication Failure*

The failure of communication systems is a problem that must be addressed. Not only does it hurt the economy of the affected regions, but it can also bring catastrophic harm to human life if it is not resolved accordingly.

Communication failures happen mostly in extreme conditions. When systems break down, people are not able to communicate with one another in a timely manner. This causes inefficiencies and delays for emergency response teams either before, during, and/or after natural, or even man-made, disasters. The damage to communication systems, along with increases in network traffic, disrupts relief operations. Making it difficult for rescue management to continue [14].

To prove this point, we only need look at the recent past. In 2004, means of communication were damaged during Hurricane Katrina resulting in serious challenges for both rescue teams and victims. In 2000, following the fireworks explosion in the Netherlands the Global System for Mobile communications (GSM) network went out of service after overloading [14]. Many other similar events have proven that communication systems have their downsides and limitations. Installing flexible and quick telecommunication infrastructures and restoring connectivity right away even if temporarily is crucial, so that rescue crews can synchronize their actions.

Communication technology has evolved and become a part of our daily lives. It plays such a major role in a country's economic growth. If a disaster were to happen, developed countries are able to reduce losses due to telecommunication infrastructure efficiency and ability to implement systems almost immediately.

Unfortunately, this is not always the case for developing nations as they "suffer from high quantities of victims and hard economic losses" [14]. Hence, it is important "to design or select more resilient technologies that are capable of operating in challenging conditions"[14]. During the first 72 hours of a disaster, rescuers have higher possibilities of saving lives. But only if they are able to quickly exchange information with local, state, federal, or even national, government agencies. Providing fast and reliable ways to access information can also lead to a better disaster management process. What this means, essentially, is that being able to deploy communication networks quickly and efficiently can save lives during times of crisis.

In order to address communication failure and proposed solutions for communication systems, research done focused on extreme events based in different aspects such as natural or man-made disasters, types of disasters (ex: earthquakes or tsunamis), geographic location, and whether the affected countries were developed or undeveloped [14]. One of the challenges when restoring communication according to EL Khaled, Z & Mcheick, H, is that the system must be able to operate without knowing previous information. It should be capable of quick installation in order to restore and strengthen the infrastructure. Able to change and cope with the demand of workload needed and withstand difficult conditions while at the same time be energy efficient [14]. And compatible with several devices so that all responders are able to communicate together during rescue operations, coordinate, and provide basic needs to affected populations efficiently and appropriately as well [14].

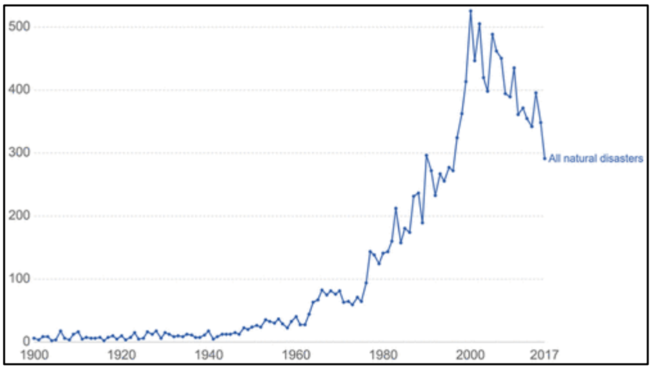


Figure A-2. Global total number of people affected by ND. This is defined as the sum of the people who were injured, affected, and left homeless after a disaster. [[14]

"Over the last decade, 3852 ND (Natural Disasters) have killed 780,000, affected 2000 million people, and cost at least US$960,000 million" [15]. Whether natural or man-made, global disasters have been happening more frequently and caused tens of millions of deaths. Figure 3 shows the number of people affected globally, it includes people injured and left homeless after a disaster. As seen in Fig. 4, some disasters include "those from drought, floods, biological epidemics, extreme weather, extreme temperature, landslides, dry mass movements, wildfires, volcanic activity, and earthquakes" [16]. In 2010 alone, the earthquake in Haiti claimed 230,000 lives.

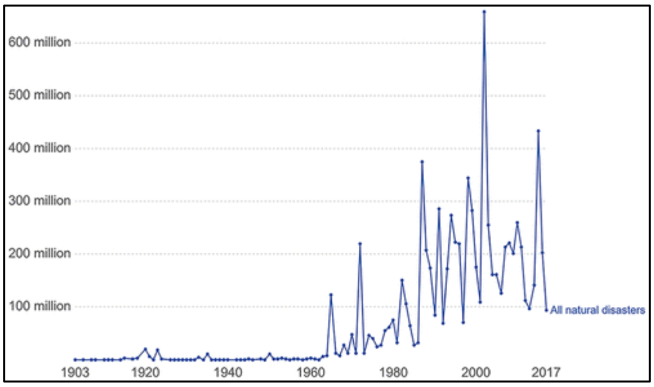


Figure A-3. The number of global reported ND events. This includes those from drought, floods, biological epidemics, extreme weather, extreme temperature, landslides, dry mass movements, wildfires, volcanic activity, and earthquakes. [[14]

In 2010 alone, the earthquake in Haiti claimed 230,000 lives. There are many findings that reveal major causes of communication failure [17], [18]. The main two are infrastructure damage and traffic network congestion. Events such as hurricanes, floods, earthquakes, and even man-made disasters can destroy physical components in a communication system, particularly cell towers and cables. Furthermore, disruptive events have also caused hundreds of billions of dollars in economic losses (Fig A-4).

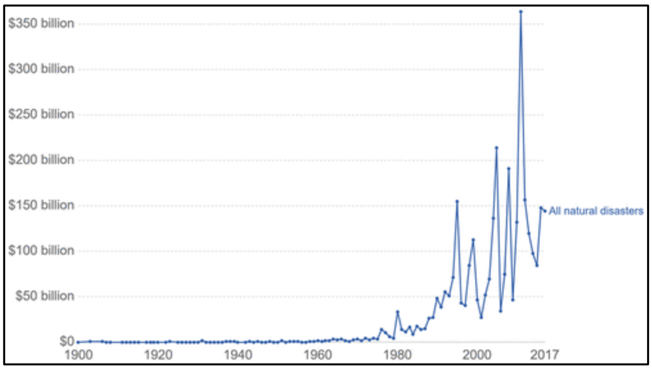


Figure A-4. Total economic cost of damages as a result of global ND in any given year, measured in current US$, includes those from drought, floods, biological epidemics, extreme weather, extreme temperature, landslides, dry mass movements, extraterrestrial impact. [[14]

Physical damages leave vulnerable communication networks that take time and money to restore. For example, in 2001 during the New York attacks on 9-11, major routing centers were destroyed, leaving many parts of Manhattan without telecommunication. Nevertheless, thanks to the internet and packet switched digital technology, they were able to reroute communication avoiding broken areas using old telephone and cable networks. However, this method is not ideal and still susceptible to physical damage since the medium of transmission is copper wiring buried underground.

Underground connections are more difficult to repair as it takes lots of time to pinpoint the fault's location and are expensive as well. Even if infrastructure systems can withstand harsh conditions, communication systems can still be interrupted by congestion which also take time to restore due to communication overloading. According to the technical report on telecommunications and disaster mitigation, "Mobile phone networks recorded a 92% blocking rate, with call volumes increasing 10-fold," during the 9-11 attacks [17]. Both fixed and mobile communications overloaded after many people tried to communicate at the same time verifying the safety of others. This event was a major disaster that took the life of hundreds of firefighters. After official authorities realized that the towers were about to collapse, they warned police officers and they were able to escape from danger. Unfortunately, that was not the case for the firefighters. Due to communication restrictions between technologies and little communication between the two agencies, they did not get the warning.

D. *Internet and Bandwidth Comprised*

Consumer demand for broadband communication services has continued to increase over time. However, during the COVID-19 pandemic, this demand has increased.

So much so, that providers in the Organization for Economic Cooperation and Development (OECD) countries have noticed a "60% increase in Internet Traffic since the beginning of the pandemic" [19]. This increase was caused by approximately "1.3 billion OECD citizens" working from home or studying from home in the middle of this crisis [19]. Fig.6 below demonstrates the median growth of Internet Traffic in some of the OECD countries from months September 2019-March 2020. This data was accumulated by Packet Clearing House and documented by [34].

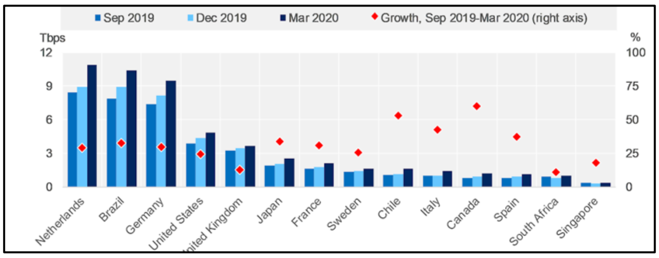


Figure A-5. Internet bandwidth at Internet exchange points, by country.

In relation to the high demands, OECD policy makers began to seek out solutions to keep the internet demand under control by suggesting operators to interconnect Internet Exchange Points (IXP) and upgrade IXP ports to prevent congestion and maintain infrastructure. While this could solve the problem for meeting consumer demand, several private operators may fail to comply with said policies due to competition in the business markets. Furthermore, such upgrades are possible in "metropolitan areas" because of the infrastructure and technology laid out in city areas. The same does not apply to rural or low-income areas where Internet Service Points are at a far distance and hard to access [19]. Also, low-income households may not be able to afford expensive broadband subscriptions [19].

Overall, as the pandemic progresses, the consumer demand for such services continues to grow. To keep up with consumer demands, operators in OECD countries face many challenges. If they do suffice with the high demand, many rural and low-income areas cannot access the same upgrades that metropolitan areas can. At last, such upgrades increases the suppliers cost which low-income households cannot afford.

Design Idea Abstract **— *When choosing our design idea, we asked ourselves three major questions: is it ambitious? will we learn something we can take forward into the industry? and will the technology still be relevant in the future? We decided to look at an Alphabet company called X for inspiration. X is currently researching and developing a project called Taara which is an initiative that is attempting to use FSOC systems to provide fast, inexpensive internet to underserved locations around the world. Our project was heavily inspired by this initiative. It answered all the questions we asked ourselves as well as provides a potential solution to our societal problem.***

III. Design Idea

This section of the report will describe the list of features our project will aim to accomplish. We'll also be discussing our design's source schematic. Doing so will give us better intuition on how the system will behave.

A. Features

The main feature of the device is to establish a free-space optical communication (FSOC) channel. By showcasing how a communication channel can be established using light instead of cables, we can potentially begin a public discussion on how to use this technology to address our digital divide.

The system should also be capable of fast deployment. This is because the fast deployment of the device can help with the recovery of areas from a national disaster. At least as a temporary measure until a more permanent solution is implemented.

An established connection would have access to an online database. The database will help us detect any errors in our system because it will record the messages sent/received in the local network. Along with collecting information such as time the data is sent/received. The data collected can help us see low transferring rate because an object is interfering with the connection in our device.

B. Hardware

This section will cover hardware technologies currently available that can aid in addressing our digital divide. But we'll delve more deeply into FSOC and review the design from our source. We will divide the circuit into different sections and explain the function of each component.

C. Sofware

Similar to the Hardware Design section, we'll summarize the different software methods that could be used to implement our desired feature set.

D. Safety

This section will cover the necessary precautions that we will follow during our experiments and testing. We must follow OSHA rigidly with no exceptions. As with many electrical engineering projects there can be serious, if not deadly, consequences if safety is not taken seriously. Project managers or project leaders can be held responsible for the safety of their co-workers which, aside from the moral detriment that can come with an accident, there can be serious career ramifications. Hence, as aspiring leaders, we must always be vigilant for the safety of everyone involved in a project.

Features

Below is a table where we have chosen our measurable metrics. A measurable metric is a physical capability of our device. It is a metric in which we can do physical measurements to determine whether the device succeeded in achieving our desired goals.

Table 4.
Team 3 Punch List

Features	Measurable Metrics
We will establish a free-space optical communication channel	Establish the channel within a 2-meter distance.
Show how deployment can aid in emergency scenarios.	Portable.
Cost Effective	Cheap parts to repair.
Online web database.	A database which can store logs; such as data transfer rates.

A. Optical Communication

The primary objective of our design idea is to establish a free-space optical communication channel. This is because we want to showcase the free-space optical communication technology how f

B. Deployment

Having non-invasive installation is a major advantage of FSOC. Areas where trenching can disturb, or even cause unwanted damage, are places where our project could really shine. The transceiver/receiver could be place on a pole, drone, or even a blimp. Not unlike Google's Loon project.

C. Cost Effectiveness

We go over the economics in length in the Funding and Marketability sections of this report. For that reason, what we'll say about economics here is this: it's the necessary component of making an FSOC system a formidable tool against the digital divide. By reducing overall costs of traditional broadband infrastructure, particularly in remote regions of the world, more people would be able to go online. Thereby progressing closer to bridging the digital divide.

D. Database

Physical damage leaves vulnerable communication networks that take time and money to restore. For example, in 2001 during the New York attacks on 9-11, major routing centers were destroyed, leaving many parts of Manhattan without telecommunication. Nevertheless, thanks to the internet and packet switched digital technology, they were able to reroute communication avoiding broken areas using old telephone and cable networks. However, this method is not ideal and still susceptible to physical damage since the medium of transmission is copper wiring buried underground. Underground connections are more difficult to repair as it takes lots of time to pinpoint the fault's location and are expensive as well. Even if infrastructure systems can withstand harsh conditions, communication systems can still be interrupted by congestion which also take time to restore due to communication overloading. According to the

International Telecommunication Union, "Mobile phone networks recorded a 92% blocking rate, with call volumes increasing 10-fold," during the 9-11 attacks [17]. Both fixed and mobile communications overloaded after many people tried to communicate at the same time verifying the safety of others. This event was a major disaster that took the life of hundreds of firefighters. After official authorities realized that the towers were about to collapse, they warned police officers and they were able to escape from danger. Unfortunately, that was not the case for the firefighters. Due to communication restrictions between technologies and little communication between the two agencies, they did not get the warning.

After the attacks in New York, many people relied on wireless point-to-point links to reestablish connection. These links were installed within a couple of days and they have been accepted as permanent backup ever since [17]. Wireless and unlicensed technologies can facilitate "the supply of communications to critical relief operations without significant cable installations" and/or licensing, which is where our FSO device comes in place [14]. The New York attacks in 9-11 showed that even in a developed country with plenty of technology, there is a need for devices that can be used as alternative routes for communication. Our project can be used as a temporary alternative until repair and restoration of the original system is completed. Or it can be used in regular conditions since it can handle extreme conditions.

The Indian Ocean earthquake of 2004 was another catastrophic event that claimed the lives of almost 200,000 people across different countries and affected more than 1.7 million. One of the deadliest, most powerful, and most destructive in recorded history according to the US Geological Survey website. The earthquake created a tsunami that destroyed villages, roads, and a large portion of coastal infrastructure leaving many displaced and without food or water services [14]. This was one of the first events where global internet mediated technology provided a quick response to bring appropriate services. However, since communication systems were not working at full capacity, humanitarian help did not arrive on time. Many lives could have been saved, if lack of infrastructure and communication would not have been a problem. With a proper established communication system, early warning information would have arrived in a timely manner to communities at risk, however, this was not the case. There are many other disasters that show that inadequate communication systems can cause fatal consequences. Communication failure "is a common and larger problem affecting all underdeveloped countries in the world" [14]. Even when infrastructure damage is not the problem, congestion of communication can affect efficiency response and increase human and economic losses. The magnitude of the impact is determined by the country's ability to mitigate the situation. According to the case studies of communications systems article, developed countries that have a better infrastructure are able to reduce deaths and promote life-saving actions [14]. On the contrary, undeveloped communities suffer from lack of effective resource mobilization.

As mentioned before, communication provides a way for people to know whether their loved ones are safe during a global disaster and helps bring essential care to communities affected. Thus, it is necessary for countries to have alternative ways of communication in case traditional means are disrupted. It is also important to act efficiently during the 72 golden hours following a disaster, so that first responders succeed in all aspects of disaster management [14].

Hardware

The hardware idea section will focus on the macro-view design choices of the transmitter/receiver of system. We'll talk about why we chose an FSOC system over a system like a constellation of satellites or an optical fiber network.

It will pertain to the analysis, costs, digital simulations, and physical construction. For example, we'll be using and documenting results from electrical engineering software simulation tools (e.g. LTSPICE, MultiSim) as well as using electrical engineering hardware tools like the Analog Discovery 2 (AD2). The AD2 is almost like an electrical engineers swiss army knife.

But before that, we'll look at different technologies that could be theoretical solutions to our digital divide. We'll elaborate on which we chose the design that we did. We'll also delve into what things worked and the things didn't work with that design.

So, in short, the hardware section will include how we arrived at both the limitations and the successes of our chosen design. It will include what we did when we encountered problems and how we attempted to solve them. Ultimately, we'll answer the question: was the design able to fulfill our feature set and measurable metrics?

Hardware Alternatives

A. Satellites

Another wireless solution to the Digital Divide issue that's been successfully implemented are satellites. Satellites have many advantages but become impractical at localized ranges. Also, launching a satellite comes with a slew of international and national regulations which need to be adhered to rigidly.

Many, if not most, broadband networks today use satellites. Billion-dollar ISP companies invest heavily on them because of their capabilities in being able to transmit secure channels. They are incredibly well suited for connecting channels at very large distances. Particularly, when it comes to distances like crossing the Pacific and Indian Oceans.

However, launching a satellite to connect a population the size of a rural city or metropolitan area is just not practical. Satellites can cost anywhere between 50 million to 400 million dollars [20]. So, launching a satellite for every city or small region just doesn't make financial sense. It would be simpler to have a cabled network. In fact, the best solution would be to have a combination of satellites and cabled networks. And indeed, that is what is done today.

There are also international and national space laws that need to be followed if one is to launch a satellite. Adhering to these regulations can be just as costly.

Despite satellites having such a niche market, they still have a significantly prominent role in communications engineering. In the long run though, the best solution may end up being satellites in conjunction with FSOC technologies. It's easy to imagine having a satellite establish long range broadband connection to a localized network and then those localized network use FSOC technologies.

B. *Fiber Optics*

Another feasible solution would be to stick with fiber optics which is one of the cornerstones in communication networks. This technology is capable of meeting high-speed data requirements and creating reliable communication infrastructures. However, one of the main reasons preventing fiber optics from fulfilling the last mile is that it cannot reach all the parts of the world. The last mile refers to "the last physical segment of the connection between the network and the end-user" [22]. Especially in high density populated areas where fiber optic cabling is not easily deployable.

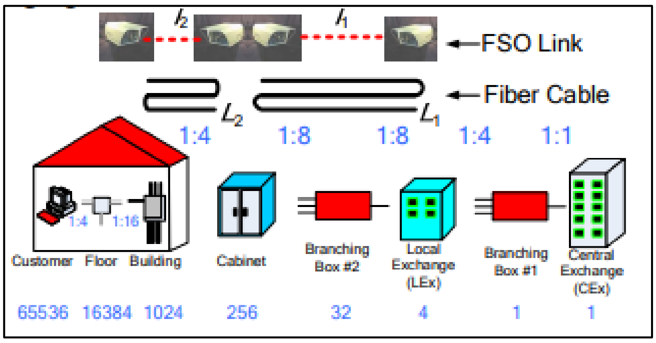


Figure A-6. A dense urban area geometric model. [[35]

Also, if an area that needs connectivity has no cabling already routed, the installation costs will be expensive because it will require manpower to dig the trenches where the fiber ducts go. The figure above shows a comparison of both wired and wireless situations, this is a representation of the geometric model used in to calculate the number of network elements required per urban area while doing cost analysis [35]. And even if the cabling was installed and there was no installation cost involved, as mentioned before, underground connections are more difficult to repair as it takes lots of time to pinpoint the fault's location, which can still bring up the cost.

Moreover, having to deal with civil work, digging the trenches could be intrusive depending on the area as well. For example, if it is close to private premises the owner might not be in favor. "An additional benefit the FSO system involves is the short setup time compared to optical fiber. This enables earlier earnings, and the payback period becomes shorter" [22]. That is one of the reasons that FSOC was chosen for this project because it is small in size, requires no cabling for installation, and thus, cost effective.

Hardware Idea

In our view, free-space optical communications (FSOC) will become the telecommunications industries golden standard. We believe that they're particularly well suited for deploying local broadband networks, cheaply and quickly, to underserved communities throughout the globe. They're also well suited for deploying after, or during, a catastrophic event. One that could damage currently placed broadband infrastructure.

Additionally, FSOC systems don't need to compete with the other alternative solutions. For example, one could easily imagine a system of satellites working in conjunction with FSOC systems. Such a system could theoretically provide fast, affordable internet anywhere in the world.

A. *Our Source*

The digital construction of the design will be the first stage; this is the most important step because this is where you can make lots of simulation errors without compromising the actual circuit. With software such as PSPICE and Multisim the input/output signal behavior can be analyzed and measured to compare with actual results. On the physical construction side, tooling such as an oscilloscope, DMM, and function generator will help obtain actual measurements and test for expected results. Another important tool is the spectrometer, it is used to measure laser levels which will assure the laser is working within the safety guidelines and regulations of safety (see section IV).

B. *Hardware Analysis*

Due to demand in fiber optic communication systems, maintenance and installation costs can be quite costly. Hence, the need to focus in a more attainable free-space optical wireless technology is a must. Not only is FSO capable of reaching high bandwidth networking speeds, but it also uses bandwidths that are outside limitations and require no licensing. Although this project can reach such parameters, we decided to reduce the scope of the project to something more realistic, limiting the rate speed to 10Mbps. One of the circuits chosen was the Sven Brauch's design (see figure below).

C. *Simulations*

The simulations section we will showcase and discuss our simulated results and collected data. Simulating is an important part of any engineering project because having an accurate prediction of how a circuit should behave makes troubleshooting that circuit much simpler. Simulations can also prevent unnecessary costs on wasted parts. This becomes increasingly more important in the industry because simulating can save a company millions of dollars.

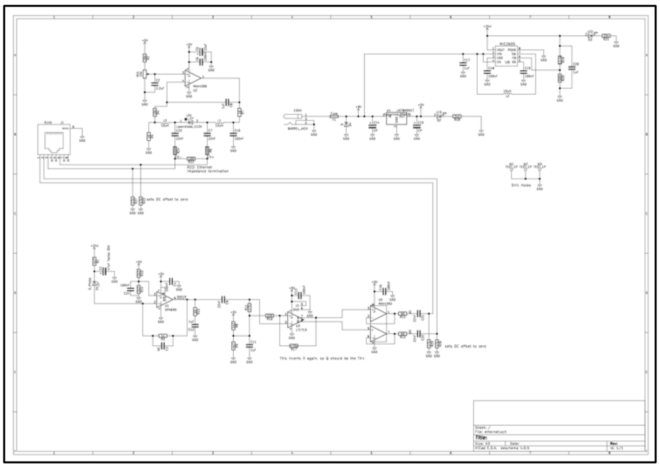


Figure A-7. Design chosen for the project. *[[6]* [6]

There are three main components in FSO systems, the transmitter, receiver, and the line of sight (LOS) transmission channel. A transceiver is composed of a combination of both transmitter and receiver. The design of choice will consist of two transceivers, with identical circuitry that will allow for full duplex optical communication. The advantage of full duplex is the ability to send and receive data at any time compared to half duplex or single communication systems.

The Operational Amplifiers

In this section, we'll breakdown the design idea into blocks. Each block will represent a different operational amplifier from the source schematic [[6]. By analyzing the design in this way, we believe, ultimately, that we'll obtain a better understanding of the system as a whole.

Also, since there are many components to this circuit, understanding each their function will give us a better intuition on where to start looking if we ever intend to make any modifications, enhancements, or even troubleshooting.

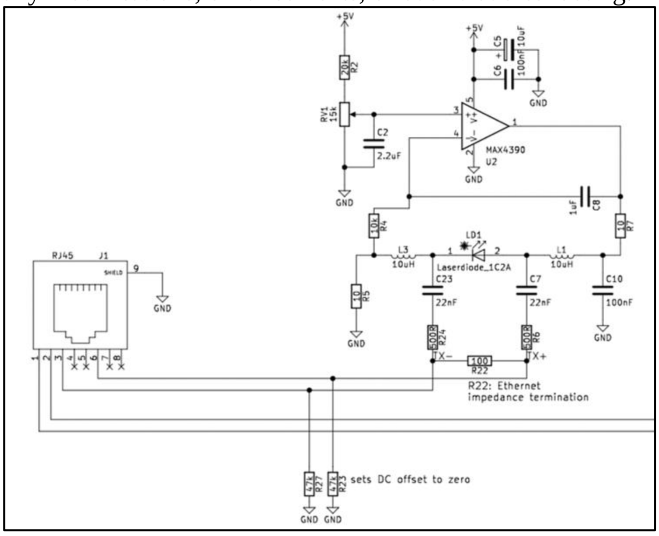


Figure A-7. Design chosen for the project. [[6][[6]

We can start with the transmitter. It's shown in the figure above. The input is shown as an ethernet port (RJ45). Note how the leads are connected to each end of the component Laserdiode_1C2A.

The analog signal from the transmitter is captured by the photosensitive diode. Which is immediately fed into the OPA695 which is a current feedback amplifier. This is done so we could amplify the weak signal (the change in current) being captured by the photodiode.

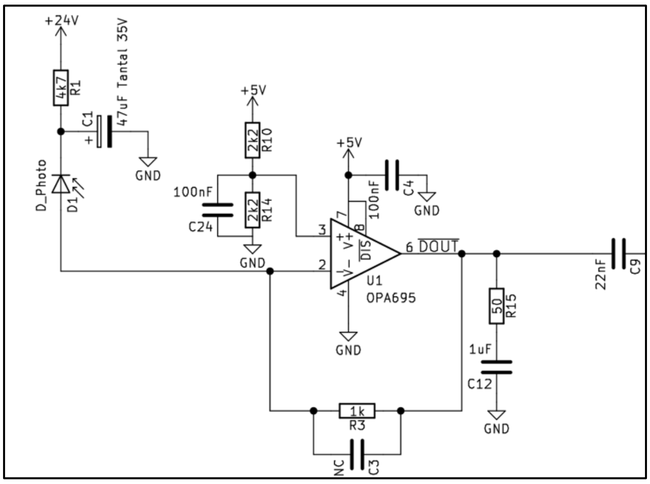


Figure A-7. Design chosen for the project. [[6]

The LT1713 is our comparator. Essentially, it's used for the logic necessary in our design in order to convert our analog signal to a digital one.

The signals are then fed into the MAX4392 as shown below. These are used as the buffers to "clean the signals".

Recall that in physics a voltage is defined as a potential difference. This means we need two reference voltages as our output. And as we should expect, this is reflected in the original schematic below.

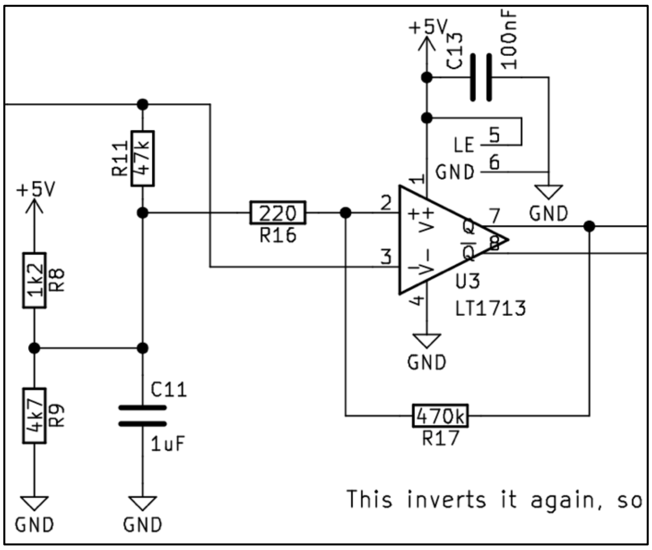


Figure A-7. Design chosen for the project. [[6]

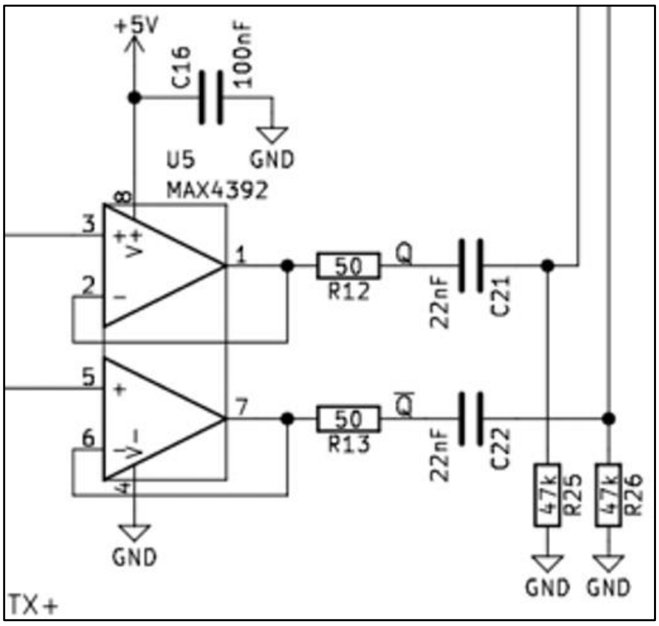


Figure A-7. Design chosen for the project. [[6]

The remaining two components of the schematic are the LM78M05CT and the MIC2605. Since our project is focused primarily on the communication aspect of the device, and not the power, we won't be really discussing these components.

What we will say, however, is that both of these components are different types of power regulators for the system.

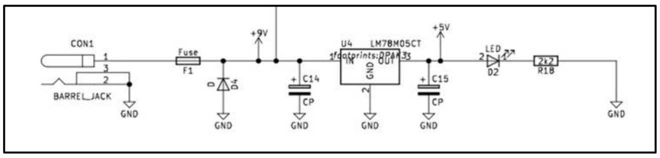


Figure A-7. Design chosen for the project. [[6] [[6]

Specifically, the LM78M05CT, shown above, is being used to regulate the main voltage source. Which is coming through from the barrel jack as shown below. While the MIC2605, shown below, is a pulse-width modulation (PWM) regulator. The MIC2605 is being used to boost the voltage.

The regulators are needed, not only to protect the device, but because of the bias voltage needed for the photosensitive diode. According to our source [[*6*], the bias voltage needed is approximately 35V. The schematic does a good job of illustrating this to us as well.

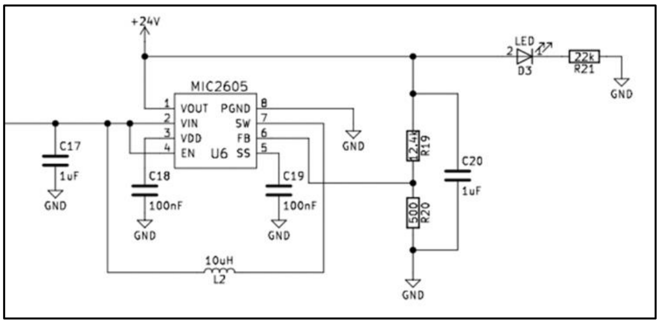


Figure A-7. Design chosen for the project. [[6][[6]

Software

The software design section will primarily focus on creating the internet protocols (TCP/IP) needed to bridge the ethernet links of the transmitter/receiver devices. Like in the hardware section, we'll delve deeply into what internet protocols are and why we need to use them. The section will include what options were available to us and elaborate why we chose the protocol we did. It'll explain the concepts of layers, packets, host transmissions, etc. This may involve researching the request for comments (RFC) of the TCP/IP we choose to use. We'll explain what RFC is, why we may even need to refer to it, and if we do refer to it, explain that as well. Once we establish a connection and transmit data the next step is to make an online database to store data. The data stored will be the time we receive messages sent and received from one end to the other.

Software Allternatives

A. IPv6 vs IPv4

There are currently two different standards for IP, Internet Protocols. IPv4 is the current standard used globally for all communication systems, mainly Fiber Optics. The new implementation of IPv6 is still underway as it consists of many bugs when establishing a reliable communication over low-powered devices. As stated in *Design Considerations for Low Power Internet Protocols* "code space is tight on many systems" [[*24*]. As a result, when an application does not fit, developers cut out portions of the networking stack and stop working with other devices". In other words, low powered devices are not compatible enough to compensate space for an IPv6 header as they follow IPv4 protocol. This results in developers leaving out older information to allow newer information to be allocated. Hence, for this design we will be working with IPv4 protocol as it is the current protocol being used with little to no bugs.

B. UDP vs. TCP

UDP, User Datagram Protocol is a layer that comes before the Internet Protocol layer. It is an unreliable and connectionless protocol because the client sends a packet without establishing a connection with the server. UDP header does not include an IP-address, it simply attaches a pseudo-IP address by adding a checksum in its header. This checksum is then extracted and added to a new pseudo-IP header on the receiving end and calculated to determine if the packet has reached its destination. In contrast, the TCP (Transmission Control Protocol) is a full-duplex reliable protocol since it establishes a 3-way-handshake connection from one host to another host [25]. A 3-way-handshake connection provides a secure and reliable packet transfer between any end-to-end communicating devices. Furthermore, for our proposed design, TCP is more suitable as we want to establish a fast and reliable communication system between any two end-to-end devices and quickly determine if data is received from one host to another.

Software Idea

To begin the implementation of our Software design for the Free Space Optical Transceiver (FSO). We will be using an end-to-end communication program to test data transfer from the transmitter to the receiver over a precise bandwidth of 10Mbps. This will require our design to follow strict protocols from the list of the publication Request for Comments (RFC), TCP/IP. Transport Control Protocol (TCP) and IPv4 (Internet Protocol version 4) will be used to establish reliable connections leaving little room for error.

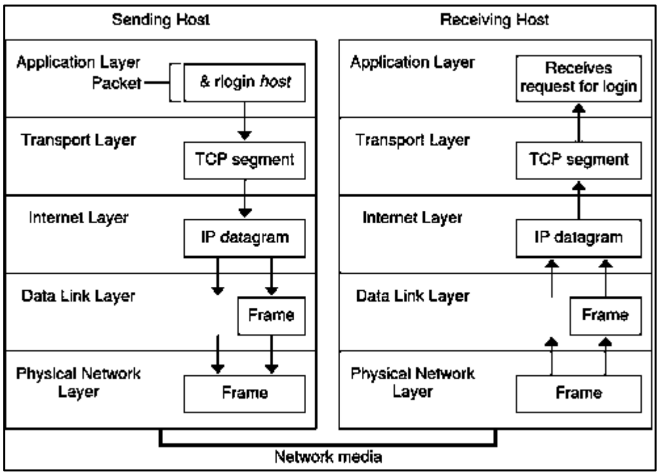


Figure A-8. Internet Protocol Layers []. [[38]

As shown in Figure A-8, both hosts (end-to-end communication devices) will step through each layer of the TCP/IP Protocol to transfer data in forms of a packet. However, we will specifically focus on the Internet Layer, Transport Layer, and the Application Layer. In the Application Layer, a user will send a message or a command from a device which is formatted into a TCP packet. In the TCP Protocol Layer, TCP segment divides up streams of data received from the Application layer into segments and attaches a header to each segment. The header includes source/destination ports, segment ordering information like sequence number and acknowledgement number (ACK), and checksum, a way to determine that data transfers without any error.

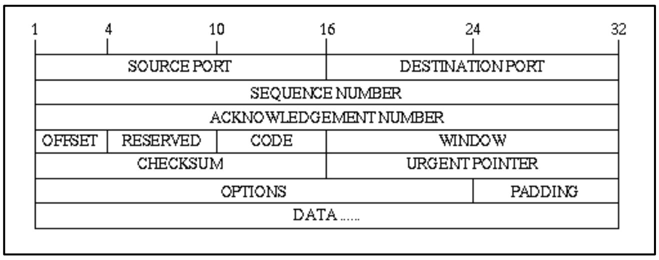


Figure A-9. TCP Segment Header Format. [[25]

The TCP segment header is as shown in Figure A-9. In the Internet Protocol Layer, the transport layer protocol (TCP) passes its segments and packets down to the Internet Layer where the IP Protocol handles the packets and assigns the datagrams with IP addresses. This allows us to track if the sent packet is in fact delivered on the receiving host end.

A. *Packet Loss and How to Recover*

Although TCP/IP protocols ensure reliable data transmission, at the IP layer, packets can be lost due to network congestion or noise gateway failure. To recover lost packets for retransmission, a sequence number is assigned to each packet transmitted. This requires for the receiving host to send back a response by acknowledging the packet (ACK). During the transmission of a packet, a time-out interval is active, in which ACK must be received or a packet will be retransmitted. The checksum field in Figure A-10 is added as a form of security to avoid corrupt data on the receiver end. The receiver checks this field to determine if the packet received is damaged or not.

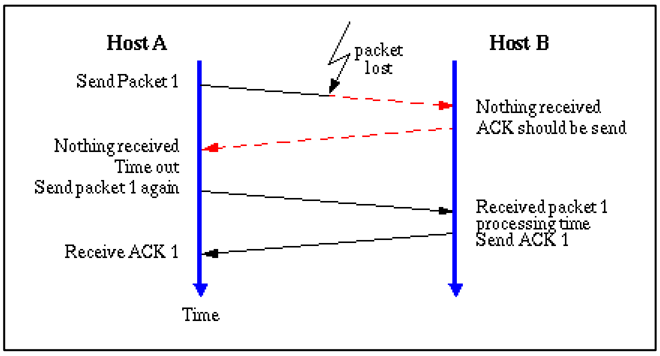


Figure A-10. Data transmission between two devices. [[25]

When testing the rate at which data is being transferred for our Transceiver, we can calculate Round Trip Time (RTT), the time it takes for a segment from a stream of data to transmit at a specific speed of internet and receive an ACK. However, this only resolves the problem with corrupt data and can cause delay in sending other segments of data as the sending host must wait for an ACK. As a solution to network congestion, we can use the window method as shown in Figure A-11 below [[25]. This method allows the transmitting host to send as many bytes of data as can be allocated on the receiving hosts' end. Also, the ACK sent back to the transmitting host will be cumulative meaning that the ACK will send the sequence number of the packets last received from the stream of data.

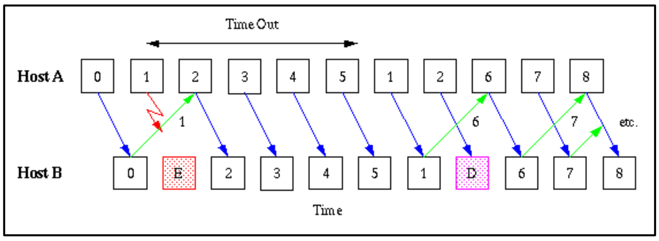


Figure A-11. Data transmission between two hosts. [[25]

To summarize, our transceiver will be using TCP/IP protocols from the list of RFCs, to test and establish a reliable data transfer connection between two devices where one will transmit data (Raspberry Pi 3) and the other will receive it (any other device or computer). The two end-to-end devices will be connected to the transceiver using the ethernet ports for data transmission. We will use a time-out cycle to calculate the RTT which will determine at what rate the data is transmitting and being received. We will be using a window size to allocate space on the receiving host end to avoid corrupt data and congestion control.

B. Web Database

An online data base will help people see relevant information to everyone on the local server. The web database will only be accessible to people on the local network. The Raspberry Pi has a library called Apache. The primary coding languages will be Python version 3.0 and HTML 5. Other web development tools such as Apache, Flask, and CSS will be used. The data in the database will be stored on a CSV file and uploaded onto the web page.

C. Weather Alert System

Considering our modem of transmission is a class IIIa laser, our device will have limitations when weather is a factor. Certain weather conditions containing "average relative humidity of 67.5% or higher" like haze, fog, and rain will delay the transmitting signal [33]. Since we cannot control the weather, we decided on building an alert system to inform the user when they can expect a delayed signal due to harsh weather conditions. Using a DHT11 temperature/humidity sensor we will measure the humidity percentage whenever a client is requesting to make a connection to our server. If the relative humidity is 65% or higher, a disclaimer or an alert will be sent to the client/user.

Safety

As with any engineering project, or experiment, safety will always be a prioritization. Our project may pose some safety hazards and so we must take the appropriate precautions. We will go over safety protocols - making sure that our system meets school and/or governmental regulations. We'll follow the State of California Department of Industrial Relations Division of Occupational Safety and Health (Cal/OSHA) standards [[27]. Their website is https://www.dir.ca.gov/dosh/ and it provides the information we would need in order to ensure the safety for ourselves and others.

A. Laser Safety

We will follow the safety standards of the State of California Department of Industrial Relations Division of Occupational Safety and Health (Cal/OSHA). Their website (https://www.dir.ca.gov/dosh/) provides all the information we would need in order to ensure the safety for ourselves and others. Now looking at the safety standards for laser. Lasers are classified into five different categories with some classes having subcategories.

The laser we plan to use is classified as a class III laser with a subcategory of IIIa. Cal/OSHA states that any laser in a class higher than I requires personal protection equipment (PPE) to be available. The necessary PPE while working on the project would be some eye and face protection equipment which can handle radiation energy. Then the class IIIa lasers needs some special sensors to either play a noise or show a visual display to indicate an excess emission of radiation that surpasses the maximum amount allowed for class I lasers. Along with the PPE, signs need to be posted at the entrance and inside of our working area to warn others of our laser. Since the laser we will be working on is IIIa laser the signs posted need to have a specific format stated by OSHA.

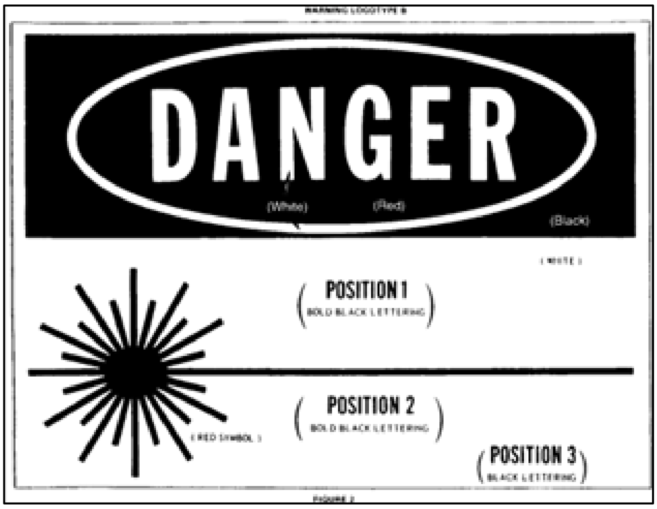


Figure A-12. Danger Label

Figure A-12 shows the specific format of the warning signs. The position 1 needs to be changed to say, "LASER RADIATION—DO NOT STARE INTO BEAM OR VIEW DIRECTLY WITH OPTICAL INSTRUMENTS". Position 2 is special label which will vary depending on the type of class IIIa laser we acquire. The information in position 2 should be the laser's maximum output radiation. Along with radiation output the medium or emitted waveform length should be added. Now adding the pulse duration is not always required and should be used when appropriate. The project will have two lasers pointing at each other, so it would be good to include the pulse duration of our laser just in case someone accidently crosses the laser. Position 3 is also replaced with the wording "CLASS IIIa LASER PRODUCT".

Next, we would just have to follow some general rules set up to protect us from the laser. When working with the laser try to avoid physical contact with the laser to prevent excess exposure to radiation, so we should include some viewpoints. The viewpoints allow a person to observe the laser without having to experience the laser radiation and if the viewpoint is compromised it will at least reduce or stops the exposure to radiation emissions from the laser. Another general rule is to include safeguards to our project, so the project does not become more harmful to others. The safeguard mechanics should disable the laser or reduce the laser's radiation emission rates to a class I laser. More specific rules can be found on the CAL/OSHA website.

IV. Funding

We had no outside funding provided to us by any person or organization. Each member agreed to split the costs out of pocket. Prior to designating the distribution of funding, we needed to establish the maximum limit amount not to exceed. On one hand to account for one of the features sets and provide a cost-effective device. On the other, so that the team would not experience unexpected additional charges as no outside funding was provided. The team decided not to exceed the amount of $600 USD as we had already done some research on the components needed for the design at the beginning of fall semester. We estimated about $100 USD just in parts per board and we wanted to build three boards, with one being a backup. In total we approximated $300 USD in components since we wanted to account for future modifications or additional integrations. We doubled the amount to account for those and that is how we resulted with the limit amount.

This was also before we got advice from different professors, which all of them recommended to build the device on a PCB board rather than a breadboard because of electromagnetic interference from capacitors and inductors. As mentioned before, Professor Moyer recommended a PCB manufacturing company where we were able to get a better deal. Not only were the boards manufactured at a cheaper price but also assembled. This was an added cost of ~ $65 USD for a complete board compared to the price mentioned before just on components. Also, this was the first time the team was introduced to PCB manufacturing process; this was a lengthy process because the team was not familiar with the components the PCB needed. Therefore, it was decided to order extra boards as part of the risk analysis.

Was the budget allocation appropriate? Yes, the allocation budget was appropriate. The amount of funding designated was mostly spent on manufacturing the boards. We still had room left to integrate an alert system which required additional humidity sensors. In the end the total cost for a complete FSOC transceiver was around $93.22 USD. This includes mounting hardware and extra expenses we had to account for. This we had estimated at $120 USD. Of course, this was not a win-win situation, the team lost money buying some laser mounts, and ordering the extra unassembled boards. But as mentioned before, ordering PCB boards was something new to the team. Nonetheless, the team was able to successfully stay within budget (see Table 5).

A. *Software Budget*

The estimated cost of the components for the transceivers is around 270 dollars. This price excludes PCB manufacturing and shipping costs. It also takes into consideration spare parts in case of defective status, short circuit or malfunction during installation and/or processing (see the appendix for the estimation list). Depending on the order quantity and requested return time frame, PCB manufacturing costs can easily reach more than 1000 dollars according to multiple sources. However, the use of PCB board vs breadboard is still in mind to consider due to performance and reliability. One of the problems with a design in a breadboard is that unwanted capacitance can be created between baseboard grids interfering with the gain and bandwidth of the amplifiers. Capacitors and inductors installed together can also influence the frequency signals and cause noise.

B. *Software Budget*

For the software front of the project, a few components were contributed from the team members. These components include of Raspberry Pi Model 3B+ with a formatted SD card and Ethernet cables to establish connection to our FSOC device. The cost of a Raspberry Pi Model 3B+ is roughly $30-40 depending on additional attachments, i.e., a case. The ethernet cable varies depending on the length of and vendors. However, the ones being used are approximately $5 with a length of 6ft and some are contributed with no additional cost. All the tools used for programming were open sources, free to install without any subscription needed. These tools include of Python v. 3.9 (Linux environment was used for python coding), Raspbian has an in-built Python IDE and Flask, a free python web development tool. Apache web frame work is also a free tool which can be used as a substitute for Flask in case of PHP implementation. In addition, PHP is also an open-source language, free to install.

C. *Cost of Maintenance*

When considering our device, we need to take preventive measures and reactive measures to maintain our device. First, preventive maintenance can be effective when weather conditions affect our signal by interfering with the line of sight.

TABLE 5.
COST ANALYSIS BREAKDOWN

Description	Number of Items	Cost	Total per Board	Loss
Assembled Boards	4	$257.16	$64.29	
Unassembled Boards	4	$157.16	Not used	$157.16
Laser mounts	2	$25.21	Not used	$25.21
Shipping Cost (Laser mounts)	N/A	$7.99	N/A	$7.99
Power supplies	2	$14.66	$7.33	
Laser Safety Glasses	1	$48.06	Testing purposes	
Triplett LAN Tester	1	$15.73	Testing purposes	
Crossover Ethernet Adapter	2	$8.99	Testing purposes	
3D printing filament	N/A	$10	$5	
Aligning screws	8	$3.20	$1.60	
Tripods	2	$20	$10	
Humidity sensors	4	$25	$5	
Total		$593.16	$93.22	$190.36

Project Timeline Abstract – Every Project has many milestones before it can be delivered. To ensure the delivery, we must break down the project into many tasks which consists of sub-tasks. Each task is given an allotted time frame for completion. Similarly, our team has a projected project timeline with many tasks and sub-tasks assigned to each team member. This will help keep us on track for the delivery of a working project at the end of our timeline.

V. Project Milestone

This section will illustrate our project milestone which will include tasks that will have a start and end date from August 2020 till April 2021. The tasks will be shown in snippets of a graphical representation to show a visual overview of the tasks. The full overview of the tasks start and end dates will be included on an excel sheet which can be accessed in the appendix.

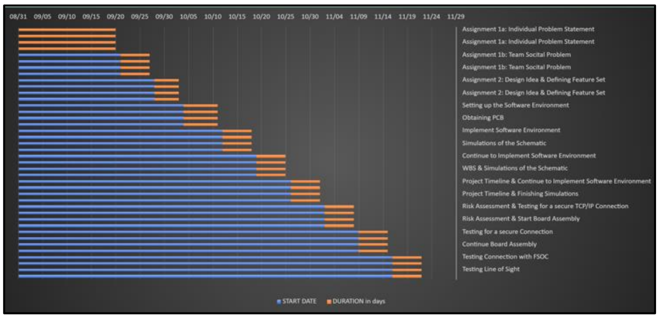


Figure A-13. Fall Term Project Timeline.

Figure A-13 is a graphical representation of the Fall 2020 – Project Timeline. There is a legend included for the Start date and the duration of the tasks. The blue bars indicate the start of the project timeline to the start of the current individual tasks. The orange bar indicates the number of days spent on the individual tasks. The Horizontal Axis labels the start of the Fall 2020 term until the end of Fall 2020 Term. The Vertical Axis lists the assignments/tasks that were worked on.

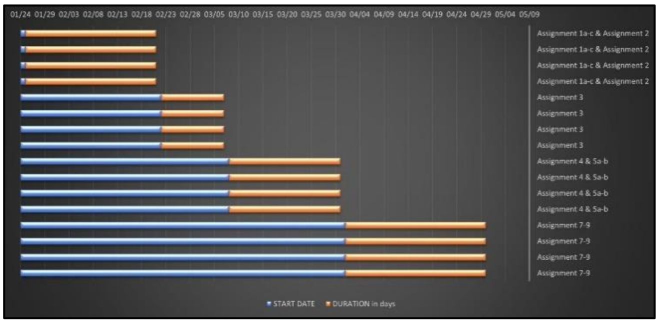


Figure A-14. Spring Term Project Timeline

Figure A-14 is a graphical representation of Team 3, FSOC Nation's, projected scope of Assignments for the Spring 2021 term, from January 2021 until April 2021. The legend again lists the start date and the duration of a tasks in days.

Work Breakdown Abstract — The success of any project can almost always be correlated with how well it was structured and adhered to. Which is why our project was structured as three major components: The Hardware Section, the Software Section, and the Combining Section. Within these sections are further subsections related to the main section. By having the projected structed in this way, we were able to easily identify what work was going to be divided between the four of us.

VI. WORK BREAKDOWN STRUCTURE

Now that there's been an introductory overview of the societal problem, how we plan to address it, and why our proposed solution is different from other wireless technologies, the rest of the report will focus heavily on the device itself. Specifically, how it will establish an ethernet connection. The project report will be subdivided into three major components: The Hardware Section, the Software Section, and the Combining Section.

By dividing the project in this way, we were able to easily identify what work each of us would be doing. Since two of us were electrical engineering students and two of us were computer engineering students, it just made sense that the electrical students handled the hardware while the computer students handled the software. The Combining Section is what it implies: the section which covers how the hardware was combined with the software.

Of course, within these major sections we have subsections. Those subsections can themselves have further subsections. And so, one can see, that although the top-down view of the structure is simple, it has quite a bit of depth. This tree-like-structure makes it very easy to divide work within the major sections as well as keep track of progress. A timetable was also made, Table 6., to further help with keeping track of our progress.

So, this means that each component is vital to the success of this project. By dividing it up in this way, the project becomes more manageable even though it still is a large undertaking. We will be able to monitor the health and status of the project and more quickly identify problematic areas more acutely. In the following subsections below, you will find a brief summary for each major section and a brief summary of their respective subsections.

A. Establishing A Wireless Ethernet Connection

The core of the project relies on establishing a wireless ethernet connection because all the other features depend on this feature to actually work properly. The way we will accomplish this is by splitting up this task into different sections to build the device. The different subsection tasks involve Simulations, Board Assembly, Testing I/O, Testing for a Secure Connection.

B. Simulations

The Simulations consist of variety of different components virtually simulated via LTSpice [*[39*] and/or similar simulation tools. These simulations will provide a deeper understanding on the signal's behavior of each individual stage and prevent from circuit failure as learned during previous labs. It is also where theoretical results are gathered to then be compared to actual experimental results. Part of simulations will require installation of manufacturer simulation models and modification of library designs when parts are not available in the program's libraries.

C. Board Assembly

Since most of the circuit components will be pre-assembled when ordering the PCB prototype, board assembly will consist of the addition any future components or upgrades done to the design. If any component results in failure, part of assembly will also consist of soldering and replacing of such components. Integrating a laser mount and a pole mount together so that the device can be mounted anywhere will be part of it as well so that the circuit board has a fixed place to stay in.

D. Testing I/O signals

The testing of input and output signals such as currents and voltages will be mostly based on the simulated results so that when testing for these signals, we have references to go by and analyze expected results. It will also be done by stages, and at the end, the input and output signals of the device as a whole will be tested. Testing will be done with measuring tools such as the analog discovery and a power supply. In order to test the input and output of the transceiver, the laser will be reflected to the photodiode, therefore, it is important to follow safety rules during testing so that we don't get exposed to the laser beam.

E. Testing for Secure Connection

Testing for a secure connection will be mostly done with computer software tools connecting a laptop with a cable to the ethernet port. However, we can also test for connection reliability when testing for input and output signals as explained in the previous step. Once a connection has been achieved, it will be transferred to the software side of the project.

F. Local Web Database

The local web data base will be recording data continually. The data collected will be the transmission time for a device to communicate to the other device. The data will be available to the people on the local network. The information on the table will be updated as soon as a button is pressed. To accomplish this local web database, we need to split this feature into different tasks. The tasks include setting up the software environment, setting up test on a raspberry pi or a laptop, test for a secure connection between the two devices, and test for a secure connection with FSOC.

G. Setting up Software Environment:

This task has Giovanne getting the raspberry pi ready with all the possible software needed for project on the pi. Ankita will be getting all the software needed for the project on a computer. The software needed will by python, html, php, and apache. Most of the software is coding languages except for apache. Apache is software which lets our device host a webpage.

H. Setting Up Tests on Raspberry Pi/Laptop

We will be setting up test code to create a CVS file and record some random data. While recording data, we will need to figure out the formatting for the data getting stored into the CVS file. Then we will open the CVS file to be displayed on this local webpage and the table will be updated with a button press. The updated table will append new data to the bottom of the table without getting rid of previous data.

I. Testing for a Secure Connection

Here we will be making a python program to communicate with another device with just an ethernet cable connecting them. The messages sent will be done by using TCP packets. Also, we will collect data here and make methods to check for an error.

J. Testing FSOC Connection

Finally, by this point our FSOC device will be ready for testing with everything included. The two devices will be able to communicate, and a web page will be available to look at information sent previously. We will run tests to observe that everything is working properly or make modifications if needed.

TABLE 6.
WORK BREAKDOWN STRUCTURE

Fall Semester				
Weeks	**Hardware**	**Software**	**Integration**	
	Establish A Wireless Ethernet Connection	**Local Web database**	**Fast Deployment**	**Assignments - Team**
7 - 15	Individual Tasks Assigned to Alex and Juan	Individual Tasks Assigned to Giovanne and Ankita	Virtual Collaborative Tasks	
7 - 8	Simulations: hardware components	Setting up software environment		Team Evaluation
9 - 10	Board Assembly	Test on Raspberry Pi and a PC		Work Break Down, The Safety Assessment Form, and Timeline
11- 12	Testing I/O	Test for a secure connection between two devices	Installation: Physical Placement of the FSOC	Risk Assessment
13 - 14	Testing for a Secure Connection	Test connection with the FSOC	Installation: test line of sight	
15				Prototype Presentation & Technical Review
Spring Semester				
Weeks	**Hardware**	**Software**	**Combining**	
1 - 15	Individual Tasks assigned to Alex and Juan	Individual Tasks assigned to Giovanne and Ankita	Virtual Collaborative Tasks	
1 - 2	FSOC Board Modifications	Check for a working web database and Work on Code to add an alert	Problem Statement, Design Idea, and Timeline Revisions	Device Test Plan
3- 4	FSOC Board Modifications	Integrate the Alert system with modified socket program	Progress Demonstration	
5- 6	Mounting a Humidity Sensor to work with FSOC	Integrating Alert to notify	Market Review Report and Presentation	
7- 8	Testing FSOC Device	Program an Alert to keep people safely away from FSOC	Individual Feature Report and Presentation	
9 - 10	Make Final mounting Gear for FSOC Device	Test the Alerts and Collecting Test Results for the Software	Progress Demonstration	
11 - 12		Modify Software to be more User Friendly	Testing Results Report	
13 - 14	Fix any errors Before Final Presentation	Final Checks to make sure the software has no issues	Prototype Demonstration	
15			Final Prototype Documentation	

VII. Risk Assesment

***Risk Assessment Abstract* — A piller in the foundation of any project are individuals capable of assesing, managing, and ultimately minimizing risk. A tool that assists us in acheving that risk management goal is called a Risk Matrix. Using this matrix we'll be able to more easily identify, and prepare for, phases in our project that have high probability of potentially negatively affecting our success.**

In this section, we will list out the risks involved with our project before deployment. We will discuss how we plan to mitigate those risks to meet the deployment time as well as rate their level of impact. After creating a Work Breakdown structure along with a project timeline, we distinguished three possible risks that could arise when testing our device. First, we can have a hardware related risk such as blowing out a fuse. Second, we can have a software related risk, meaning our webapp or TCP/IP program can crash. Third, there's a risk of our prototype's mount being displaced which can affect its line of sight. Each one of the sub-sections will define these risks and explain how we plan to mitigate them in accordance to meet the deployment time.

TABLE 7.
RISK MATRIX

Probability	5					
	4					
	3					*A*
	2					
	1			*C*		*B*
	0	1	2	3	4	5
	Impact					

A. Potential Hardware Risks

Since each member will be working on two different aspects of the project, the task has been divided between hardware and software sections in order to do a better assessment of the risks that could be presented when building an FSOC device. For the hardware portion, Alex and Juan have discussed various possibilities of hardware failure and assigned each situation accordingly as seen in Table 7. Going from left to right on the X-axis, the level of impact increases whereas the likelihood (probability) of happening increases from bottom to top on the Y-axis, with 1 being the lowest and safest route and 5 at risk of abandoning the project if both probability and impact are high. Also note that, there is no zero probability zero impact when it comes to building a project.

Our assessment priority was to begin with the risk factors that would prevent us from delivering the project. These are possible outcomes, that although might not have high chances of happening can still jeopardize the project. One of them is PCB accidental damage while testing, transporting, or during mounting installation to adjust the lasers. The device itself is a major component of the project, therefore, to mitigate the risk, additional boards were ordered to prevent any delay or extra costs on PCB manufacturing. Since accidental damage has a 50/50 chance of happening, and with a high impact if occurred, it was given a (5, 2) position. Furthermore, when testing the equipment, it is the hardware team's responsibility to meticulously avoid short circuiting from happening.

In general, as far as electric components, every component has equal probability of failure and can happened starting with being defective from manufacturing, all the way to having components either burn or blow up when troubleshooting or testing. This is a risk that could affect us in timing but can still be tolerated, rating it at (2, 2). Moreover, prior to ordering parts two or three different vendors were considered, checking for stock availability and shipping time to have a backup in case of out-of-stock status from one of the vendors. Also, because of the pandemic affecting shipping time, we ordered extra parts so that we do not have to deal with any delays.

Once we took an overview of the components in general, the ones with the highest probability of failure were discussed. The component more likely to go out first is the protective fuse shown in Figure A-7. This fuse is used as a protection from oversupplied voltage or current coming from the power supply. If there was ever a loose or wrong power supply connection, or failure, the fuse blows up to protect the circuit. And even though the fuse has higher probability to blow up, it is considered to have less impact on the project since its replacement requires of no soldering and can also be replaced in a timely manner, positioning the level of risk at (2, 4).

Additionally, since we are dealing with capacitors and inductors, if an op amp, resistor, or any other component draws more current than what can handle, it will overheat and burn. If this happens, the project can take a big hit since it will take time to assess whether one or multiple components were affected. This risk has a high impact but a fair likelihood of happening, therefore, it has been rated at (4, 3). And finally, as with any other electrical device, when it comes to lose or faulty connections, this can create an open circuit causing a short circuit on the PCB board and/or cause electric shock. Thus, it is important to check for lose connections, before turning on the device to work on it, to avoid such problems. Since this this risk causes both personal injury as well as circuit damage, it has been assigned a (5, 3) position because of the higher impact than the ones previously mentioned.

B. Potential Software Risks

The software tasks are divided in between Giovanne and Ankita, hence these two members oversee mitigating any risks involved with the software crashing. Looking at the risk assessment Table 6, we can rate this risk as a (5,2) as the probability of the software crashing are less likely as it will only crash if new changes are to be implemented or if wrong information is provided. Its level of impact is rated highly likely since we will be using the software program to test the functionality of our device and resolving software bugs will cost us time and push back the testing. However, when implementing the Webapp, two separate approaches were implemented in case of one approach failing. This provided a form of safety net and helped each member resolve any issues that arise during the implementation. After having a working version, we planned on merging the two approaches with our TCP/IP program into one and added debug statements to catch our errors of any future errors that may occur. Debugging is our way of mitigating around the software crashing. Instead of the program crashing, an error message will be displayed which will rely where the error has occurred and the cause of the error. This allows us to immediately debug the problem instead of seeking the cause of the software crashing. Therefore, it results in not only a solution to the problem, but minimizes the time needed to resolve the problem.

C. Personal Injury Risks

As with any electrical device, there are always risks that are outside of our control. Therefore, being aware of the unknown unknowns can allow us to mitigate the situation. For example, according to [[*28*], there are about 30,000 electrical shocks in the United States reported annually. With 5% of them resulting in burn unit admissions. One way to avoid that, is by using electrical protective equipment such as grounding or protective gloves. It is each member's responsibility to use safety precaution to mitigate the risk and avoid injury. As mentioned before, this is a potential risk with a high impact that needs to be avoid. The following risk, while working on the soldering of components are physical burns from soldering equipment. This is a hazard that can easily happen if the working area has a lot of wired connections and is not organized. Therefore, to avoid getting burned a clean space with a bench has been assigned, free of tangled wires and on a ventilated space so that the next associated danger of fume inhalation can be prevented as well. Again, prevention is important to avoid personal injury. Moreover, since we are working with a laser, one of the main risks is eye exposure to the laser beam which can cause blindness. This is something that although has a low probability of happening, it can cause major permanent damage when not handled properly. To avoid laser exposure, we are using laser protective goggles, proper attire, and if the laser beam is exposed for a while, the beam will be shielded to avoid exposure. All personal injuries have been rated with a high impact and median percent change (5, 3).

VIII. Design Philosophy

When we set out to decide on a societal problem, and how to address it, we were looking for three things:

- First, we wanted it to be ambitious by positively affecting as many people as possible. Lofty goals and complex problems are what we, as engineers, are expected to overcome. So, we wanted to do that here.
- Second, we wanted experience. The kind that can impress recruiters from current or future technology companies.
- Which takes us to the third point. The technology needs to be modern and likely in high demand in the near-term future.

Taara is an X initiative. X is a branch of Google's parent company Alphabet and their initiative checked off all of the things we were looking for.

For example, X's Taara initiative is trying to use FSOC systems to provide internet coverage to underserviced communities around the world.

According to their website, when experimenting on a different FSOC initiative called Loon, they experienced surprising success in establishing broadband connections [3]. Loon is different from Taara because it takes place in low earth orbit. That's about 2000km above the ground. Taara, by contrast, is proposing to take the same FSOC technology from Loon down to the surface of earth.

So far, Taara has teamed up with local fiber broadband networks in India. They' even already successfully deployed a system in the state of Andhra Pradesh. Currently, they plan on expanding to other states in India. All this in order to become a backbone network for cost-effective, high speed internet connectivity.

Our design philosophy, therefore, was heavily inspired by what the Taara team is doing. We hope to build a rudimentary FSOC system that can prove itself as a viable, cost-effective way for addressing our digital divide. Even though it'll be a small system, it will provide the proof needed to showcase how little risk there is in adopting these systems. Especially, when compared to their potential social and economic benefit.

IX. Deployable Prototype Status

Deployable Prototype Status Abstract — Under the face of pandemics and strict deadlines, engineers must learn to surmount seemingly insurmountable obsticles when testing the deployable prototype. In order to stay within our "path to critical success", we have come to a consensus when delegating tasks or experiments. This is reflected in our usage of the Test Plan tables located at the end of this section.

As engineers, we've all thought at one point or another: "What goes into making that product?" Well, there really is no adequate way of describing the experience unless having gone through it yourself. It's really no wonder why product design is a pivotal course to the engineering curriculum. Your forced into unfamiliar, uncomfortable situations with other individuals, whom may or may not like you very much, and to come up with solutions. Half the time, it feels like you're making it just from the skin of your teeth. At least, it does for those of us who don't yet have the experience the others may have.

In this portion of the project, we'll be discussing the ways our team strived to make our FSOC device on its path to success. We'll have two main sub-sections: hardware and software. We'll be discussing the range of experiments, both digital and physical, that were performed to better understand the FSOC system.

We'll also be discussing about what worked for the system and what didn't. Needless to say, the system we've chosen does have it limitations and we'll be discussing about the ones we encountered along the way.

A large part of a project's success, we believe, hinges on whether the group can come to a consensus efficiently and effectively.

A. *Hardware*

The hardware section will contain all the testing that we did to understand how the FSOC system worked. We'll first have a brief review of the major components in our FSOC system. Then the hardware section is broken into two parts:

1. Simulation Testing & Results
2. Hardware Testing & Results

In Simulation Testing & Results we'll analyze each operational amplifier (op-amp) using simulations tools like LTSpice and MultiSim. In Hardware Testing & Results we'll be analyzing the fabricated PCB board in order to determine whether we were able to establish an ethernet connection.

B. *Software*

The software sub-section will contain the descriptions and relevant data that was observed during the experiments on our software. This includes things like socket program and web database testing.

Hardware

We'll very briefly review some of the major parts of our FSOC system. We won't be spending too much time on reviewing since we've covered each op-amp in section III. Design Idea.

A. *Transmitter*

The purpose of the transmitter is to transform electrical signals into light by changing the brightness of the laser diode, sending wireless data via free space or stratosphere [6]. It consists of a constant current source, which will offset the brightness through an AC coupling (see figure below).

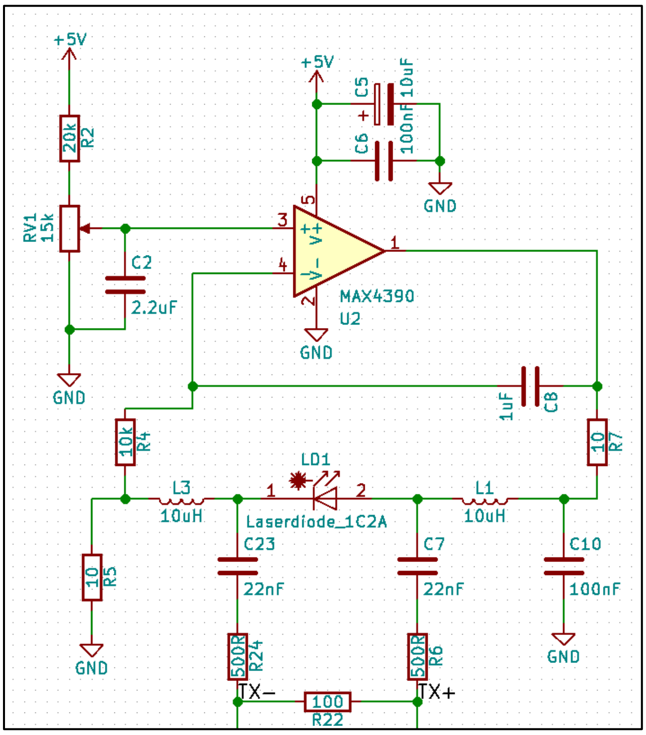


Figure A-15. Transmitter design. [[6] [[6]

B. *Laser*

The laser will play a major role in the transmitter section. The laser diode will be driven by a non-inverting transmitter configuration, capable of emitting 635nm of visible red light. A laser diode is a semiconductor device that produces light, sometimes invisible, in response to a current. One advantage of the laser output is that it stays monochrome and heavily concentrated on one frequency; thus, it can reach long travel distances [23]. And because of their low cost, size, and high-power efficiency, most industries are focusing on using semiconductor lasers for FSO technology [4].

C. *Receiver*

The receiver's task is to detect optical signals generated by the transmitter and to perform optical-electrical conversion. It consists of a transimpedance amplifier that converts the photocurrent signal of the diode into a power signal [23].

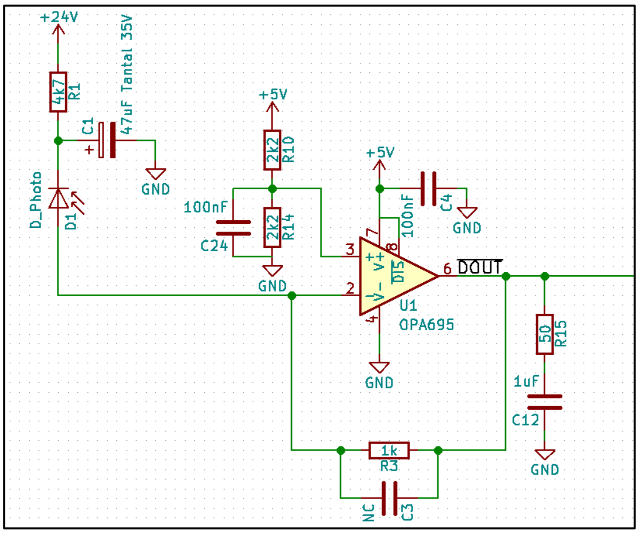


Figure A-16. Receiver design. [[6] [[6]

D. *Photodiode*

One of the main components of the receiver is the photodiode. A photodiode produces current in response to light, they are responsible for collecting the data transmitted and send it to the receiver. And as mentioned before, once the receiver obtains the signal it will convert it into a voltage wave and amplify it by a current feedback op amp (OPA695) often referred as a transimpedance amplifier.

E. *Wide Input Range Boost Regulator*

The DC booster generates high power density and can power large loads. In other words, it will match the load voltage to the supply voltage. Moreover, the high bias voltage produced by the boost regulator will reduce the inherent capacitance of the photodiode allowing it to have a faster response [6].

F. *Comparator and Buffer*

The comparator helps transmit data into the Ethernet card or any kind of network device connected to the receiver. It has the capability of polarity identification, switch driving and/or 1-bit analog to digital conversion. Also, with its inverting and non-inverting outputs it makes it easier to drive a differential pair. In other words, double output with same level of magnitude, but opposite in polarity. However, a buffer is still required to amplify the high output current needed to drive the loads at a high speed [6].

Simulation Testing & Results

A. *MAX4390*

We first simulated the transmitter which used the MAX4390 op-amp. Here we used LTSpice as our simulator tool and an LT1677 in place of the MAX4390. Since these are virtually identical op-amps, the discrepancy makes no difference to our results.

In our simulation we used a sine wave as the carrier signal and a triangle wave as the message. Where the carrier was set 8V peak-to-peak at 50Hz. The results are shown in Fig.11.

As a reminder, voltage output V_1 is manipulating the intensity of the laser diode by affecting current flow through its anode. So, based on our simulations results, we would expect the laser to jump up luminosity, it would then very subtly vary in intensity, fall back down in luminosity, vary again, rinse & repeat.

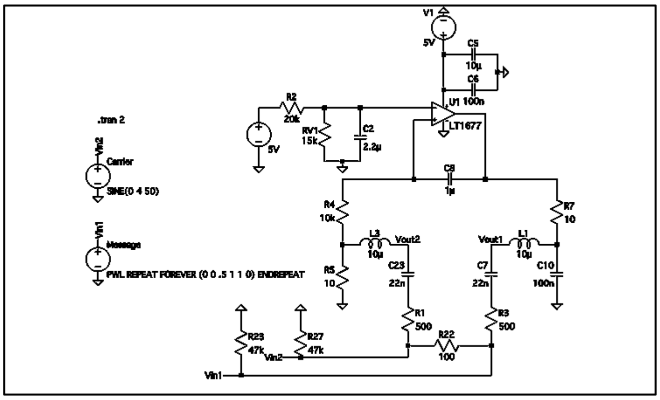


Figure A-17. MAX4390 Op-Amp design on LTSpice.

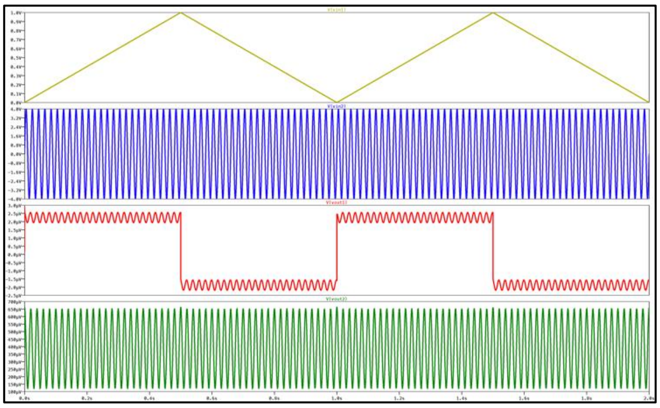


Figure A-18. Results of the MAX4390 simulation.

B. *OPA695*

After finishing transmitter simulations, we started to virtually take apart the receiver.

The following two simulations were done with NI Multisim. Since there was not an OPA695 default model on this interface, the OPA694 op-amp was chosen for simulation since both current feedback amplifiers have similar characteristics (Figure A-19).

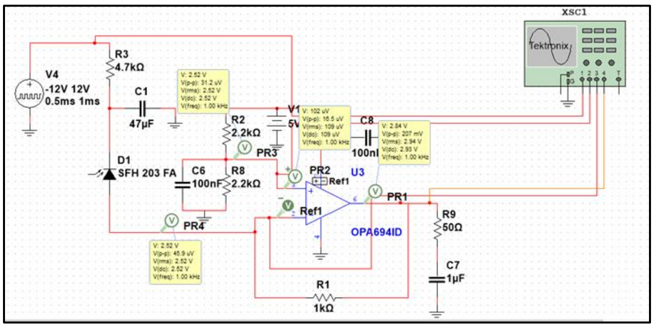


Figure A-19. OPA695 Op-amp design on Multisim

During simulation, various input signals were tested on the circuit to familiarize with the output results. Figure A-20 shows simulation results using an arbitrary pulse signal as the input. Figure A-21 shows a frequency modulated input signal.

It was observed that as the frequency decreased, the amplitude of the output signal would increase in amplitude and vice versa.

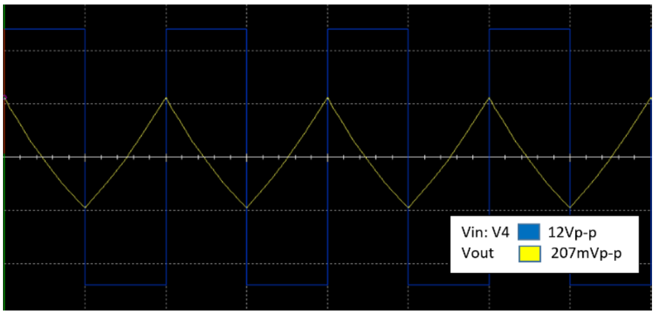


Figure A-20. OPA694 Simulation Results using an input pulse wave.

Notice that the blue signal at the bottom (Figure A-21), was the signal coming from the photodiode. As mentioned before, the signal detected by the photodiode will be converted into an electrical signal which will be then amplified by the current feedback amplifier of the receiver. And as seen by the yellow output signal, the output was amplified going from about 11µV to 36mV as well as inverted.

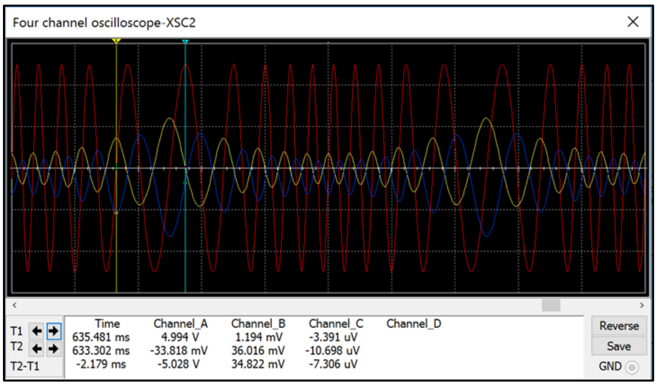


Figure A-21. FM input signal OPA694 simulation results.

The data sheet we referred to for the OPA695 can be found at:

- https://www.ti.com/lit/ds/symlink/opa695.pdf?ts=1602354461139&ref_url=https%253A%252F%252Fwww.google.com%252F

C. LT1713

After obtaining the results from the previous op-amp, the LT1713 comparator was tested. Figure A-22 shows the circuit setup done on Multisim. The comparator is the second stage of the receiver, responsible for analog to digital conversion. With the feedback resistor going to the non-inverting input terminal, this adds a comparator with hysteresis configuration. Hysteresis cleans up noise off the signal and ignores fake off switching signals which provides stability.

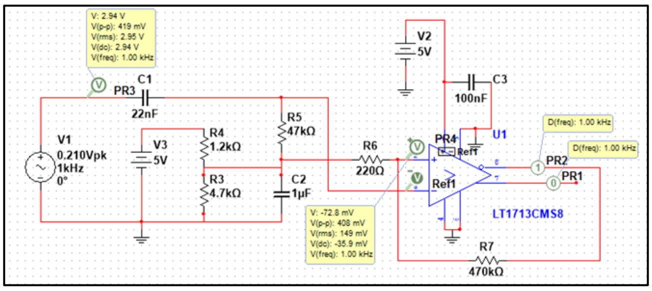


Figure A-22. LT1713 Op-amp design on Multisim.

To test this op-amp, the triangular output wave obtained from the results in Figure A-23 was used as the input signal as seen in the figure below.

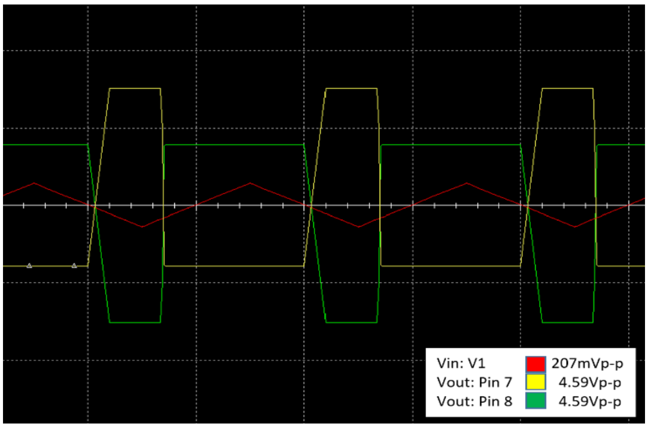


Figure A-23. LT1713 Simulation Results with triangular input wave.

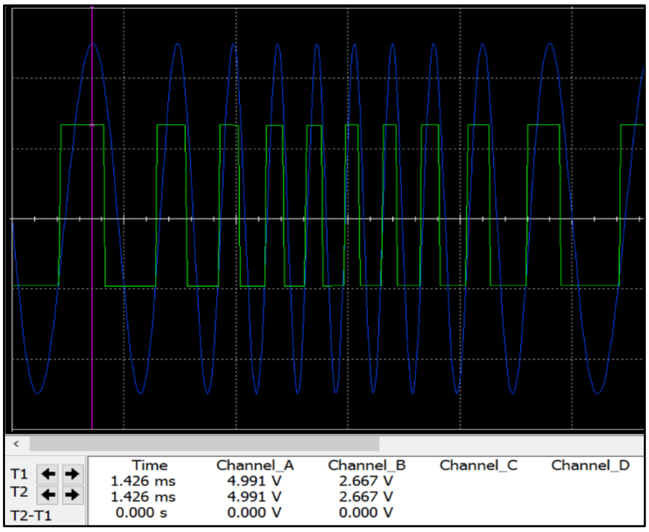


Figure A-24. FM Input Signal LT1713 Simulation Results.

A second test was done with a frequency modulated input signal (Figure A-24), it was observed that in both cases the output signal was converted to a digital or pulse signal. Moreover, by using a digital probe on both output terminals, the probes detected the outputs switching from 0s and 1s which in the actual circuit will be the information obtained from the receiver.

The data sheet we referred to for the LT1713 can be found at:

- https://www.analog.com/media/en/technical-documentation/data-sheets/171314f.pdf

D. MAX4392

The final stage, or op-amp, in the receiver are two MAX4392s. Note that the MAX4390 and the MAX4392 have the same specifications. This is confirmed by their data sheet below:

- https://datasheets.maximintegrated.com/en/ds/MAX4389-MAX4396.pdf

Ideally, at this stage, we should expect for Vin1 and Vin2 of the MAX392 to be equivalent to that of the message and carrier signals from the MAX4390. If we allow for this condition, then we should expect Vout1 and Vout2 of the MAX4392 to also be equivalent to that of the MAX4390.

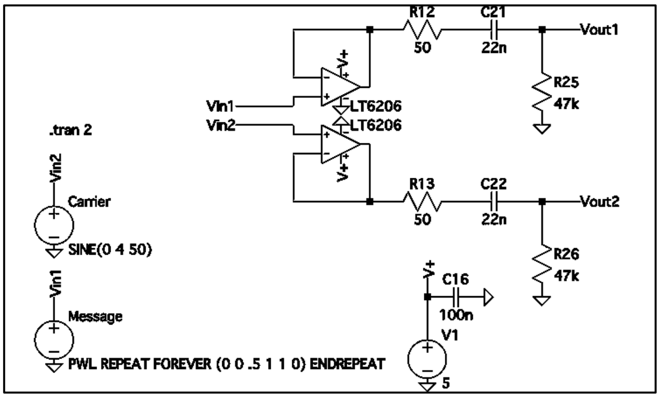


Figure A-25. MAX4392 Shown with Test Message and Carrier Signals.

Sure enough, our simulation results confirmed our expectations. They are shown below in Figure A-26. Use the appendix to compare Figure A-18 and Figure A-26. Notice how similar the results are.

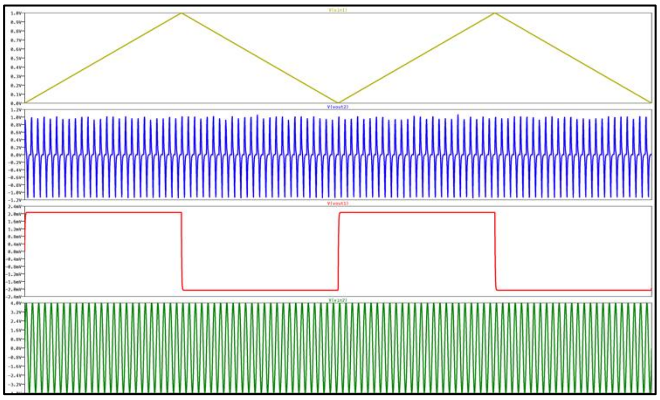


Figure A-26. Simulation Results from MAX4392.

E. LM78M05CT & MIC2605

As mentioned earlier in the report, we neglected to simulate these components. There were two reasons for this. The first, we wanted to primarily focus on the telecommunication aspects of the device and not power regulation. And the second, simulating these components provide no real value in terms of building intuition in how our system should behave.

F. Entire Circuit on LTSpice

Finally, when we put all these blocks together, we can simulate our FSOC system. Below is an LTSpice design of our FSOC system. In this simulation, and similarly in the ones before it, we determined a sine wave to be our carrier. This time however our message is going to be a square wave.

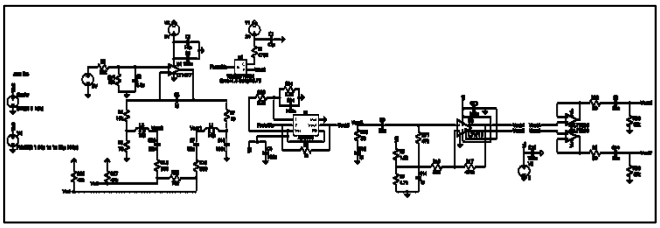


Figure A-27. Entire circuit design on LTSpice.

V_{out1} is colored in the dark blue. Located at the top of the results shown below. This is our carrier and message signals modulated together and it's controlling the behavior of our laser. Based on these results we can determine that the laser is varying in brightness very dramatically. This, so far, is as expected from a simple input like ours.

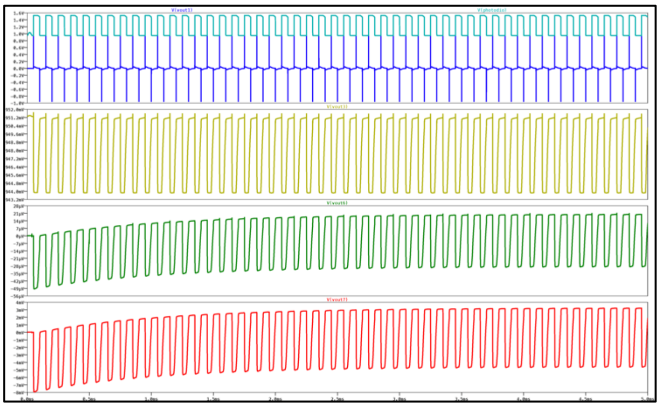


Figure A-28. Simulation results of the entire circuit on LTSpice.

If we look at the light blue, we can see how our photodiode is responding to the varying brightness. Again, we're seeing exactly what we want to see - a square wave formation.

If we now look at V_{out6} and V_{out7}, we see that our signal was reconstructed. Note how V_{out6}, the green signal, is in micro-volts. Essentially transforming that output as a virtual ground. Recall how voltage is defined as a potential difference. So, by taking V_{out7}, which is the red one, and comparing that to V_{out6} (in this case "ground"), we get our message back.

With our simulations completed, we not only grew in our understanding of this FSOC system, but we also grew in confidence that the device could work in practice. And so, we would proceed with fabricating this design idea.

Hardware Testing & Results

A. Did Our Device Turn On?

During debugging of our device, various tests were implemented. Yet, there is still more testing that will take place to deliver a deployable prototype.

As we learned during lectures, testing is a crucial step to provide reliability and assurance that the device works. For example, when our fabricated circuit boards arrived, the first test was the "power on" test to make sure they worked. Each board was connected to a 9V power supply; however, they did not turn on. The next thing to check was the fuses; these quick blow fuses rated at 350mA, protect sensitive components from current overload. Since they were ceramic, it was hard to visually tell if they were blown thus the resistance had to be measured. It was noticed that every fuse installed kept blowing, so the following thing was to change the power supply to 9V batteries and use glass type fuses. With glass fuses, it was easy to see that they kept blowing as soon as power was delivered to the circuit. And because the turn on test kept failing, the next step was to check for a faulty connections or shorted components.

After inspection of the boards, the safety diode next to the fuse was found to be assembled backwards. Hence every time the boards were connected to any power supply, current flowing in the wrong direction of the diode (reversed bias) created an open circuit which in turn blew the fuse out. Once this problem was corrected, the transceivers turned on and the next step was to test for connectivity.

B. Testing Connectivity

To confirm connectivity, the most crucial step was to test for input and output signals at different stages of the circuit. Beginning with DC values, the voltage from the power supplies was measured, to make sure 9V was supplied to the boards. This examination was done when the boards were not turning on. From there, every known value was measured following the schematic and order of components to make sure that the appropriate voltages were supplied. For example, each of the amplifier's positive power supply terminal must receive 5V to turn on. Since the linear voltage regulator oversees the delivering of this quantity, the test started at the output of the regulator.

After checking these values, the next step was to compare virtual simulations to actual results obtained using the Analog Discovery 2 (AD2) tool. As mentioned before, virtual simulations were one of the main objectives that helped understand the behavior of the circuit. And although it sounds easy, this is where most of the time was spent trying to get connection. From simulations, it was known that the signal going from the output of the current feedback amplifier OPA695 to the output of the comparator LT1713 would go from a sine to a pulse wave. This was enough information to expect similar responses at the end of the receiver. However, before obtaining these results several other tests were performed.

First, when connecting the computer to the ethernet jack, there was no signal recognition at the input of the transmitter. Therefore, testing for continuity at these locations was the next phase. An ethernet cable was cut to have access to the transmitting lines TX- and TX+, and a sine wave was introduced using the AD2 wave generator. Prior to test connectivity using this method, a Local Area Network/Telephone line tester [[40] was purchased to test that the ethernet ports. However, this tester seemed not to work as it was connected to every ethernet port possible and even to a working telephone line. The only instance where the third led light of this device started to dimly blink, was when a mirror was used to reflect the laser's beam into the photodiode while at the same time going in and out of the photodiode's center. The third led light represented the Ringing/AC Voltage test and if it blinked it signified that there was signal present at the connection. It was believed that by moving the laser's beam back and forth, some sort of analog signal was created making the light blink. And although this proved connectivity, the results were not convincing.

It was then decided to cut the ethernet cable and follow the second connectivity test. With a known signal at the transmitter's input, both input and output signals were tested at every stage. Since there was no response at the receiver's end, a couple of adjustments were performed. One of them was to adjust the laser's intensity, using a mirror to reflect the laser's beam into the photodiode, and change the distance between the transceiver and mirror. As the distance decreased, the signal slightly increased in amplitude. Once a signal was obtained at the output of the receiver, the computer and transceiver were connected one more time.

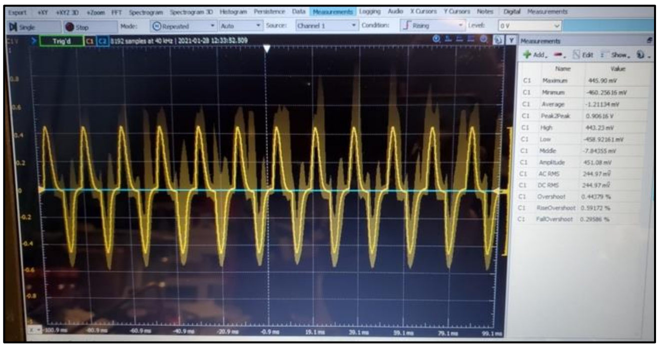


Figure A-29. Ethernet Signal Detection.

With no signal at the transmitter and knowing that the circuit was responding accordingly, the next move was to test different ethernet cables. It was also observed that each cable sent a distinct signal, making it difficult to distinguish an ethernet signal from interference (noise) of the circuit. Therefore, to be more secure of what ethernet signal to look for, the slashed ethernet cable previously utilized to test for continuity was connected to the computer. The signal shown on Figure A-29 was seen on channel 1 of the oscilloscope and this signal determined which ethernet cable to use. Finally, when connecting the computer to the transceiver, an ethernet connection was successfully established. Note that only one board was used during the final connection due to the second board not passing the smoke test. And ethernet connection was achieved during the second semester.

This was some of the testing done to get the laboratory prototype going. As mentioned before, two of the features not successfully accomplished last semester were to establish an ethernet connection and prove the device is capable of fast deployment in case of emergencies. Therefore, as shown on the work breakdown structure and project timeline, our device test plan for this semester will begin with:

- Testing for a secure connection
- Testing connectivity between two devices
- Testing the line of sight
- Testing for alerts and collecting test results from the software.

When testing for a secure connection, the main objective will be to position the transceivers at further distances and compare the amplitude of the signals coming from the receiver to the ethernet port. Even though an ethernet connection was established, these signals seemed to be very small. Thus, it is important to ensure that the signal received from one device will have enough amplitude to be recognized by the other. If the signal is weak and there is no connection, the next step will be to re-evaluate the circuit and find ways of increasing the gain of the op amps. Once both transceivers pass the secure connection test, the next goal will be to connect two devices (laptop and Raspberry Pi) to the transceivers and establish an internet connection between them. Part of this step will require both hardware and software testing to transmit data. Additionally, during and after testing of transmission, the line of sight will also be tested. Both line of sight and establishing a secure connection between two devices will take most of the time as this will assist in accomplishing the next feature which is fast deployment. Lastly, when testing for alerts and collecting results from the software, humidity DHT11 sensor will get tested under a set of conditions so that any failure in communication affected by weather can be detected beforehand.

C. *Power on Test*

TABLE 8.
DC MEASURED VALUES

Component	Input	Output	Expected
Fuse	9.33V	9.11V	9V
R2	5.03V	2.51V	5V (Input)
R11	4.01V	3.99V	4.6V
R12	3.56V	3.59V	4V
R16	4.0V	4.0V	4.5V
R17	141.2mV	141.2mV	149mV
L1	124.7mV	121.2mV	N/A
C1	32.45V	0V	30V
U4 LM78905	9.11V	5.03V	(9V, 5V)
Photodiode	32.45V	2.53V	(30V, 2.5V)
U6 MIC2605	9.11V	32.5V	(9v, 24V)
U1 OPA695			
Pin 3	2.52V		2.50V
Pin 6	2.51V		2.67V
Pin 7	5.03V		5V
U2 MAX4390			
Pin 1	2.51V		2.5V
Pin 3	1.03V		1.1V
Pin 4	313.7mV		400mV
Pin 5	5.03V		5V
U3 LT1713			
Pin 1	5.03V		5V
Pin 2	4.0V		4.5V
Pin 3	3.99V		~2.5
Pin 7	4.89V		4.59
Pin 8	147.3mV		207mV
U5 MAX4392			
Pin 1	3.60V		4V
Pin 7	141.4mV		2mV
Pin 8	5.03V		5V

To meet some of our feature's sets, these were some of the testing results obtained on the hardware side. A couple modifications were required as testing was executed to improve the results and as the changes came along, the test plan was updated.

The main objective of this test was to make sure the device turned on with no issues along with verifying that every component on the device worked as well. As mentioned before, the first points of interest when it came to testing were the known or expected values. Most of these values were the DC quantities, and as shown on Table 8, our measurements agreed with the expected results.

D. *Ethernet Connectivity for One FSOC Device*

When it came to testing for ethernet connectivity, each FSOC device was tested on its own to ensure connection between the device and host was established. Most of the testing performed on the hardware end was based on signal analysis. Since communication alone deals with random signals, it was hard to find and general ethernet waveform to reference as far as dimensions due to variations in frequency and amplitude. Nevertheless, one of the signals referenced when testing connectivity, was the signal shown on Figure A-30. According to Ben Eater, an expert on hardware networking and creator of educational videos on YouTube, this is what a 10 Mbps ethernet signal looks like coming from the ethernet port. He further explained how this signal goes through a physical layer process using the Manchester's encoding scheme, to then be translated to a digital signal and be ready for transmission [*[29*].

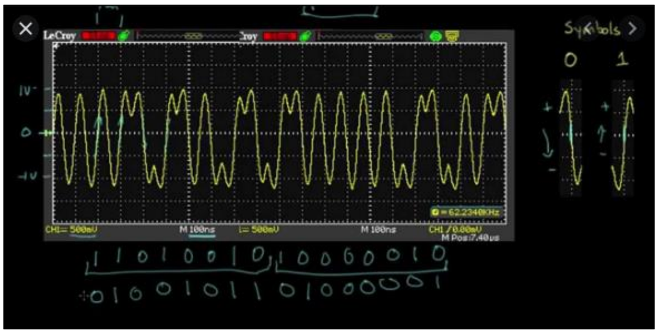


Figure A-30. Theoretical representation of ethernet signal using Manchester's encoding scheme. This image was captured from one of Ben Eaters YouTube videos. Check out his channel for all sorts of cool stuff. [[[29]

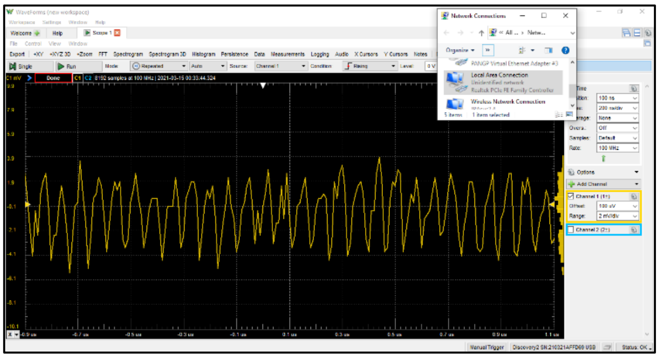


Figure A-31. The encoded signal at the output of our receiver's current feedback amplifier.

The same signal was obtained at the output of the feedback amplifier (see Figure A-31) and came straight from the photodiode's response when the board was connected to the ethernet network. A 2 bits per every 100ns frame was measured from this signal. This represented about 20Mbps which confirmed that our device was capable of 10Mbps data transmission.

The next test was at the receiver and the signal shown on the top image of Figure A-32, is also the signal referenced every time the line of sight needed to be adjusted to connect a different host, for example a laptop, raspberry pi, or desktop. It was observed that as the ghosting signal on the background started spreading out while moving up and down, the computer would begin identifying a network connection. This was again used as reference to connect, and the signal needed to be scaled in milliseconds per division (see bottom image of Figure A-32). However, when time scaling the same signal in microseconds per division, it was observed that the ghosting on the background was a response happening around every 30 microseconds (about 25 to 30 Mbps). This was the second confirmation that our device was capable of high data transmission.

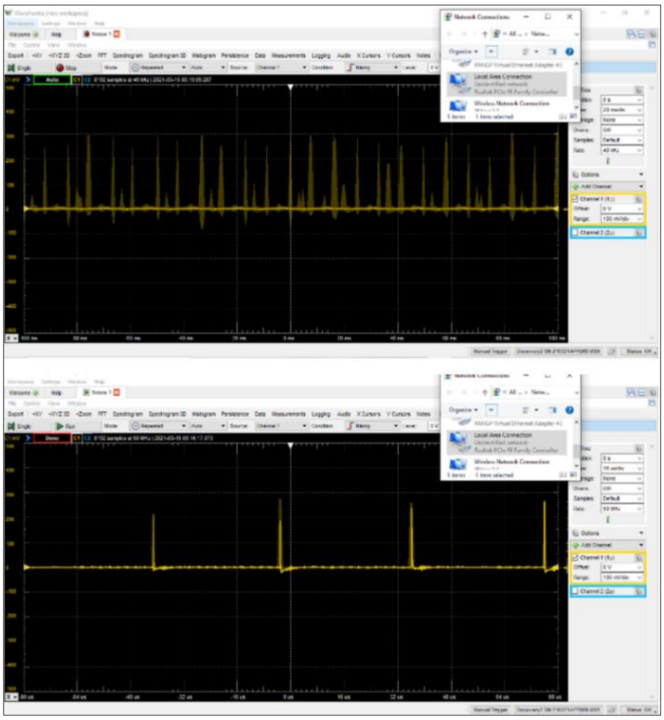


Figure A-32. Line of sight reference signal at the receiver end.

These were the main test results that allowed us to meet the first feature set which was to establish an ethernet connection. Each transceiver went through this process and after integrating the software, a 0% loss was successfully achieved as shown on Figure A-32.

E. *Connectivity Between Two FSOC Devices*

Going further into testing, the communication channel was tested next. With the two transceivers properly aligned and connected to a host with an ethernet cable, various tests were performed. Unfortunately, the host on the other end was unreachable when pinging the network connection. Pinging is a method used to verify that a network connection is present between two devices. There were a couple of instances where the connection timed out and, in the end, resulted in high percentage loss. This test was performed at about 0.4 meters of distance and it did not change since consistency throughout the testing was needed to eliminate all unknown variables. After multiple tests, it was believed that the message being sent through the media channel (laser's beam) gets lost in translation when going from electrical to optical and/or optical to electrical conversion.

F. *Modifications*

With the issues presented from the previous test, new modifications were done on the design thinking on solutions to this problem. It was observed that most signals at the receiver were smaller compared to virtual simulations. For example, the signal of the current feedback amplifier was about 4 millivolts in amplitude compared to 36mV from simulations. Therefore, the first change to the design was to remove the feedback resistor of the comparator (see R17 on Figure A-7). With no feedback resistor, the hysteresis configuration of this amplifier would be eliminated. Since, all the signals tested on the receiver were responding accordingly, it was assumed that besides noise, some of the data in the signal was removed at the comparator stage. However, once the resistor was removed, the testing results showed no improvement. The signal at the receiver was smaller (200mV compared to 400mV), and the noise was causing some interference in the circuit that the computer identified a signal at the ethernet port without having the line of sight pointing at the photodiode.

Figure A-33. Shifted Response After Second Modification

The second modification happened on the transmitter side. According to Sven Brauch, by removing the resistor connected in parallel to the terminals of the laser (see R22 on Figure A-7), the modulation amplitude of the transmitter would increase [6]. Still, after testing the signals, the only change observed happened at the end of the receiver. When looking for this signal, the response was shifted to an earlier time starting at about 32 microseconds compared to 456 microseconds (Figure A-33) prior to the change.

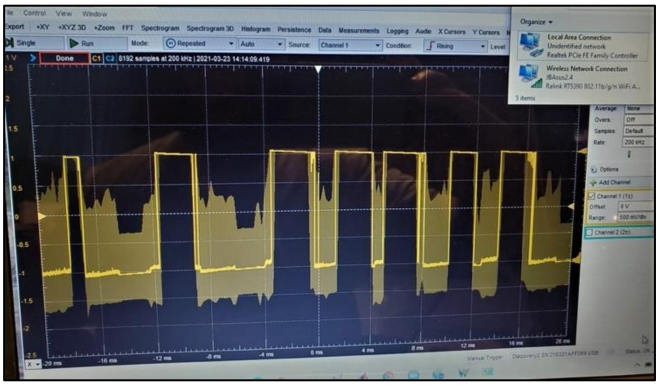


Figure A-34. Improved signal at the buffer stage of the receiver.

As mentioned earlier, the amplitude of the signal at the output of the current feedback amplifier (Figure A-31) was very small. Thus, the next adjustment was to increase the feedback resistor of this amplifier to increase the gain (see R3 on Figure A-7). After increasing the gain, the signals at the receiver improved overall. The pulse signal at the buffer improved in size and quality going from about 400mV peak to peak to 2 volts peak to peak as shown of the figure above. The signal at the receiver increased as well going from 200mV to 400mV in amplitude and can be seen in yellow on the Figure A-35 compared to the signal shown on Figure A-33.

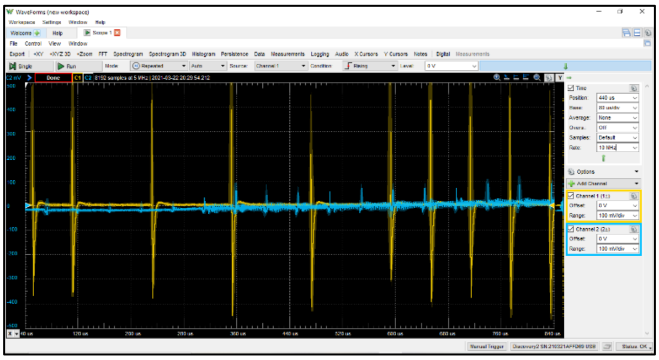


Figure A-35. Improved receiver response

G. Portability Test

Additionally, with the new modifications in place another feature set was improved, fast deployment and portability. As shown on Table 9, the time that it took to connect both transceivers to the ethernet was around 15 to 20 minutes. And even though this timing met the requirements, with the new improved signal coming from the receiver, it was noted that it took less time to adjust the line of sight to establish an ethernet connection.

TABLE 9

PORTABILITY TIMING TEST

Before (min:sec)	**After** (min:sec)
20:02	5:20
15:35	6:32
17:50	12:45
5:50	9:17

Software

A. Socket Program Testing

One of the main programs we made for the project is a socket program to test the transfer rate of our device. Along with testing the data sizes we could send with our device. We need to test the socket program beforehand though, so we know that the socket program is not providing us with false results. The method of preforming this test involves running the program on two different devices and make sure the two devices can transfer packets between themselves. The expected result for this test is that the two devices can successfully transmit the packets between themselves. There should be no data loss when transmitting the packets. The time to transmit the packets should be fast because our computer has the power to transmit something that is more than 10mbits in a second. We had a simple socket program just sending text between the server and client. The simple socket program was tested before proceeding with the final socket program. The final socket program is sending files through the sockets instead of just text.

The first simple socket program we tested is sending a simple message between two devices. The setup for the test requires two different devices which for this test we used a raspberry pi 3b+ and a windows laptop. The two devices are connected with an ethernet cable, so the socket program will send the packets through the ethernet cable. The socket program is two different programs one being the server and the other is the client. The server and client programs communicate with each other to send data through a TCP socket. When testing the programs, we encountered some issues initially because the client program was having issues finding server program on the other device. The solution to the issue was that the client program needs to be modified every time we use a different device because the program requires the IP address of server program which is different for each device. Once we resolved our small connection issue, we successfully sent packets between the two devices. The packets sent simply had a small message for the server program to display on the other device's terminal. The packets were sent quickly in about 0.04 of a second with a high of 0.06s and a low of 0.05s. The amount of time it took to send the packets was good and no data loss was experienced. The socket program is currently working properly with no errors.

The modified socket program was tested using the same test as before which is just running the socket programs repeatedly and observe the behavior of the socket programs. The setup of the test is to have the two programs the client and the server program running on two different devices. The two devices are connected to each other with an ethernet cable. The programs are running on python 3. The devices used in this test was a windows desktop and a windows laptop. The server program must be running first. Then the client program can be activated on the other device. As soon as the client is activated the two programs talk to each other.

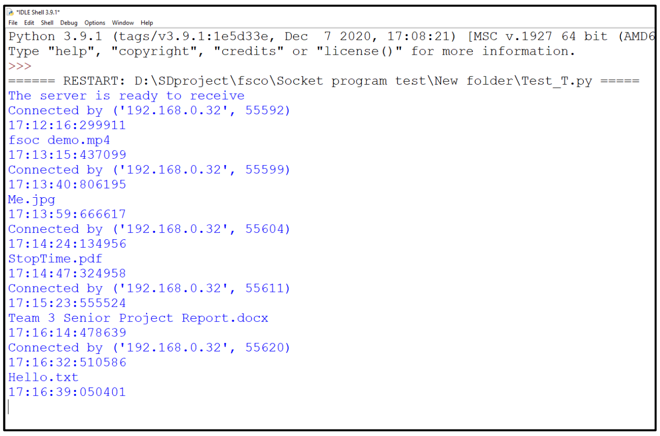


Figure A-36. Socket Server Results.

Figure A-36 shows us running the server program and we have established multiple client connections. The client connections have all been met with no errors. The time to meet the different client connections is different. The user plays a role in how long the client sockets take to finish. The time to receive a file less than 10mb takes less than a second. Within milliseconds it takes a file to be transferred from the client to the server. The server is constantly running and meets requests even after two hours of being idle.

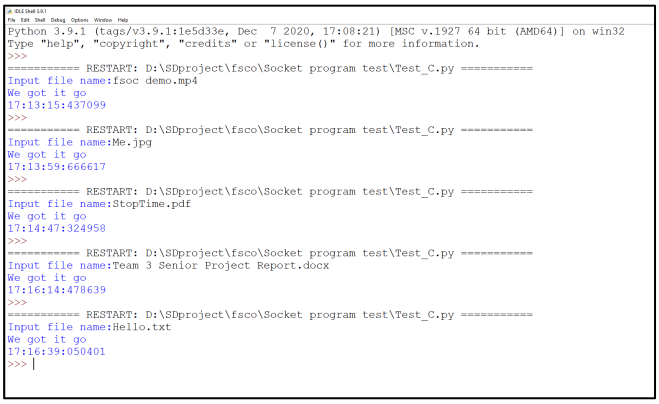


Figure A-37. Socket Client Results.

Figure A-37 is the client response when it is connecting to the server. The client is simply connecting to the server and sending a file over the socket. The client is running repeatedly to make different requests. We sent small data files and the biggest file sent was 10mb which is the video. The program works properly, and we can send any type of file. No matter the file we can send it over the TCP socket.

The socket program test was successful. We found interesting features about our socket program. The server will be responsive even after two hours of being idle. The multiple different client requests are met one at a time, before the server accepts another request it must finish one client request first. We can program the server to have multiple client sockets being met at one time, but to keep it simple we only accept a single request. Then we can send any type of file through the TCP socket connection.

B. *Interagtion – Alert System Test*

To ensure the reliability of the alert system, we had to test two main components before integrating it to the socket program. First component to test was the humidity sensor for its accuracy in the range and average of humidity readings. The second component we had to test was the alert being sent out as expected. To test the humidity percentage, we used DHT11 and DHT22 sensors. Both take readings, store them as serial data, and can be displayed using either programming language C or Python.

Since the final integration was going to be in Python, we chose to stick with Python for the Alert system as well. To test the sensors' reliability, we sampled a few ranges of humidity. Once the range seemed to match on both sensors, DHT11 and DHT22, we chose to continue with DHT22 because it leaves little room for error as its serial data readings for humidity are only off by a margin of ± 2% compared to the ±5% of the DHT11 sensor. Also, DHT22 accounts for a higher range reading compared to DHT11.

After confirming the reliable serial data read from the DHT22 sensor, the next step was to program the serial data read for an alert. Taking the humidity percentage read, if the concentrated relative humidity was ≥65%, we would send out an alert about the connection being delayed. After the alert was functional at the desired humidity range, we limited one delayed connection alert per connection. At last, we integrated the alert system to the main Socket program. Now, the alert would only be shown every time a new host tries to make a connection with our system and if the humidity % would delay the connection. The results of the alert can be seen in Figure A-38 below.

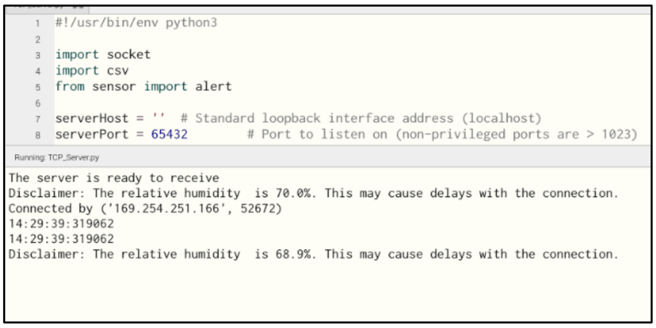


Figure A-38. Alert System Output

C. *Web Database Test*

The web database feature will be a tool for users of our device to spot errors with our device. Now to make sure this feature works we ran a couple of different tests to make sure it preforms the way we want it to. The first test is to use this tool provided by Flask to debug our web database. The tool will let us monitor the web database and report any errors when a user tries to access the web database. The following test will have two different people accessing the web database on different devices and in two different situations. One case will be two people trying to access the web database at the same time. Then the next situation requires the people to access the web database at different times. The web database should be able to handle the different cases without having the web database crashing on a user. Then the next test has us making random test data, so it can be displayed on our web database. The test will confirm that we can properly display data no matter if it is one piece of data or a long list of data entries. The expected results will be that our web database is functional no matter the data size. If there are two people on different ends of the device, they will still be able to look at the results at the same time without encountering errors in the web server. The data being displayed on the web database does not have any errors like a blank spot where data should be or if data exceeds one page that the data will be displayed fine on the different page. The tests explained are the only tests that will be conducted on the web database. We will start to explain the results of using the flask app tool on the web database.

The first test to examine the online web database requires us to use this debug tool from flask to make sure the web database is fine. To use the debug tool, we need to have the web database set up properly and have the html layout be loaded correctly. When running the test of our final web database we did it on a single device. The same device would be used to host the web database and access the web database. The device we will be using is a windows laptop. Then we made sure to refresh the page five times to catch any errors. I pressed the refresh button a few seconds apart from each other.

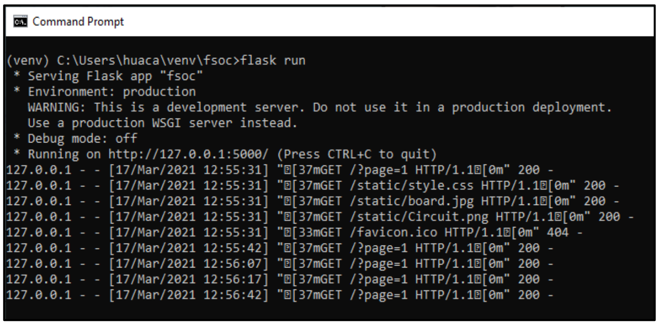


Figure A-39. Flask Debug Tool.

Figure A-39 is the results from the test we ran. The first observation from the results seen is that there is no error when accessing the online web database. If an error occurred there would be red text under one of the get requests seen in Figure A-39. Another observation seen is that if it is the first time the device is accessing the web database along with getting the web database it is collecting extra information. The extra information is the cadence style sheet (CSS) styling file to make the web database more appealing, images that are used in the web database, and a final check for any symbols. At the end of the GET requests seen in Figure A-39 have a 200 which means it was successful in returning the requested data from the web server. Then we did get one 404 GET request, but that is because we do not have any symbols. Since there were no symbols, it returned a 404 to signify that the requested data does not exist in the web server. The single 404 request is normal, and we expected that to happen. The 404 error does not affect the web database. After the 404 error that is when we refreshed the page to initiate another GET request to the web database. Refreshing the web database did not require all the data from the first request like the CSS styling, the images, and the symbol check. The reason for this is because our devices browser caches the web database and it check to see if any new data is seen if no new data is seen then it does not to recollect the images or styling sheet.

Figure A-40. Web Application.

Figure A-40 is displaying how our web database looks like on our device during the test we ran. The web database does not look broken. Nothing is missing like the images and the 404 we got on the debug tool did not affect the web database. I repeated the test three more times on my device and the repeated tests gave us the same results. One of the repeated tests was done on a raspberry pi instead of a windows laptop. The following test will require us accessing the web database on two different devices in two different situations.

The two-device test will have two devices connected to each other with an ethernet cable. We ran the test on two windows devices one being a laptop and the other device being a desktop. The first step to setup the test is to make sure the ethernet cable is connected properly and the ethernet connection is detected by both devices. Once the devices detect the ethernet cable connection we need to run the flask program on one device. I ran the flask program on the laptop because all the flask software was downloaded already on the laptop. Then from there we need to find out the IP address of the ethernet connection made on the webserver host side. After we get the IP address, we turn off the wi-fi or take out the ethernet cable connecting the device to the network. We are turning off the internet to make sure we are connecting to our web database and not anything else that may be on the internet. The next step is to open a web browser any web browser will work and type in the web address http://127.0.0.1:5000/ on the device hosting the web database. The web address we type in first is just checking if our device has a web application. We can use this web address on any device hosting the web database. Then on the other device we type the IP address we found, so we would type in http://169.254.232.87:5000/. Now the second web address will change because the IP address varies between different devices. Finally, everything is ready for running the two-device test. The first step is to have the web address that we got beforehand and put them in the web browser to open the web database. Now we want to test if the two devices when trying to access the web database at the same time it will not crash the web server. We pressed enter on both devices at the same time will less than a millisecond difference.

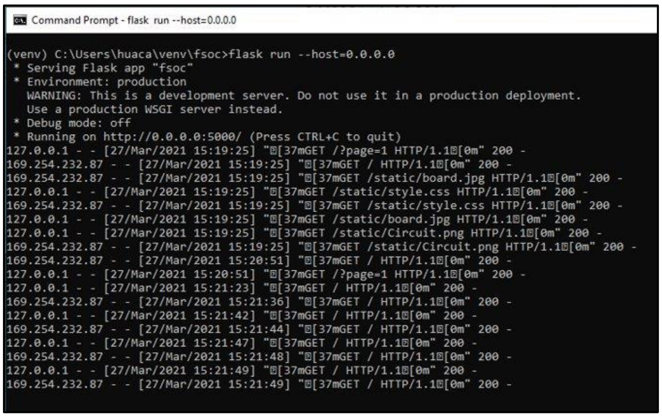


Figure A-41. Two Device Test.

is the result of the two-device test. The web server is still functional even though we got two requests in less than a milli-second. We can see this because the flask debug tool reports the time of the request made to the online web database. The time stamp for the two requests is the same all the way down to the second. Even though the requests were received at the same time they share the resources and take turns to meet the requests. Figure # shows how the webserver meets requests in a cycle kind of form. One request is met then switching to the other request being made and finally it returns to the first request. Again, we see similar results as the single device test. If it is the first request to the online web database, then along with the first request we have additional requests to get the images and CSS styling file used for the online web database. The additional request besides the first one is where we see this cycle of meeting requests. I ran additional request quickly one after the other to observe if the online web database can handle it. Nothing was broken the web database was stable and the time it took to meet the requests was less than five seconds. To observe the status of the web server more we left the server on for more than 2 hours just being idle. After the two hours we tried to run another request to see if the web server was still active. The web server was nonresponsive it did not meet a request after 2 hours of being idle. Eventually after two more request the web server wakes up and meets the requests being made. Our online web database needs to have constant requests to be made or else the device hosting web server falls asleep and does not meet requests. With the nonresponsive server it means that a laptop is not the best for running web database. Overall, we were successful the online web database was able to meet to simultaneous request and sequential request to the web database. Our online web database is not perfect, and it becomes unresponsive if left idle for more than two hours. The final test is test if can display data properly on our online database.

Random test data was made to see if can display data properly. We set up three different cases to display data properly on our online web database. Case one has no data to display in our online web database, case two displays five data values, and case three display fifteen data values. We already made sure the web database can be opened by a user, so we just activate the web server and open the online web database. When we open the online web database, we ran case one first. The results are straight forward. The expected result is that we just have an empty table with no data and just the table headings. We got the expected results nothing unusual happened. Then I went ahead to the second case. The second case is where we have five data entries just before the limit where we make a new page to display data. We got to display data properly and everything came out as expected. The five data entries were displayed and nothing more was shown. The third case is where we display 15 data entries in our online web database. The fifteen data entries will make an additional page to display the excess data that can be accessed by pressing a button on the bottom of the database. The first page is displaying the first ten data entries. The second page is displaying the remaining ten data entries. The data is entered in order and no data is misplaced. Then I quickly switched back and forth between pages to see if any errors occurred. No errors were experienced during the changing of pages. After switching between pages, we observed how to change data dynamically with the online web database still open. When changing data being displayed, the web database still displayed data properly. We decreased the data entries from fifteen to five. The second page disappeared displaying the excess data for the online web database. We can display large amounts of data without having the online web database crash. The amount of data in we can display will vary on the amount of memory available in our device. The test was successful.

We thoroughly tested our online web database with different tests. The first test made sure that we could open and host a web page on our device. Then the second test made sure that our device hosting the web page can let other devices access the web page as well. The web page is our online web database. The online web database is not perfect and there are some limitations that we encounter. The first limitation was encountered in the second test. Our online web database cannot be left idle for more than two hours or else our device will become unresponsive. The third test we had was testing if we can display properly on our online web database. We entered in random data sizes to see if any data is not displayed properly. Data was added while the online web database was on and it added data correctly. The next limitation encountered is that we cannot display an infinite amount of data we are limited by our device's free memory.

D. *Testing Ethernet Connectivity Between Two FSOC Devices*

When trying to test for an ethernet connection for our communication channel, we had to take several factors in account. First being that autoconfiguration of a connection is not always accurate. We realized this as soon as we failed to establish a connection without any changes to our connection. To mitigate these limitations and to meet our feature, we went down the path of manually configuring our ethernet connection.

At first, we manually configured the IPv4 ethernet connection properties through network settings for one device to ensure that we had a private known network connection for one device. After this was set up, a ping test was done to confirm the connectivity of the ethernet connection. The results of one device ping test can we have seen in Figure A-42.

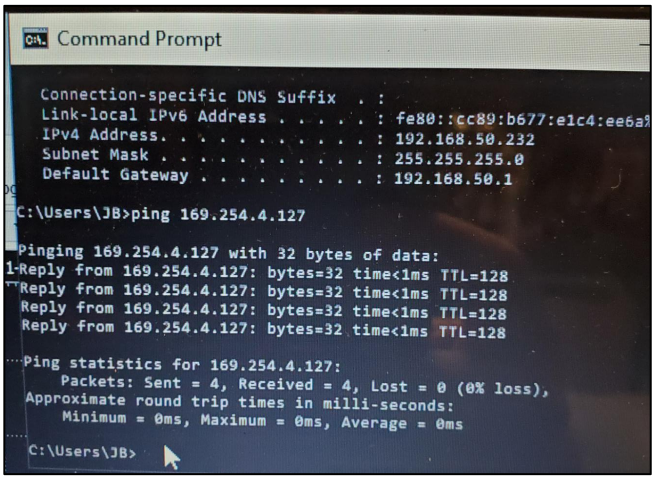


Figure A-42. Ethernet Connection Using Once Device.

Furthermore, now we had secured a communication channel by connecting a device with an ethernet cable to our FSOC device. We confirmed the ethernet connectivity using a ping test. The ping test successfully shows 4 packets being sent and received with 0% packet loss during the transmission. Each reply is received after reflecting the laser at a mirror to duplicate the connection of one device. The reply is from the duplicated, private known, manually configured IPv4 ethernet connection. It is important to note that during this manual configuration, we also set a metered connection of 10Mbps to meet the limitation of the circuitry of our FSOC device.

In relation, we now had confirmed a communication channel was active using an ethernet connection which was manually configured using one device. We wanted to dwell deeper into the project after meeting our feature and see if we can replicate this communication channel using an ethernet connection with two devices.

When manually configuring two different devices' ethernet connection, we had forgotten to consider that each device will generate its own IP address if it does not connect to a public DHCP server for a network connection. Usually, public network connection IP addresses first octet begins with "192." Since our device was dealing within a local privately setup network, meaning the IP addresses first octet would begin with "169", we neglected the gateway portion of our local network connection. Hence resulting in a failure when trying to make an ethernet connection across two different devices at a certain distance. Figure A-43 demonstrates the failed attempt of a ping test from one device to another. This results in a Destination Host unreachable error.

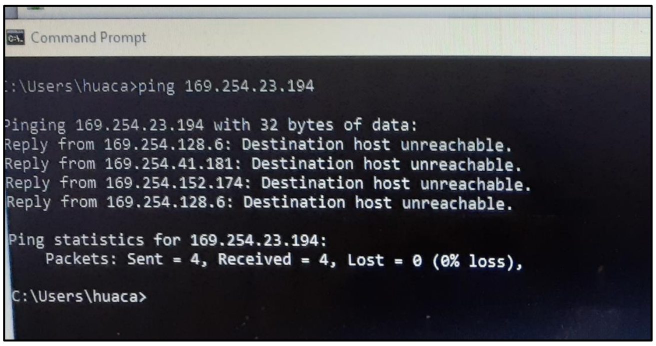


Figure A-43. Ethernet Connection Using Two Devices.

To try and troubleshoot this failed ping attempt, we even configured the default gateway of both devices to one another's. Figure A-44 reflects all the manual configurations of our private IPv4 ethernet connection with the default gateway being set to that of the other device, vice versa.

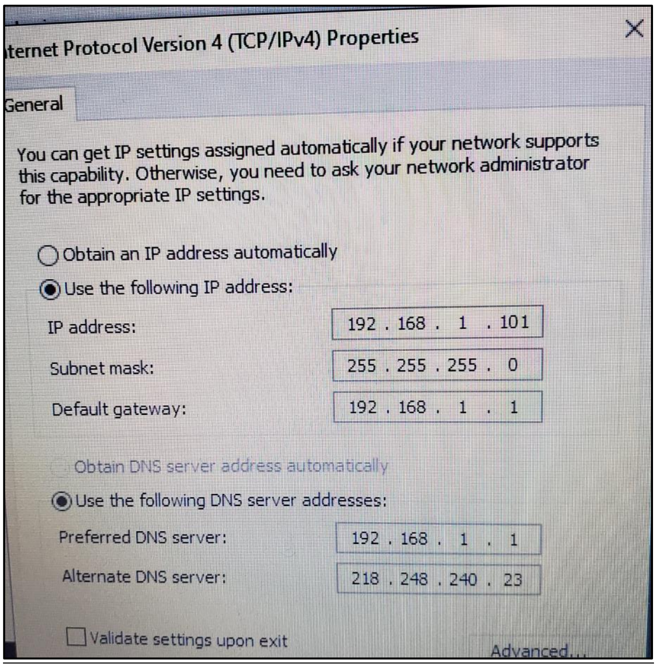


Figure A-44. IPv4 Manually Configured Network properties.

After ensuring all settings were correct for our private network's manual configuration for both devices, we continued to do a ping test. However, we reached a limitation as we continued to see an ethernet connection and failed to ping it through our communication channel between two devices as sometimes the connection would time out and other times destination host is unreachable. This led us to the conclusion that while our FSOC device can establish an ethernet connection through a communication channel with one device, it fails to do so with more than one device. The reason behind the failure is unknown as we could not pinpoint where the device's connection fails to communicate to the other end device.

TABLE 10.
PLANNED TESTS & THEIR RESULTS

Tests & Results				
Test Name	Description	Expected Results	Results	Pass/Fail
Socket Program Test	The test will have us making a socket program to test the type of data we can transfer rate with our device. Along with determining the transfer rate of our device.	We are expecting to have our device transfer data at 10Mbps. If the data being transferred with our device is less than 10Mbps we should not experience any data loss.	See page 28 under Section IV. Deployable Prototype: Sub-Section: Software: Sub-Section A	Pass
Power on Test	The test is to simply supply power to the device made. Making sure the device we have built turns on without any issues.	We expected the device to turn on properly. Along with having the computer's ethernet port recognize the device we made.	See page 34 under Section IV. Deployable Prototype: Sub-Section: Hardware: Sub-Section F part a)	Pass
Web Database Test	The test will be having two people access the web database at the same time. Along with having different data sizes that need to be displayed on the webpage.	We expect two people to access the web database at the same time with no issues. Then no matter the data size we have the web app should be able to display data properly	See page 29 under Section IV. Deployable Prototype: Sub-Section: Software: Sub-Section B	Pass
Testing Ethernet Connectivity for one FSOC device	This test consists of powering on one FSOC device connected to another device through an ethernet cable.	We expect to see a visible ethernet connection being established as well as a ping test with less than 25% packet loss.	See page 34 under Section IV. Deployable Prototype: Sub-Section: Hardware: Sub-Section F part b)	Pass
Testing Ethernet Connectivity between two FSOC devices (Optional Test)	This test consists of powering on two FSOC devices, each connected to a host device. The two devices are aligned within a 2-meter distance. Each host is connected to the devices using an ethernet cable.	We expect to see a visible ethernet connection being established as well as a ping test with less than 25% packet loss.	See page 35 under Section IV. Deployable Prototype: Sub-Section: Hardware: Sub-Section F part c)	Fail
Alert System Test	We will be using the humidity sensors, DHT11 and DHT22 to test humidity ranges. After getting an accurate average reading, we will be integrating an alert when desired in the socket program.	We expect to see an alert whenever the relative humidity is ≥65% for the alert system. This should only be displayed when a host tries to establish a connection to the server.	See page 29 under Section IV. Deployable Prototype: Sub-Section: Software: Sub-Section A part a)	Pass
Portability Test	We will see how fast we can set up our device and have a stopwatch to time ourselves.	We are expecting it to take no more than 20 to 30 mins to set up without having to rush. People can take their time and double check everything is fine.	See page 36 under Section IV. Deployable Prototype: Sub-Section: Hardware: Sub-Section: F part e)	Pass

Table 11.
Test Plan Schedule

<table>
<tr><th colspan="5">Fall Semester</th></tr>
<tr><th>Weeks</th><th colspan="2">Hardware</th><th colspan="2">Software</th></tr>
<tr><td>1 - 15</td><td colspan="2">Individual Tests assigned to Alex and Juan</td><td colspan="2">Individual Tasks Assigned to Giovanne and Ankita</td></tr>
<tr><td>7 - 15</td><td colspan="2">Review source design and documentation</td><td colspan="2" rowspan="2">Socket Program and Web app implementation</td></tr>
<tr><td>7 - 8</td><td colspan="2">Simulation Tests</td></tr>
<tr><td>9 - 10</td><td colspan="2">Simulation Tests</td><td colspan="2" rowspan="2">Socket Program Debugging</td></tr>
<tr><td>11- 12</td><td colspan="2">Simulation Tests</td></tr>
<tr><td>13 - 14</td><td colspan="2">Debugging: Power On</td><td colspan="2">Web Database Debugging</td></tr>
<tr><td>15</td><td colspan="2">Debugging: Power On</td><td colspan="2"></td></tr>
<tr><th colspan="5">Spring Semester</th></tr>
<tr><th rowspan="2">Weeks
1 - 15</th><th colspan="2">Hardware</th><th colspan="2">Software</th></tr>
<tr><td>Alex</td><td>Juan</td><td>Ankita</td><td>Giovanne</td></tr>
<tr><td>1 - 2</td><td>Testing with Triplett Lan (Fig. 44)</td><td>Mirror Test</td><td rowspan="2">Testing Alert System using DHT22 Temp/Humidity Sensor</td><td rowspan="2">Testing Alert System using DHT11 sensor.</td></tr>
<tr><td>3- 4</td><td colspan="2">Testing Connectivity between one device</td></tr>
<tr><td>5- 6</td><td colspan="2">Testing Connectivity between two devices</td><td colspan="2" rowspan="2">Testing Socket program and Alert System integration</td></tr>
<tr><td>7- 8</td><td colspan="2">Testing Connectivity between two devices</td></tr>
<tr><td>9 - 10</td><td colspan="2">Fast Deployment/Portability Test</td><td colspan="2">Web Database Test / Socket program Modification Test</td></tr>
<tr><td>11 - 12</td><td colspan="2">Fast Deployment/Portability Test</td><td colspan="2">Collect Test Results</td></tr>
<tr><td>13 - 14</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>15</td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

X. Marketability Forecast

Marketability Forecast Abstract — At the time of writing this report, we've are already begun to see the catalyst effects of COVID-19 on the technology sector. Right now, more than ever before, being connected online has become no less than an imperative. Even President Joe Biden has gone on record to say there are plans to make narrowing the digital divide an urgent policy for his administration. Because of these unexpected times, and urgency to get these regulations and programs online, the FSOC market capitalization is expected to reach, at least, an approximate 1 billion dollars by 2025.[41]

As of today, the digital divide continues to grow as the need for internet services is also growing. Our proposed device, the FSOC or free space optical communication basically is being developed for this need by including features such as: an optical communication channel. This channel will allow data to be transmitted and received at a fast rate without the need of wires or RF, radio frequency. The FSOC can be useful for ISPs or Internet Service Providers as they can increase their coverage in areas without any infrastructure to support Fiber Optic Cables. Also, it can be useful to consumers who want to set up a localized network for their own usage without any subscriptions. At last, the concept of this FSOC device is perfect for emergency contact in case of natural disasters and a localized network as it is a stand-alone device which not only cost effective but is quick to deploy.

A. Government

You can't have a discussion about the U.S. market without at least mentioning the U.S. government. The following excerpt is from a U.S. White House briefing dated January 20th, 2021. We think it speaks for itself when pertaining to the U.S. government's role.

"**Provide $130 billion to help schools to safely reopen**. Schools need flexible resources to safely reopen and operate and/or facilitate remote learning. The president's plan will provide $130 billion to support schools in safely reopening. **These funds can be used to** reduce class sizes and modify spaces so students and teachers can socially distance; improve ventilation; hire more janitors and implement mitigation measures; provide personal protective equipment; ensure every school has access to a nurse; increase transportation capacity to facilitate social distancing on the bus; hire counselors to support students as they transition back to the classroom; **close the digital divide that is exacerbating inequities during the pandemic**; provide summer school or other support for students that will help make up lost learning time this year; create and expand community schools; and cover other costs needed to support safely reopening and support students."

- The White House [[42]

B. Target Consumers

Internet need is continuously growing as consumers demand for faster speed and reliable connectivity. World Internet Service providers (WISPs) are trying to plan and address this need in rural areas. In the article, *Zyxt: A Network Planning Tool for Rural Wireless ISPs*, it is noted that about 45% of rural communities in the world's population are using dial-up internet connectivity which is ~9,000 bps and increasingly getting slower [30]. The idea of our device's communication channel can help mitigate this disparity as it is cost effective and can support a localized network of 10Mbps in comparison to the ~9,000 bps dial-up.

The increase in internet as discussed in the societal problem section has caused network traffic to occur more. This network traffic has affected enterprises and campuses here in the united states. Our FSOC device can help reduce network traffic as said by [[*30*] "OWTNs are effective solutions for the "last-mile" or "first-mile" problems. Even though optical fiber cables have been widely used, there are still many end-users who do not have their own fiber connection to the Fiber To The Home (FTTH) service. OWTN provides a high bandwidth connection over a large distance for remote end-users (e.g., residents in rural areas)". Now when [[*30*] refers to OWTN that means Optical Wireless Terrestrial Network which is a bigger scale project using FSO communication with satellites. The people on earth would send a beam of light to a satellite and the satellite sends the light to the proper location elsewhere on the planet. Our device has the potential to connect people in hard-to-reach areas here on earth to the internet. People who do not have fiber optic cables laid out or they do not want to use fiber optic cables we can use FSO communication device instead. The FSO communication gets rid of any negative performance issues which may have been experienced with fiber optic cables. We are providing people with more options to be connected to the internet. Our devices can be used to be connect to big internet providers, but our device can be used more locally too.

People at home may have their own personal network connecting devices together and our FSO communication device is perfect at doing the job. The author [[*30*] also talks about how FSO communication devices have been used in homes and offices. One of clear fact [[*30*] pointed out was that "OWHNs provide an effective solution to the proliferation of communication devices and services in office and home networks. OWHNs provide sufficient data rates and channel capacity at a low cost and are thus strong candidates for future home networks". Our FSO communication device could be a simple personal use device. The personal device is cheap compared to other options in the market that is not completely bad.

C. Competetors

Fiber Optic Cables – in natural disasters they get destroyed and cost a whole lot to repair. Our device is the backup temporary plan as it is cheap and stand-alone.

fSONA is an industry known company that sells free-space optical communication devices.

- http://www.fsona.com/technology.php
- https://www.youtube.com/watch?v=9sn3GFdFC0o

D. Classification

FSO systems sometimes called optical wireless communication (OWC) systems, employ Infrared (IR), visible light (VL), or ultraviolet light (UV) as the medium channel and can be deployed in four different environments: indoor, outdoor, space, and underwater. They are also classified according to range mode such as short, or long distance.

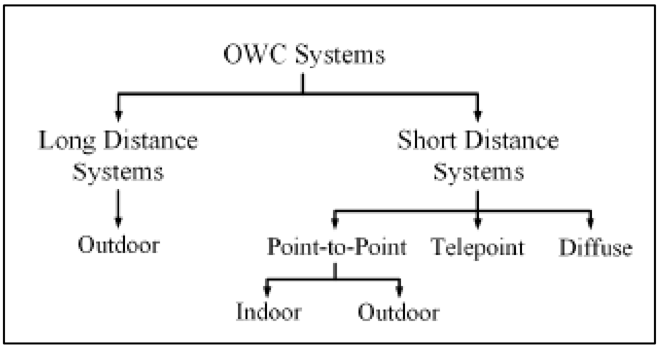


Figure A-45. OWC Systems Classification [[37]

According to [[37], our device is classified as an outdoor, point-to-point, short distance system with direct line-of-sight (see Figure above). Moreover, under a subset of OWC, it is also considered a visible light communication (VLC) system because it uses visible light to transmit data, with signals ranging between 780nm to 375nm. VLC is seen as a green system because it does not produce electromagnetic interference, thus it can be used in places where RF systems are not allowed.

E. Global Market Forecast

According to the Emergen Research website, the global market for free space optics communication technology is expected to increase at a compounded annual rate growth (CARG) of 33.3% by 2027 (see Figure A-1). As mentioned before, one of the main reasons for this boost, has been the demand for fast internet connectivity and data transmission. The need for a secure and flexible high speed wireless communication market has also amplified. Additionally, the potential integration of 3G, 4G, 5G and future wireless technologies to enhance FSO systems performance, along with restrictions in other communication technologies that utilize copper wires, fiber cables, and/or radio frequency, have created a new expansion for low-cost communication technology. About 3.5 billion dollars forecasted by 2027 in revenue, 2 billion in the data transmission segment alone. The VLC global market alone is predicted to grow at a much faster rate than FSOC systems in general. However, since VLC devices fall under a broad classification, we have narrowed down the forecast to optical laser communication market. This market took a hit due to the pandemic and US-China trade war, however, it is still expected to grow and continue to remain steady with a CARG of about 13% to 14% by 2024.

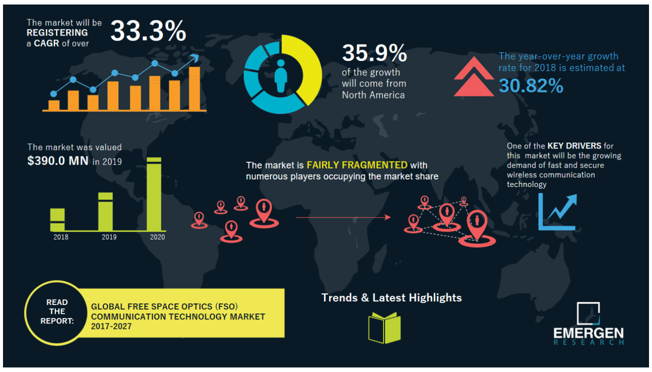


Figure A-46. Global Free Space Communication Market Forecast [36]

F. Cost Analysis

To obtain a better and more realistic estimation we were able to compare prices with a similar device. One of our inspirations was the Twibright Lab's RONJA project, able to deploy a transceiver capable of achieving the same data transmission speed. Their Metropolis model, a 10Mbits/s point-to-point full duplex link that can achieve data transmissions over a range of 0.85 miles. According to their website, as of October 2017 they have registered 153 installations. This model was listed at about $114.85 for materials and electric components only and requires about 70 hours of labor to build.

Furthermore, according to BroadbandUSA [[38], a program from the National Telecommunication and Information Administration (NTIA), the cost for a network transceiver in 2017 was around $100 to $500 dollars. Assuming there were no costs associated with buried fiber deployment which can easily bring up the cost to hundreds of thousands of dollars. These were two of the closest comparisons we were able to find based on functionality and specs. As mentioned before, the cost for one FSOC Nation transceiver is around $71.62 (materials and shipping only). Therefore, based on the previous assessments, it has been decided that the cost of one transceiver will be $120 dollars. On one side, to account for future modifications during the semester, and on the other, to continue achieving a low-cost feature.

XI. Conclusion

In conclusion, our team was able to produce a FSOC system that connected two computers wirelessly to the ethernet. Admittedly, however, the system we were able to construct had its faults. For example, although we had a channel, in the end, we determined, as Sven does in his experiment with the system, that this particular system is too sensitive to line of sight.

That being said, our rudimentary FSOC system is still capable of proving that the potential impact of this technology is profound. As we've discussed in length, we hold a firm conviction that FSOC technology will inevitably become the industry standard.

A. *Socital Problem*

The ditital divide shows the issue of internet disparity through out the entire world. Internet acess speed is not evenly availbe to everybody. Then the communcation system we have currently is not perfect either. Issues are present in our current communcation system. To be more specific optic fiber cables are not perfect. The optic fiber cables comes with issues like broken underground lines. The breaking of the optic fiber cables takes both a lot of time and money. Money and time a resource which everybody may not be able to afford. We want to propose the idea of an FSOC to help with the issue of optic fiber cables. The FSOC device will be a small portable device which can be placed instead of the optic fiber cables. The device since it is small will not require all the space that optic fiber cables use. Then the FSOC device will be using a frequncy which is not going to be interferring with other communication signals currently out. Since the FSOC device is not using an interferring signal it will be less invase than optic fiber cables. Now the FSOC device is above ground the repares of the device is fast and the deployment of the device is also fast. The fast deployment speed makes the device good to use during emergencies because we can establish a network fast. First responders can use the FSOC device to have a reliable internet to communicate and send help to the right location to help first.

B. *Design Idea*

The FSOC is made by using components such as a transmitter and a reciver. The transmisstion device will include a laser to send messages out. Next the reciver has a photodiode to collect the data being transferred from the transmitter.The photodiode will be using a special component called a dc bosster to bounce the incomming signal to see the signal. Along with the special componts such as the laser and the photodiode we will be using smaller compnents such as op amps, capaciters, and resistors. The FSOC device is planned to built on a pc board and the device should be able to transmite data about two meters . Following the hardware device we will be using a raspberry pi connected to the device with an ethernet cable to send the messages in our FSOC device. The raspberry pi will allow our FSOC device to send these reliable messages by sending packets of information using TCP/IP protocals. The IPv protcal we will be using is IPv4 because it is the current protocal being used in the optic fiber cables. Then we will set up software to calculate the transfer rate of the messages being sent. Along with sending messages software will be inclused to make an online database to store information. Information such as the messages sent/recived and the time messages are recived/sent. The online database can be used to detect any errors which may occure in our system for certain messges not sent well. The FSCO device does some come with some ocupational safety concerns. The saftey concerns will require us to post signs around our working area to warn people about our device. The FSCO device will be using a laser wich can cause both skin and eye damage if exposed to the laser for long periods of exposer that exced the OSHA standers for not being hazardous.

C. *Work Breakdown*

The way we achieved in creating our FSOC device is by completing small tasks slowly leading up to the final deployable device. The small tasks revolve around the features we included for device in the punch list. Then we made a table to showing all the tasks that are under the main features. The table is our work breakdown structure, and we briefly describe all the smaller tasks. The work breakdown structure is used as a reminder to us, so the team knows what needs to be done.

D. *Project Timeline*

Along with the work breakdown structure there is a timeline for planning out when tasks had to be done. The timeline has listed out all the project milestones. There are two different ways we represent the project milestones. The first is the graphical description as seen the project milestone section. The second representation of the timeline is in a table format which clearly states what each has done. The table for the timeline is located in the appendix.

E. *Risk Assessment*

The FSOC device has a variety of different risks attached to it. The team decided to split the risk into three different categories hardware risk, software risk, and personal risk. The majority of the project's risk stems from the hardware. A minority of risks include malfunctioning parts like a resistor or capacitor. The biggest risk was in the delivery of our PCB boards during the pandemic. A replacement PCB board would take too long a time to actually obtain. Unfortunately, we did encounter this issue. However, we were still able to successfully proceed with the project despite the delays.

There were also risks in the software end. Program crashes, if a program crashes, then we just debug the program with specific tools we have in place for debugging the code. Now the least probable risk that has the highest impact on not functionality of the project, but people. The FSOC device is using a laser, so we need to make sure we set up the device in such a place that is not going to harm others. We will include shields too to protect people from our device.

F. *Device Test Plan*

Our team then entered the phase of the project where we must show that, with data from our experiments, that our device is capable of meeting the feature set that we've committed to. In order to achieve this, each group member has been tasked to test the limitations of our device. We are using two table, one to keep track of the different experiments we plan on conducting and the second to make sure we're on schedule. Testing will continue for many weeks and this report will continue to adjust accordingly.

G. Testing Results

After seven months of testing this without question this was the most difficult part of the project. And that was because many times we were afraid that we were going to be unable to meet our feature set. For example, there was the time when fuses kept blowing out, after that there was the line-of-sight issue, and then there was the problem with the pining. However, throughout all the turbulence we were able to keep to our critical path of success. As a group we were eventually able overcome all the setbacks and the result is a an FSOC system that met our measurable metrics and feature set. However, although our device did, in fact, meet all of those features, it is not a perfect system. Ultimately, we think it should be emphasized that our experiment with FSOC systems succeeded in achieving its primary objective: showing that FSOC systems are a cost-effective alternative to addressing our digital divide.

H. Marketability Forecast

Finally, we believe that the future for FSOC systems is very bright. Not only because of the proven technology, as our experiment attempted to convey, but also because of the political climate. As we mentioned, President Biden's Administration, along with a majority of voters, are marching towards an infrastructure revolution. Perhaps one that we have not seen since the early 1900's. As of this writing, the administration has proposed a clean 100 billion specifically to address broadband infrastructure. [43]

Acknowledgment

Throughout our entire senior design experience, we were guided by exceptional CSUS professors that made our path to success a positive outcome. From helping us understand the nature of the circuit, have the design ready for PCB manufacturing, all the way to debugging process and establish an ethernet connection. Team 3 FSOC Nation would like to thank Professors Matthew Thomas and Carl Haynie for helping with circuit analysis. Professor Kristopher Moyer for introducing us to the PCB manufacturing world and helping us obtain the files needed for manufacturing. And last but not least, Professors James Cottle, Neal Levine, and Russ Tatro who prepared us for what is expected out in the professional engineering industry.

References

[1] "California State University, Sacramento," *Wikipedia*, 30-Sep-2020. Image of CSUS logo on cover the page. Available: https://en.wikipedia.org/wiki/California_State_University,_Sacramento. [Accessed: 01-Oct-2020].

[2] "Global State of Mobile Networks (August 2016)," *Opensignal*, 27-Oct-2019. [Online]. Available: https://www.opensignal.com/reports/2016/08/global-state-of-the-mobile-network. [Accessed: 23-Oct-2020].

[3] "Taara," X, the moonshot factory. [Online]. Available: https://x.company/projects/taara/. [Accessed: 23-Oct-2020].

[4] Aditi Malik, Preeti Singh, "Free Space Optics: Current Applications and Future Challenges", *International Journal of Optics*, vol. 2015, Article ID 945483, 7 pages, 2015. Available: https://doi.Aorg/10.1155/2015/945483.

[5] Ronja.twibright.com. 2020. Home. [online] Available at: <http://ronja.twibright.com/> [Accessed 22 September 2020].

[6] S. Brauch, "Linux, Games, Programming and some random science stuff," 19-Feb-2017. [Online]. Available: http://blog.svenbrauch.de/2017/02/19/homemade-10-mbits-laser-optical-ethernet-transceiver/. [Accessed: 21-Sep-2020].

[7] J. Strickland, "How Does the Internet Work?" *HowStuffWorks*, 07-May-2010. [Online]. Available: https://computer.howstuffworks.com/internet/basics/internet.htm. [Accessed: 23-Oct-2020].

[8] "How technology is improving the standard of living in developing countries," The NYU Dispatch, 14-May-2018. [Online]. [3] Available: https://wp.nyu.edu/dispatch/2018/03/07/how-technology-is-improving-the-standard-of-living-in-developing-countries/. [Accessed: 02-Oct-2020].

[9] "Digital divide," Wikipedia, 26-Sep-2020. [Online]. Available: https://en.wikipedia.org/wiki/Digital_divide. [Accessed: 02-Oct-2020].

[10] U.S. Department of Commerce, National Telecommunications and Information Administration (NTIA). (1995). Falling through the net: A survey of the have nots in rural and urban America. Retrieved from, http://www.ntia.doc.gov/ntiahome/fallingthru.html.

[11] Anita Ramsetty, Cristin Adams, Impact of the digital divide in the age of COVID-19, Journal of the American Medical Informatics Association, Volume 27, Issue 7, July 2020, Pages 1147–1148, https://doi.org/10.1093/jamia/ocaa078

[12] (2020) A Voice from the frontline: the role of risk communication in pandemic response, Journal of Communication in Healthcare, 13:1, 6-9, DOI: 10.1080/17538068.2020.1758427

[13] UNICEF, "The State of the World's Children 2017: Children in a Digital World," 06-Dec-2017. [Online]. Available: https://www.unicef.org/publications/index_101992.html. [Accessed: 23-Oct-2020].

[14] EL Khaled, Z., & Mcheick, H. (2019). Case studies of communications systems during harsh environments: A review of approaches, weaknesses, and limitations to improve quality of service. International Journal of Distributed Sensor Networks. https://doi.org/10.1177/1550147719829960

[15] Technical report on telecommunications and disaster mitigation, Version 1.0, 06/2013. Geneva: ITU-T Telecommunication Standardization Sector of ITU, ITU-T Focus Group on Disaster Relief Systems, Network Resilience and Recovery, 2013.

[16] Roser, M Ritchie, H. Natural catastrophes, 2018. https://ourworldindata.org/natural-catastrophes

[17] Nelson, C, Steckler, B, Stamberger, J. The evolution of hastily formed networks for disaster response technologies case studies and future trends. In: Proceedings of the IEEE global humanitarian technology Conference, 2011, https://ieeexplore.ieee.org/document/6103680

[18] Menon, VG, Pathrose, JP, Priya, J. Ensuring reliable communication in disaster recovery operations with reliable routing technique. Mob Inf Syst 2016; 2016: 9141329.

[19] "Keeping the Internet up and Running in Times of Crisis." OECD, 2020, www.oecd.org/coronavirus/policy-responses/keeping-the-internet-up-and-running-in-times-of-crisis-4017c4c9/.

[20] "The Cost of Building and Launching a Satellite," Globalcom Satellite Phones. [Online]. Available: https://globalcomsatphone.com/costs/. [Accessed: 05-Oct-2020].

[21] "Promoting Cooperative Solutions for Space Sustainability: Secure World," Promoting Cooperative Solutions for Space Sustainability | Secure World. [Online]. Available: https://swfound.org/. [Accessed: 05-Oct-2020].

[22] Hörack, G., Pezzei, P., Leitgeb, E., & Tischlinger, M. (2016). Economic aspects of free space optics as an alternative broadband network connection for the last mile. In Proceedings of the 2016 10th International Symposium on Communication Systems, Networks and Digital Signal Processing (pp. 1-5). IEEEXplore. https://doi.org/10.1109/CSNDSP.2016.7574021

[23] "Design of Integrated Circuits for Optical Communications, 2d Ed." Vol. 27, no. 6, 2012, pp. Reference & Research Book News, 2012–12-01, Vol.27 (6).

[24] H. Ayers, P. Crews, H. Teo, C. McAvity, A. Levy and P. Levis, "Design Considerations for Low Power Internet Protocols," 16 th International Conference on Distributed Computing in Sensor Systems, Marina del Rey, CA, USA, September 1, 2020

[25] H. Frystyk, The Internet Protocol Stack, Jul-1994. [Online]. Available: https://www.w3.org/People/Frystyk/thesis/TcpIp.html. [Accessed: 23-Oct-2020].

[26] Raj, A, et al. "Terrestrial Free Space Line of Sight Optical Communication (TFSLSOC) Using Adaptive Control Steering System with Laser Beam Tracking, Aligning and Positioning (ATP)." 2010, pp. 1–5.

[27] C. O. S. H. A. Division of Occupational Safety and Health, "Cal/OSHA," Organization Title. [Online]. Available: https://www.dir.ca.gov/dosh/. [Accessed: 23-Oct-2020].

[28] M. Zemaitis. "Electrical Injuries." Ncbi.nlm.nih.gov. [Online] Available: https://pubmed.ncbi.nlm.nih.gov/28846317/ [Accessed on Nov 2, 2020].

[29] Eater B, "Analyzing actual Ethernet encoding / Network tutorial," 29-Oct-2014. [Online]. Available: youtube.com/watch?v=i8Cmibhvz0c. [Accessed: 21-Mar-2021].

[30] Thomas Pötsch, Salman Yousaf, Barath Raghavan, and Jay Chen. 2018. Zyxt: A Network Planning Tool for Rural Wireless ISPs. In <i>Proceedings of the 1st ACM SIGCAS Conference on Computing and Sustainable Societies</i> (<i>COMPASS '18</i>). Association for Computing Machinery, New York, NY, USA, Article 16, 1–11. DOI:https://doi.org/10.1145/3209811.3209874

[31] I. K. Son and S. Mao, "A survey of free space optical networks," Digital Communication and Networks, vol. 3, no. 2, pp. 67-77, 2017, doi:https://doi.org/10.1016/j.dcan.2016.11.002.

[32] How the TCP/IP Protocols Handle Data Communications - System Administration Guide: IP Services, 1 Aug. 2011, docs.oracle.com/cd/E18752_01/html/816-4554/ipov-29.html.

[33] S. Ghoname, H. A. Fayed, A. A. El Aziz and M. H. Aly, "Performance analysis of FSO communication system: Effects of fog, rain and humidity," 2016 Sixth International Conference on Digital Information Processing and Communications (ICDIPC), Beirut, 2016, pp. 151-155, doi: 10.1109/ICDIPC.2016.7470809.

[34] Packet Clearing House, Internet exchange point directory reports. Retrieved on Wednesday 14th of October from http://www.pch.net/ixpdir/summary

[35] Rokkas, Theodoros & Kamalakis, Thomas & Katsianis, Dimitris & Varoutas, Dimitris & Sphicopoulos, Thomas. (2007). Business Prospects of Wide-Scale Deployment of Free Space Optical Technology as a Last-Mile Solution: A Techno-Economic Analysis. Journal of Optical Networking - J OPT NETW. 6. 10.1364/JON.6.000860.

[36] "Free Space Optics Communication Technology Market By Platform (Airborne, Terrestrial, Satellite), By Application (Disaster Management, Last Mile Access, Data Transmission, and Others), By End-Use (Healthcare, Defense, Telecommunication, Others), By Region Forecasts to 2027," Emergen Research. Available: https://www.emergenresearch.com/industry-report/free-space-optics-communication-technology-market. [Accessed: 20-Feb-2021].

[37] A.S. Hamza, J. S. Deogun and D. R. Alexander, "Classification Framework for Free Space Optical Communication Links and Systems," in IEEE Communications Surveys & Tutorials, vol. 21, no. 2, pp. 1346-1382, Secondquarter 2019, doi: 10.1109/COMST.2018.2876805.

[38] "Costs at-a-Glance: Fiber and Wireless Networks," BroadbandUSA. Available: https://broadbandusa.ntia.doc.gov/sites/default/files/resource-files/networkcosts_factsheet_may_2017.pdf [Accessed: 20-Feb-2021].

[39] G. Alonso, "LTspice: Generating Triangular & Sawtooth Waveforms," LTspice: Generating Triangular & Sawtooth Waveforms | Analog Devices. [Online]. Available: https://www.analog.com/en/technical-articles/ltspice-generating-triangular-sawtooth-waveforms.html. [Accessed: 01-Nov-2020].

[40] Amazon.com: Triplett Line-Bug 4 Telephone and LAN Line Tester - Detect Damaging Currents on RJ11 and RJ45 Lines (9615): Industrial & Scientific. [Online] Available: https://www.amazon.com/Triplett-Line-Bug-Phone-Line-Tester/dp/B0002THPO8. [Accessed on Feb 2, 2021].

[41] "Free Space Optics (FSO) Communication Market Analysis, Size, Trends, Forecast 2025," *www.transparencymarketresearch.com*. https://www.transparencymarketresearch.com/free-space-optics-market.html (accessed May 02, 2021).

[42] "President Biden Announces American Rescue Plan," *The White House*, Jan. 20, 2021. https://www.whitehouse.gov/briefing-room/legislation/2021/01/20/president-biden-announces-american-rescue-plan/.

[43] "Biden proposal include $100 billion for power infrastructure," *Energy Central*, Apr. 06, 2021. https://energycentral.com/news/biden-proposal-include-100-billion-power-infrastructure (accessed May 03, 2021).

GLOSSARY

Bandwidth A range of frequencies within a given band, in particular that used for transmitting a signal.

Communication means of sending or receiving information, such as telephone lines or computers.

Debugging identify and remove errors (from computer hardware or software).

Encoding Convert (information or an instruction) into a particular form.

Full-Duplex A point-to-point communication system with two or more connected devices capable of communicating between one another in both directions.

Internet Protocol (IP) Set of rules that define how data is sent over the internet or other network.

Laser a device that generates an intense beam of coherent monochromatic light (or other electromagnetic radiation) by stimulated emission of photons from excited atoms or molecules.

Protocol a set of rules governing the exchange or transmission of data between devices.

Transceiver a device that can both transmit and receive communications, in particular a combined radio transmitter and receiver.

Transmission Control Protocol (TCP) A standard that defines how to establish and maintain a network conversation through which application programs can exchange data.

Telecommunication Communication over a distance by cable, telegraph, telephone, or broadcasting.

Ultra-wideband Radio technology that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum.

APPENDICES

APPENDIX FIGURES

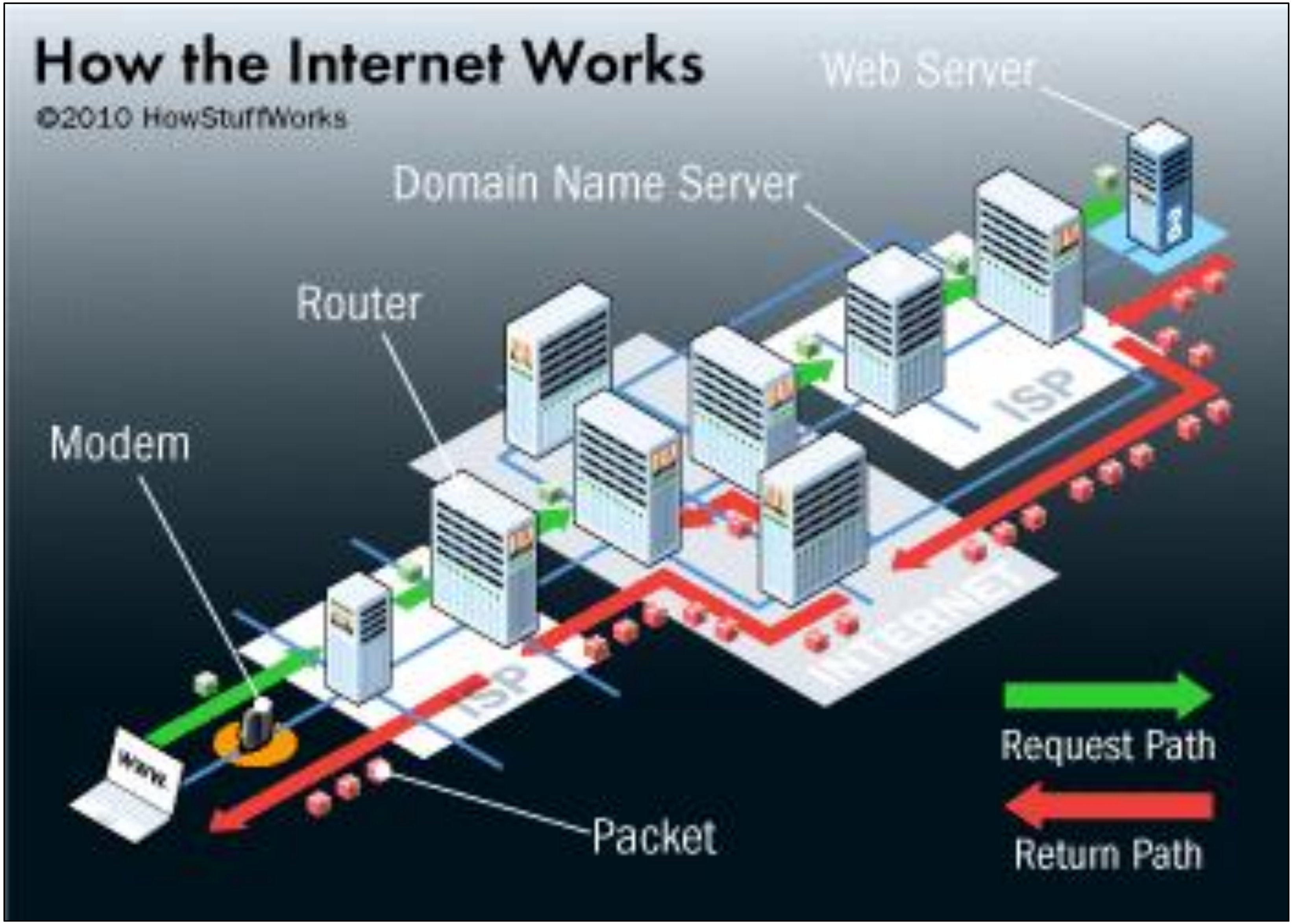


Figure A-1. How the Internet Works

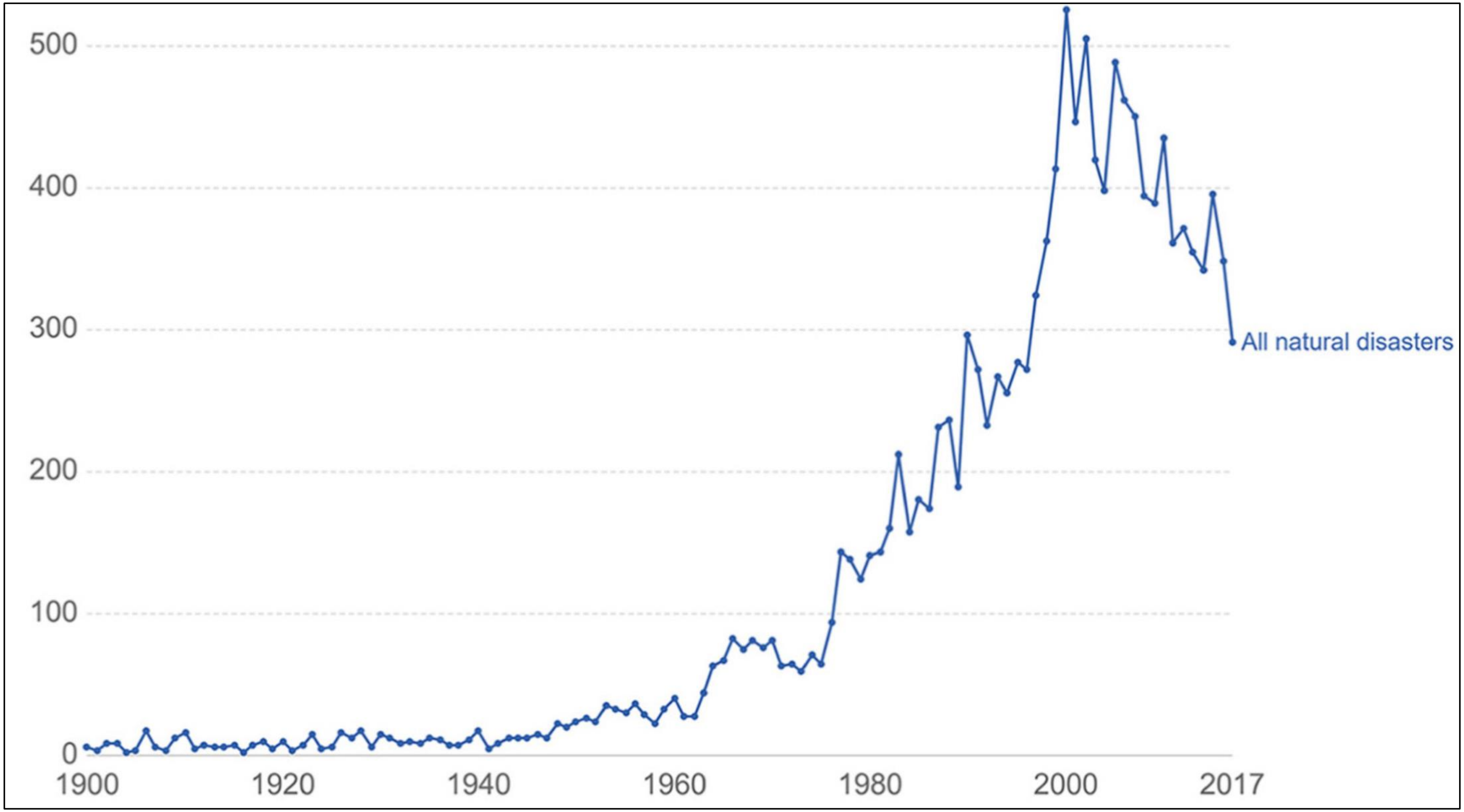


Figure A-2. Global total number of people affected by ND. This is defined as the sum of the people who were injured, affected, and left homeless after a disaster.

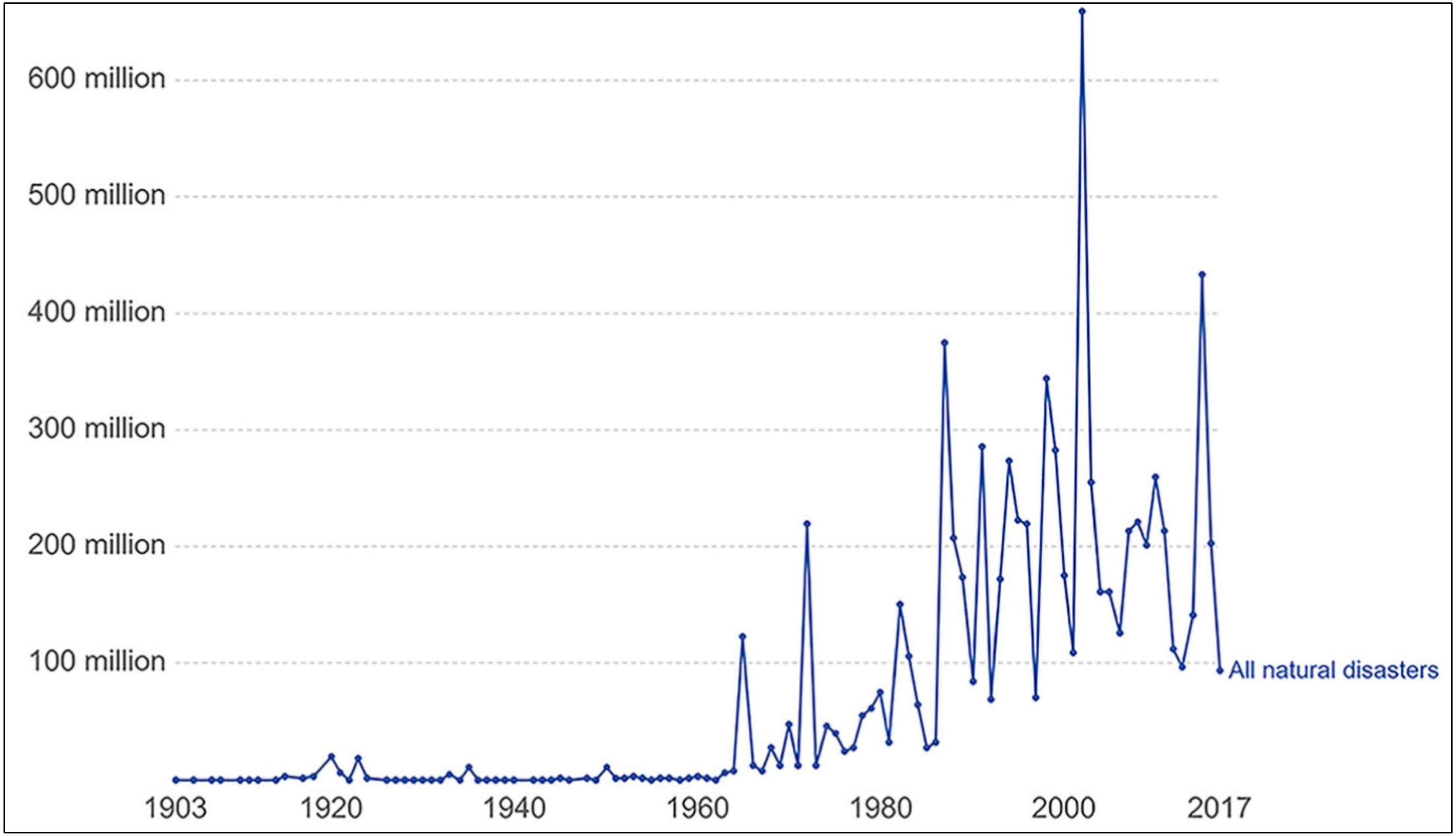


Figure A-3. The number of global reported ND events. This includes those from drought, floods, biological epidemics, extreme weather, extreme temperature, landslides, dry mass movements, wildfires, volcanic activity, and earthquakes.

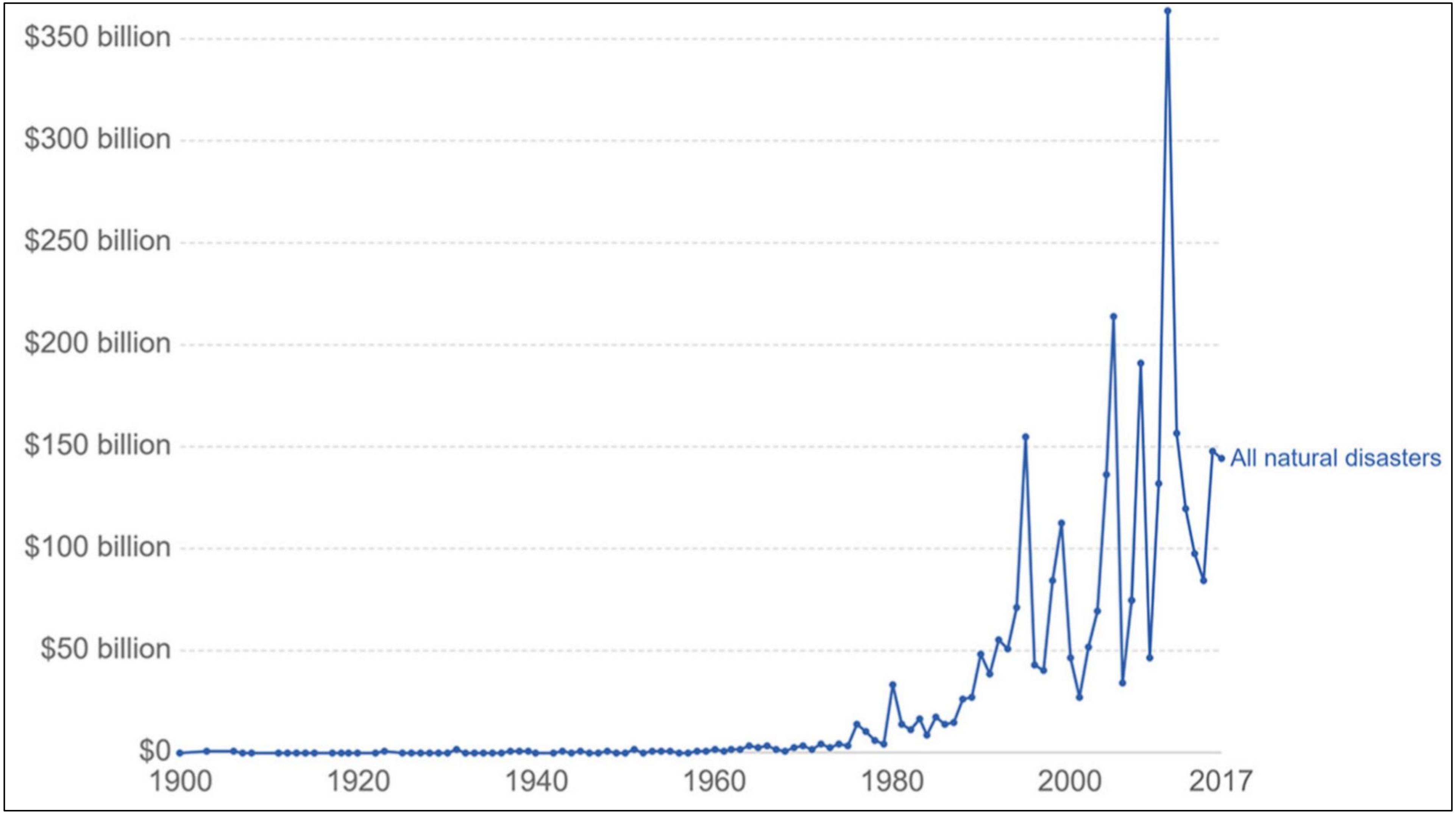


Figure A-4. Total economic cost of damages as a result of global ND in any given year, measured in current US$, includes those from drought, floods, biological epidemics, extreme weather, extreme temperature, landslides, dry mass movements, extraterrestrial impact.

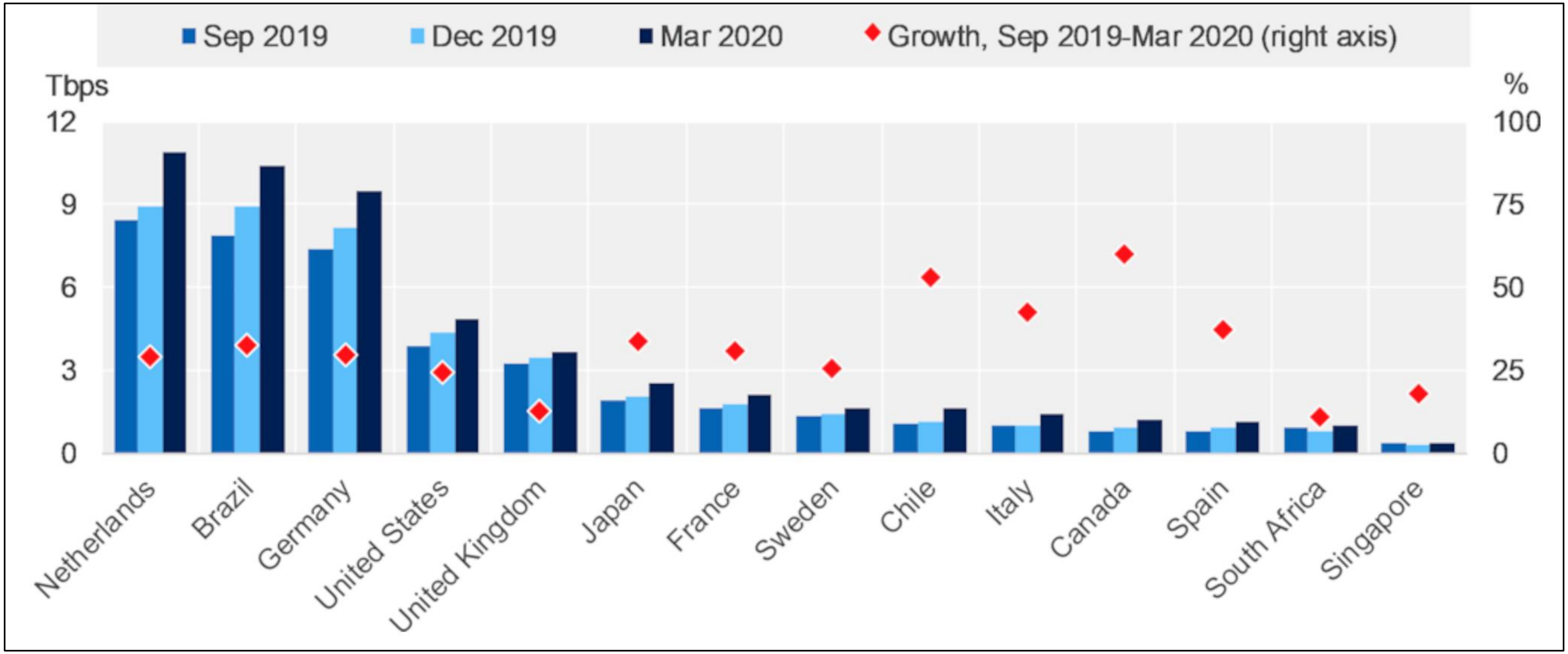


Figure A-5. Internet bandwidth at Internet exchange points, by country.

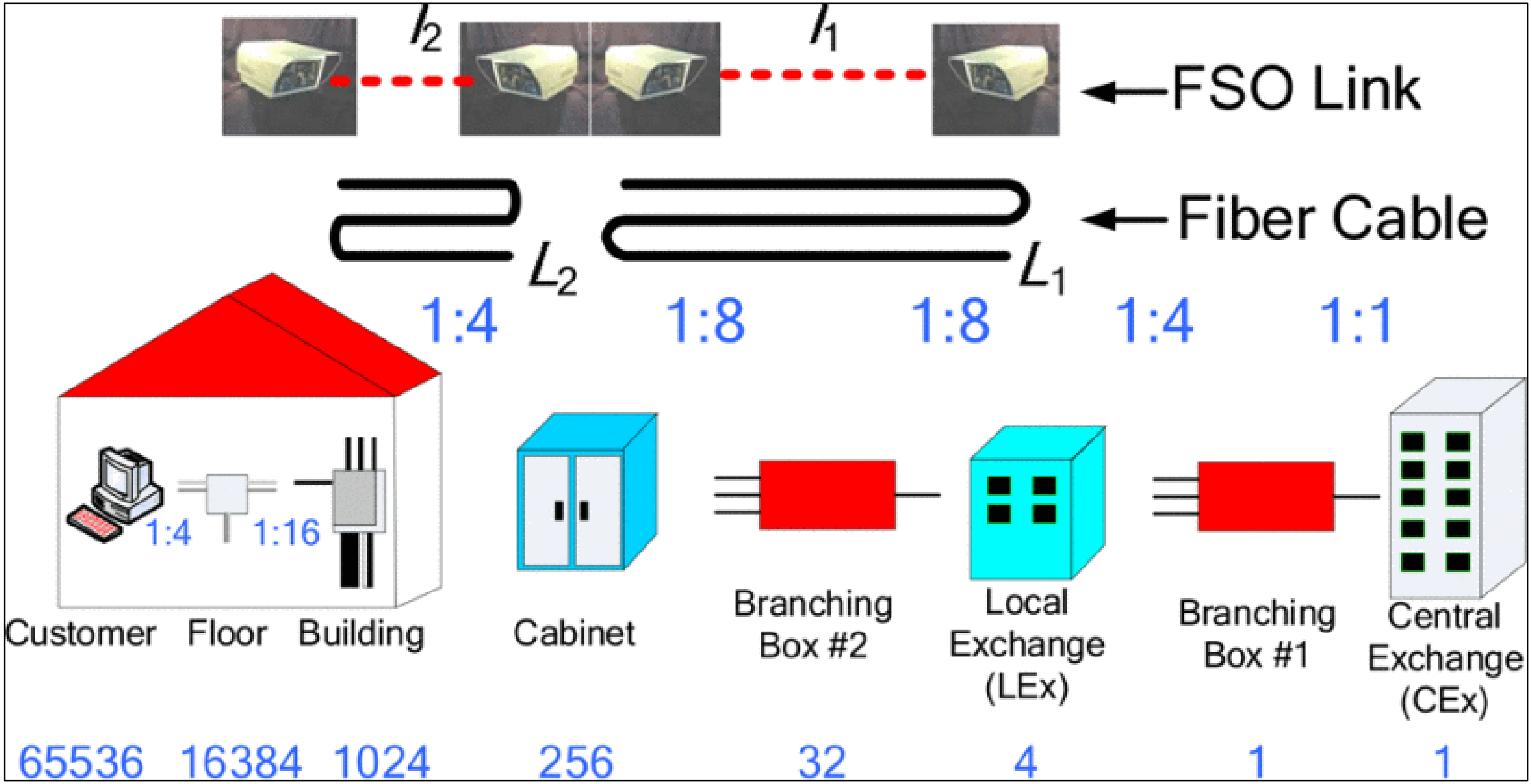


Figure A-6. A dense urban area geometric model.

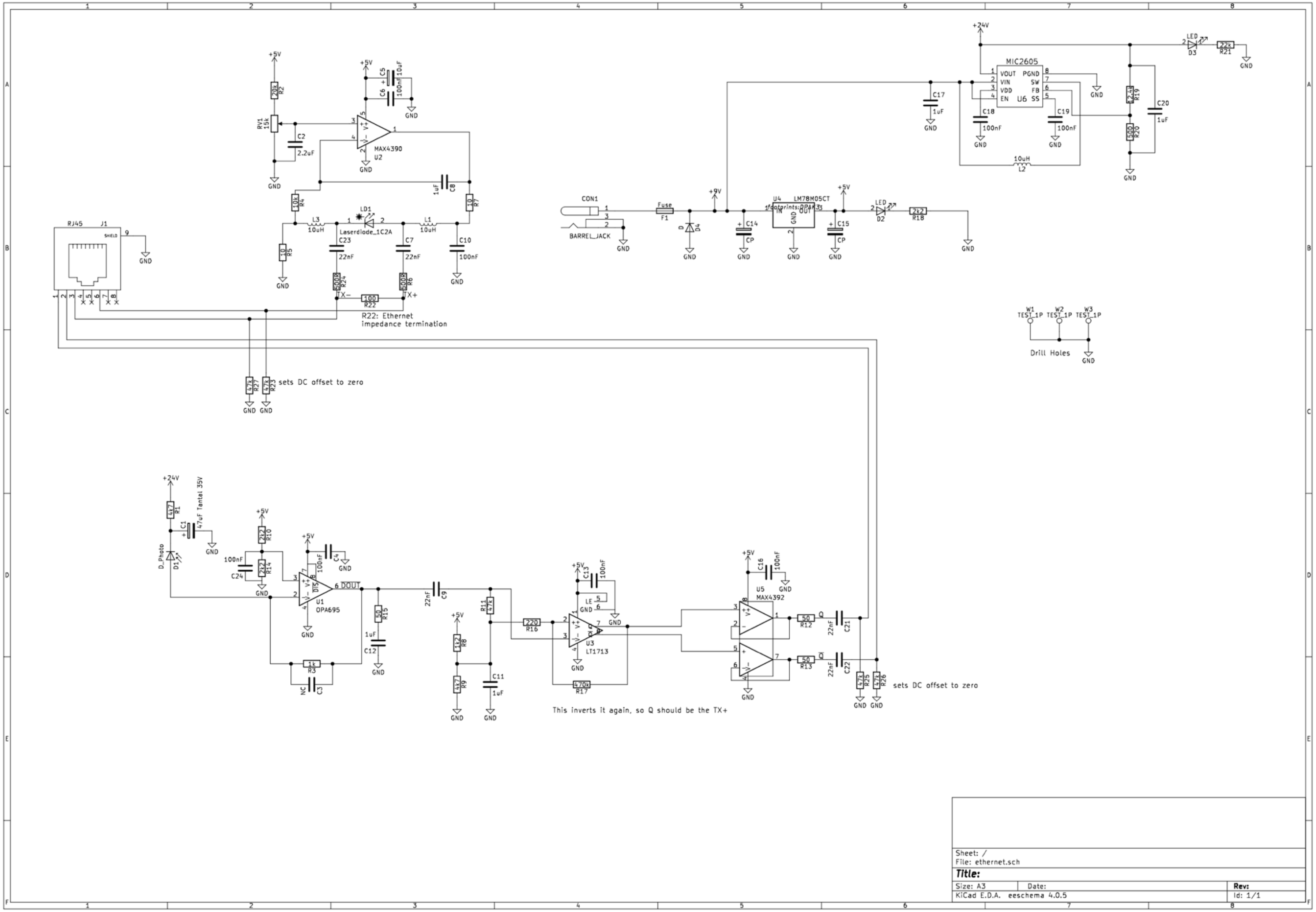


Figure A-7. Design chosen for the project. [[6]

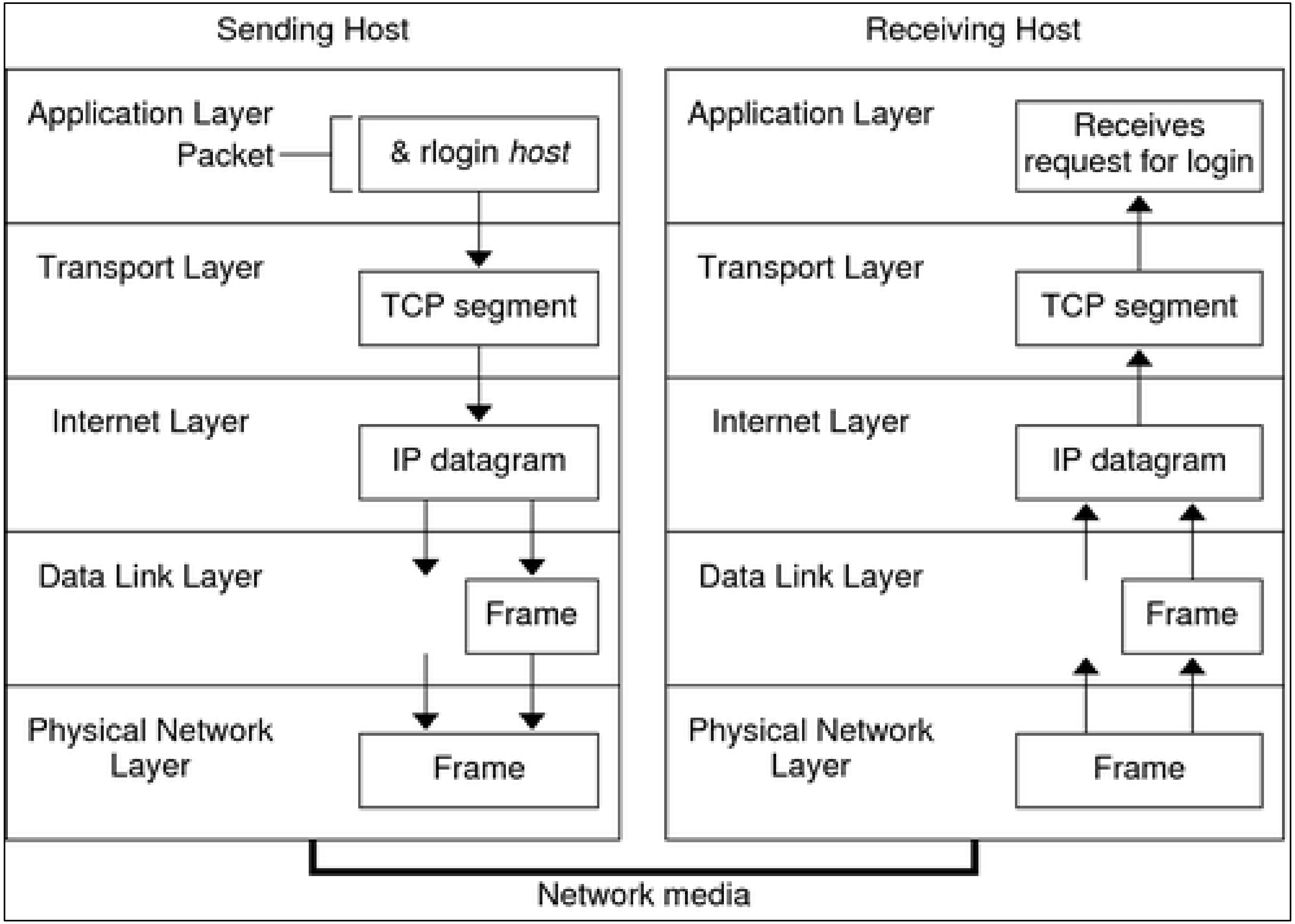


Figure A-8. Internet Protocol Layers [].

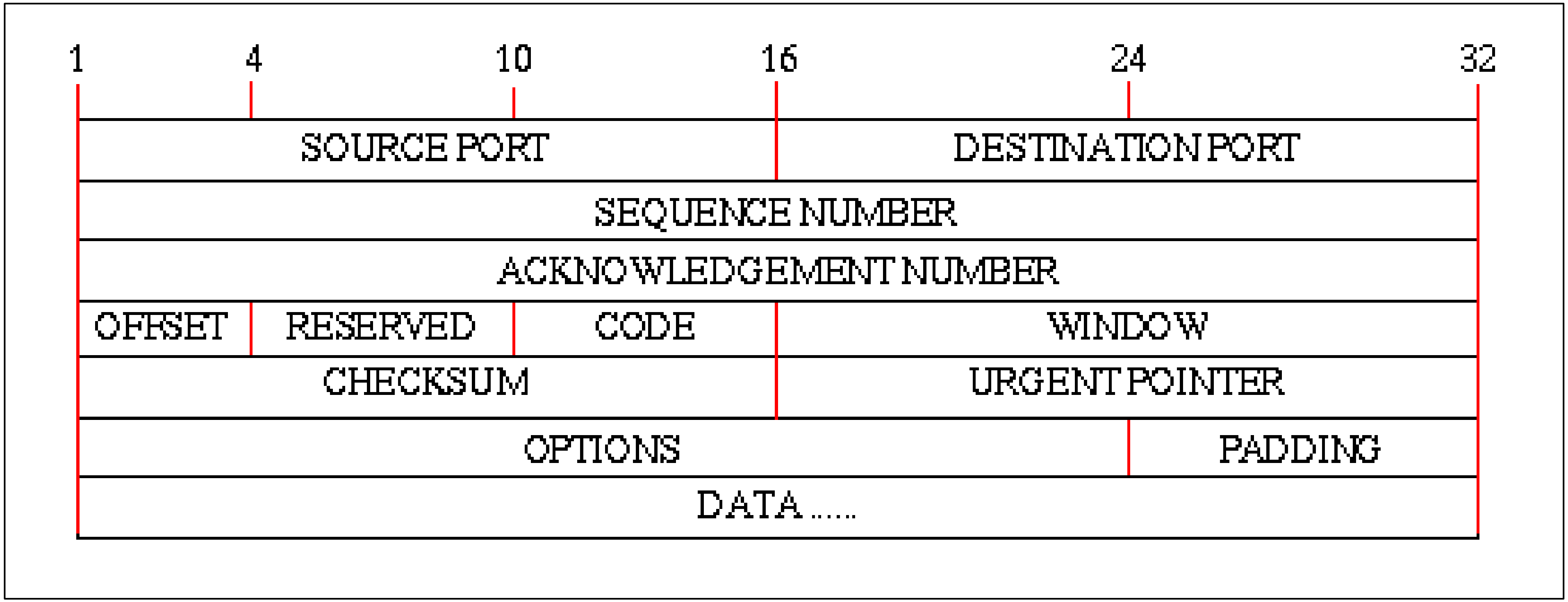


Figure A-9. TCP Segment Header Format.

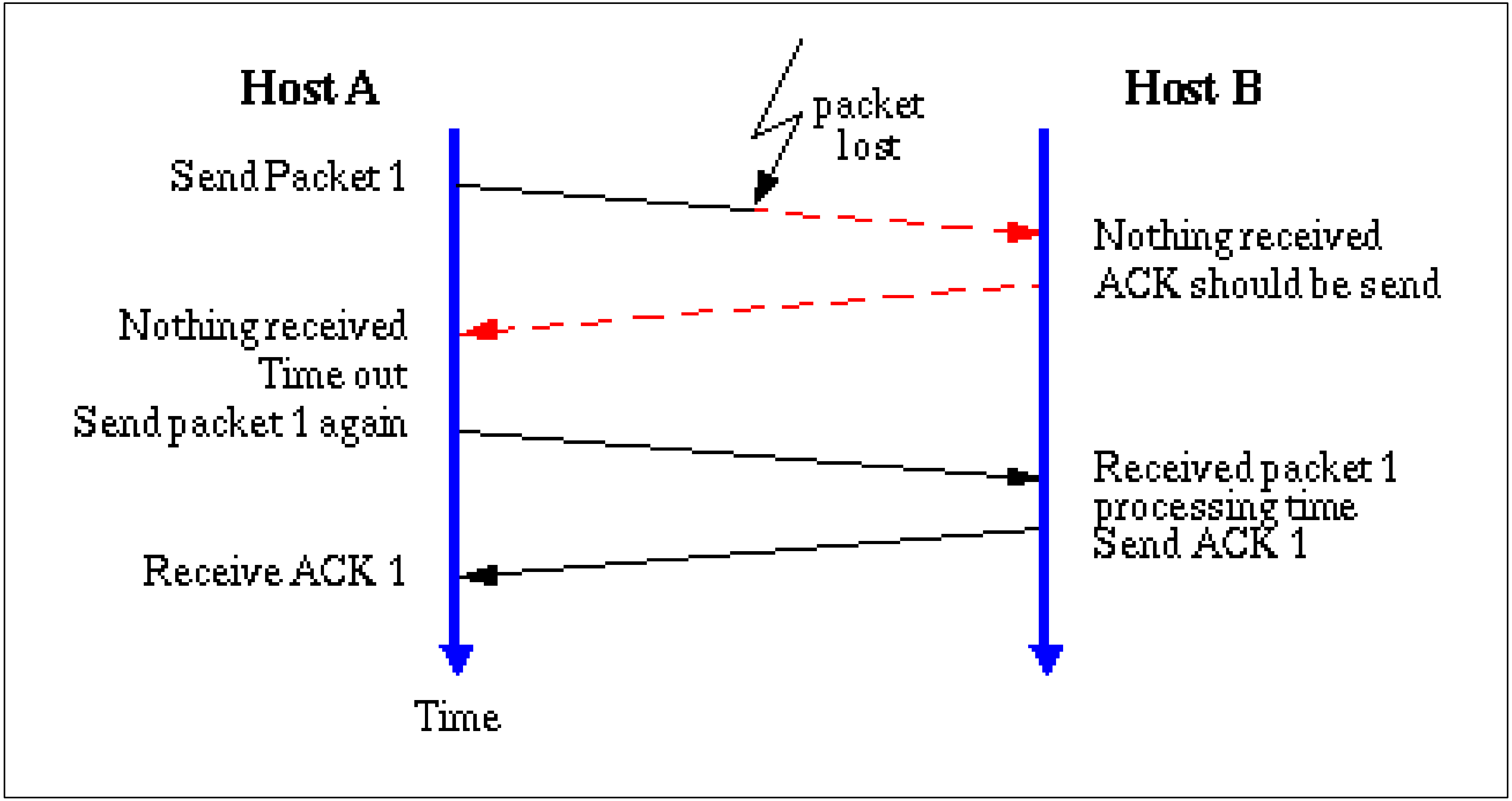


Figure A-10. Data transmission between two devices.

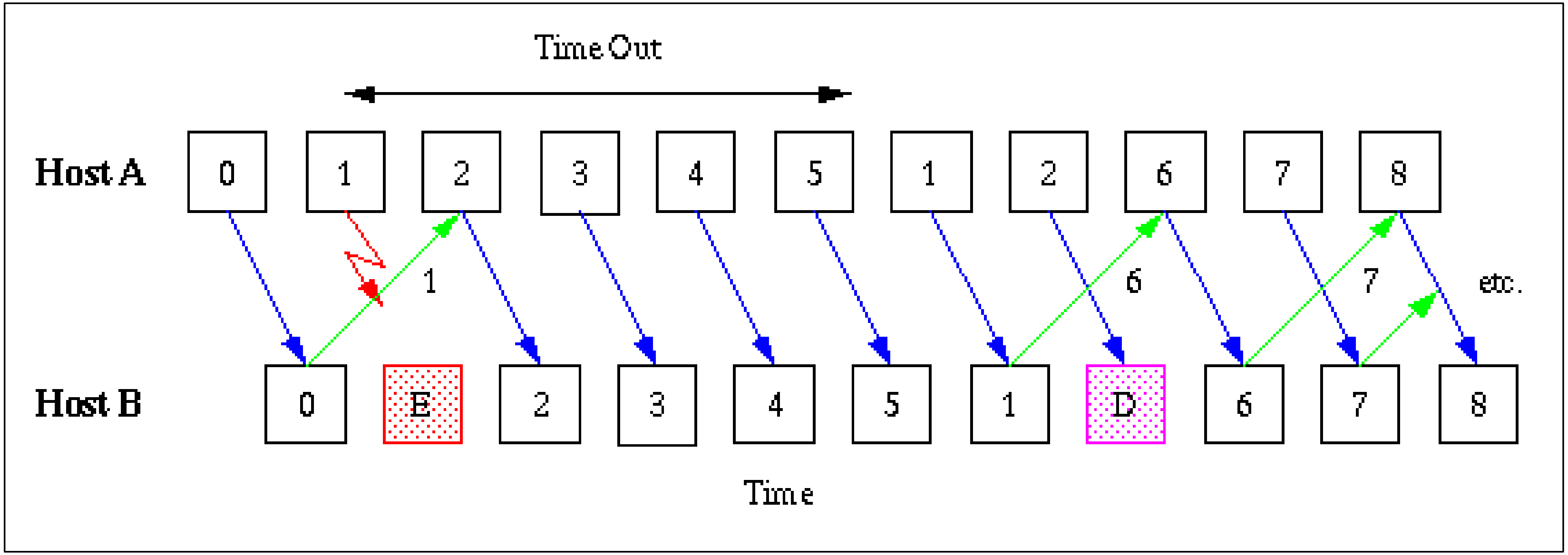


Figure A-11. Data transmission between two hosts.

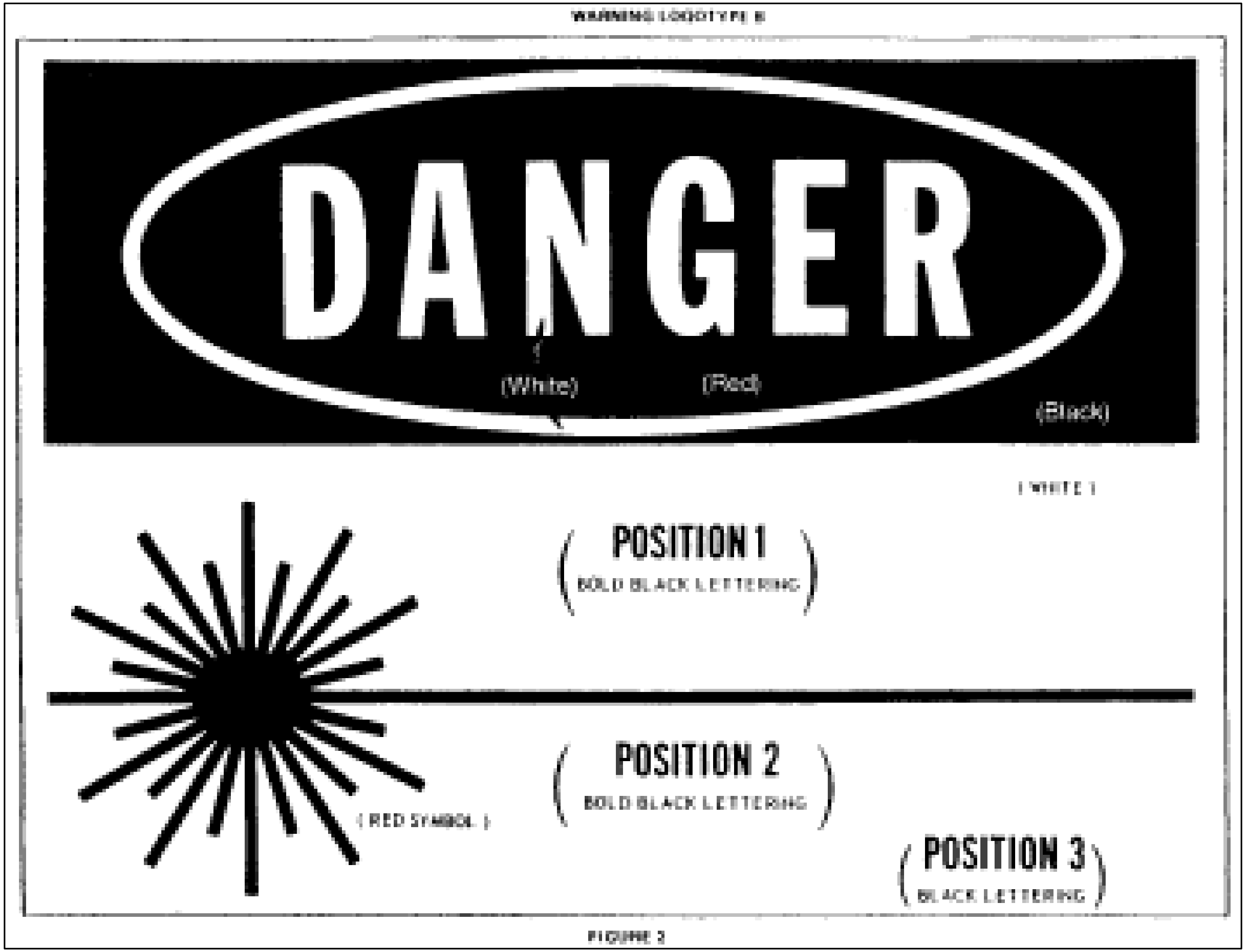


Figure A-12. Danger Label

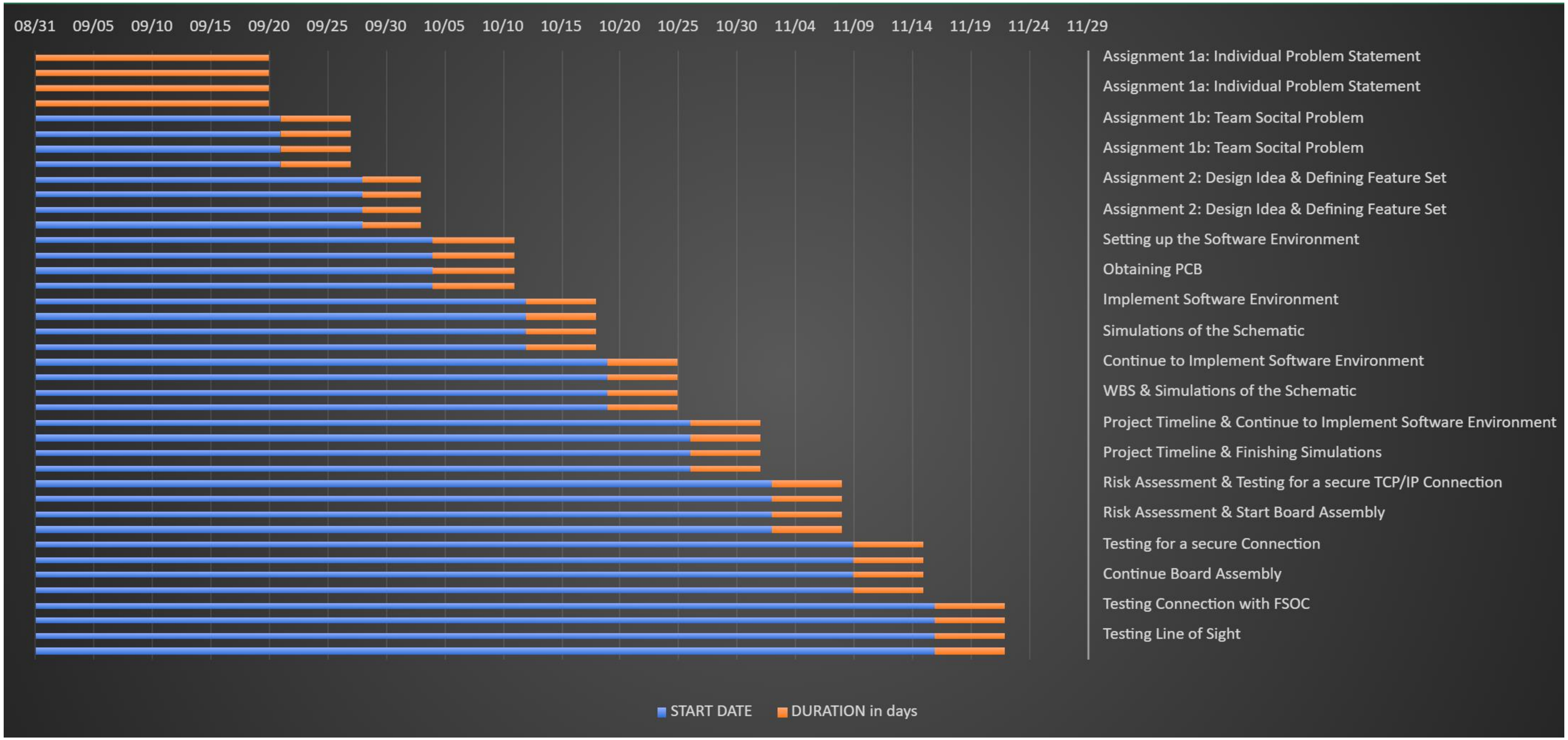


Figure A-13. Fall Term Project Timeline.

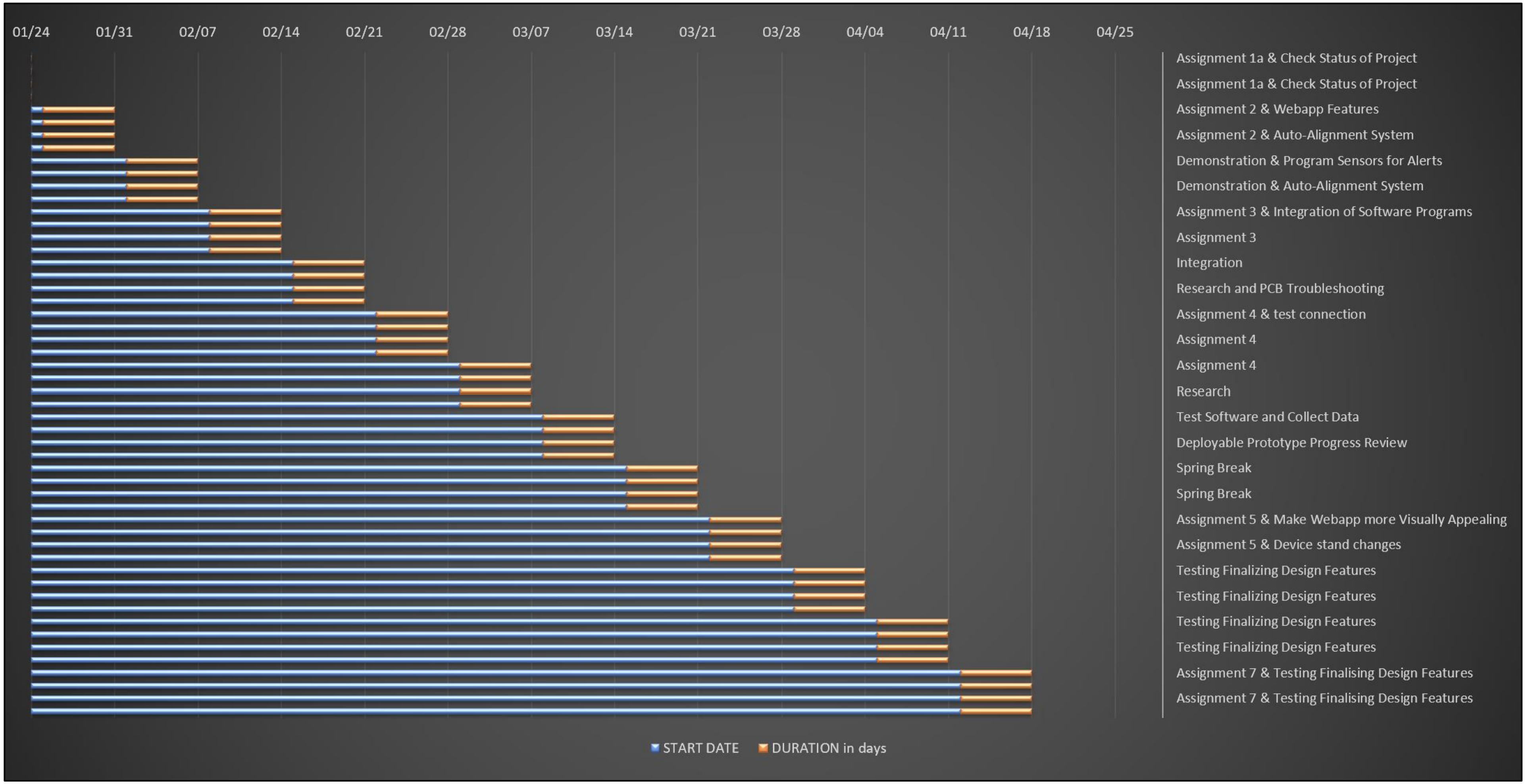


Figure A-14. Spring Term Project Timeline

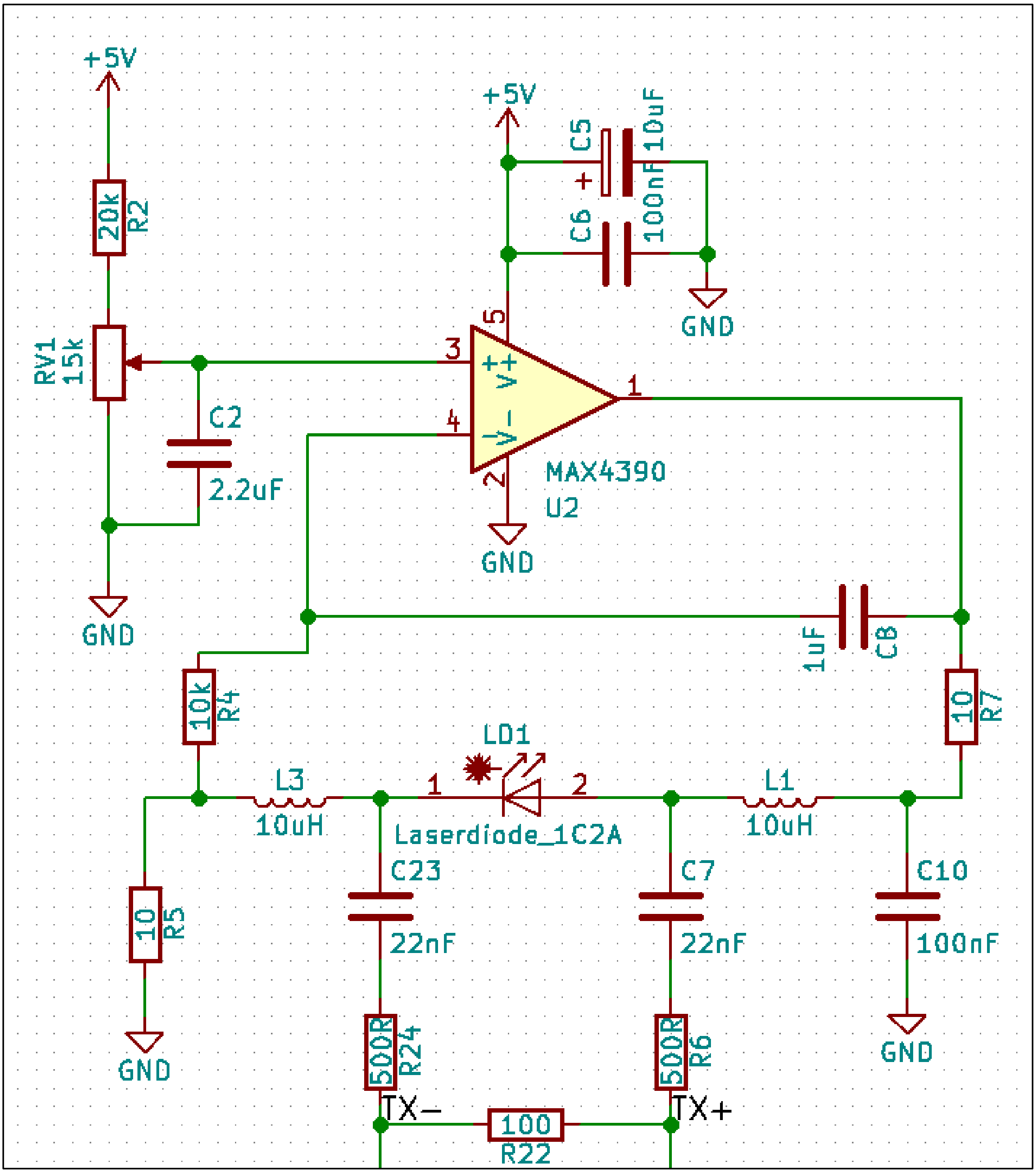


Figure A-15. Transmitter design. [[6]

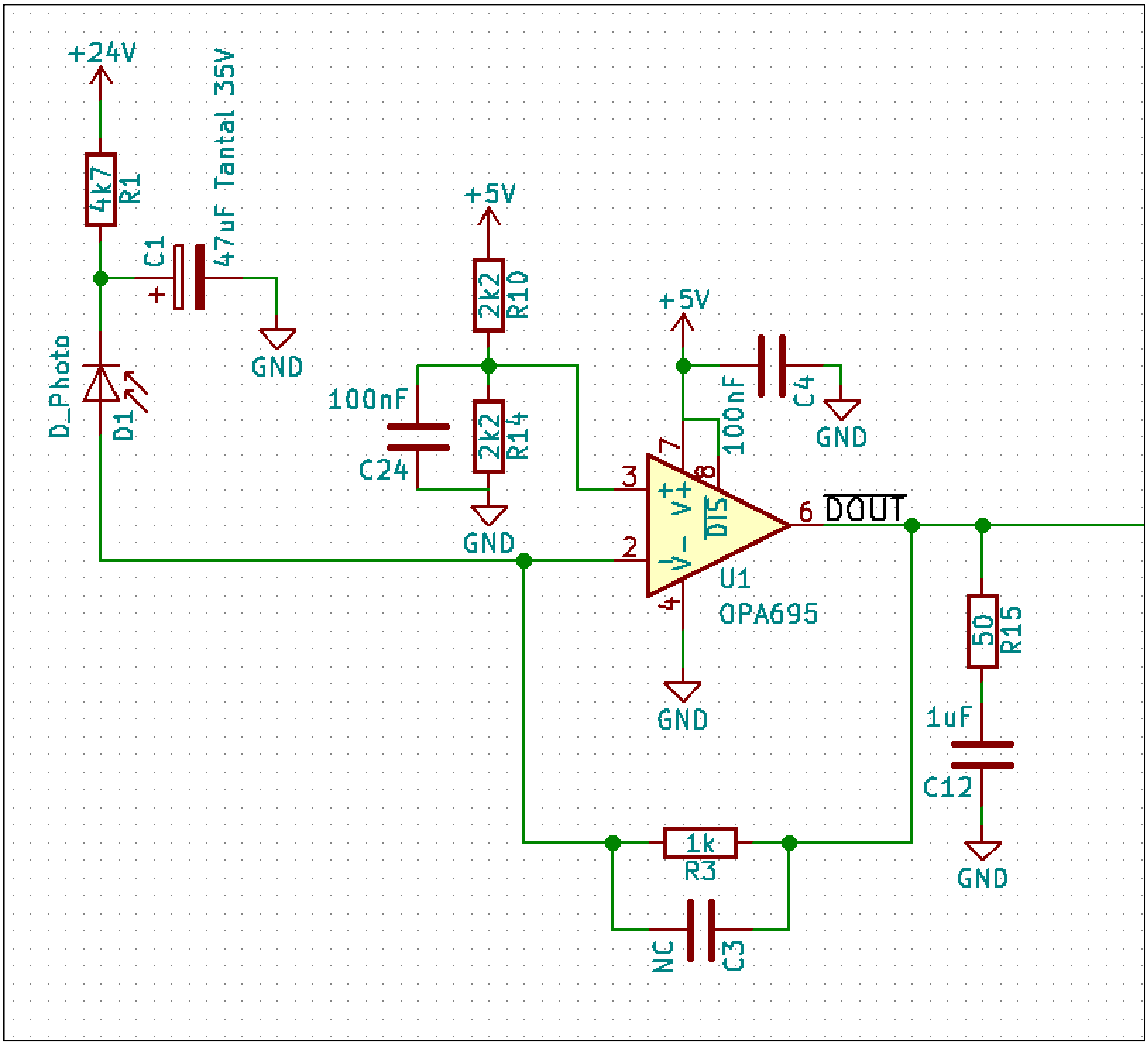


Figure A-16. Receiver design. [[6]

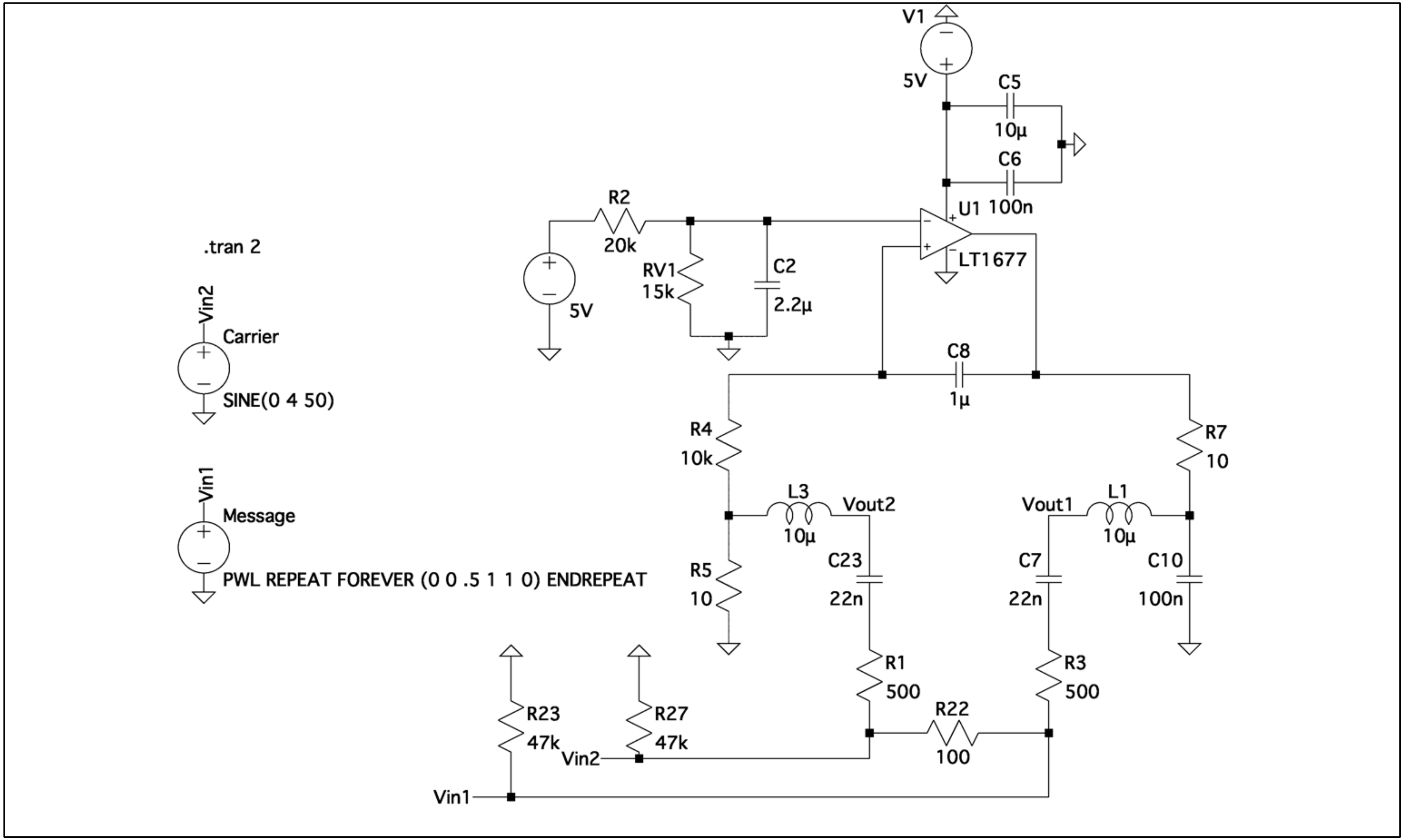


Figure A-17. MAX4390 Op-Amp design on LTSpice.

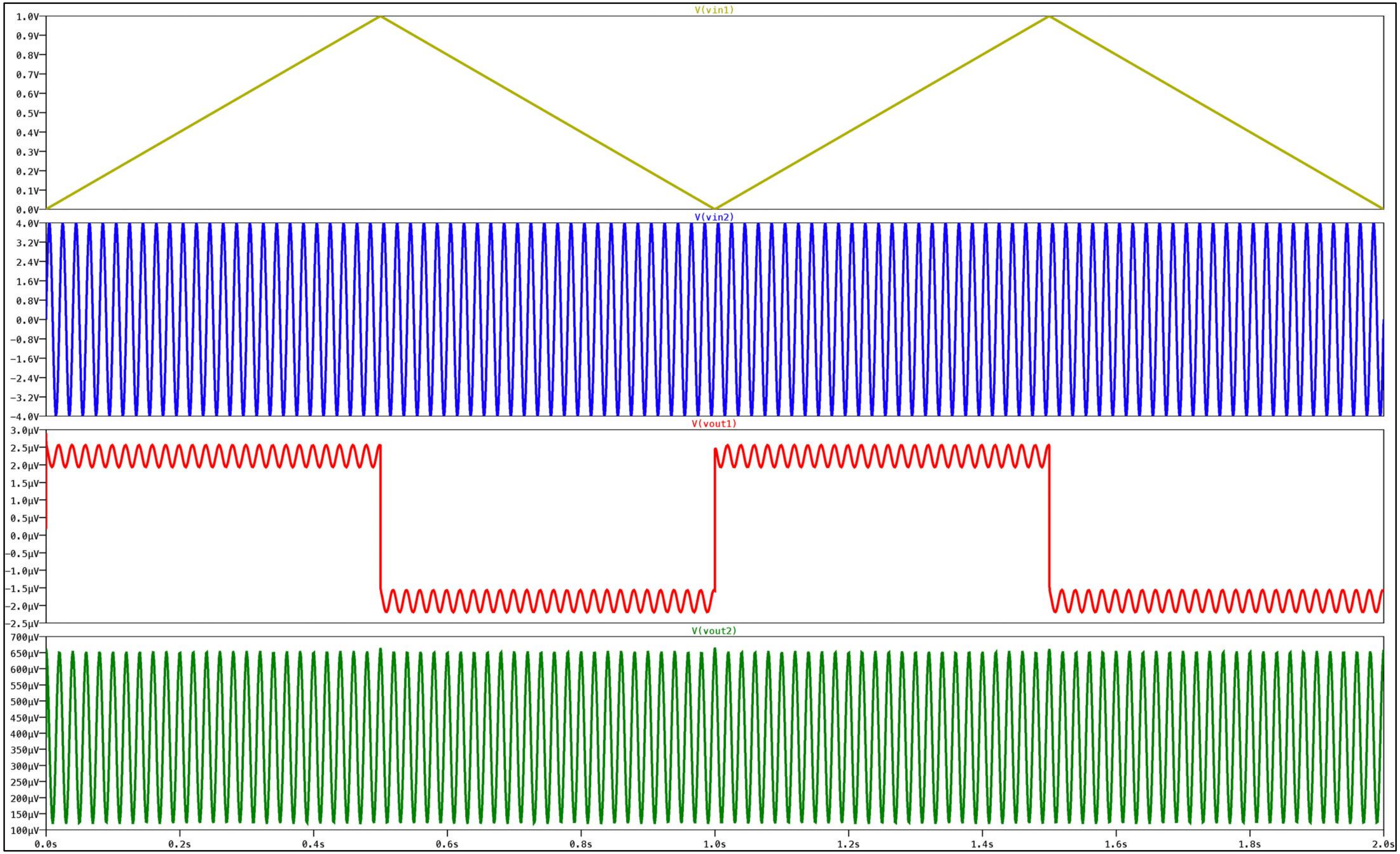


Figure A-18. Results of the MAX4390 simulation.

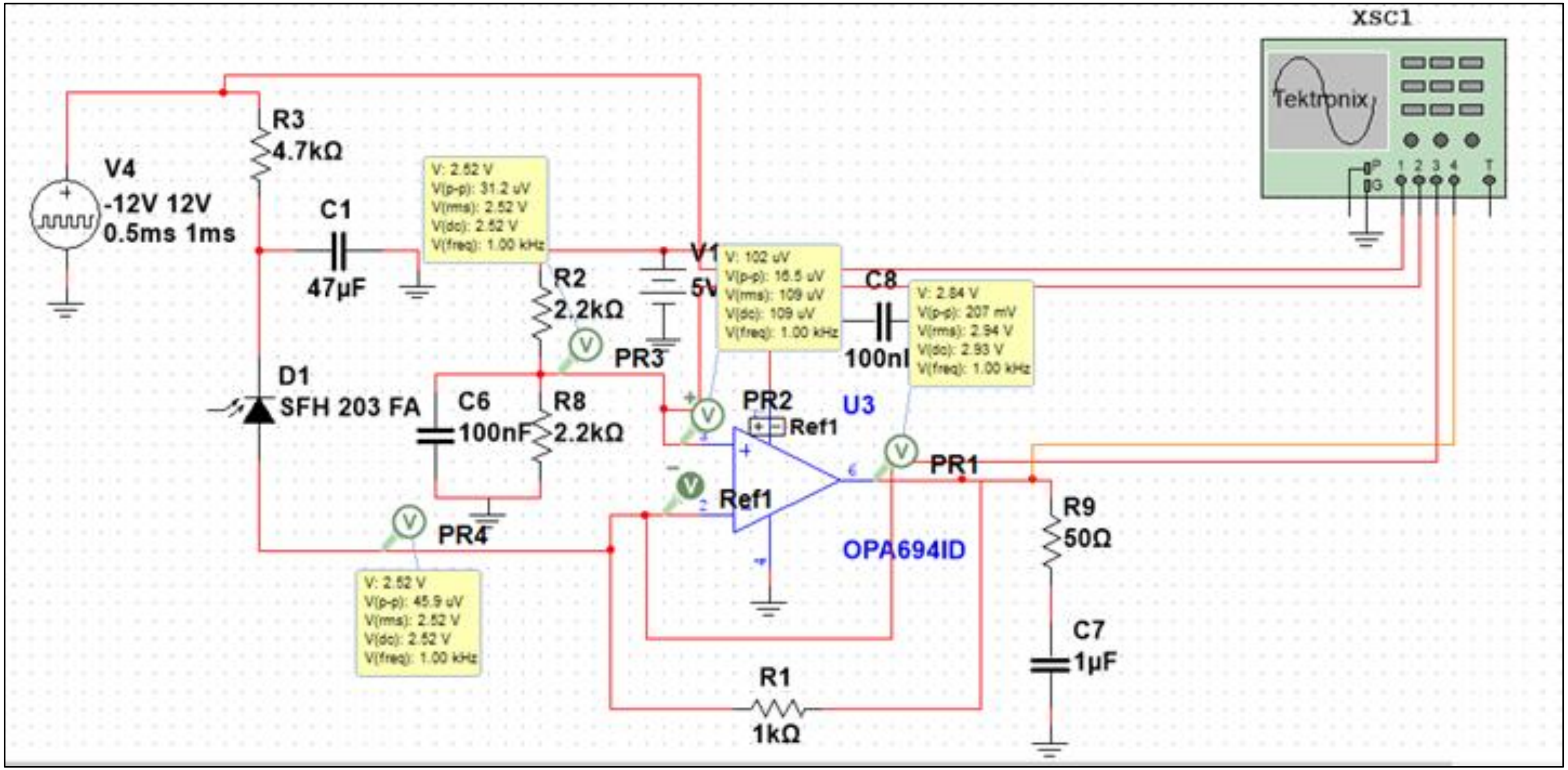


Figure A-19. OPA695 Op-amp design on Multisim

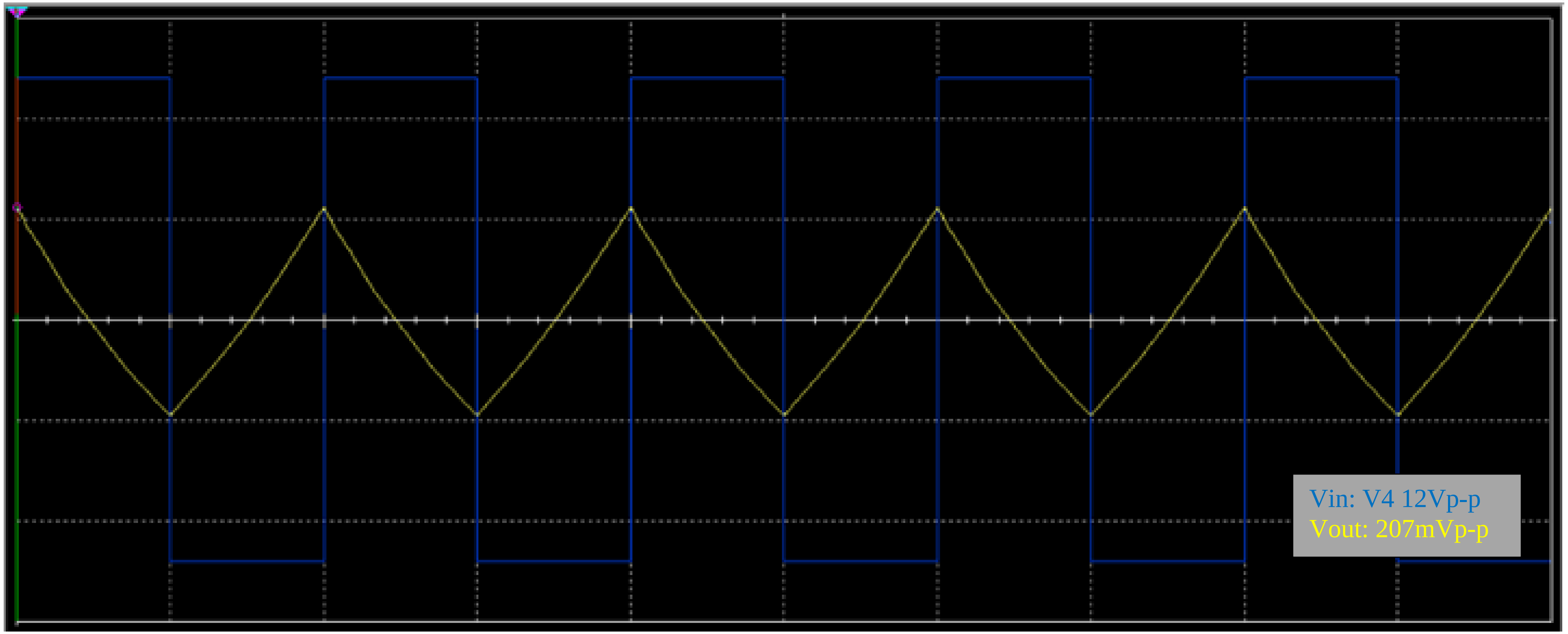


Figure A-20. OPA694 Simulation Results using an input pulse wave.

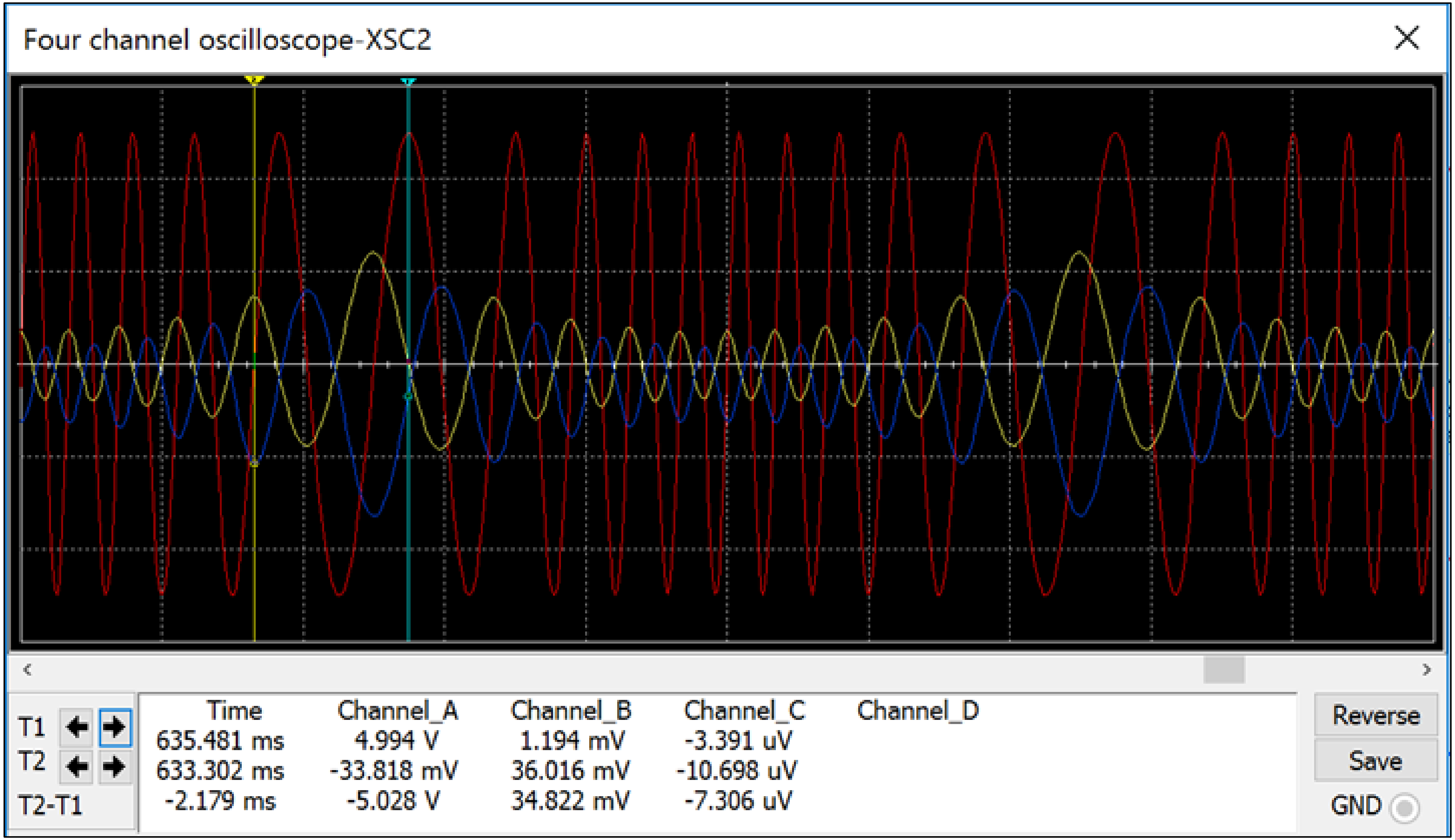


Figure A-21. FM input signal OPA694 simulation results.

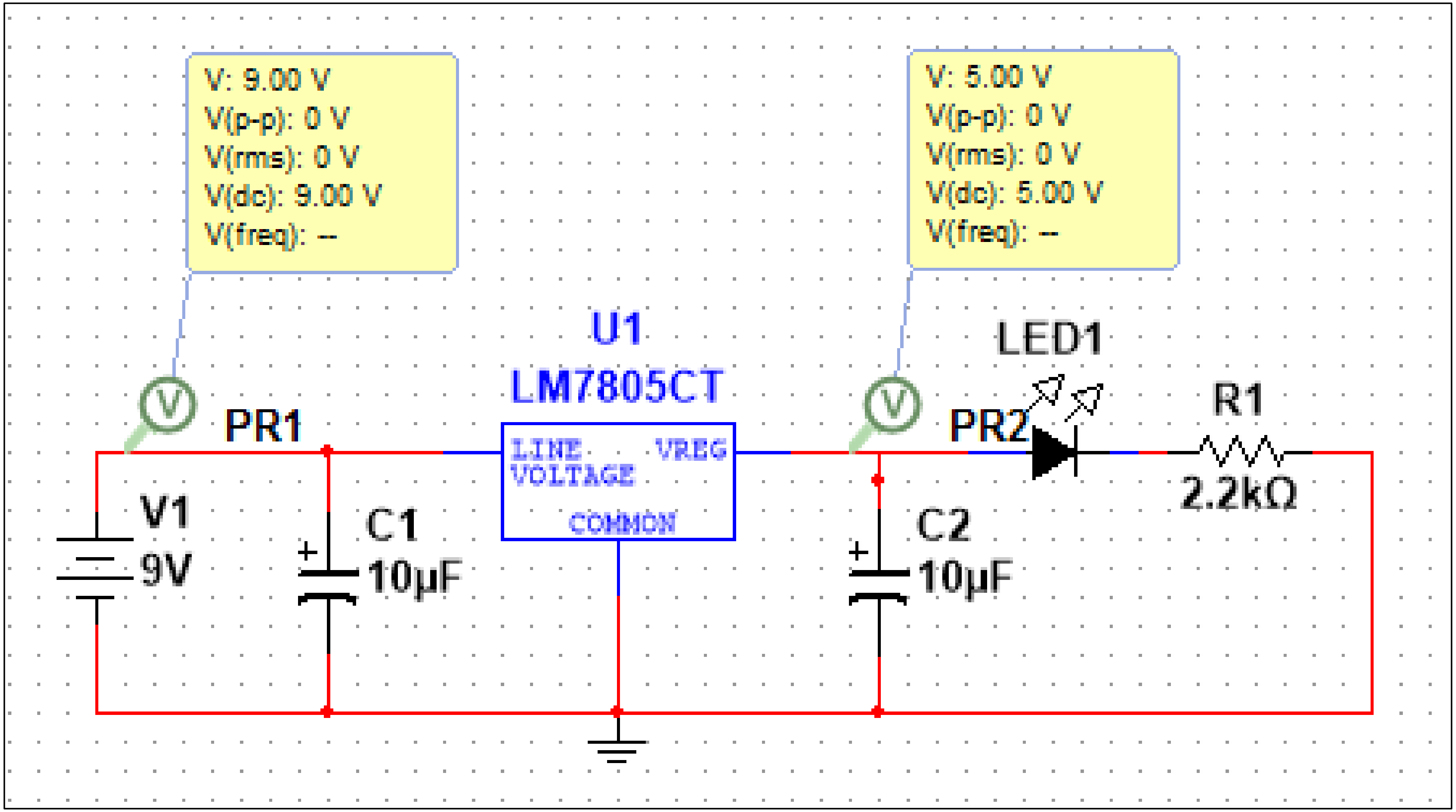


Figure A-22. LT1713 Op-amp design on Multisim.

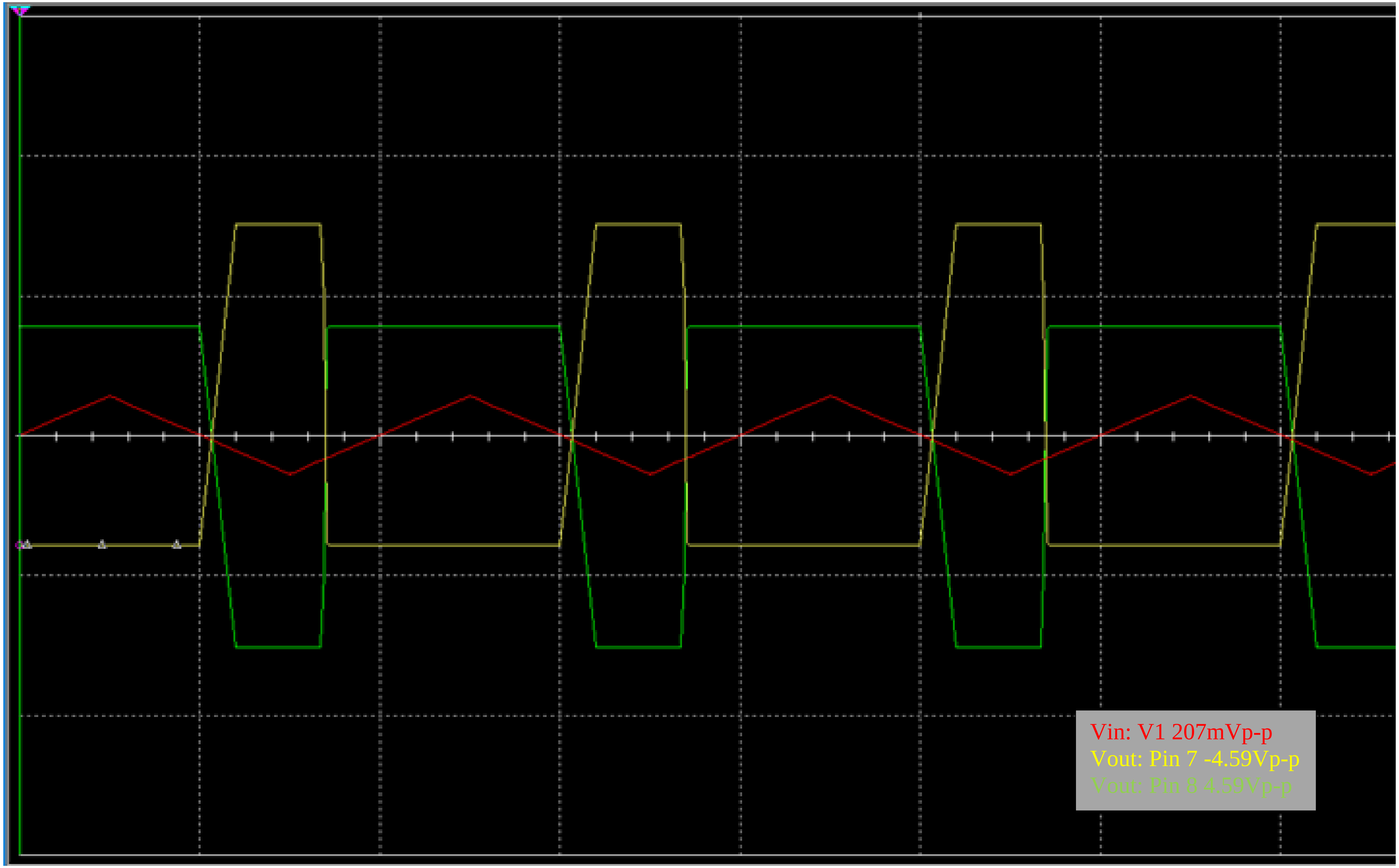


Figure A-23. LT1713 Simulation Results with triangular input wave.

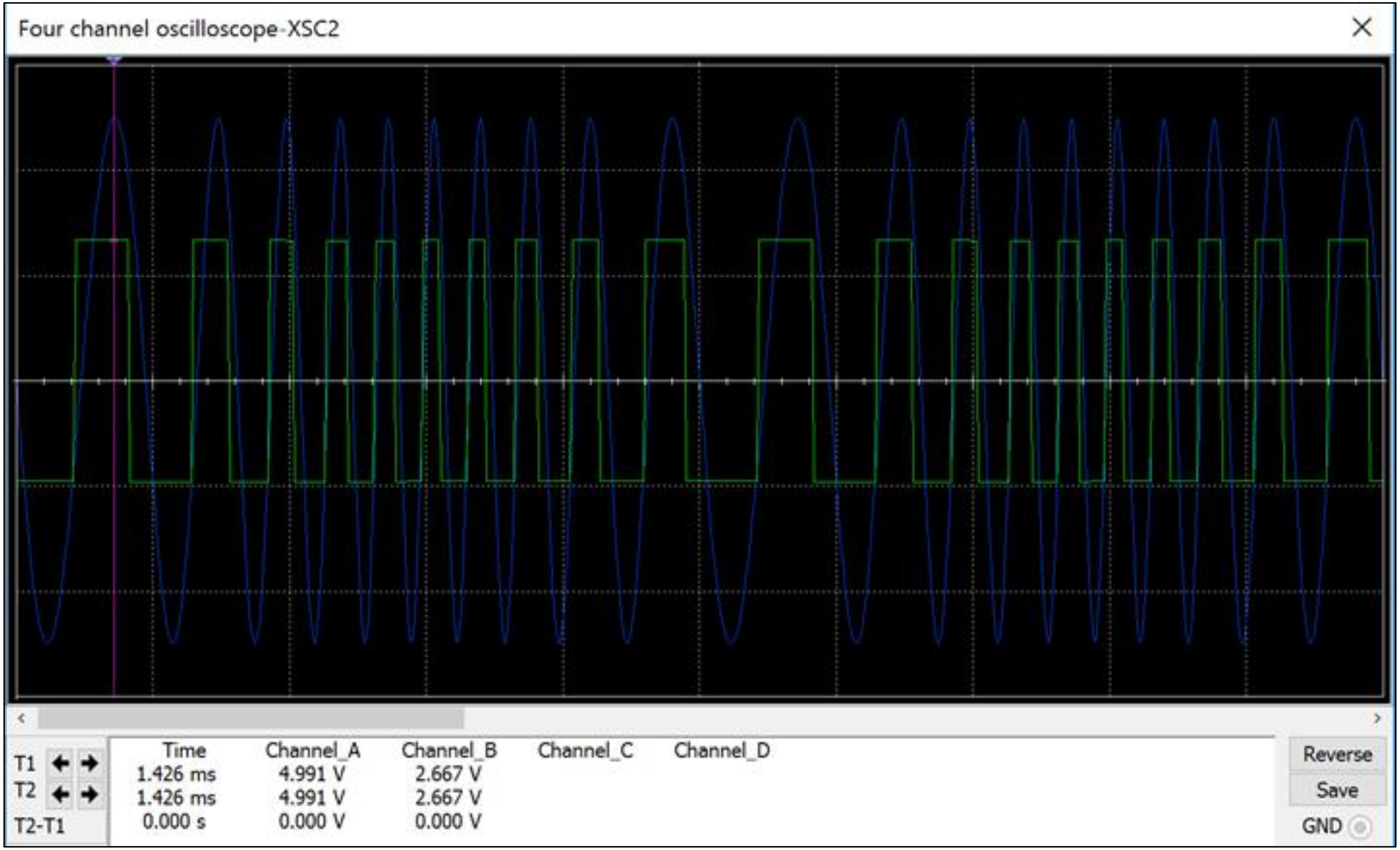


Figure A-24. FM Input Signal LT1713 Simulation Results.

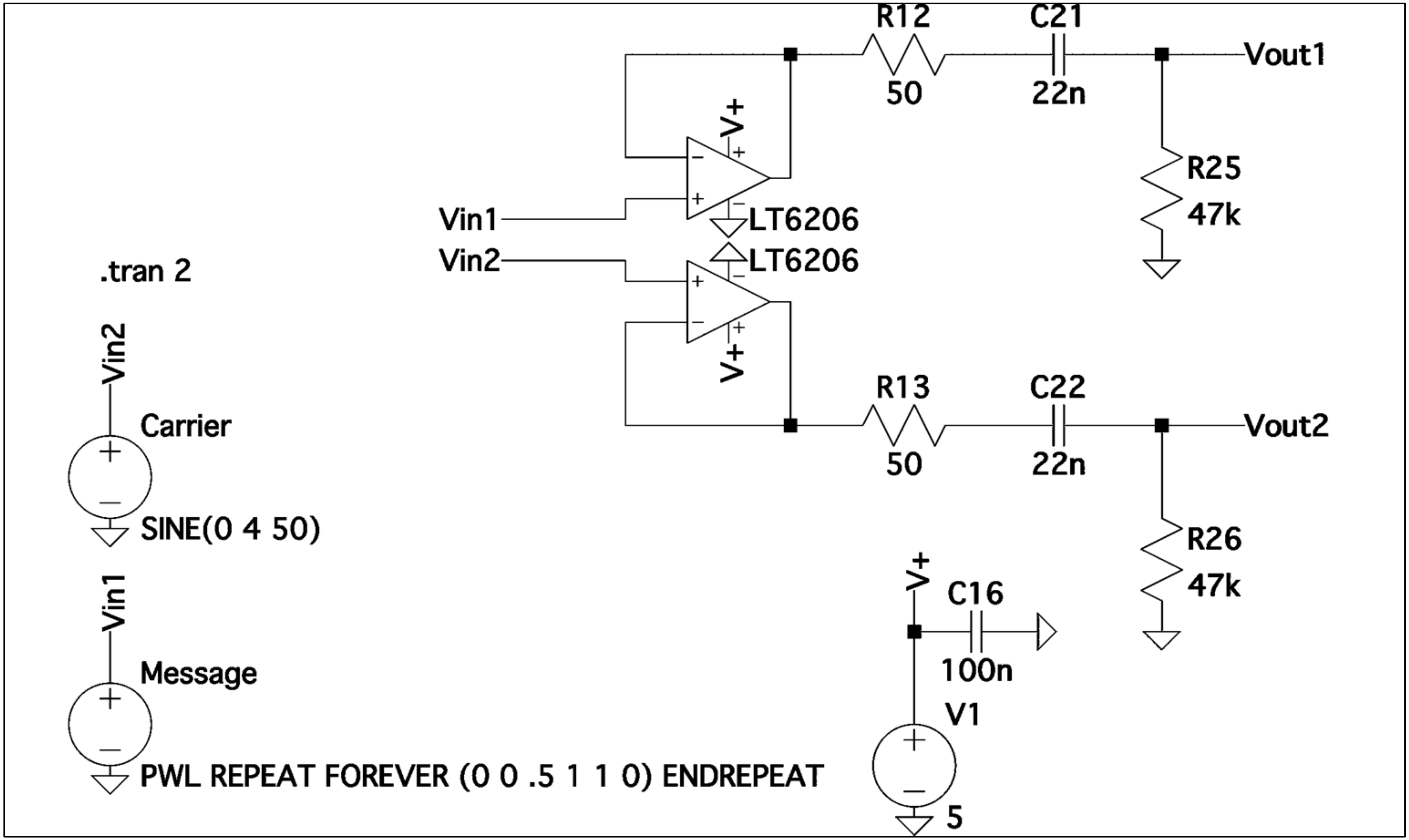


Figure A-25. MAX4392 Shown with Test Message and Carrier Signals.

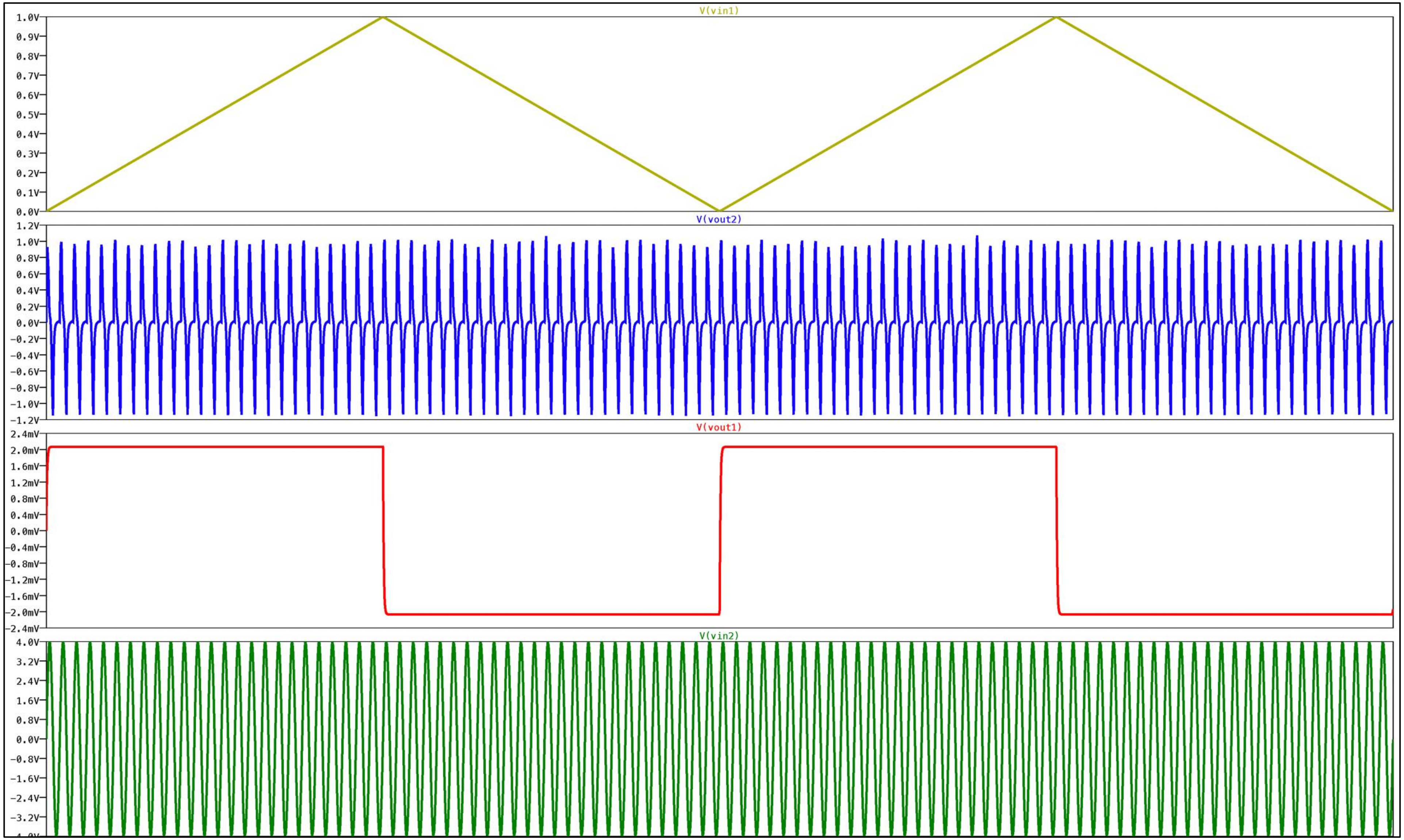


Figure A-26. Simulation Results from MAX4392.

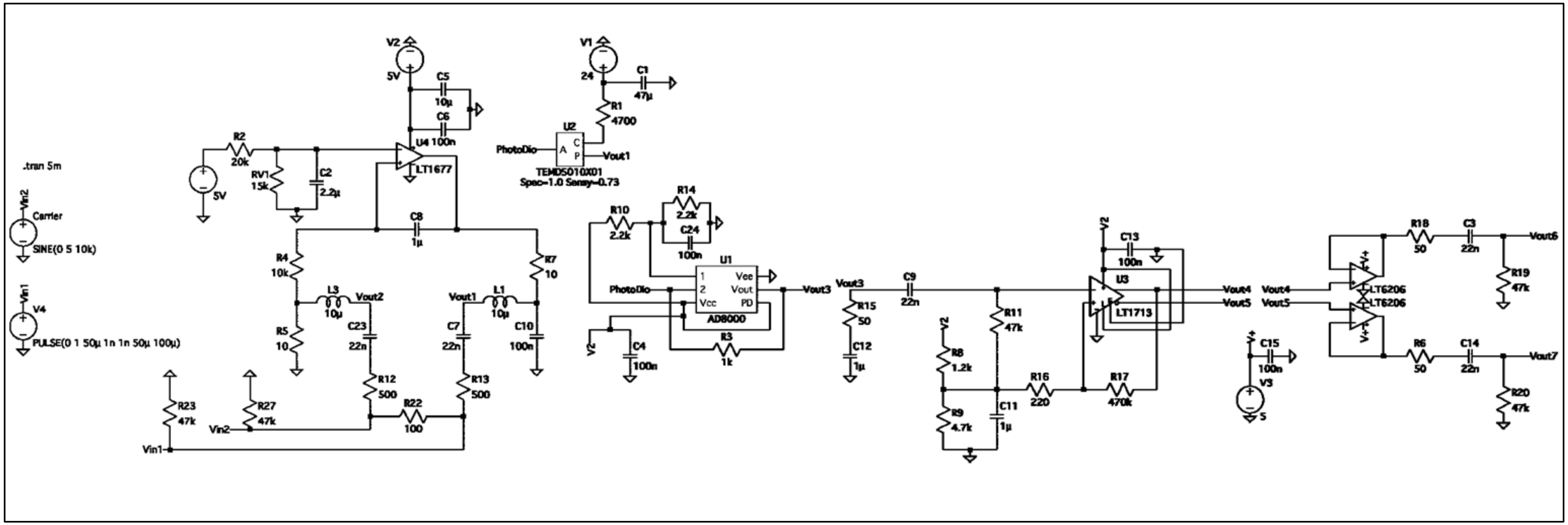


Figure A-27. Entire circuit design on LTSpice.

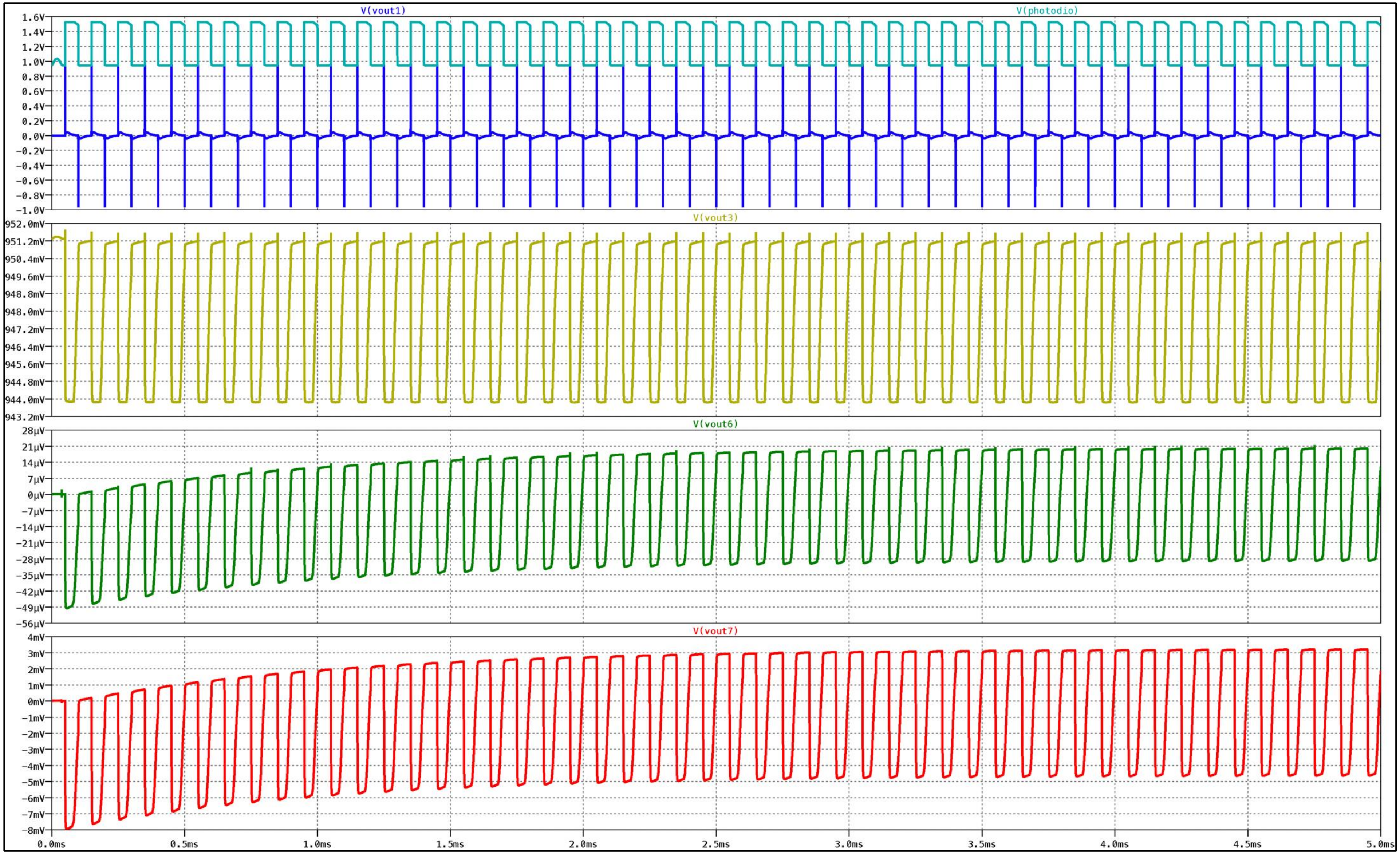


Figure A-28. Simulation results of the entire circuit on LTSpice.

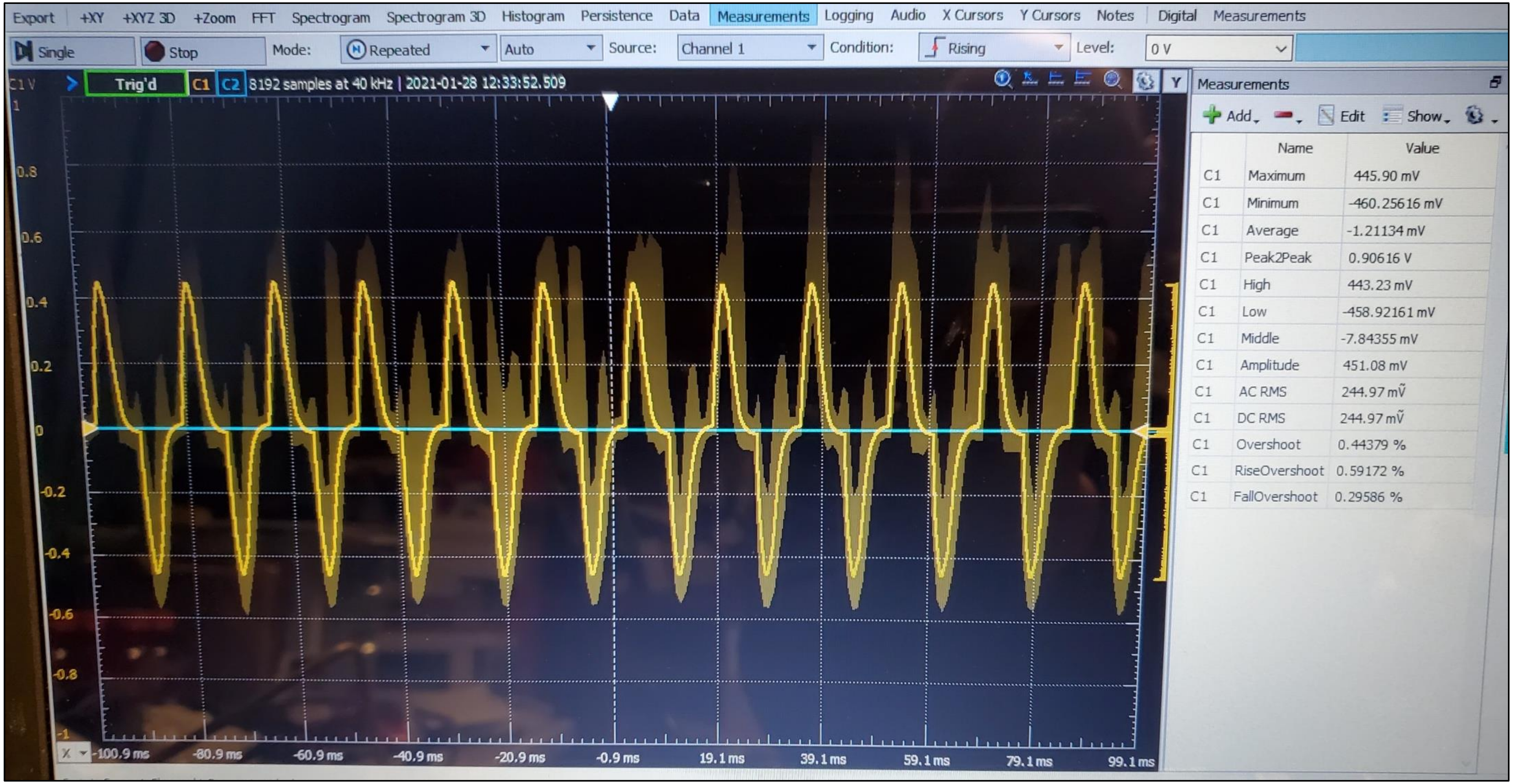


Figure A-29. Ethernet Signal Detection.

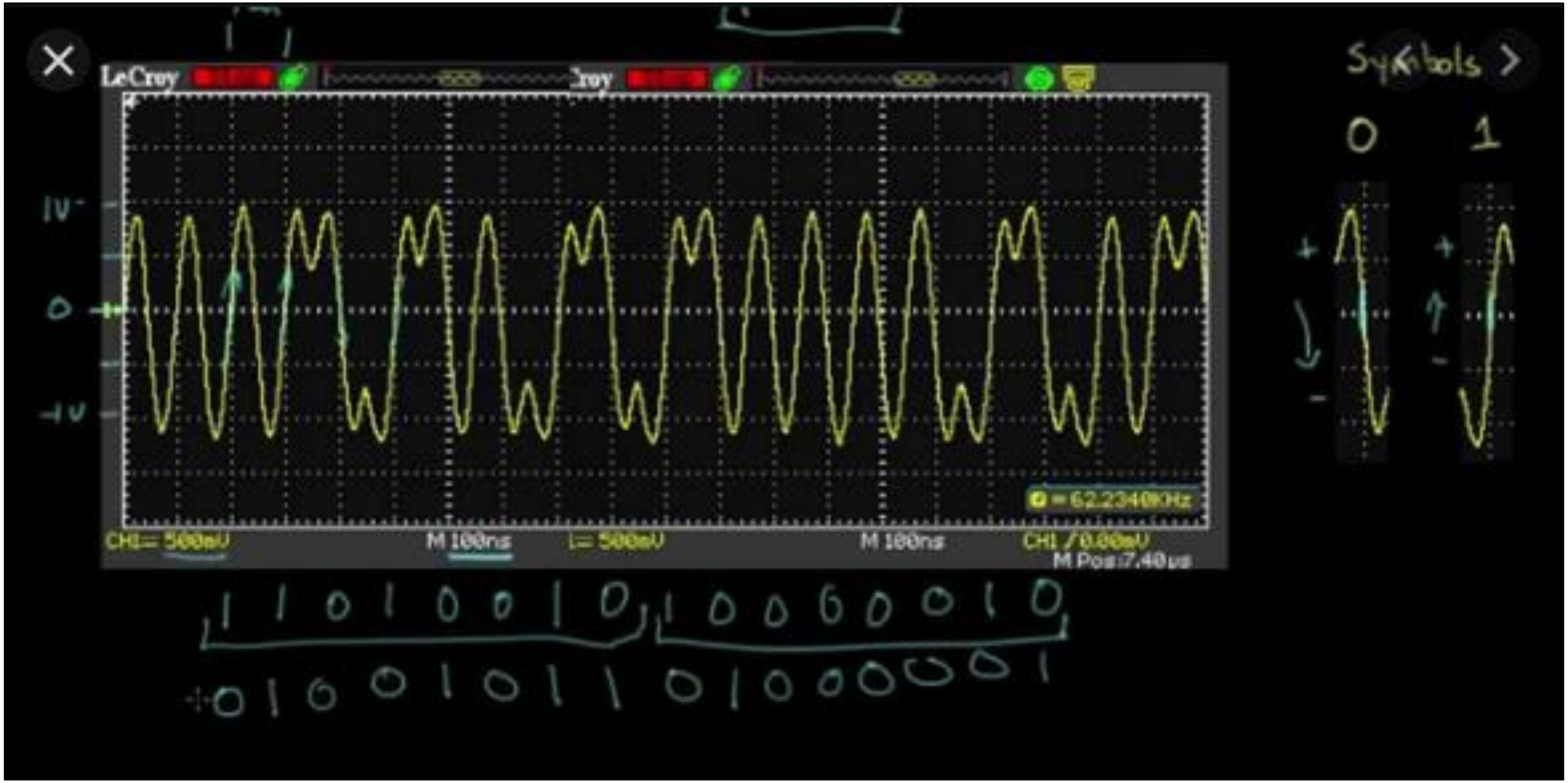


Figure A-30. Theoretical representation of ethernet signal using Manchester's encoding scheme. This image was captured from one of Ben Eaters YouTube videos. Check out his channel for all sorts of cool stuff. [[29]

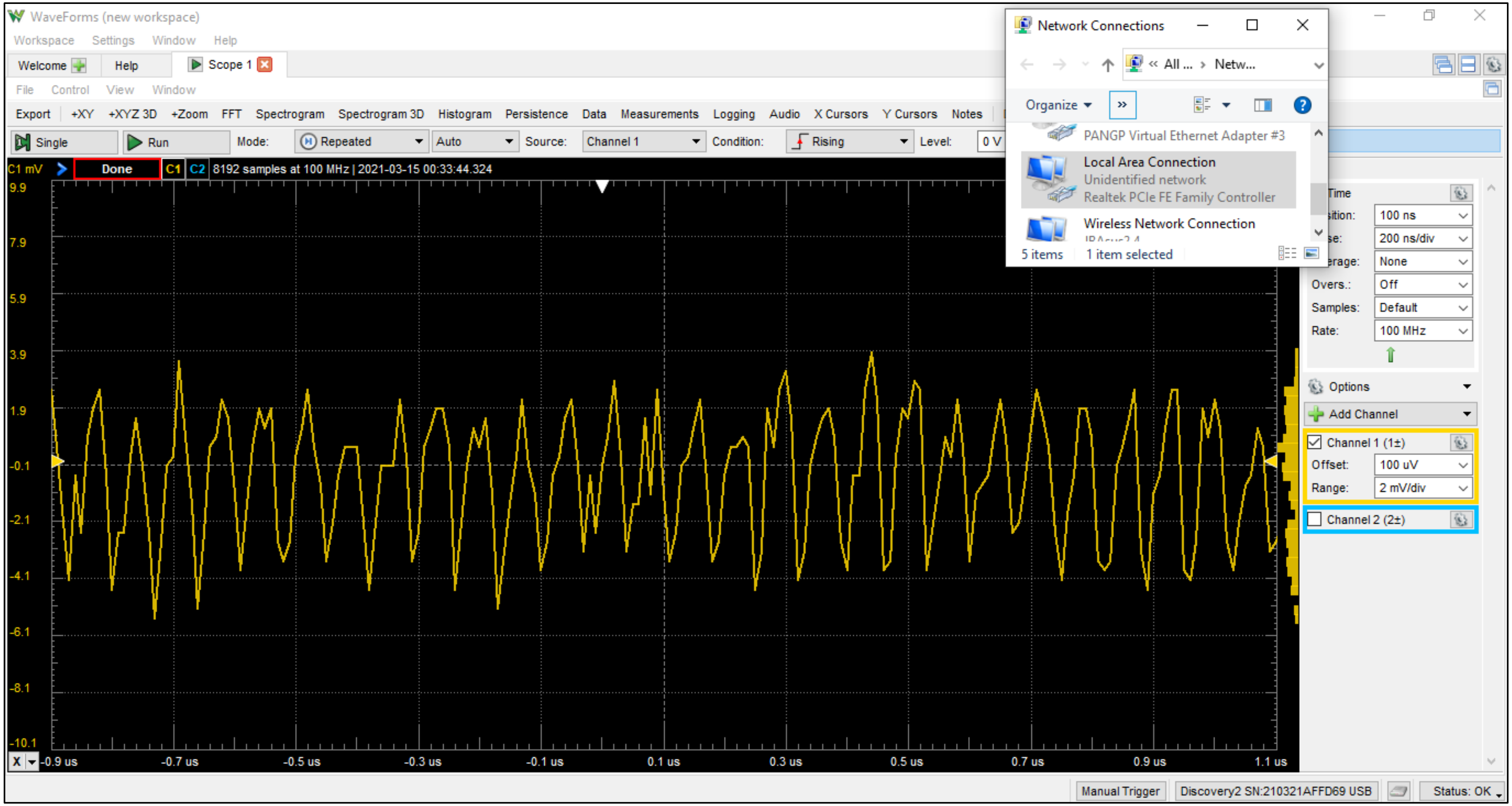


Figure A-31. The encoded signal at the output of our receiver's current feedback amplifier.

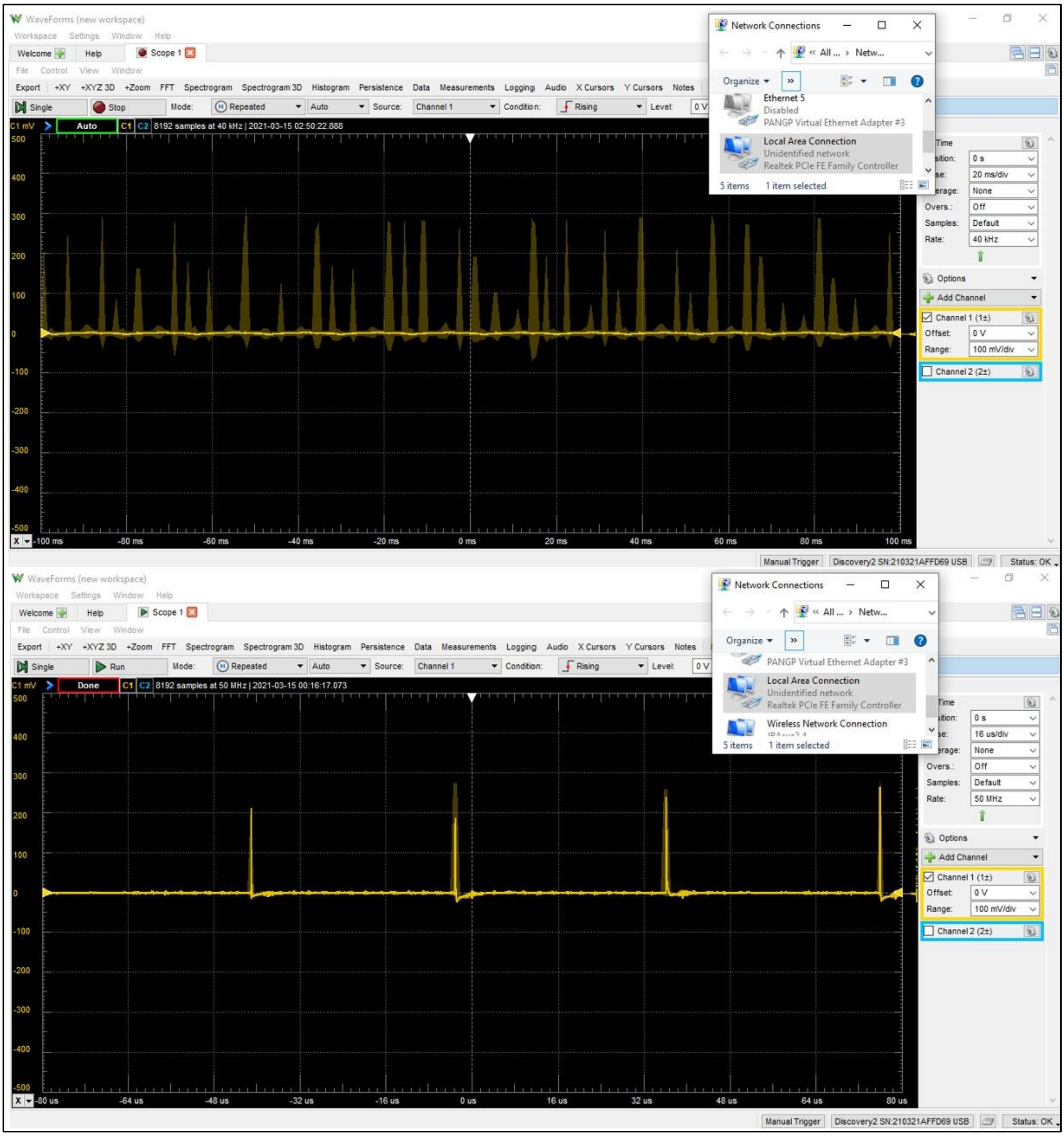


Figure A-32. Line of sight reference signal at the receiver end.

Figure A-33. Shifted Response After Second Modification

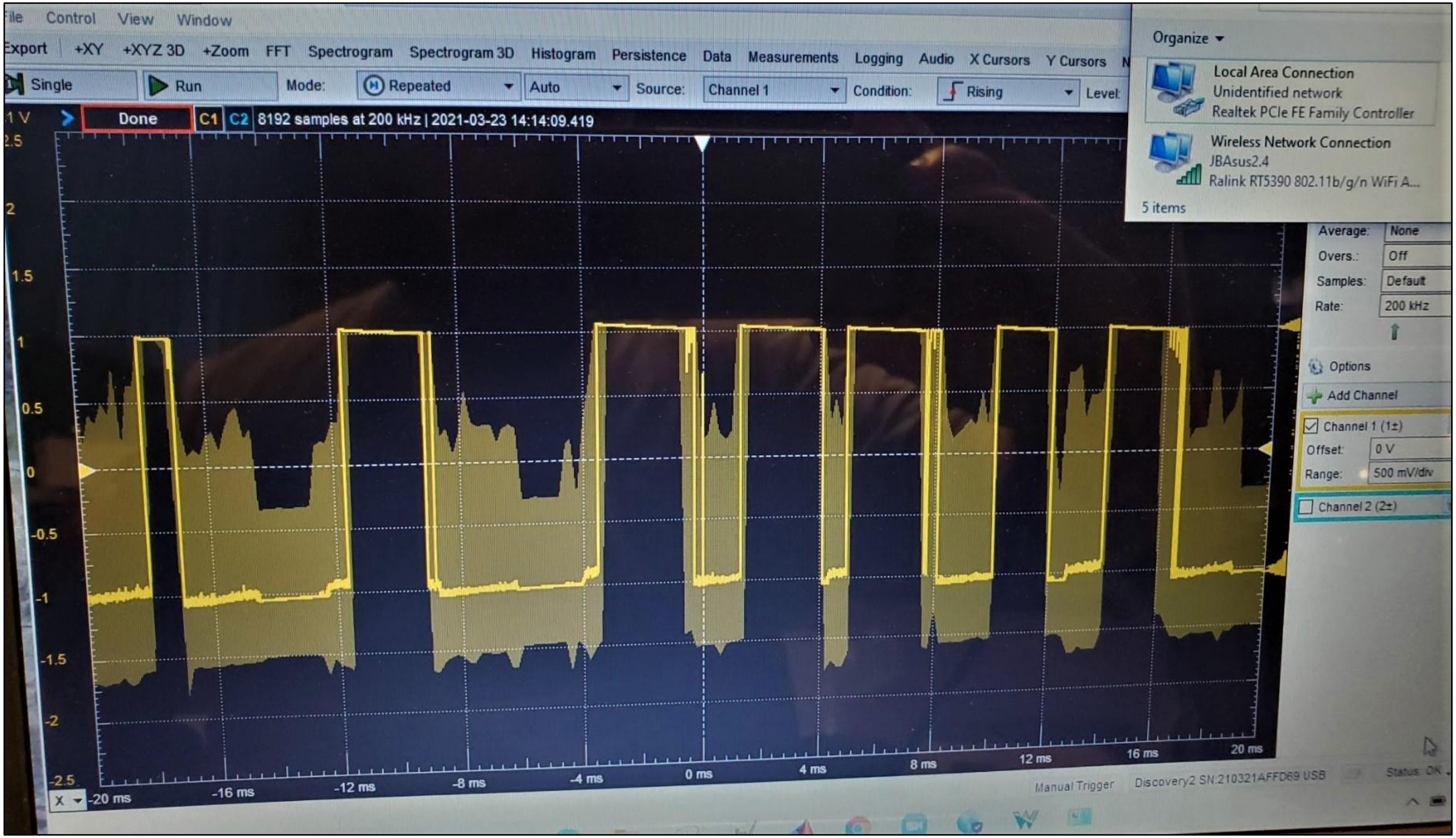


Figure A-34. Improved signal at the buffer stage of the receiver.

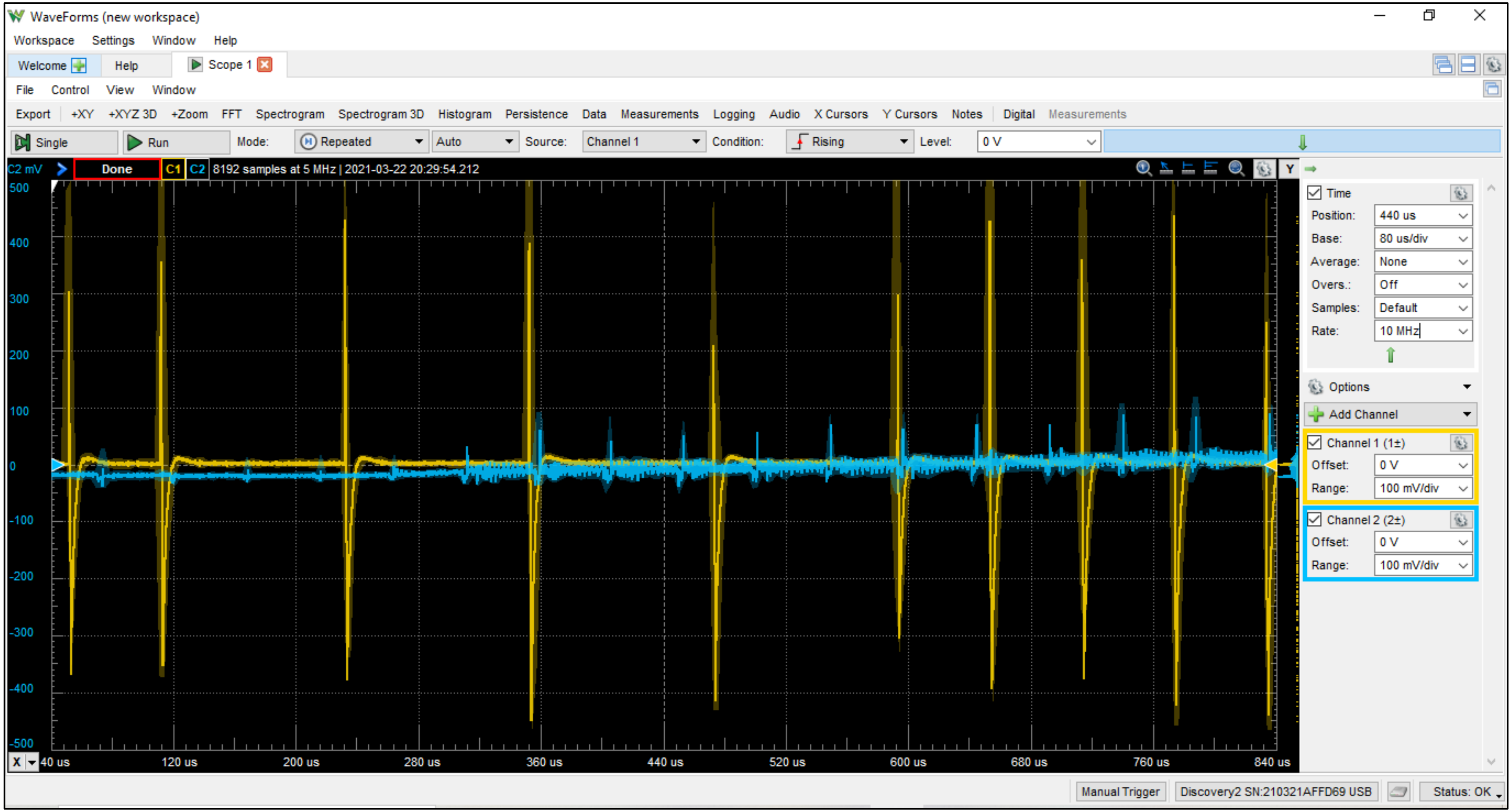


Figure A-35. Improved receiver response

```
*IDLE Shell 3.9.1*
File  Edit  Shell  Debug  Options  Window  Help
Python 3.9.1 (tags/v3.9.1:1e5d33e, Dec  7 2020, 17:08:21) [MSC v.1927 64 bit (AMD6
Type "help", "copyright", "credits" or "license()" for more information.
>>>
====== RESTART: D:\SDproject\fsco\Socket program test\New folder\Test_T.py =====
The server is ready to receive
Connected by ('192.168.0.32', 55592)
17:12:16:299911
fsoc demo.mp4
17:13:15:437099
Connected by ('192.168.0.32', 55599)
17:13:40:806195
Me.jpg
17:13:59:666617
Connected by ('192.168.0.32', 55604)
17:14:24:134956
StopTime.pdf
17:14:47:324958
Connected by ('192.168.0.32', 55611)
17:15:23:555524
Team 3 Senior Project Report.docx
17:16:14:478639
Connected by ('192.168.0.32', 55620)
17:16:32:510586
Hello.txt
17:16:39:050401
```

Figure A-36. Socket Server Results.

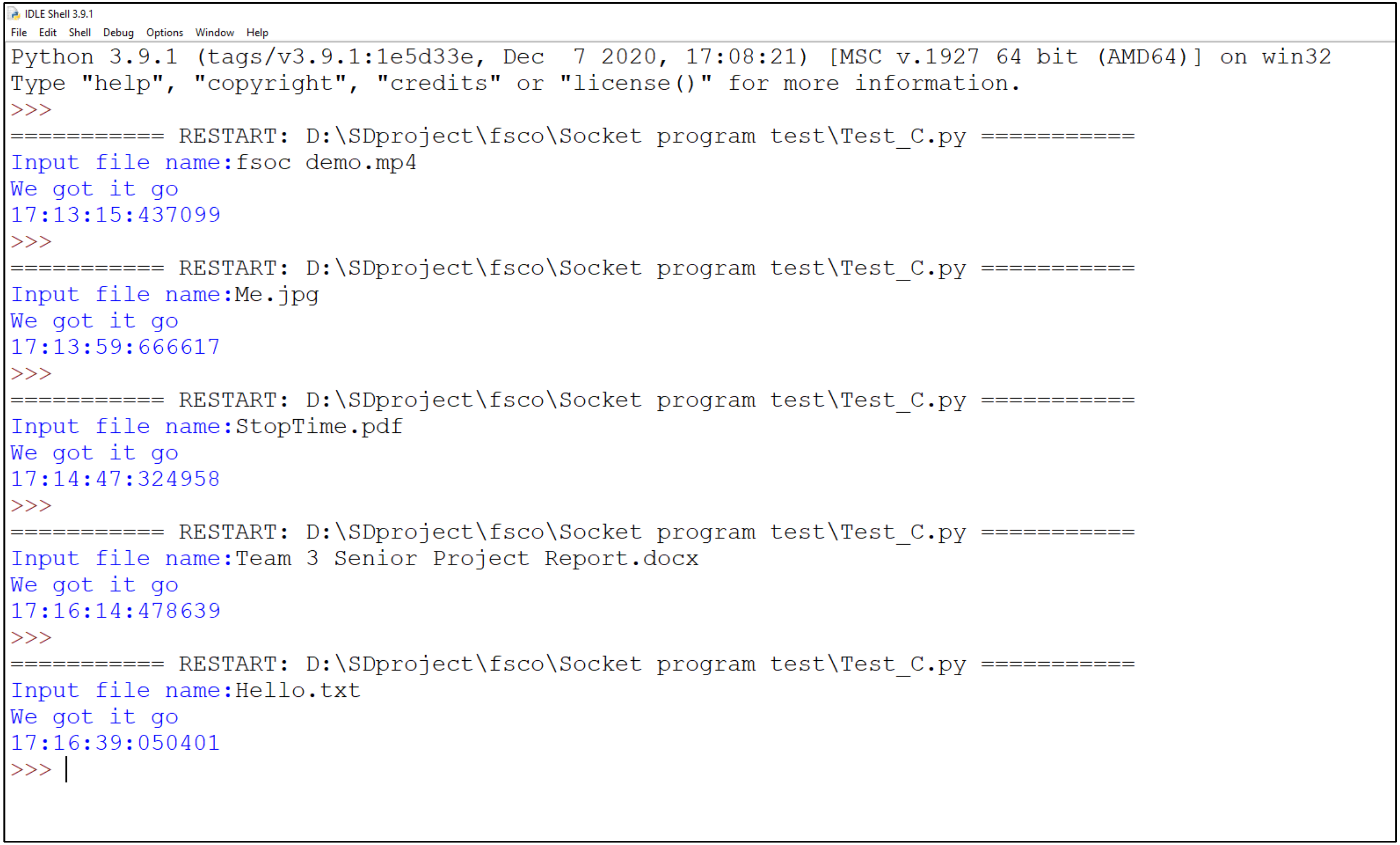


Figure A-37. Socket Client Results.

```python
#!/usr/bin/env python3

import socket
import csv
from sensor import alert

serverHost = ''  # Standard loopback interface address (localhost)
serverPort = 65432        # Port to listen on (non-privileged ports are > 1023)
```

Running: TCP_Server.py

```
The server is ready to receive
Disclaimer: The relative humidity  is 70.0%. This may cause delays with the connection.
Connected by ('169.254.251.166', 52672)
14:29:39:319062
14:29:39:319062
Disclaimer: The relative humidity  is 68.9%. This may cause delays with the connection.
```

Figure A-38. Alert System Output

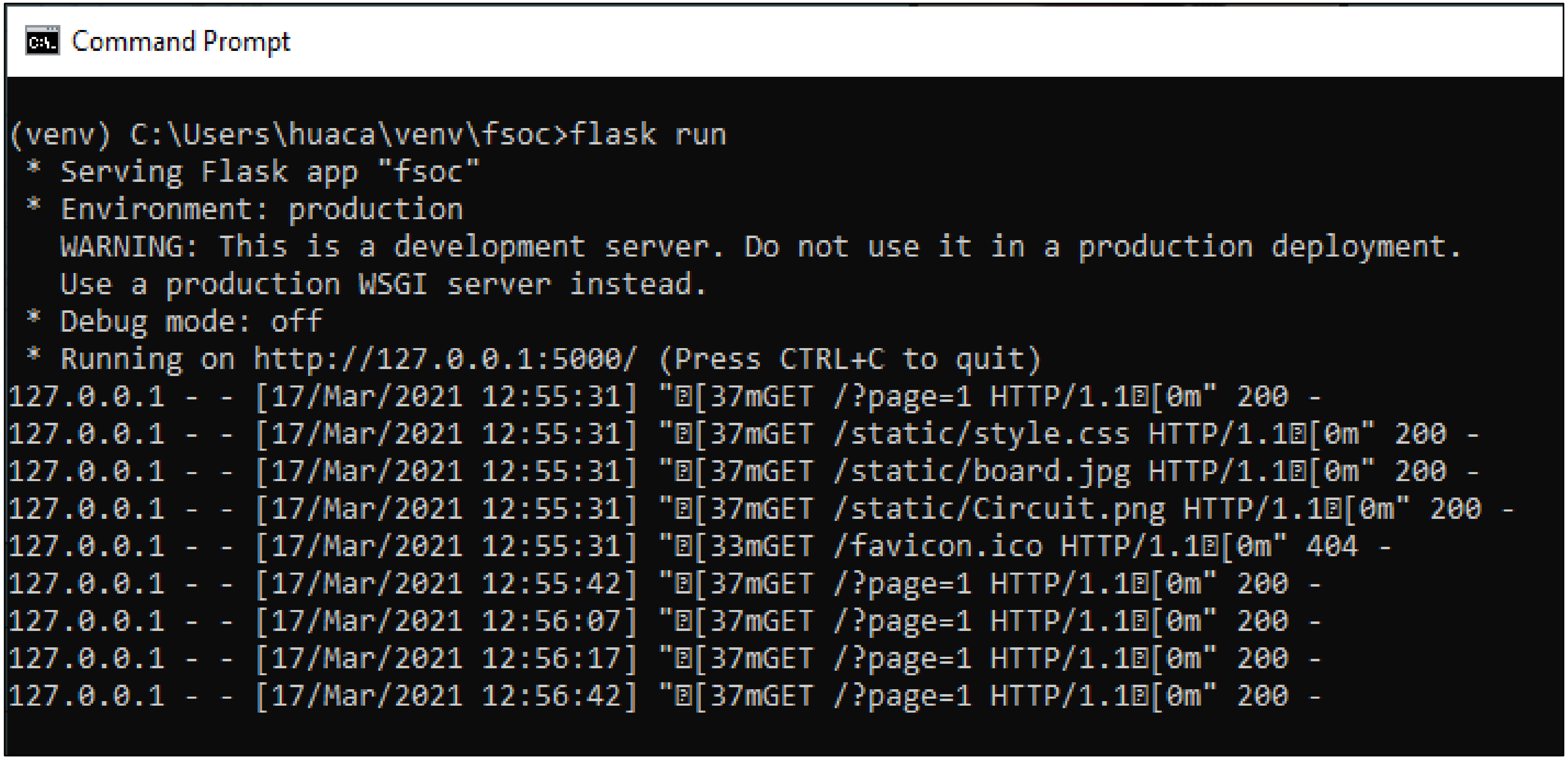
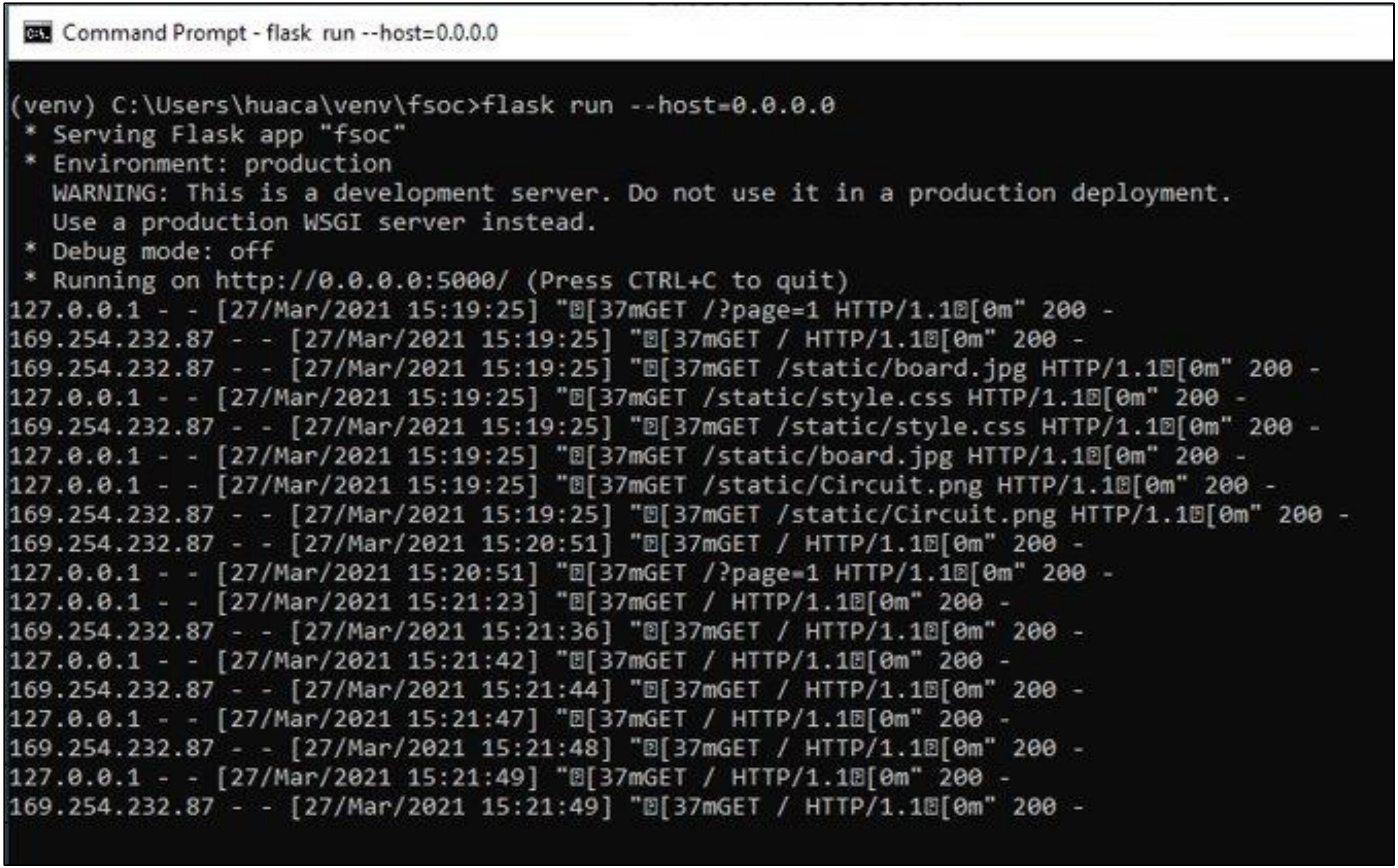


Figure A-39. Flask Debug Tool.

Figure A-40. Web Application.



```
Command Prompt - flask run --host=0.0.0.0

(venv) C:\Users\huaca\venv\fsoc>flask run --host=0.0.0.0
 * Serving Flask app "fsoc"
 * Environment: production
   WARNING: This is a development server. Do not use it in a production deployment.
   Use a production WSGI server instead.
 * Debug mode: off
 * Running on http://0.0.0.0:5000/ (Press CTRL+C to quit)
127.0.0.1 - - [27/Mar/2021 15:19:25] "□[37mGET /?page=1 HTTP/1.1□[0m" 200 -
169.254.232.87 - - [27/Mar/2021 15:19:25] "□[37mGET / HTTP/1.1□[0m" 200 -
169.254.232.87 - - [27/Mar/2021 15:19:25] "□[37mGET /static/board.jpg HTTP/1.1□[0m" 200 -
127.0.0.1 - - [27/Mar/2021 15:19:25] "□[37mGET /static/style.css HTTP/1.1□[0m" 200 -
169.254.232.87 - - [27/Mar/2021 15:19:25] "□[37mGET /static/style.css HTTP/1.1□[0m" 200 -
127.0.0.1 - - [27/Mar/2021 15:19:25] "□[37mGET /static/board.jpg HTTP/1.1□[0m" 200 -
127.0.0.1 - - [27/Mar/2021 15:19:25] "□[37mGET /static/Circuit.png HTTP/1.1□[0m" 200 -
169.254.232.87 - - [27/Mar/2021 15:19:25] "□[37mGET /static/Circuit.png HTTP/1.1□[0m" 200 -
169.254.232.87 - - [27/Mar/2021 15:20:51] "□[37mGET / HTTP/1.1□[0m" 200 -
127.0.0.1 - - [27/Mar/2021 15:20:51] "□[37mGET /?page=1 HTTP/1.1□[0m" 200 -
127.0.0.1 - - [27/Mar/2021 15:21:23] "□[37mGET / HTTP/1.1□[0m" 200 -
169.254.232.87 - - [27/Mar/2021 15:21:36] "□[37mGET / HTTP/1.1□[0m" 200 -
127.0.0.1 - - [27/Mar/2021 15:21:42] "□[37mGET / HTTP/1.1□[0m" 200 -
169.254.232.87 - - [27/Mar/2021 15:21:44] "□[37mGET / HTTP/1.1□[0m" 200 -
127.0.0.1 - - [27/Mar/2021 15:21:47] "□[37mGET / HTTP/1.1□[0m" 200 -
169.254.232.87 - - [27/Mar/2021 15:21:48] "□[37mGET / HTTP/1.1□[0m" 200 -
127.0.0.1 - - [27/Mar/2021 15:21:49] "□[37mGET / HTTP/1.1□[0m" 200 -
169.254.232.87 - - [27/Mar/2021 15:21:49] "□[37mGET / HTTP/1.1□[0m" 200 -
```

Figure A-41. Two Device Test.

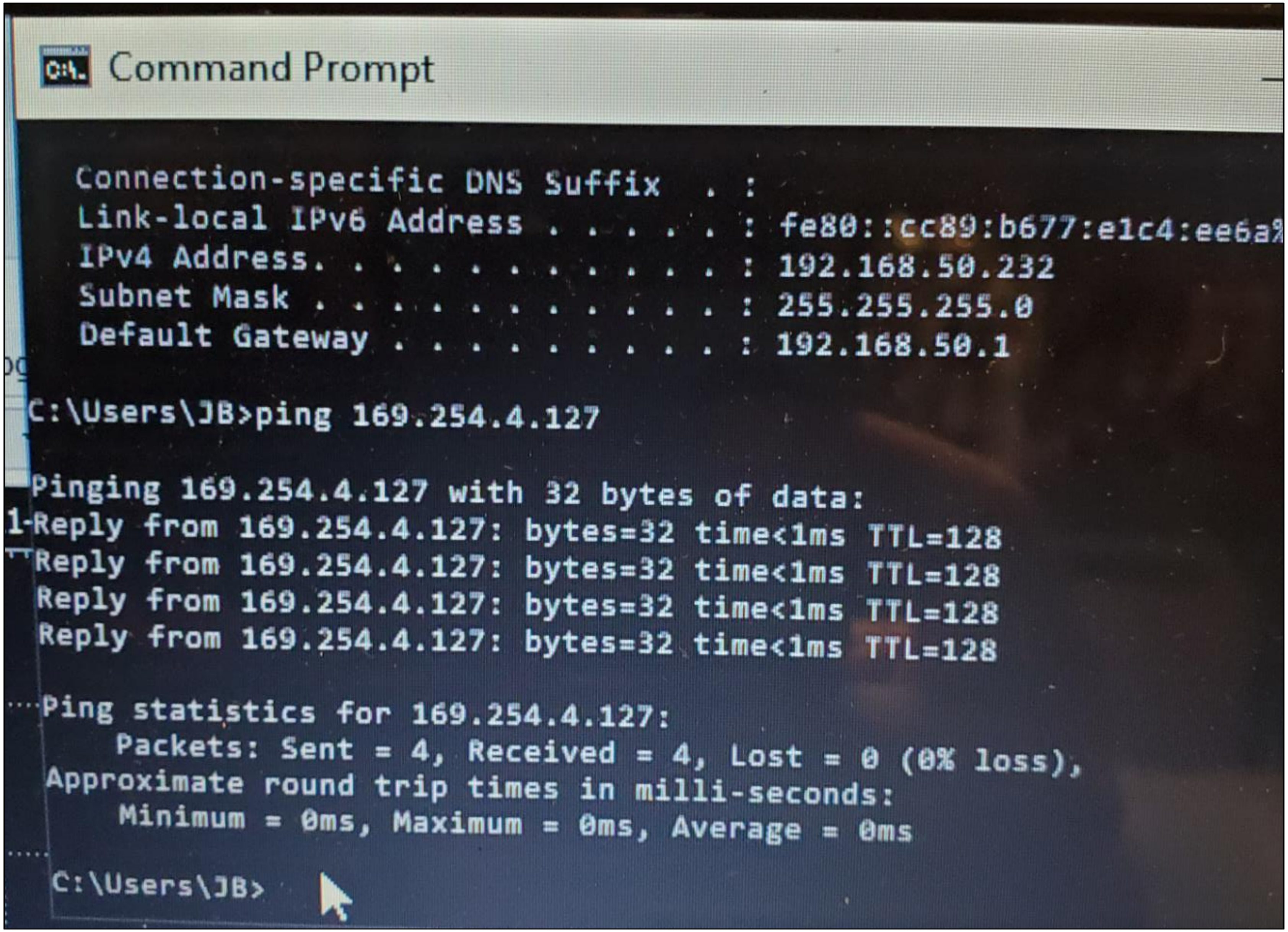


Figure A-42. Ethernet Connection Using Once Device.

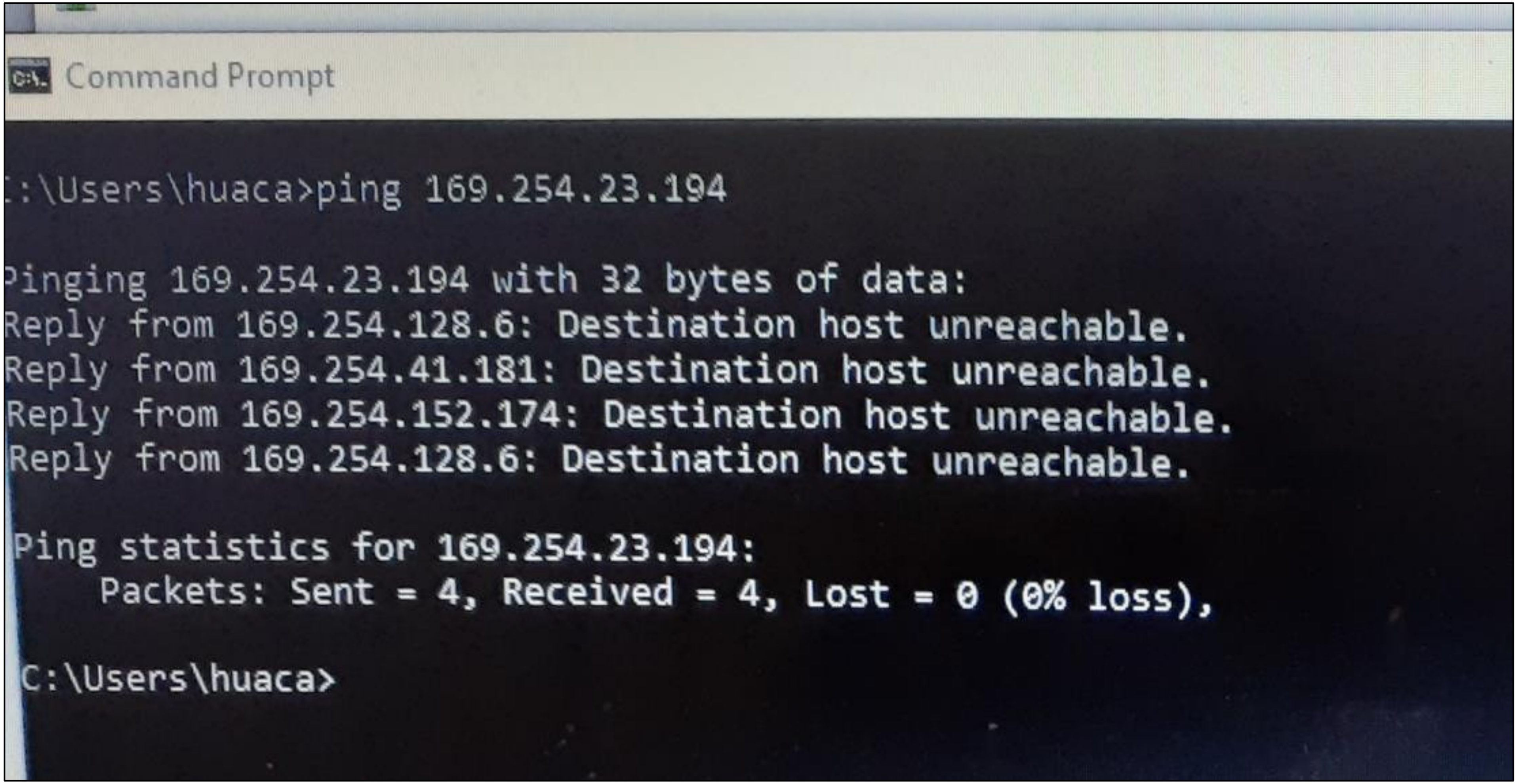


Figure A-43. Ethernet Connection Using Two Devices.

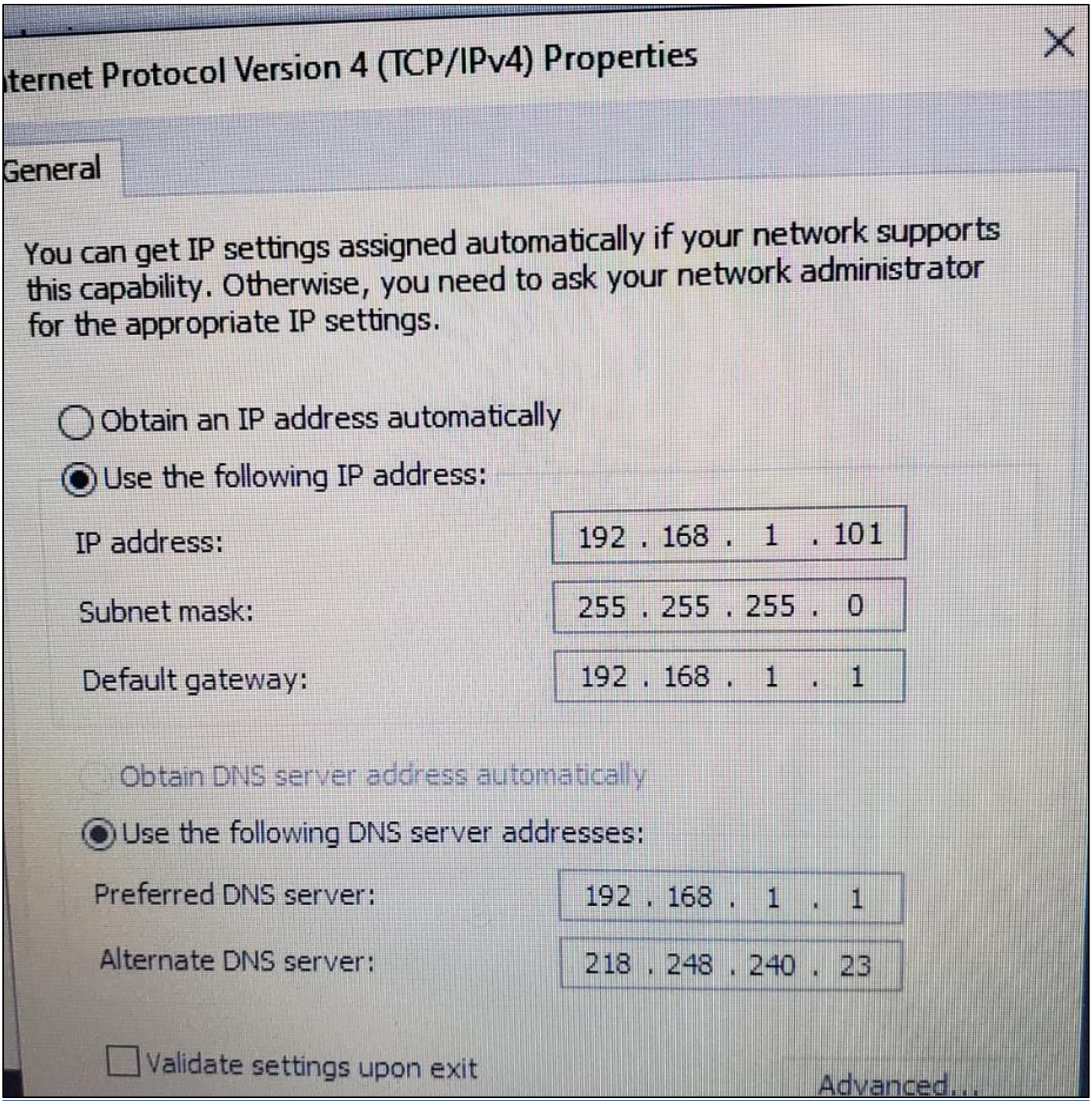


Figure A-44. IPv4 Manually Configured Network properties.

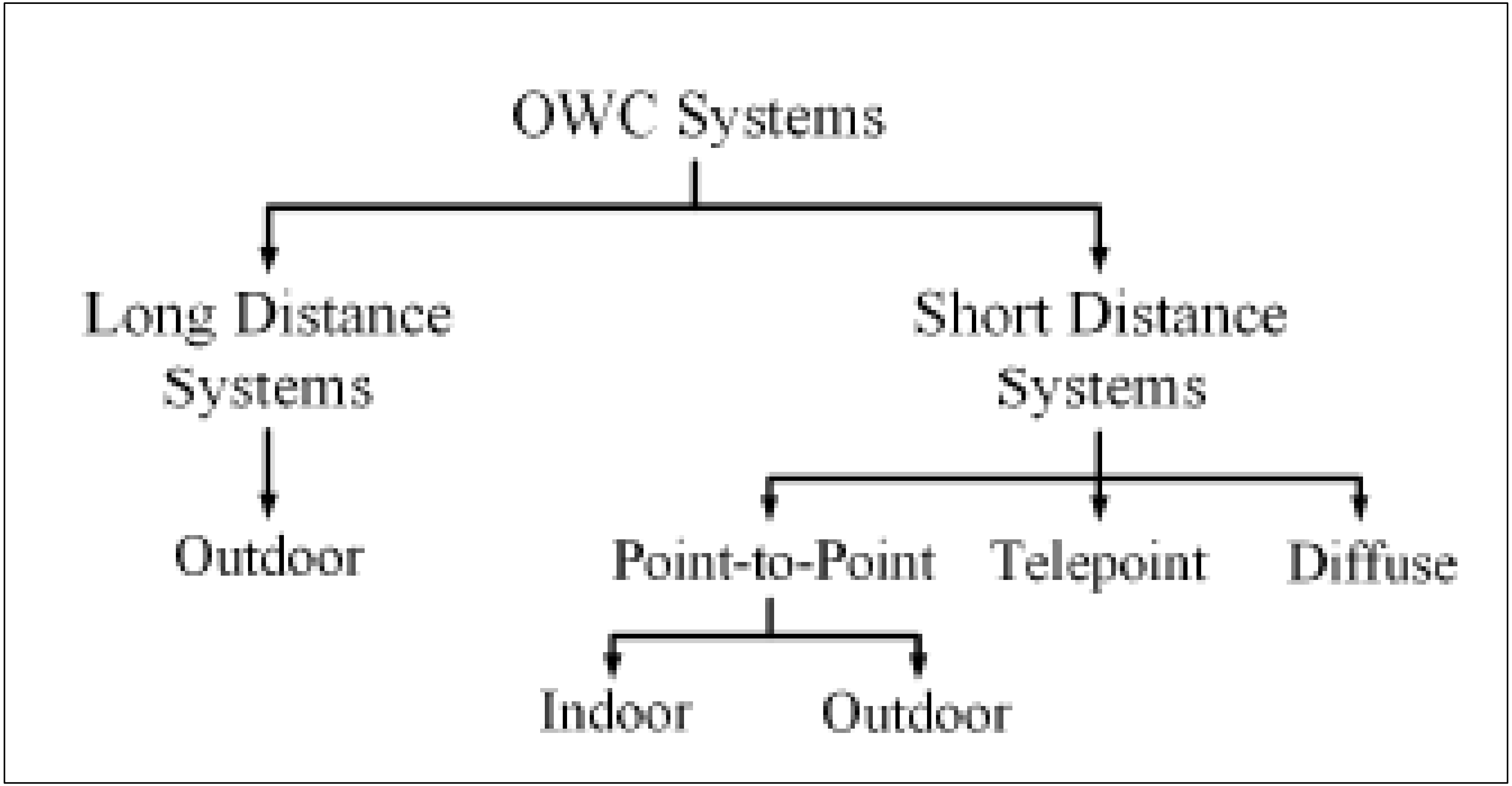


Figure A-45. OWC Systems Classification

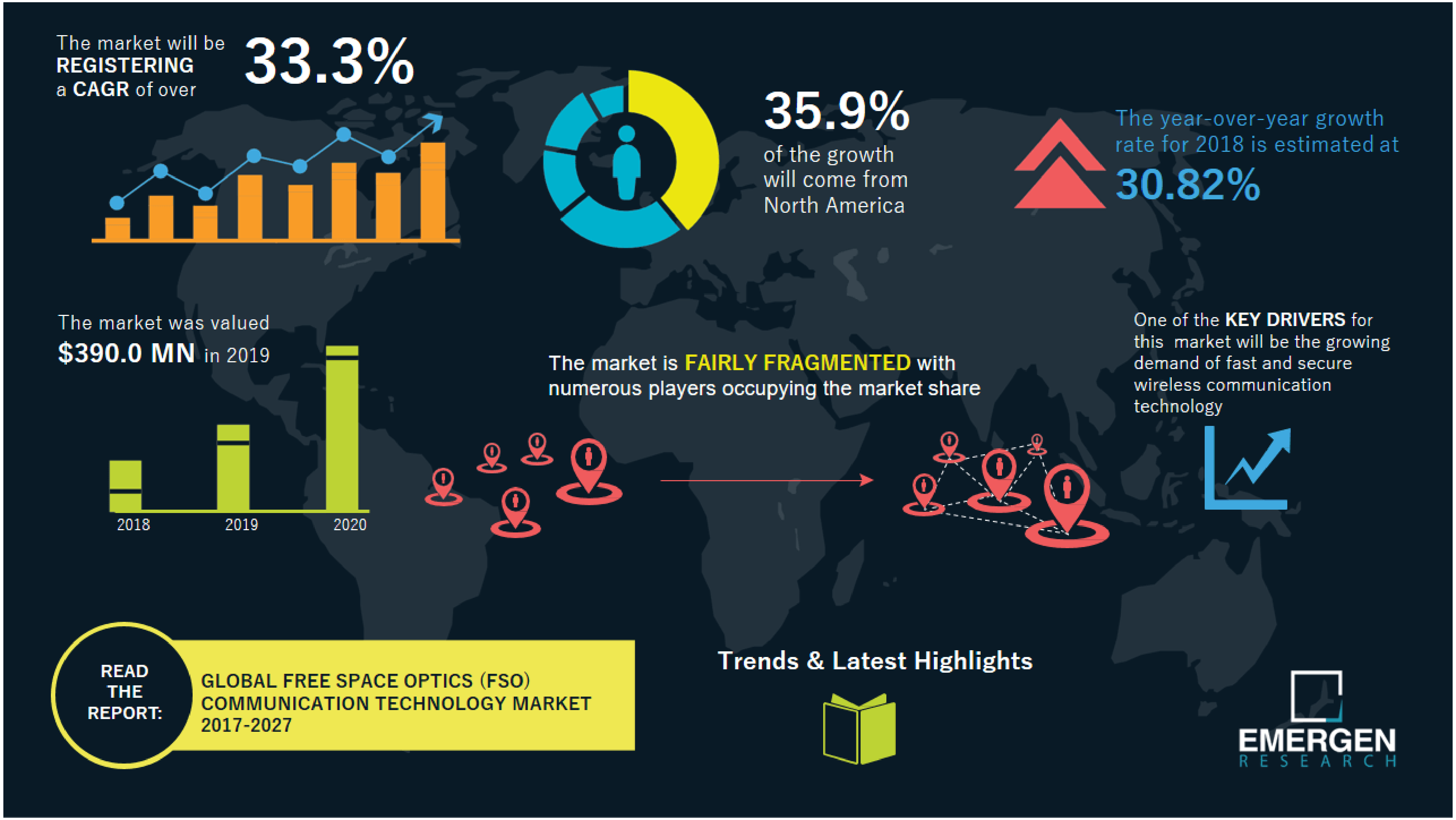


Figure A-46. Global Free Space Communication Market Forecast

APPENDIX B. USER MANUAL

Thank you for selecting our Free-Space Optical Communication transceiver. This transceiver is a communication device capable of point-to-point full-duplex connection with data transmission rates up to 10Mbps. This product was designed to be quickly deployable and lightweight to achieve easy portability so that you can take it whatever you want.

The FSOC transceiver connects to most laptops, Raspberry pi's, or any device with a RJ45 ethernet port using an ethernet cable (ethernet cable not included).
It also comes with an integrated alert system to monitor humidity conditions and allow users to decide whether they want to.

Safe Handling Information

The FSOC system is designed to be used both indoors and outdoors and it must be handled with care to avoid hardware damage.

WARNING
Please read the following warning before installation.

- This product contains a class IIIa laser, please avoid direct eye exposure during installation and while operating the system.
- Do not remove the power cord when the device is turned on.
- This device must be placed at high sites to avoid laser exposure.
- This is not a toy, please keep away from children.

Included Materials

2 - Power supply adapters (9V 1A 110VAC rating 5.5 x 2.1mm positive tip)
2 - FSOC transceivers
8 - Laser alignment screws 5/32" thread by ¼" length
2 - Mounting tripods

Set-up Procedure

1. Place the transceivers on desired locations away from any blockage within a 2-meter distance.
2. Connect the power supply male connector to the transceiver. Do not connect to an electrical outlet yet.
3. Connect each transceiver to selected sever or client host devices using an ethernet cable compatible with 10Mbps data transmission (CAT 5 ethernet network or above with a RJ45 connector, shielded twisted pair (STP) is recommended).
4. Congratulations! You are almost there to connect to the world wide web.

Operation Procedure

1. Once you have selected the desired location of the transceivers, connect the power supply to a regular 120Vac electrical outlet.
2. Carefully point the laser beam into the photodiode to begin the adjustment process.
3. Once the laser beam is reflecting into the photodiode, use the alignment screws to slightly adjust the Line of Sight (LOS) and establish an ethernet connection.
4. See page # under "Ethernet Connectivity for One FSOC Device" for troubleshooting if the connection has not been established.

Software Procedure

Before starting the software up, we need to ensure that the raspberry pi 3b provided to you is connected with your own personal device. The connection between the two devices will be an ethernet connection.

Once you see both devices recognizing the ethernet connection. Your personal device needs to have at least python 3.6 installed or the software will not work. Then you can go to the next sections of the user manual.

TCP Socket Program Server Side this software is already installed on the raspberry pi given with our devices.

Activation Steps - TCP Socket Programming

Step 1

Find the Socket Server Program's IPv4 IP address

Step 2

Modify the client program and add the server's IPv4 address you found in Step 1. In this case the Raspberry Pi which is acting like a server in our project.

The name of the Client Socket program would be: Client_Socket.py. There is only one variable that you need to modify. The name of the variable is called serverHost. The only thing that needs to be modified is the IPv4 address.

Do not delete the single quotation marks when adding the IPv4 address.

Step 3

Save and Exit the program. Then activate the Client Socket Program by whatever method it is done on your own personal device to run python 3.

Step 4

When asked to enter in a file name make sure that the file you enter in is in the same directory as the Client Socket Program that you just ran in Step 3.

Step 5

The program will terminate after Step 4, but if you need to send multiple files just repeat Step 3 and 4 to send more files.

Online Web Database the code to run the online web database is located on the raspberry pi provided with the boards.

Activation Steps - Online Web database

Step 1

On the terminal of the raspberry Pi
Enter in the command: cd var/www/piapp/

Step 2

Next enter in the command: . venv/bin/activate
Yes, make sure to add the period with the space to the command

Step 3

The following step is to
enter in the command: cd fsco

Step 4

Enter in the command: export FLASK_APP=fsco

Step 5

Now when trying to activate the online web database there are methods of doing this. The first is to run the online web database only on the pi using the command.
Enter in the command: flask run
If you want the online web database to be recognized by the local network and in this case your own device that is connected to the raspberry pi, then run the following command
Enter the command: flask run host=0.0.0.0

Step 6

To turn off the online web database you need to type in ctrl+c to the terminal to deactivate the currently running web database.

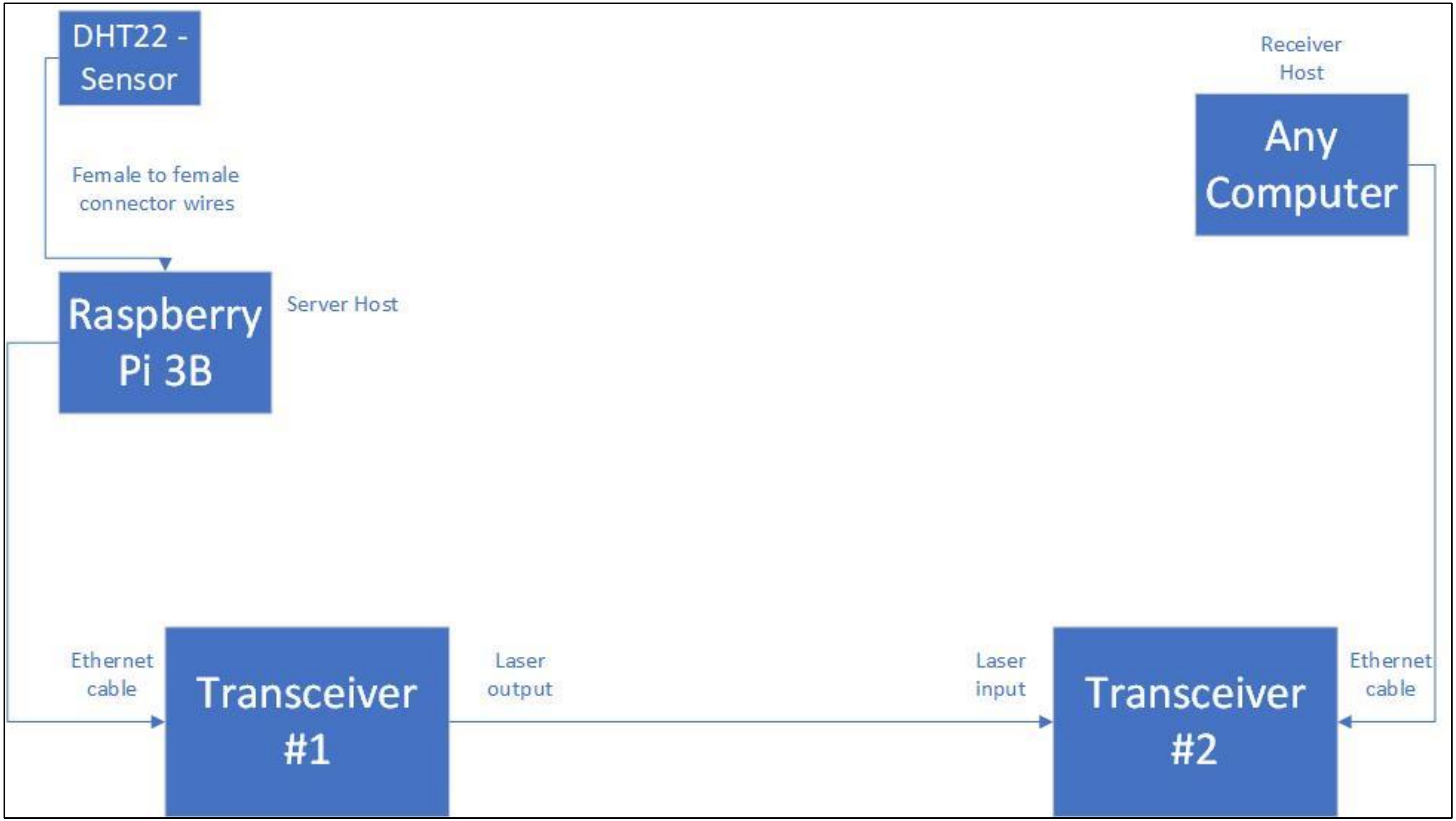


Figure C- 1. Hardware Block Diagram

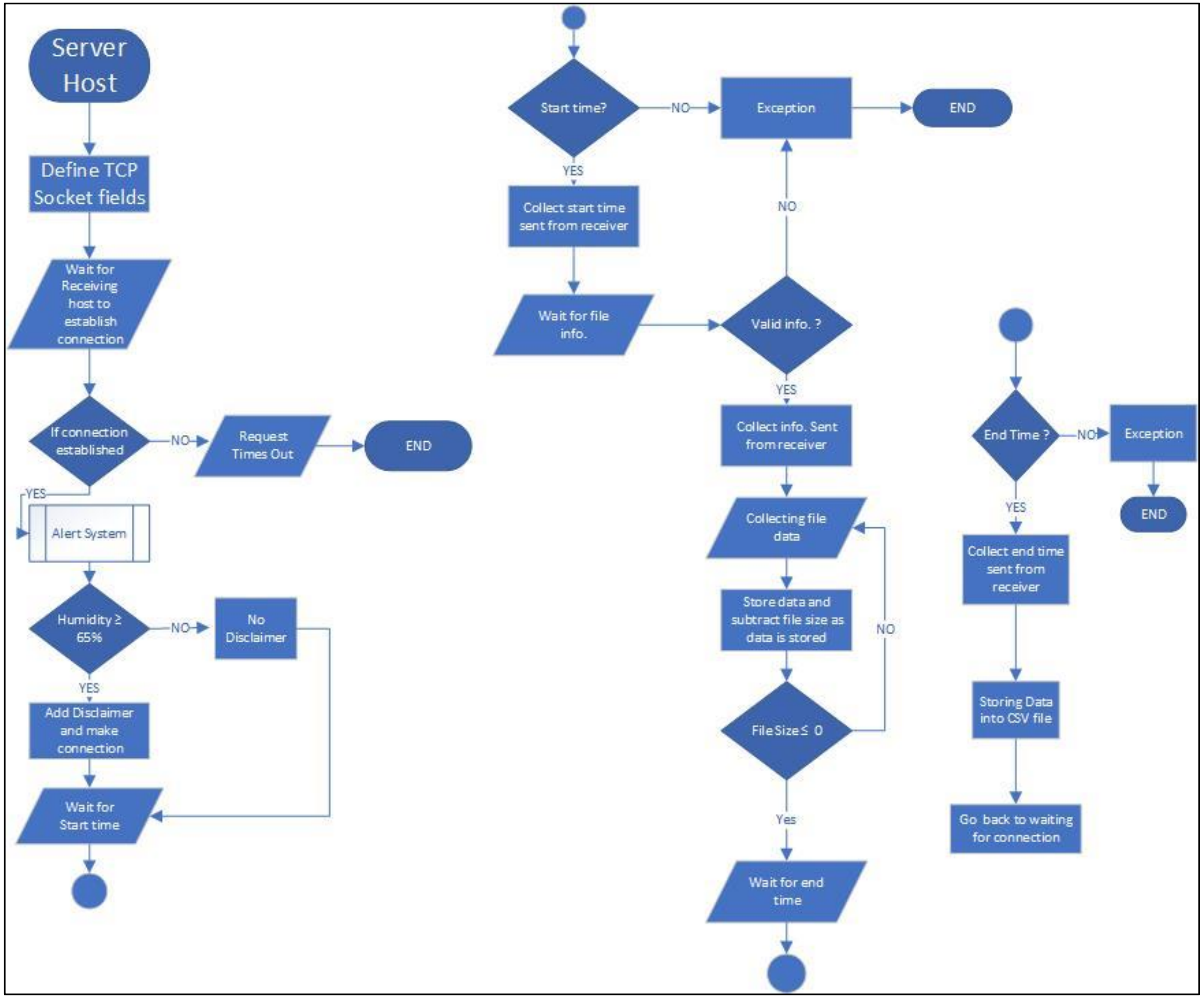


Figure D- 1. Server Socket Flow Chart

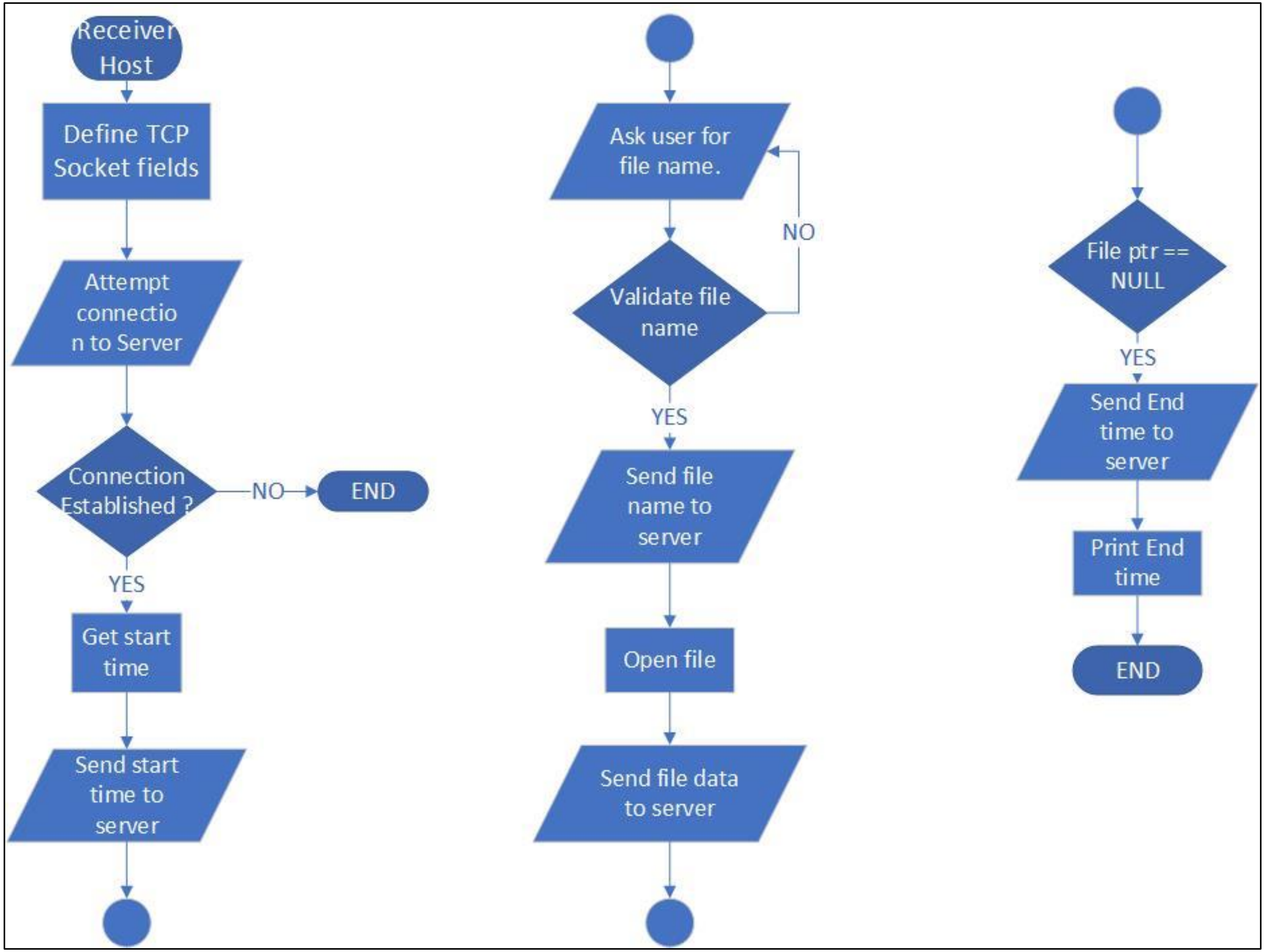


Figure D- 2. Client Socket Flowchart

```
<!doctype html>

<html>
<head>
    <title>
        FSO Communication Device
    </title>
</head>
<body style="text-align:center;">
    <h1 style="color:black;">
            FSO Coumnication device
    </h1>

    <h4>
            Table 1: Transfer Rate
    </h4>

    <table style="border:1px solid black;margin-left:auto;margin-right:auto;padding:4px;border-spacing:20px;">

        <tr>
            <th>Connection Established      </th>
            <th>Connection Closed           </th>
        </tr>
        {% for item in data %}
        <tr>
            <td>{{ item.StartTime }}</td>
            <td>{{ item.StopTime }}</td>
        </tr>
        {% endfor %}
     </table>

   {% for page in total_pages %}
       {% if request.args.get('page') == str(page + 1) or (request.args.get('page') == none and page == 0) %}
         <a href="{{str(request.url).split('?')[0] + '?page=' + str(page + 1)}}" class="btn btn-primary mt-4 mb-3">{{page + 1}}</a>
       {% else %}
         <a href="{{str(request.url).split('?')[0] + '?page=' + str(page + 1)}}" class="btn btn-outline-primary mt-4 mb-3">{{page + 1}}</a
         >
       {% endif %}
   {% endfor %}


</body>
</html>
```

Figure D- 3. Html Template Code

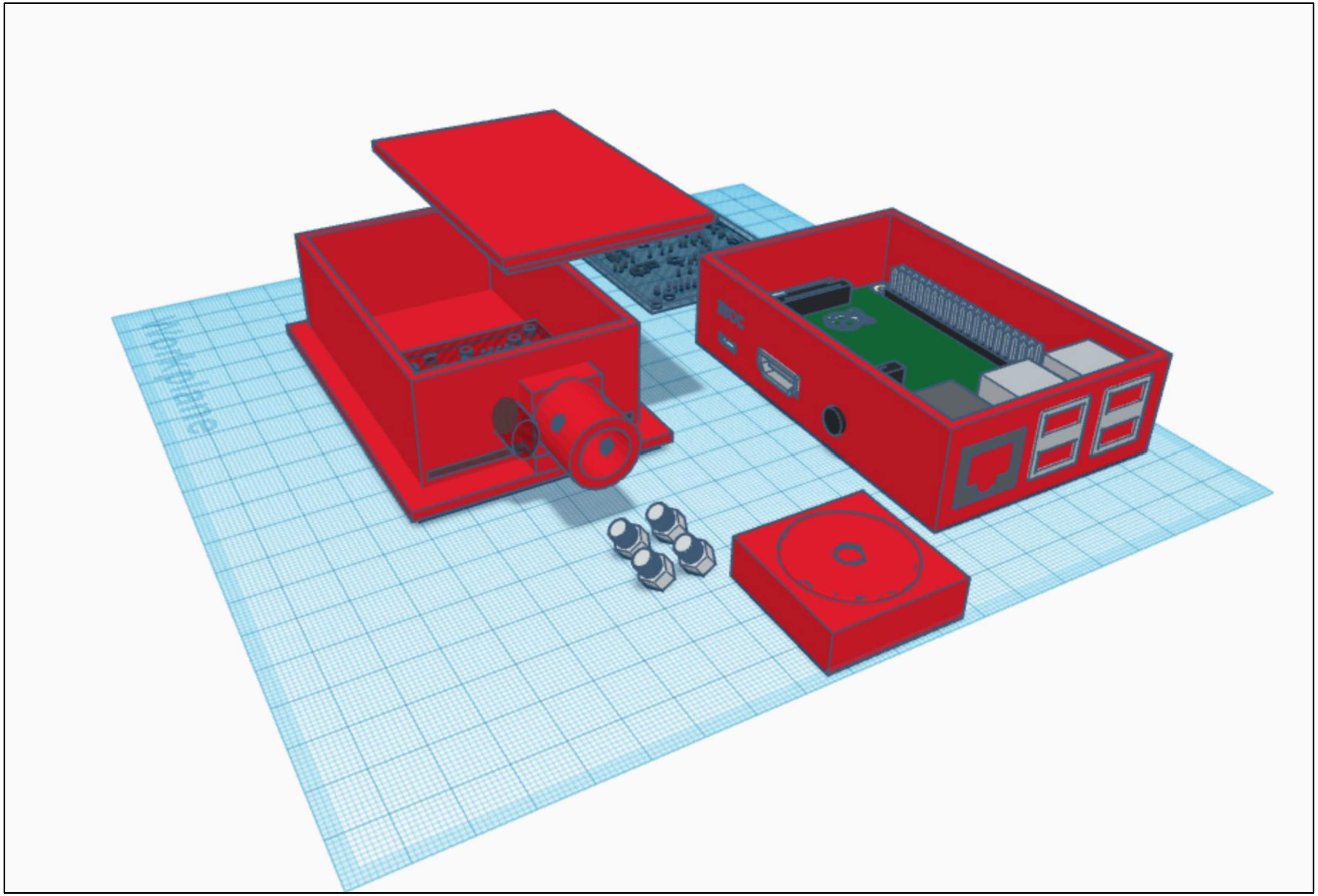


Figure E- 1 Printed Mounting Gear designed by Juan Bonilla

Appendix F. Vendor Contacts

Team 3 FSOC Nation would like to thank the people on this contact list for providing technical advice and guidance throughout the course of the project.

First, and for most our California State University of Sacramento professors and mentors:

- James Cottle
- Neal Levine
- Russ Tatro
- Carl Haynie
- Thomas Matthews
- Kristopher Moyer

We also want to thank Advanced Circuits for helping us through the manufacturing process of the FSOC device.

- Printed Circuit Board Design Check - FreeDFM.com | Advanced Circuits (4pcb.com)

And lastly, we'd like to mention all the other vendors that we've contacted in order to complete our project.

- Amazon
- Adafruit
- Digikey
- Mouser Electronics

Juan R Bonilla Vera

Objective	To obtain a full-time entry level electrical engineering position and put my skills to work	
Education	Bachelor of Science, Electrical & Electronic Engineering California State University Sacramento, CA	Expected: May 2021
Related Course Work	Network Analysis Electromechanical Conversion Power System Analysis I Applied Electromagnetics Signals and Systems	Electronics I & II Intro to Feedback Systems Modern Communication System Probability and Random Signals
Skills	**Hardware**: FPGA Design, Digital I/O and Processor Design, High Frequency Microstrip Microwave Design, Feedback and Control Systems, Signal Processing, Wireless Analog and Digital Communications **Software**: MATLAB, PSPICE, Multisim, ADS/Cadence Allegro Integration, and NI Virtual Bench	
Employment	Bentec Medical Inc • Production Supervision • Research and Development • Silicone Extrusion • Compression, Transfer, and Injection Molding	Woodland, CA June 2006 – July 2015
	H&R Block • Tax Income Preparer	Woodland, CA Jan 2007 – April 2012
Honors and Activities	ASWCC Director of Sustainability at Woodland Community College	Woodland, CA 2016-2017
	Tau Beta Pi member	Sacramento, CA November 2019

Figure G- 1. Juan's Resume

Alexander W. Amaya

alexw.amaya@gmail.com

Professional Skills

- Adaptable
- A Good Communicator
- Efficient
- Independent
- Organized
- Quick to learn
- Reliable

Hardware Skills

- Circuit Analysis
- Digital Signal Processing
- Network Analysis
- Modern Communication Systems

Software Skills

- MATLAB/Simulink
- Microsoft Office Suite
- PSpice/LTSpice
- Visual Studio (C#)

Project Experience

- Free-Space Optical Communication Transceiver/Receiver.
- Pulse detector with Bluetooth capable transmission.
- A simplified traffic light system.
- Unity based computer games. Both systems and design. Includes things like artificial intelligence and procedural generation.

Leadership Experience

Staff Services Analyst – California Public Employees Retirement System (CalPERS)

12/10/2012 – 01/19/2018

- Ten years of service with the State of California in a variety of roles.
- At CalPERS specifically, I had been given the opportunity to lead in an informal capacity. Guiding and educating the rest of our team when complications or complex problems came up.
- Ensured that all assignments were completed at the agreed service level expectations. Of course, always aiming to exceed those expectations. While adhering to quality assurances and timelines.
- Participated in the Internal Advanced Agent (IAA) team. This meant providing advanced level analytics and technical assistance. Not just to our participants but to all freshman agents that would call the senior line.
- Expert level proficiency in CalPERS laws and regulations regarding the retirement and health programs.

Education

Electrical Engineering, Communications – California State University, Sacramento

2018 – currently enrolled

Electrical Engineering – Los Rios Community College District, Sacramento City College

2010 – 2015

Figure G- 2. Alex's Resume

Ankita Jaswal

Objective:

To obtain an internship with an emphasis on computer software or computer hardware.

Education:

California State University, Sacramento; — August 2016 - Present

Bachelor of Science, Computer Engineering — Expected Spring 2021, GPA: 3.3

Knowledge and Skills:

Software Applications:
P-Spice, Microsoft Office, Adobe Reader/Acrobat, GIT, Eclipse, Xilinx Vivado

Computer Languages:
C, Verilog, System Verilog, Java, HTML, Python, MySQL

Hardware:
Propeller, Arduino, Analog Discovery, FPGA, Raspberry PI

Computer Skills:
OS installation, data recovery, computer maintenance, file defragmentation, error troubleshooting/debugging, registry cleanup, boot analysis, network setup

Personal Skills:
Multilingual, Team player, Critical Thinking, Customer Service, Communication, Organization

Project Experience:

Pulse Detector: As part of the Network Analysis course, we constructed a pulse detector based on the principle of photo plethysmography. By using a light emitter, light detector, and op-amps, the AC-signal received is filtered which is proportional to the heartbeat.

Prototype of Database for Phone Locator Application: During a Software Engineering course at Sac State, my scrum team and I created a prototype for a Phone Locator App using GUI in java and GIT through Eclipse.

Automated Sprinkler System: During the Computer Interfacing in a team of four, we constructed an automated sprinkler system using a Raspberry Pi and a Parallax Propeller. Each was programmed using Python and C on a Linux terminal.

Work Experience:

Kohl's - *Omni Sales Associate/Supervisor* — August 2016 - January 2017

The role of this job was to complete online orders which required good organizational skills, good teamwork, and detail orientation. This job also required me to provide customer service through good communication skills.

Intel – Technical Intern — January 2020 - August 2020

During this semester long internship, I was assigned a project to develop a working solution for a web application for my team. This project required the use of technical tools such as Python, PHP, and Json.

Figure G- 3. Ankita's Resume

Giovanne Villanueva

venturavillanueva@csus.edu

Summary

Analytical Computer Engineering student skilled in digital logic design.

Education

CALFORNIA STATE UNIVERSITY OF SACRAMENTO

- Major: Bachelor of Science in Computer Engineering
- Expected Graduation Date: Fall 2021
- Related coursework: Circuit analysis, Logic Design, Computer Hardware Design

Skills & Abilities

SOFTWARE

- Java
  - Completed a project which used linked list and arrays to build a library interface.
- C++
  - Experience with multi-threading for communication from a microcontroller to a microprocessor.
- Verilog
  - Developed a clock divider which ran processes at different frequencies than the original program.
- VHDL
  - Created finite state machine to manage a multiplier.

COMMUNICATION

- Presented technical information to groups smaller than fifty people.

Experience

LAB ASSISTANT | SACRAMENTO STATE | 2020 TO PRESENT

- Answer students' questions and explain parts of lab to students

MARKETING OFFICER | IEEE | 2018 TO PRESENT

- Prepare documentation to advertise IEEE events.
- Participate in officer meetings and provide essential feedback.

VOLUNTEER | FOOD PANTRY | 2013 TO 2017

- Stocked food pantry shelves
- Guided patrons through the food collection process.

Figure G- 4. Gio's Resume

Appendix H. Project Timeline

PROJECT TIMELINE Fall 2020

AT RISK	TASK NAME	SUB TASK NAME	STATUS - % Completed	ASSIGNED TO	START DATE	END DATE	DURATION in days
	Assignment 1a: Individual Problem Statement	Research	40	Giovanne	08/31	09/20	20
	Assignment 1a: Individual Problem Statement	Research	70	Juan	08/31	09/20	20
	Assignment 1a: Individual Problem Statement	Research Design Idea	40	Alex	08/31	09/20	20
	Assignment 1a: Individual Problem Statement	Research Software & Design Tools	80	Ankita	08/31	09/20	20
	Assignment 1b: Team Socital Problem	Report Safety Concerns & Research	100	Giovanne	09/21	09/27	6
	Assignment 1b: Team Socital Problem	Research Hardware Design & Cost Analysis	100	Juan	09/21	09/27	6
	Assignment 1b: Team Socital Problem	Research Schematic & Format Paper	100	Alex	09/21	09/27	6
	Assignment 1b: Team Socital Problem	Research TCP/IP Protocols & Python	100	Ankita	09/21	09/27	6
	Assignment 2: Design Idea & Defining Feature Set	Research on Communication misinformation	100	Giovanne	09/28	10/03	5
	Assignment 2: Design Idea & Defining Feature Set	Research on Communication failures & Research on Design Implementation	100	Juan	09/28	10/03	5
	Assignment 2: Design Idea & Defining Feature Set	Researching Design schematic & Formatting Assignment 2	85	Alex	09/28	10/03	5
	Assignment 2: Design Idea & Defining Feature Set	Research on Tabular Data for Assignment2 & Practicing Software Tools	75	Ankita	09/28	10/03	5
	Setting up the Software Environment	Webpage Development	72	Giovanne	10/04	10/11	7
	Obtaining PCB	Using Kicad & Compile Parts list and Compiling special file for PCB	100	Juan	10/04	10/11	7
	Obtaining PCB	Contacting PCB Vendor & Hardware LTS Simulations	100	Alex	10/04	10/11	7
	Setting up the Software Environment	Setting up Web Page Environment & Reviewing Hardware Components	63	Ankita	10/04	10/11	7
	Implement Software Environment	Web Page Adding a Simple Table & Updating WebPage with Button	77	Giovanne	10/12	10/18	6
	Simulations of the Schematic	Using Kicad to Run Simulations & Pspice Simulations	90	Juan	10/12	10/18	6
	Simulations of the Schematic	Order PCB Board& Hardware LTS Simulations	100	Alex	10/12	10/18	6
	Work Breakdown Structure (WBS)& Implement Software Environment	Writing a Program to Record Data to a csv & Researching Bandwidth Issues	75	Ankita	10/12	10/18	6
	Continue to Implement Software Environment	Restoring Raspberry Pi & Formating Paper	93	Giovanne	10/19	10/25	6
	WBS & Simulations of the Schematic	Simulations and Fixing issues with PCB	100	Juan	10/19	10/25	6
	WBS & Simulations of the Schematic	Editing the Report /WBS & Conatcting PCB Vendor	90	Alex	10/19	10/25	6
	WBS & Continue to Implement Software Environment	Testing CSV with Webpage with Flask	75	Ankita	10/19	10/25	6
	Project Timeline & Continue to Implement Software Environment	Merging My Current Webpage w/ CVS Program & Timeline	75	Giovanne	10/26	11/01	6
	Project Timeline & Finishing Simulations	Start Designing FSOC Base & Timeline	50	Juan	10/26	11/01	6
	Project Timeline & Finishing Simulations	Sumilations & Timeline	100	Alex	10/26	11/01	6
	Project Timeline &Continue to Implement Software Environment	Testing Webpage with Server/Host Connections	50	Ankita	10/26	11/01	6
	Risk Assessment & Testing for a secure TCP/IP Connection	Debugging webapp	100	Giovanne	11/02	11/08	6
	Risk Assessment & Start Board Assembly	Risk Assessment	100	Juan	11/02	11/08	6
	Risk Assessment & Start Board Assembly	Risk Assessment & LT Spice Simulation	100	Alex	11/02	11/08	6
	Risk Assessment & Testing for a secure TCP/IP Connection	Debugging Socket Program	100	Ankita	11/02	11/08	6
	Testing for a secure Connection	Software Interation Video	100	Giovanne	11/09	11/15	6
	Continue Board Assembly	Board Assembly	100	Juan	11/09	11/15	6
	Continue Board Assembly	Continued Simulation	100	Alex	11/09	11/15	6
	Testing for a secure Connection	Debug Webapp & Socket Program	80	Ankita	11/09	11/15	6
	Testing Connection with FSOC	Final Report Fixes & CSS Research	80	Giovanne	11/16	11/22	6
	Testing Line of Sight	Board Assembly	100	Juan	11/16	11/22	6
	Testing Line of Sight	PPT Presentation: Deployable Prototype	100	Alex	11/16	11/22	6
	Testing Connection with FSOC	Debug Webapp & Socket Program	100	Ankita	11/16	11/22	6

Figure H- 1. Project Timeline Fall 2020

PROJECT TIMELINE Spring 2021

AT RISK	TASK NAME	SUB TASK NAME	STATUS - % Completed	ASSIGNED TO	START DATE	END DATE	DURATION in days
	Assignment 1a & Check Status of Project	Web Database and Software Troubleshooting	75	Giovanne	11/24	01/24	61
	Assignment 1a & Check Status of Project	Troubleshoot The Circuit Board	70	Juan	11/24	01/24	61
	Assignment 1a & Check Status of Project	Troubleshoot The Circuit Board	90	Alex	11/24	01/24	61
	Assignment 1a & Check Status of Project	Software Testing & Research: Humidity Sensor	94	Ankita	11/24	01/24	61
	Assignment 2 & Webapp Features	Web database and Socket programming Testing	80	Giovanne	01/25	01/31	6
	Assignment 2 & Auto-Alignment System	Troubleshoot The Circuit Board	80	Juan	01/25	01/31	6
	Assignment 2 & Auto-Alignment System	Troubleshoot The Circuit Board	100	Alex	01/25	01/31	6
	Assignment 2 & Webapp Features	Web database and Socket programming Testing	90	Ankita	01/25	01/31	6
	Demonstration & Program Sensors for Alerts	Testing Humidity Sensor & Modify Socket Program	100	Giovanne	02/01	02/07	6
	Demonstration & Auto-Alignment System	Troubleshoot The Circuit Board	85	Juan	02/01	02/07	6
	Demonstration & Auto-Alignment System	Troubleshoot The Circuit Board	100	Alex	02/01	02/07	6
	Demonstration & Program Sensors for Alerts	Testing Alert System	70	Ankita	02/01	02/07	6
	Assignment 3 & Integration of Software Programs	Modify: socket program	80	Giovanne	02/08	02/14	6
	Assignment 3 & Connecing FSOC devices	Testing LOS Alignment System: Mirror Test	100	Juan	02/08	02/14	6
	Assignment 3	Troubleshoot The Circuit Board	100	Alex	02/08	02/14	6
	Assignment 3 & Integration of Software Programs	Programming Sensors for alert systems on Pi	90	Ankita	02/08	02/14	6
	Integration	Integration and research connection issues	75	Giovanne	02/15	02/21	6
	Integration	Integration and research connection issues	20	Juan	02/15	02/21	6
	Research and PCB Troubleshooting	Research: Market review & Troubleshoot PCB	90	Alex	02/15	02/21	6
	Integration	Integration and research connection issues	100	Ankita	02/15	02/21	6
	Assignment 4 & test connection	Integration and research connection issues	75	Giovanne	02/22	02/28	6
	Assignment 4 & test connection	Integration and research connection issues	25	Juan	02/22	02/28	6
	Assignment 4	Research: Market review & Troubleshoot PCB	100	Alex	02/22	02/28	6
	Assignment 4 & test connection	Integration and research connection issues	100	Ankita	02/22	02/28	6
	Assignment 4	Testing Connection issues on Windows	70	Giovanne	03/01	03/07	6
	Test Results	Testing the FSOC Device for Connection issues	50	Juan	03/01	03/07	6
	Research	Individual Feature Report	100	Alex	03/01	03/07	6
	Prototype Video Script	Testing Connection issues on Linux(Pi)	90	Ankita	03/01	03/07	6
	Test Software and Collect Data	Individual Feature Presentation	100	Giovanne	03/08	03/14	6
	FSOC Modification	Test Results and Collecting Data	100	Juan	03/08	03/14	6
	Deployable Prototype Progress Review	Research: Internet Protocols	50	Alex	03/08	03/14	6
	Final Software Test	Script for Final Presentation	100	Ankita	03/08	03/14	6
	Spring Break	Test Software and Collect data	100	Giovanne	03/15	03/21	6
	Spring Break	Modification: Hardware and Test Modification	90	Juan	03/15	03/21	6
	Spring Break	Project Presentaion	100	Alex	03/15	03/21	6
	Spring Break	Testing Software for proper functionality	100	Ankita	03/15	03/21	6
	Assignment 5 & Make Webapp more Visually Appealing	Test Software and Collect data	100	Giovanne	03/22	03/28	6
	Assignment 5 &Device stand changes	Modification: Hardware and Test Modification	90	Juan	03/22	03/28	6
	Assignment 5 & Device stand changes	Project Presentaion	100	Alex	03/22	03/28	6
	Assignment 5 & Make Webapp more Visually Appealing	Testing Software for proper functionality	100	Ankita	03/22	03/28	6
	Testing Finalizing Design Features	Test Results and Descliamer Label	100	Giovanne	03/29	04/04	6
	Testing Finalizing Design Features	Making Hardware Mounts	100	Juan	03/29	04/04	6
	Testing Finalizing Design Features	Working on End of Year Report	100	Alex	03/29	04/04	6
	Testing Finalizing Design Features	Test results	95	Ankita	03/29	04/04	6
	Testing Finalizing Design Features	End of Project Report and Disclaimer Label	80	Giovanne	04/05	04/11	6
	Testing Finalizing Design Features	End of Project Report and Mounting Gear Assembly	85	Juan	04/05	04/11	6
	Testing Finalizing Design Features	End of Project Report	100	Alex	04/05	04/11	6
	Testing Finalising Design Features	End of Project Report and Finalizing Testing	100	Ankita	04/05	04/11	6
	Assignment 7 & Testing Finalising Design Features	Project-Post Audit Report	100	Giovanne	04/12	04/18	6
	Assignment 7 & Testing Finalising Design Features	Project-Post Audit Report	90	Juan	04/12	04/18	6
	Assignment 7 & Testing Finalising Design Features	Project-Post Audit Report	100	Alex	04/12	04/18	6
	Assignment 7 & Testing Finalising Design Features	Project-Post Audit Report	100	Ankita	04/12	04/18	6

Figure H- 2Project Timeline Spring 2021.