Optical Communications Low-Cost Payload
System Requirements Specification

Version 3.7

02/04/2025

Document Control

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Change Summary

The following table details changes made between versions of this document:

Version	Date	Modifier	Description
1.0	10/24/2024	All Team Members	Created initial document
2.0	11/25/2024	Brian Barker	Began implementation of first revisions.
2.1	11/25/2024	Jessica Sammons	**Implemented revisions of section 1:** explained scope, detailed origin of project, updated reading suggestions section, added hierarchical numbering to document conventions. Also updated the references to contain the prevalent datasheets being used.
2.2	11/26/2024	Jessica Sammons	**Implemented revisions of section 2:** explained where project came from and what the project will be used for in Product Perspective section, removed requirements

			from Product Features section – adding feature descriptions, removed requirements from Design Constraints sections – adding design constraint paragraph descriptions, removed requirements from Operating Environment section – adding description of operating environment and inoperable environments, created user guide and uploaded to Github (will be continuously updated throughout project) to be added to User Documentation section, removed requirements from Assumptions and Dependencies section – adding descriptions of the assumptions and dependencies, created use case diagram and updated corresponding sections with new use cases and actors (Section 2.3) **Implemented revisions of section 3:** updated requirements according to the comments made. **Implemented revisions of section 4:** updated requirements according to comments made on SRS v1. **Revision of section 5:** made changes to requirements according to comments made. **Revision of section 6:** made changes to requirements according to comments made.
2.2	11/26/2024	Mosely Tector	Updated all system requirements (external interface, behavioral) to reflect how the software interacts with hardware and how hardware interacts with hardware to transmit data across the laser. Updated operational requirements to reflect how the laser will be tested and how the laser will operate in the future, though many of the specifics of final design implementations are still TBD. Updated safety procedures and design constraints to reflect constraints developing and operating the laser. Created a more detailed state machine diagram in section 7 to reflect the different states the system can maintain, the inputs required to change states, and the outputs sent upon state change. Updated the TBD list to reflect design parameters required for final operation.
2.3	11/27/2024	Brian Barker	Final revision of the System Requirements Specification v2 document. Updated the formatting throughout the document to correctly list headers in hierarchical order. Changed Section 2's font for consistency. Fixed figure errors in Section 7.2.3.
3.1	12/02/2024	Lexi Colebank	Fix requirements numbering back title block.

3.2	01/14/2025	Jessica Sammons	Updated Section 1 and 2 in accordance with the comments made by the TA. Updated the requirements in all sections in accordance with the comments added by the TA.
3.2	01/14/2025	Lexi Colebank	Inserted comments provided by the TA with small changes made to each section. Updated section 3 and 4 resolving some of the comments regarding the comments separating requirements to multiple ones. Assigned comments to people with the most knowledge. Created section 9 Public Health, Safety, and Welfare with all 5 subsections added for the team to work off based on the Jira assignments.
3.3	1/15/2025	Lexi Colebank	Added more comments from v1 provided by the TA to add more information on the changes needed. Worked through section 3 resolving comments.
3.4	1/21/2025	Lexi Colebank	Started working on Section 9.1 Global Affects and discussing all the impacts that a laser communication system can have. Also worked more on section 3 determining what is a TBD and replacing it with the designated <TBD.#>.
3.5	1/23/2025	Lexi Colebank	Worked on section 9.1, adding information regarding global effects. Started expanding and adding requirements to section 6 regarding operations.
3.5	1/23/2025	Brian Barker	Created and formatted the remaining sections of Section 9 Public Health, Safety, and Welfare.
3.5	1/23/2025	Jessica Sammons	Worked on Section 4.2, Related Features requirements to make them more appropriate to what is expected. Update the Functional Requirements section (4.3) in accordance with comments made. Began working on Section 9, adding information regarding the economic effects of the project and system.
3.6	2/3/2025	Brian Barker	Formatted the incorrect numbering of the headers throughout the entire document.
3.7	2/4/2025	Jessica Sammons	Completed the Safety section in section 9. Performed peer review.
3.7	2/4/2025	Brian Barker	Completed Section 9.7 Environmental and corrected Requirement numbers throughout the document. Formatted the TBD list and the Table of Contents to accurately reflect the document.

Table of Contents

1. Introduction

1.1. Purpose and Scope

The purpose of this SRS is to describe the Low-Cost Optical Communication Payload system and its subsystems of Commercial-Off-The-Shelf (COTS) parts including the Nvidia Jetson Nano Developer Kit, the Nvidia Jetson TX2 Developer kit, and the Laser Drivers being used to accomplish optical communication. The system will achieve the customer goal of a 1 Mbps transmission speed using laser diodes to transmit and receive data across a 1-foot range. The project received at the start of development by the previous senior design team was guided by Dr. Rojas. The previous team consisted of Troy Clifford, Andrew Marinello, Sarah Shiffer, Daniel Unger, Max Wilson, and Ashley Young. The previous senior design team achieved a transmission rate of 1-55 bps using the Jetson Nano and Jetson TX2 Developer kits. The legacy team (the previous senior design team) had more budget and time constraints than us, so they were not able to achieve 1 Mbps transmission rates. Upon researching the components, the team has decided to implement a new laser driver to increase the data rates. Our current scope includes transmission of greater than 55 bps.

A low-cost optical communication payload system is beneficial for allowing data transfers that are greater than 55 bps. We are not able to reach 1 Gbps with the equipment we have been provided, so our project scope has been decreased to the scope of 1 Mpps. Through optical communication, there is an opportunity for loss-correction algorithms and data redundancy that cannot be used in Radio Frequency (RF) transmissions alone. This SRS will describe the system in its entirety as well as each subsystem being used and implemented into the design.

1.2. Intended Audience and Reading Suggestions

This document is intended for developers, users, and project managers to gain a better understanding of the use and purpose of the Low-Cost Optical Communication Payload system. The following contains requirements pertaining to interfaces, behavioral and non-behavioral, and operational uses. A general description of the system is included in the section immediately following this, Section 2. The documentation writers suggest that stakeholders read through the general description section first, reviewing the use cases and assumptions sections. Technical developers are suggested to begin reading at Section 3 and continue through to the other requirements sections. A general reader is suggested to begin at the general description section and move through the document in numerical section order.

1.3. Document Conventions

The requirements in this document are numbered in hierarchical order, with the highest priority having a numbering of 1.0, the next highest 1.1.0, and the next 1.1.1.0. Each requirement defined in this document is considered to have its own priority.

1.4. Project References

Hardware User Manual provided by Dr. Rojas

Software User Manual provided by Dr. Rojas

Standard Operating Procedure created by Development Team

CS165CU-Manual.pdf from ThorLabs. Discussing the digital cameras used in this project.

PM400-Manual.pdf from ThorLabs. Discussing the Optical Power and Energy Meter used in the project.

JetsonNano_DataSheet_DS09366001v1.1.pdf from Nvidia. Discussing the NVIDIA Jetson Nano used to transmit data in this project.

LD15CHA Datasheet.pdf from Wavelength Electronics. Discussing the Laser Driver used in this project.

LDS9-SpecSheet.pdf from ThorLabs. Discussing the 9V Battery Supply used in this project.

1.5. Definitions, Acronyms, and Abbreviations

1.5.1. Definitions

This section lists terms used in this document and their associated definitions.

Table 1: Definitions

Term	Definition
ttyTHS2	Tegra High Speed pin 2. The device ID for the pin being used to receive data.

1.5.2. Acronyms

Table 2: Acronyms

Term	Definition
SRS	System Requirement Specification
OCS	Optical Communication System
RF	Radio Frequency
Gbps	Gigabit per second
COTS	Commercial Off-The-Shelf
LOS	Line Of Sight

1.5.3. Abbreviations

Table 3: Abbreviations

Term	Definition
TX	Transmit
RX	Receive

2. General Description

2.1. Product Perspective

The Optical Communication Low-Cost Payload System is a low-cost, simplistic product capable of satellite communication through free space. The system is designed to fit into the confined space of a 1-foot by 1-foot cube satellite. The main goal of this system is to provide reliable transmission across free space while maintaining an acceptable height and weight budget, as well as keeping overall system costs low. This system will be beneficial for military communications by providing more reliable transmissions than the traditional RF communication devices used in satellites currently. RF data transmission is more prone to interference from EM waves, requiring data redundancy and bit-error checking algorithms. In contrast, optical data transmission operates mostly outside of these constraints, allowing data loss-correction algorithms and data redundancy to be forgone.

2.2. Product Features

The Optical Communication system will transmit an image file in the form of a bitstream using a laser driver and diode. The system will receive the bitstream, decode the bitstream back into an image, and display the image on a monitor.

The user uploads an image of their choice to the software on the transmission side of the system. For the purposes of this document, the transmission side of the system can be considered the NVIDIA Jetson Nano, the laser driver and diode, and the corresponding C/C++ code segments to the NVIDIA Jetson Nano. The transmission side of the system also contains a monitor, keyboard, and mouse. The transmission side of the system then sends the user-uploaded image as bits to a device driver to be serially transmitted by the laser driver and diode.

The laser driver and diode will be placed such that it is facing the photodetector and within 1 foot distance. The receiving end of the system uses a photo detector to convert the received light pulses into a binary code, rebuilding the image and displaying it on the corresponding monitor. The receiving end of the system can be considered the Nvidia Jetson TX2 and the corresponding code C/C++ segments to the NVIDIA Jetson TX2. The receiving side of the system also contains a monitor, keyboard, and mouse.

In summary, the user can upload an image of their choice to the transmission code to be transmitted using the laser diode. The user can then see the reconstructed image on the receiving side of the system displayed on the receiving monitor.

2.3. User Classes and Characteristics

Dr. Eduardo Rojas

Dr. Eduardo Rojas, the product owner, would like to see an increase in data rates while keeping the costs of the system low.

Defense Companies

Defense Companies will find reliable data transmission and receiving, efficient data rates, and security algorithms to be useful in pertinent communications between government entities protecting our nation. This could mean international strategic communications or secret, local communications. The efficient and secure transmission of data is the most pertinent aspect of this user's experience.

Test Engineer

The Test Engineer validates the data transmission and receiving using tests laid out in a test plan document. The Test Engineer shall also be able to diagnose and repair any faults found during testing. The test engineer shall also implement security algorithms to test and verify during transmission.

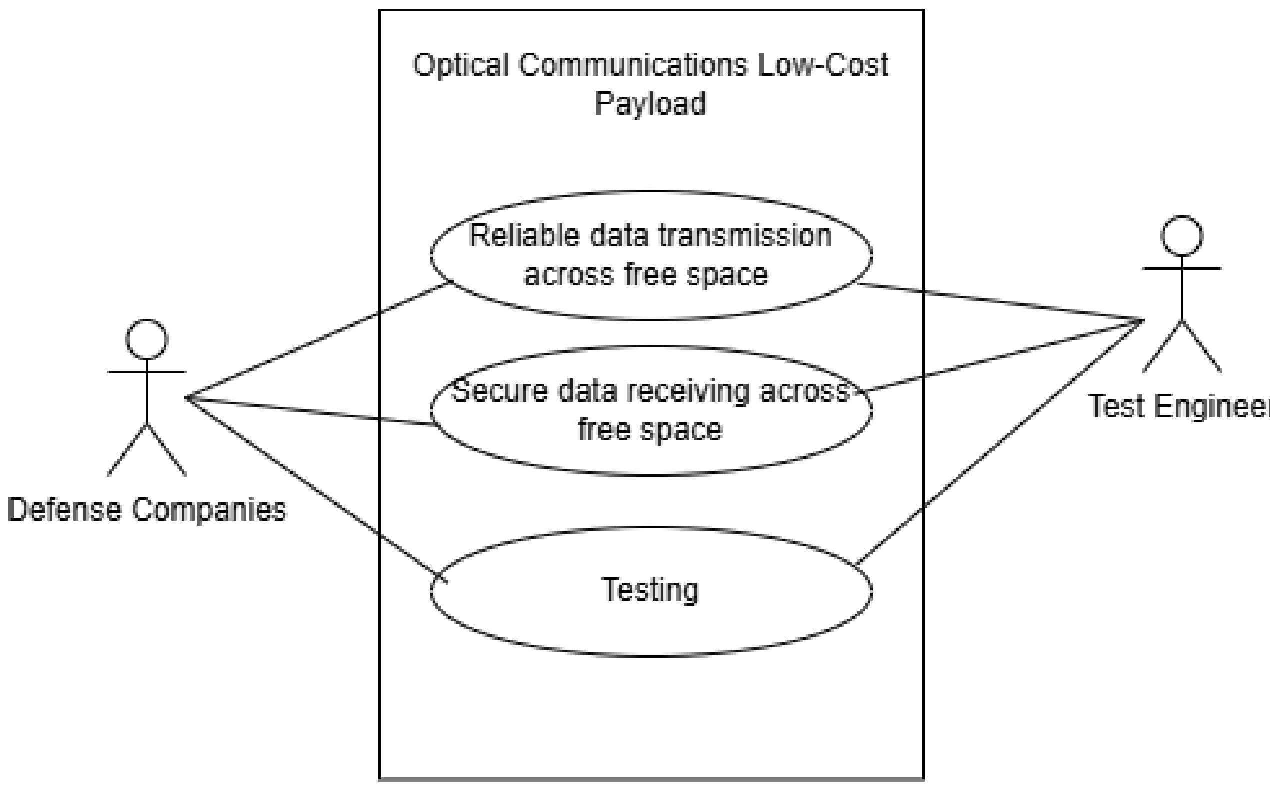

Figure 1: System Operation Use Case Diagram

2.3.1. Use Cases

Reliable Data Transmission Across Free Space

Ensuring that data transmitted through free-space optical communication channels reaches its destination accurately despite challenges like atmospheric interference, misalignment, or environmental factors.

Secure Data Receiving Across Free Space

Ensuring data integrity and confidentiality in free-space optical link, particularly in scenarios where interception or jamming is a concern.

Testing

Implementation of test plans to verify proper integration of system components and correct data transmission.

2.3.2. Scenarios

Scenario 1: Image Transmission

Description: The test engineer will send an image through the transmitting side of the system to the receiving end of the system

Actors: Test Engineer.

Precondition: The system has power and is connected to designated computers.

Trigger Condition: The Test Engineer sends a signal to the receiving end of the system.

Steps:

1. Test Engineer uploads files into the Nvidia Jetson Nano software.
2. Nvidia Jetson Nano sends the signal one bit at a time, following an optical communication data sync protocol.
3. Laser Diode takes the GPIO voltages turning the diode on/off accordingly.
4. The receiver then takes in the laser and converts the on/off voltage to the TX2 pin.
5. The TX2 then reads the data to convert the image.

Scenario 2: Image Receiving

Description: The Test Engineer will verify displayed image sent to the receiving end of the system.

Actors: Test Engineer.

Precondition: The system has power and is connected to designated computers.

Trigger Condition: The Test Engineer sends a signal to the receiving end of the system.

Steps:

1. The photodetector reads the binary bitstream and sends the bitstream to the Nvidia Jetson TX2.
2. The Nvidia Jetson TX2 decodes the bitstream into a reconfigured image.
3. The Nvidia Jetson TX2 code displays the reconfigured image on the corresponding monitor.

2.4. General Constraints

The constraints of our system include the need for the system to be tested in the dark as the laser is not extremely powerful. Testing must also be done using safety glasses to protect team members' retinas in case of an accident occurring with the laser. The team has a total of two safety glasses, so only two people may be present at the time of testing. This can slow down the development process as it makes the system difficult to test.

Another constraint of the system is the initial use of the Nvidia Jetson Nano and Nvidia TX2 by the previous senior design team, as these components cause bottlenecking in the transmission and receiving rate of the system. This hinders the current team's ability to increase the data rate to 1 Mbps.

The system is not fully contained within a weather-proof system and will not be tested in windy or rainy conditions as of the time this document is written. This, along with the general strength of the laser driver and diode, keeps the test distance between the laser driver and the photo detector within 1 foot.

Finally, the system has budget and time constraints. The project timeline is constricted to about 6 months total. The project is also constricted to a budget of $1,000. These requirements limit the type of hardware we can purchase, which can limit the speed and accuracy of the transmission of the system.

2.5. Operating Environment

The system is designed with Commercial-Off-The-Shelf parts for operation in typical Earth, ground atmospheric conditions. The system functions most successfully in temperate, dry conditions such as the lab. This means that the typical operating temperature of the environment is 68-73 degrees Fahrenheit. The system has not yet been exposed to wind or rain when attempting transmission. As the current components in use are not space grade, the current system will not be of use in any space environment.

2.6. User Documentation

2024 Optical Communications Low-Cost Payload User Guide.docx

2.7. Assumptions and Dependencies

The system is assumed to be correctly wired and powered at time of use, with the proper implementation of resistance in the laser driver and diode. The system is also assumed to have an image to be transmitted loaded into the software at the time of transmission. The system is assumed to have wires which are not torn or at risk of causing a shortage in the system at all times during development.

The system depends on an Ethernet connection to access public libraries for the Nvidia Jetson Nano and Nvidia TX2 software. The system also depends on a power source such as a computer connection to power the receiver. The system depends on the connected monitors to run the transmitting and receiving code which encodes the image to a binary bitstream and decodes the image back to a displayable file.

The system also is assumed to have performance that is consistent with the operating specifications of each component. Calibration of each component will be performed in order to assure that the components are operating at their specified performance. The system hardware is assumed to be performant enough to reach speeds of at least 1Mbps.

3. External Interface Requirements

3.1. User Interfaces

Req. 3.1.1: The user shall plug in the power source through the computer

Req. 3.1.2: Activate the laser using the laser driver.

Req. 3.1.3: The user shall provide input into the NVIDIA Jetson.

Req. 3.1.4: All activation of the system shall be performed via startup script in the Terminal.

Req. 3.1.5: The user shall be able to select an image through the terminal shell by calling out the image file in the main transmission code.

Req. 3.1.6: The user shall view the image from the NVIDIA Jetson TX2 output directory.

3.2. Hardware Interfaces

Req. 3.2.1: The system shall use an NVIDIA TX2 to transcode the received serial bitstream back into an image.

Req. 3.2.1.1: They NVIDIA TX2 shall take the 3.4V signal and convert to a 1-bit signal.

Req. 3.2.2: The NVIDIA Jetson TX2 shall connect to the optical sensor through UART pins to receive image input.

Req. 3.2.3: The optical sensor shall send the received serial bitstream to the NVIDIA Jetson TX2 through UART pins on the TX2.

Req. 3.2.4: The system shall use an HDMI cable to send image data to the physical display monitor.

Req. 3.2.5: The system shall use a physical display monitor to show the received image feed to the user.

3.3. Software Interfaces

Req. 3.3.1: The transmitting board (NVIDIA Jetson Nano) shall write an image as a buffer to the ttyS0 device by using standard Linux file operation system calls (open(), read(), write(), close()).

Req. 3.3.2: The Jetson Nano shall open the file “/dev/ttyS0” using the Linux system call “open()” to gain access to UART device “ttyS0”.

Req. 3.3.3: The Jetson Nano shall use the Linux system call “write()” to write the name and size of the image before transmitting the image data.

Req. 3.3.4: The Jetson Nano shall use the Linux system call “write()” to write the image data all at once to the UART device “ttyS0”.

Req. 3.3.5: The Jetson Nano shall use the Linux system call “close()” to release the UART device “ttyS0” when the Nano is done writing the full image.

Req. 3.3.6: The Jetson TX2 shall open the file “/dev/ttyTHS2” using the Linux system call “open()” to gain access to UART device “ttyTHS2”.

Req. 3.3.7: The Jetson TX2 shall use the Linux system call “read()” to read the name and size of the image before reading the transmitted image data.

Req. 3.3.8: The Jetson TX2 shall use the Linux system call “read()” to read image data from the UART device “ttyTHS2” in 4095-byte chunks.

Req. 3.3.9: The Jetson TX2 shall put all data read in from “ttyTHS2” into a heap-based byte array the size of the image.

Req. 3.3.10: The Jetson TX2 shall print the elapsed time in seconds and data rate in Mbps of the full image transfer.

Req. 3.3.11: The Jetson TX2 shall use the Linux system call “close()” to release access to the “ttyTHS2” device once it is done reading all the image data.

Req. 3.3.12: The Jetson TX2 shall write the image file to the directory “/home/amarjon/OPTICS Fall 2024/receive” under the name of the original file.

Req. 3.3.13: The Jetson TX2 shall write the image file to directory stated using standard Linux system calls “open()”, “close()”, and “write()”.

Req. 3.3.14: The ttyS0 driver shall send the image data serially through the UART pins found on the bottom of the NVIDIA Jetson Nano.

Req. 3.3.15: The receiving board (NVIDIA Jetson TX2) shall receive data in a buffer through the ttyTHS2 device driver.

Req. 3.3.16: The ttyTHS2 device driver shall receive data through the third pin from right in pin section J17 on the NVIDIA Jetson TX2.

Req. 3.3.17: The system shall be able to transmit images of any format.

3.4. Communications Interfaces

Req. 3.4.1: The system shall use a laser to transmit the serial bit stream through free space.

Req. 3.4.2: The PDA20C2 photoreceiver shall intercept the laser.

Req. 3.4.3: The system shall communicate asynchronously using UART with 1000000 Hz baud rate with the 8N1 (1 start bit, 8 data bits, 1 end bit) packet format from the transmitter to the receiver module by an optical communication system.

4. Behavioral Requirements

4.1. Stimulus

Req. 4.1.1: The system shall initiate data transmission within 5 seconds of receiving a compressed image file from the NVIDIA Jetson Nano.

Req. 4.1.2: The system shall begin recording received bitstream data using the photodetector once detecting the first packet transmission light by the laser diode.

Req. 4.1.3: The Jetson TX2 shall always listen for data until it receives the size of the incoming image through UART transmission, at which point it will begin attempting to receive the image.

4.2. Related Features

Req 4.2.1: The system shall transmit an image file as a bitstream using the laser driver and diode.

- Req 4.2.1.1: The laser driver shall be within the line-of-sight (LOS) of the receiver at the start of transmission.

Req 4.2.2: The system shall store the transmitted bitstream as an image.

- Req 4.2.2.1: The system shall allow users to open the received image in the Jetson TX2's folder "/home/amarjon/OPTICS Fall 2024/receive".

Req 4.2.3: The system shall provide troubleshooting steps through the terminal interface.

- Req 4.2.3.1: The system shall provide instructions to ensure proper transmission to receiver alignment.
- Req 4.2.3.2: The system shall provide instructions to ensure that the system is receiving power.
- Req 4.2.3.3: The system shall provide instructions to ensure proper wiring between hardware devices.

4.3. Functional

Req. 4.3.1: The input image file shall be read into the transmitting process's heap memory.

Req. 4.3.2: The input file image shall be transmitted through the UART TX pin on the transmitting board (NVIDIA Jetson Nano).

Req. 4.3.3: The bitstream read from the laser by the optical receiver shall be read through a UART device driver on the receiving board (NVIDIA Jetson TX2) to a char pointer.

Req. 4.3.4: The system shall send data bits serially through the UART device driver using non-blocking code using a single thread.

Req. 4.3.5: The system shall transmit data without applying additional encoding of the transmitted bitstream.

Req. 4.3.6: The system shall output the received bitstream without performing decoding of the received bitstream.

5. Non-behavioral Requirements

5.1. Performance Requirements

Req. 5.1.1: The hardware shall transmit the serial bitstream at a rate of at least <TBD.1>.

Req. 5.1.1.1: The serial bitstream shall be received at a rate of at least <TBD.2>.

Req. 5.1.2: The hardware shall transmit a signal at a speed that the receiving computer is able to adequately decode all data.

Req. 5.1.3: The hardware shall transmit at least 95% of the data without errors or loss.

Req. 5.1.4: The system shall transmit data through at least <TBD.5> inches of free space.

Req. 5.1.5: The transmitter system shall not draw any more than 20 mW.

Req. 5.1.6: The RX shall receive the serial bitstream through free space without outside interference through air with less than or equal to 8 micrograms/cubic meter of dust.

5.2. Safety Requirements

Req. 5.2.1: The carrier signal (laser) shall be oriented directly to the centerline within 1 degree of the receiving photodetector.

Req. 5.2.2: The laser shall not be operated without a member of the project team to verify its proper use.

Req. 5.2.3: The system shall have no possible shorting hazards.

Req. 5.2.3.1: The system shall have no exposed wiring.

Req 5.2.3.2: The system shall be inspected to be secure at all connection points prior to operation.

Req. 5.2.4: The laser diode power shall not exceed 5 mW.

Req. 5.2.5: The laser diode current shall not exceed 40 mA.

Req 5.2.6: The laser driver’s current shall be limited to ensure laser diode maximum power is not reached.

Req 5.2.7: The laser driver’s current limit shall be set to 20mA using a test circuit.

Req. 5.2.8: The system shall be turned off when not in use.

Req. 5.2.9: The system shall be tested in an enclosed space while wearing LG16B - Laser Safety Glasses (1550 nm) eye protection.

5.3. Availability

Req. 5.3.1: The system shall operate at 95% availability during its lifetime.

5.3.1. Security

Req. 5.3.1.1: The system shall only be used by authorized project members defined in a personnel control document.

5.3.2. Maintainability

Req. 5.3.2.1: The operator shall replace the system diode in the occurrence of burnout.

Req. 5.3.2.2: The operator shall connect the laser driver to the corresponding hardware devices according to the Hardware User Manual.

Req. 5.2.2.4: The software developer shall be able to use the same UART library when increasing the data transfer rate of the system up to 12.5 Mbps.

Req. 5.3.2.5: The software developer shall have to use a new communication protocol, like USB 3.0, and shall use the appropriate library for communicating with such hardware when increasing the data transfer rate past 12.5 Mbps.

Req. 5.3.4.4: The hardware developer shall have to replace the laser driver when increasing the data transfer rate of the system past 1 Mbps.

Req. 5.3.5.5: The hardware developer shall have to replace the photoreceiver when increasing the data transfer rate of the system past 5 Mbps.

5.3.3. Portability

Req. 5.3.3.1: The system code shall only be portable to systems running on Ubuntu 18.04 with a processor architecture of AARCH64.

5.4. Design and Implementation Constraints

5.4.1. Design Constraints

Req. 5.4.1.1: The optical communication system shall fit within 1U (10x10x10 in <TBD.3>).

Req. 5.4.1.2: The system shall cost under $20,000 USD.

Req. 5.4.1.3: The optical communication system shall weigh less than 20 pounds.

Req. 5.4.1.4: The system shall operate between 65-80 degrees Fahrenheit.

Req. 5.4.1.5: The system shall operate using the NVIDIA Jetson Nano to transmit data.

Req. 5.4.1.6: The system shall operate using the NVIDIA Jetson TX2 to decode data.

Req. 5.4.1.7: The system shall operate on Earth's surface within the current laboratory decided upon by the Product Owner.

Req. 5.4.1.8: The system components to be purchased shall be approved or denied by Dr. Rojas and shall be purchased from the vendor (likely through a website) upon approval.

Req. 5.4.1.9: The system shall constantly maintain Line of Sight (LOS) between transmitter and receiver when operating.

5.4.2. Implementation Constraints

Req. 5.4.2.1: The system shall use COTS components.

Req. 5.4.2.2: The transmitting laser shall use a 1550 nm wavelength Diode.

Req. 5.4.2.3: The transmitting laser shall use a 1550 nm wavelength laser driver (IR-B class).

Req. 5.4.2.4: All system code implementation shall be done in C++ and C.

6. Other Requirements

6.1. Operations

Req. 6.1.1: The user shall initiate the data stream transmission using the software interface.

Req. 6.1.2: The data stream transmission shall stop once all sent data is received.

Req. 6.1.3: The system shall be tested by increasing laser diode/optical receiver distances up to 1 foot.

Req. 6.1.4: The laser shall send static data at the final stages of development.

Req. 6.1.5: The NVIDIA Jetson Nano shall have a power button accessible to the user for use and operation.

Req. 6.1.6: The NVIDIA Jetson TX2 shall have a power button accessible to the user for use and operation.

Req. 6.1.7: The laser receiver shall have a power button accessible to the user for use and operation.

Req. 6.1.8: The laser driver shall be powered on with a 5V source through the NVIDIA Jetson Nano.

Req. 6.1.9: The laser diode shall output no more than 10 mW.

Req. 6.1.10: The laser diode shall receive no more than 35 mA.

Req. 6.1.11: The laser diode shall output <TBD.5> with a range of 5% error.

Req. 6.1.12: The laser diode shall receive <TBD.6> with a range of 5% error.

Req. 6.1.13: The laser diode shall receive data through the “MOD INPUT” pin on the laser driver.

7. Analysis Models

7.1. Data Flow Model

7.1.1. Data Sources

The data sources and their inputs to the system identified in the data flow model are as follows:

- NVIDIA Jetson Nano Desktop
  - Transmitted bitstream
    - The bitstream is taken from an image stored in the Jetson Nano's file system in the same directory as the transmission script. This image is predetermined by the user.

7.1.2. Data Sinks

The data sinks and their system outputs identified in the data flow model are as follows:

- Nvidia Jetson TX2 Desktop
  - Received bitstream

7.1.3. Data Flow Diagrams

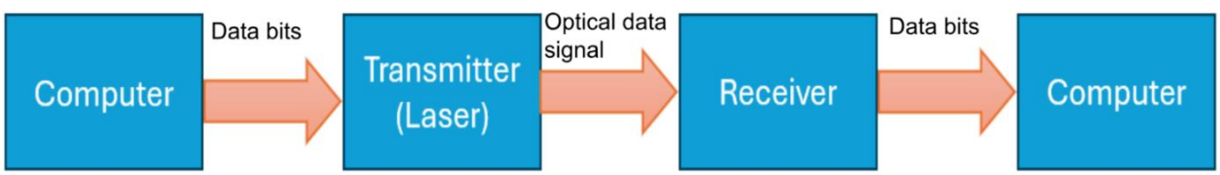

Figure 2: Level 0 Flow Diagram

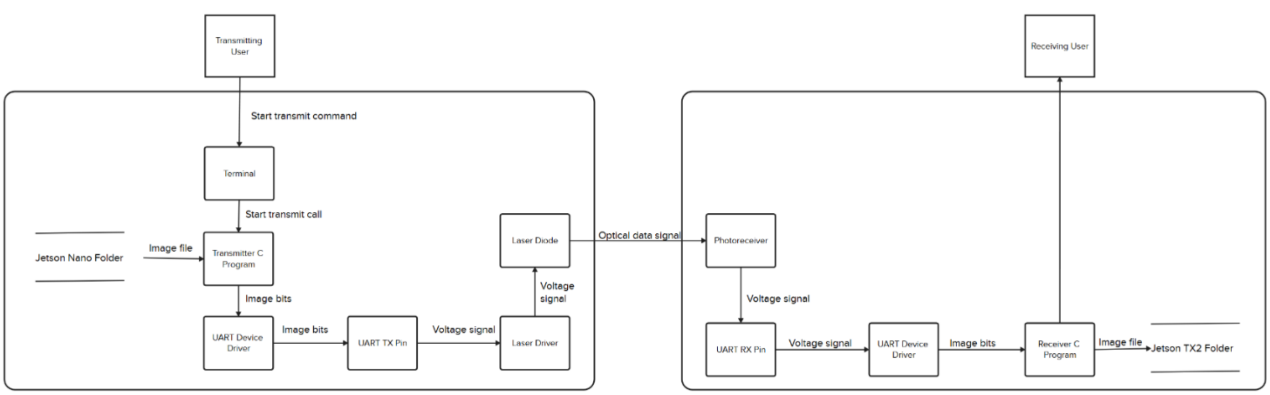

Figure 3: Level 1 Flow Diagram

7.2. State Model

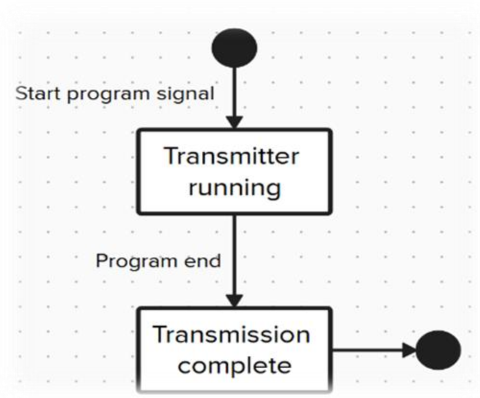

Figure 4: Transmitter State Model Diagram

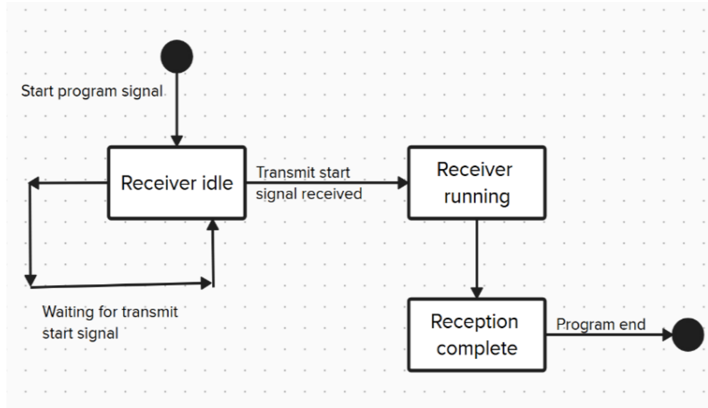

Figure 5: Receiver State Model Diagram

8. To Be Determined List

8.1. To Be Determined

Table 4: To Be Determined List

TBD	Req Number	Justification
TBD.1	Req. 5.1.1	The bit rate is currently changing from 1Mbps to 1 Gbps based on new components that need to be received
TBD.2	Req. 5.1.1.1	The bit rate is currently changing from 1Mbps to 1 Gbps based on new components that need to be received
TBD.3	Req. 5.1.5	The free space distance is currently changing
TBD.4	Req. 5.4.1.1	The components we currently have do not fit within a cubic box and need to be upgraded per the final requirements of 1 Gbps.
TBD.5	Req. 6.1.12	The power on the laser diode is undecided based on the changing output power.
TBD.6	Req. 6.1.13	The current on the laser diode is undecided based on the changing output power.

9. Public Health, Safety, and Welfare

9.1. Public Health

Optical communication systems have the potential to benefit Public Health systems in our communities both directly and indirectly. One of the direct impacts is the ability to access telemedicine in remote areas allowing more people to have the ability to see a doctor. In the same way, education becomes more available through e-learning platforms. More digital libraries and online courses can help communities continue educating low-income communities who don't have access to higher education. The communication system also helps with connecting families all over the world when they are working in remote areas. Keeps a sense of peace and connection with family members who might be in dangerous areas.

Indirectly, optical communication systems lower energy consumption and would cut carbon emissions. However, there are some cons that allow security risks to accrue. While it allows communication to increase security information can be stolen or intercepted. This causes privacy concerns with military personnel and medical histories. There is also an issue of excessive digital engagement which can cause addiction and disturb one's sleep causing fatigue.

Overall, optical communication system allows the digital world to advance its presence in our day to day lives. With improvements in connecting rural areas to proper health care and education. It also improves social well-being and economy among people. Giving them real-time interactions with each other and up to date information on the economy allows remote work to be more accessible to those with disabilities. While there are many pros to optical communication, there is still a huge risk factor that needs to be taken into consideration such as cybersecurity threats and digital overuse.

9.2. Safety

The Low-Cost Optical Communication system addresses safety concerns pertaining to cybersecurity and data protection, operational safety, and infrastructure resilience. The transmission protocols used in the system ensure that communications are not jammed or intercepted. Since optical communications are more secure than RF transmissions, the data transmitted in the system is more reliable than that of traditional RF transmissions.

An example of the need for data protection is the use of optical communications in U.S. Air Force fighter jets and satellites. Optical communication provides a more secure way to transmit classified military data than RF transmissions. Our system specifically benefits from the greater security of optical communications by protecting against potential hackers attempting to intercept our system.

As for physical safety regarding system use, the laser is only operated within a controlled environment to address the potential risk to operator eyes. The operation of the system in a controlled environment also reduces potential hazards related to environmental factors such as wind and rain. In order to reduce risk during operation, the system undergoes a safety inspection before each use, ensuring that the laser is aligned correctly. Also, the system automatically shuts down when not in use to prevent power consumption of overheating. In order to protect the system from failures, the system is designed with modular components which make repairs and maintenance easier. The use of the Commercial-Off-The-

Shelf components makes the system more adaptable and cost effective to ensure long-term sustainability of the system.

9.3. Welfare

The potential societal benefits of this project are unlikely to be available in the near future. The most applicable future scope of this project is high-speed lossless free-space communication between Earth and space or space and space. Due to the curvature of the Earth, an optical data signal cannot be sent to any object past the horizon visible to that laser. However, it is possible to imagine everyday impacts in the far future.

Assume a system was in place where optical data signals could be sent over free space over the surface of Earth. Likely this system would replace telephone poles as the primary form of communication. Replacing the telephone poles would require workers to do, which would provide jobs in any area using this system. This would improve cash flow in the countries employing this system as well as increase the quality of life for these workers, as more people would be provided with jobs and therefore spending and saving money in these countries.

Another example that affects the everyday consumer: online entertainment around the globe, including items such as streaming services, video games, and YouTube, could all be accessed in much higher qualities at very consistent rates, which would improve the quality of life of all consumers using these systems.

9.4. Global Affect (Lexi Colebank)

A laser communication system transmits data using light beams. It offers advantages like high data rates, security, and reduced interference. However, its implementation can have several global effects, both positive and negative.

Laser communication can work outside of the RF frequency spectrum which is already very crowded and congested. The Optical Spectrum is one of the largest spectrums available and can improve inter-satellite communication similar to Starlink and allows remote areas to have high-speed data connections. Regarding security and privacy, Laser beams are highly directional, making them harder to intercept/jam compared to RF systems.

Some negative effects of a Laser communication system are mainly related to its surroundings. Laser communication requires a direct path for any data transfer to be successful. If the atmospheric conditions like storms, fog, or dust are in the way of the laser path. The data can be scattered and not fully received at the receiving end causing security issues.

9.5. Cultural (Korey Kelley)

The advent of optical communications technology, particularly for deep space exploration, marks a significant leap forward in how we interact with the cosmos. NASA's consideration of this technology as the future of high-data rate communications opens a new chapter not only in science and engineering but also in the cultural landscape of humanity.

One of the most immediate cultural impacts would be the transformation in how we perceive and interact with space data. With systems capable of transmitting data at hundreds of Gbps, scientific research could be conducted in real-time, dramatically accelerating discoveries in various fields. This accessibility could foster a culture of learning and curiosity, particularly among the youth, who might see space not as a distant frontier but as an immediate part of their educational journey. The democratization of space data could also influence how space exploration is taught, making it a more dynamic and interactive subject in schools and universities.

The ability to send high-definition images or even live video from space would change how we share cultural narratives. Space could become a canvas for global cultural expressions, where art, music, and stories from around the world are broadcast directly from the cosmos. This could enhance global unity, showcasing our shared human experience against the backdrop of the universe. Furthermore, the real-time communication aspect could lead to more collaborative scientific endeavors, nurturing a culture of international teamwork and shared scientific goals.

Furthermore, as space becomes more visually and intellectually accessible, the public's perception of space travel might evolve from an abstract concept to a tangible reality. This could influence how space is represented in popular culture, from movies to literature, potentially leading to a normalization of human presence in space. Philosophically, the ability to communicate vast amounts of data might also provoke deeper reflections on our place in the universe, our responsibilities, and ethical considerations regarding space exploration.

With enhanced communication capabilities, satellites could provide unprecedented detailed and real-time data on climate change, fostering a cultural shift towards more urgent environmental action. This technology could also highlight the need for sustainable practices in space, influencing how we think about and manage our environmental impact beyond Earth.

The narrative potential of optical communications in space could inspire new genres and themes in art and literature. Artists might explore the theme of connectivity across vast distances, or the human condition in the context of an expanding cosmic awareness. Such cultural products could influence societal values, emphasizing themes of exploration, unity, and the human spirit's resilience.

The cultural implications of deploying optical communications for space exploration are profound and multifaceted. As we stand on the brink of this technological evolution, society is poised to reimagine its relationship with space, fostering new cultural, educational, and philosophical paradigms. This technology not only connects us to the stars but also to each other in ways previously unimaginable, potentially reshaping our collective narrative about humanity's place in the cosmos.

9.6. Social (Mosely Tector)

Optical free-space communication is the next frontier in communication protocols. Given its infancy, the number of carrier wavelengths accessible is innumerable, allowing free-range use of multi-signal data transfer. Additionally, the minimum frequency in the optical domain is significantly faster than any RF signal, allowing for higher data signal frequencies. Both these pieces allow for much higher data transfer rates than RF could ever provide.

Free-space optical communication, when established with a stable connection (when the laser diode is pointing directly at the center of the receiver), operates with a much lower data loss/noise rate than RF communication. With all these factors combined, optical free-space communication offers much better data transmission protocols than RF ever has.

The target audience of these communication protocols includes RF engineers, primarily those working on extraterrestrial data transmission. Going forward, data may be transmitted over much longer distances in outer space, allowing for fast communication between Earth and farther planets. With Tesla planning on creating Mars colonies, this technology could revolutionize the growth of this new civilization, as communication will no longer be a bottleneck at growing those civilizations.

9.7. Environmental (Brian Barker)

The Low-Cost Optical Communication Payload system has both short-term and long-term environmental impacts. In the short term, it is more energy-efficient than traditional RF systems. This can lower the carbon footprint of satellite launches. Optical links also prevent RF spectrum congestion, reducing electromagnetic pollution. However, manufacturing optical components like lasers and photodetectors requires resource-intensive processes, leading to electronic waste and a higher demand for rare earth materials and metals.

In the long-term, optical communication can lessen the environmental impact of growing satellite networks by avoiding RF-related interference and spectrum saturation. Unlike RF signals, optical links do not leave residual radiation in space. However, their precision requirements may lead to increased ground station infrastructure, raising land use and energy consumption. To minimize these effects, future CubeSat missions should focus on sustainable materials, efficient ground stations, and modular satellite designs to support recycling and reuse.

9.8. Economics (Jessica Sammons)

The Low-Cost Optical Communication Payload system has positive economic impacts including providing employment opportunities and reducing costs of high-speed communications for government entities. Through further development and testing of this system, job opportunities for a multitude of disciplines in engineering and technology become available. This includes employment such as optical engineering, embedded systems designers, and quality assurance testers. Furthermore, through the use of Commercial-Off-The-Shelf components, the system minimizes costs compared to other types of communication systems. This is useful when applying the system to budget-constrained applications such as in the use of government entities adopting laser communication to replace traditional RF systems.

The negative economic impacts of this system include resource dependency, scalability, and training costs. Specialized components including laser diodes, photodetectors, and microcontrollers increase dependency on suppliers for manufacturing and could mean an increase in costs if supply shortages occur. Also, since the system uses low-cot components, the system may not be scalable to larger, commercial deployments which require more robust hardware that can increase costs. Lastly, training costs for engineers and technicians who are unfamiliar with the optical communication system could lead to extra costs for the workforce. Each of these negative economic impacts can result in an increase of government spending on the optical communication systems, which could further result in a change in the distribution of the federal budget to allot towards the defense industry.

Future adoption of this system could benefit both public and private sector economies by lowering costs of manufacturing. The model also has the potential to stimulate innovation in the technology market, growing the funding around communication technologies.