# UWA ELEC5550

## 2-Way Free-Space Optical Communication System
## Team 0-26

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## Requirements Analysis
# Volume 1

**Project Partners: The Australian National Fabrication Facility (ANFF)**

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## 1. Executive Summary

This report presents the development and analysis of requirements for the **two-way free-space optical communication system** project to be developed for the Australian National Fabrication Facility (ANFF). The system is intended to support USB data transfer over a distance of two metres, enabling the operation of common peripherals such as keyboards and mice with minimal latency. One module will be powered via a standard USB port, while the other will operate from a rechargeable power bank, ensuring portability and flexibility in deployment.

The document is structured to intuitively follow the process of determining the requirements, with analysis covering needs, goals and objectives, stakeholder analysis, relevant literature, and the top 20 ranked requirements, providing a clear baseline for achieving the system's technical and operational goals. The project scope encompasses optical transmitter and receiver design, embedded firmware development on compact MCU modules, PCB layout, prototyping within a $500 budget, and a final demonstration under typical indoor conditions. From this scope, the report explores and analyses relevant stakeholders, plotting them on a power-interest matrix to ensure visibility and proper management, and thoroughly explores the relevant literature, including existing designs, USB communication, and laser driver design. The requirements include Class 1M laser compliance through design of an adjustable current clamped laser diode driver, implementation of error correction to maintain USB data integrity during optical transmission, and various design considerations that strongly support the design process and a final product that meets the customer expectations.

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## 2. Introduction

### 2.1 Needs, Goals and Objectives

This project aims to address the need of the client, the Australian National Fabrication Facility (ANFF), who require a method to operate USB devices safely on a host, in environments where the device must by physically separated from the host due to security or otherwise – primarily an office style environment. Naturally, the requested implementation to address this need is through an optical communication system, and hence the project is named "2-Way Free-Space Optical Communication System". This project is undertaken under the supervision of the University of Western Australia, completed primarily on the university campus.

From the client's design brief, internal group discussions and class-based conversations with the client, the following goals have been determined, using the prefix G1 to reference the single project goal:

G1.1 To provide a system that can perform USB communication across free space.
G1.2 To provide a system that is safe.
G1.3 To provide a system that can function adequately for an office environment.
G1.4 To provide a timely and cost-effective delivery.

Expanding further on these goals, G1.1 flows naturally from the physical design context of the client's need. The host must be separated from the device; hence the primary goal is to provide a system that can perform communication across free space. In all aspects of life and especially with design projects, safety is a priority, hence G1.2 has been included. The remaining factors relevant to the project are external design context, and resources such as time and money. G1.3 comes from the external design context for this project explained by the client – that it should be used in an office environment. Finally time and money considerations are grouped into G1.4.

These broad goals are expanded below into specific objectives designed to encompass more specific expectations of the client. These objectives are prefixed with the letter 'O' and are numbered beginning with the ID of their corresponding goal, i.e. O1.2.3 would be the third objective corresponding to G1.2.

O1.1.1 Develop a system that transmits USB communication through an optical laser across free space.
O1.1.2 Develop an open-source system with a custom PCB for all hardware modules
O1.1.3 Develop a system that supports communication with keyboards, mice and USB storage devices. (Also traces to G1.3)
O1.2.1 Develop an optical laser system that is safe for users
O1.2.2 Develop a compact system that is safe to handle
O1.3.1 Develop a low latency and high bandwidth communication system for an efficient office environment.
O1.3.2 Develop a reliable system that does not need power external to the host and power bank.
O1.4.1 Develop a functional system within budget by the client's deadline.

The objectives for G1.1 have been split into three objectives to specify the optical communication, the hardware constraints, and the supported devices. Safety for G1.2 has been broken into two parts, one for the optical laser, and the other for the handling of the system as a whole. The office context in G1.3 has also been broken into two parts; the system power supply, and the system speed and latency.

## 2.2 Scope

This document aims to present the derivation of the project's most critical requirements from the initial need, goals and objectives described in the previous section. These requirements are clearly and thoroughly described, including brief descriptions of their intended delivery and constraints to prevent conflicting information and to aid understanding of the system as a whole. While intended delivery is briefly described, this document is intended to be used as a baseline for the formal design process, so does not delve any further into the design aspects of the project.

## 2.3 Report Structure

This report is structured such that the process of translating needs, goals and objectives into requirements can be clearly understood, as mentioned in the scope. The needs, goals and objectives are described at the beginning of the introduction to provide context into the project, followed by a thorough stakeholder analysis and extensive research into the literature relevant to the objectives and stakeholders. The requirements determined are split across two sections, with the critical requirements containing the top 20 ranked requirements, and all remaining requirements listed in the subsequent section.

The stakeholder section identifies the relevant stakeholders corresponding to the project context described previously and is an important step in determining a comprehensive list of requirements that aligns with all relevant parties.

The relevant literature section describes the literature that has initially been investigated in order to better understand the technical project context and again help determine a comprehensive list of requirements that aligns with contemporary context.

From the objectives, stakeholder analysis, and relevant literature, the requirements are determined, and the requirements section describes the requirements ranking process with a custom ranking system of four factors, with constraints, suggested delivery methods, and tracing documented for each requirement.

## 3. Stakeholders

A stakeholder is defined as any individual, group, organisation or entity who is directly involved in, impacted by, or has influence over the design, build, and use of the system [1]. For the 2-way laser communication project, numerous stakeholders have been reviewed, with their power and interest on the project as shown in Table 1.

As per the design process in Phase 1 ("Understand") and Phase 2 ("Requirements"), stakeholder identification is the foundation for defining stakeholder expectations and translating them into requirements. These requirements must then be clarified before progressing to the design stage. Stakeholder expectations are influenced by their needs**,** goals**,** and objectives (NGO) as outlined in Section 2.1**,** as well as constraints such as budget, regulations and operational limitations.

*Table 1: Identified Stakeholders*

| Stakeholder | Role | Power on Project | Interest in Project |
| --- | --- | --- | --- |
| **Client/Project Partner: Australian National Fabrication Facility** | End client for the two-way laser communication system. They provided the design brief and are responsible for setting requirements. | **High** – Defined the project brief and holds authority to address technical queries regarding requirements. AANF can approve or request changes of final deliverables based on alignment with project brief. | **High** – The ongoing requirements that need to be met could significantly impede project success. Following this, the successful deployment of the system will directly enable the objectives outlined from project brief. |
| **Project Partner Representatives: Dilusha & Jega** | The role of the project partner representatives is to liaise with the team (Team 0-26) and provide feedback and clarity of any requirements (project partner meetings). | **High –** Can help to set project direction, methodology and final deliverables through feedback provided in project partner meetings and other general queries. | **High –** The success of the project is marked against their expectations with the outcome being an assessment of the team's ability to meet technical, functional and timeline requirements. |
| **UWA Supervisor: Osaka Rubasinghe** | Acts as the primary liaison with internal team members from Team 0-26. Osaka provides feedback, clarifies requirements and ensures on track alignment with project schedule. | **High** – Influence project direction, methodology and final deliverables through feedback provided both over teams and formal meetings. | **High –** Project success is assessed against his expectations with the outcome being an assessment of team's ability to meet technical, functional and timeline requirements. |
| **Internal Members - Team 0-26** | Responsible for complete project lifecycle. This includes system design, testing, construction and final handover. | **High** – Hold full control over technical decisions, execution of design and integration processes of system, directly impacting system performance. | **High** – Project success or failure is completely dependent on the ability of team to provide the ANFF an end product solution that meets requirements. |
| **Users of Laser Communication** | Primary operators of 2-way laser communication system | **High** – End users will provide direct feedback on | **High –** System reliability and safety directly affects |

| Stakeholder | Role | Power on Project | Interest in Project |
| --- | --- | --- | --- |
| **System** | who rely on the functionality of project for it to complete intended tasks. | usability and operational requirements. | their ability to perform tasks effectively. |
| **Incident Users of Laser Communication System** | Safety of individuals who are located near the laser system who may be indirectly exposed during operation. This includes but is not limited to students and staff not using the equipment. | **Low –** No direct influence, however consideration to stakeholder safety of incident users will be considered for operation protocols. | **Low –** Potential safety risks should be managed such that the operational behaviour of the system has no adverse impact on incident users. |
| **UWA (Funding)** | Governing body who provided the budget of $500 for the project. | **High** – The budget determines what resources are available which can influence project scope and timeline. | **Low –** Funding decisions directly impact the team's ability to meet requirements and deliverables. |
| **Third-Party Suppliers** | Supply components and materials for the laser system and associated mechanical build. | **High**– Component availability, lead times and quality can influence project schedule and feasibility. | **Low** – Timely arrival of components and their reliability affect ability to meet deadlines and performance standards. |
| **Data Analytics Team** | Analyse operational metrics and usage patterns of system performance data. | **Low** – Access to high-quality data is essential for continuous improvement. | **High –** System functionality is critical and hence feedback on data analytics can provide crucial insight for continuous improvement. |
| **Emergency Services** | Provide emergency response in the case of safety incident or equipment failure. | **Low** – No direct involvement in decision making unless serious incident occurs in operation. | **Low –** Effective response plans must be in place to minimise damage done in the case of emergency. |

To effectively manage stakeholders, a stakeholder matrix was developed, with each stakeholder positioned according to their level of power and interest in the project (Figure 1). This approach allows us, the design team, to prioritise communication and engagement strategies in a manner such that influential stakeholders are closely managed while others are appropriately informed or monitored. The matrix therefore functions as a framework to align stakeholder involvement with project requirements for effective project delivery.

The matrix uses four quadrants:

1. **High Power, High Interest (Promoters)** – These stakeholders should be actively engaged as they are influential stakeholders. They need close management to ensure project alignment with requirements.
2. **High Power, Low Interest (Latents)**– These stakeholders hold decision-making authority but have limited day-to-day interest. It is important to keep them satisfied without overloading them with details.
3. **Low Power, High Interest (Defenders)** – These stakeholders are highly interested but have limited decision-making authority. Keep them informed and engaged to maintain support.
4. **Low Power, Low Interest (Apathetics)** – These stakeholders have limited influence and interest. It is still important to monitor them occasionally to ensure no unexpected concerns arise.


*Figure 1: Stakeholder Power-Interest Matrix for Relevant Stakeholders*

## 4. Relevant Literature

The relevant literature review is the next step following the understanding of the goals, objectives and stakeholders. This section is broken into 5 parts that required further insights in addressing the overall objectives. Researching key areas will shed light on requirements set from existing projects that achieved the same goals. The first part examines the broader system-level design, followed by the USB protocol which is key to understand for reliable data transfer. After understanding the broader level, the report looks deeper into the MCU, laser diode driver and receiver for a lower level understanding that will influence the generation of requirements and the important criteria to prioritise them.

### 4.1 Existing Solutions

One existing implementation of a short-range optical communication system involves PC-to-PC data transmission using Visible Light Communication (VLC), operating at a wavelength of 650nm [2]. The system was implemented using an Arduino Uno board for processing and transmission of information from one PC through the laser diode, with a photodiode receiving information into another PC. Overall, the system achieved a data transfer rate of 1kbps, and the paper summarised that while laser communication offers many benefits such as security of data transfer and low cost for required components, its most distinguished characteristic is the higher bandwidth for data transfer compared to radio waves.

The system design involved an encoder and modulator to control the laser from the computer input, a photodetector with a noise reducing low-pass filter to receive the signal, and a decoder to transmit the information to the receiving computer. The key takeaway from the software utilised is a single bit used for start-of-packet clock synchronization to prevent misalignment. Building upon that communication protocol, a request-to-send (RTS) and clear-to-send (CTS) protocol should be investigated for the 2-way communication

Photodiodes can operate in two common modes namely, Photo Conductive or Photo Voltaic mode. In another implementation of a laser communication system that required higher bit rates of transfer, a photodiode in the photo conductive mode was considered for its fast response characteristics [3]. The set up included MAXIM chips to communicate in serial rather than in voltage pulses. It highlighted the benefits of reduced losses in using serial cables in contrast with electrical cables, and the simplicity of using serial communication directly from the micro controllers. Lastly, an op-amp in positive feedback mode was used at the receiver end to saturate its output at fixed voltage levels, and to recreate clear pulses for the micro controller to read.

These two examples have shown that data can be clearly communicated through light. Both have raised concerns in regard to background light interference and have mitigated it by keeping the lights low for their test instead of implementing a corrective method to filter out unwanted noises from other light sources. Moreover, neither system was tested over 2m and used existing circuit boards such as the Arduino Uno rather than designing their own PCB from scratch. Before progressing to smaller components to design, the USB protocol must be examined in more details to come up with an optimal proposal for the 2-way optical communication design.

### 4.2 USB Communication

In regard to the data transfer rules, Universal Serial Bus (USB) 2.0 protocol [4] is a master-slave communication method, where the host sends continuous requests to the device, utilising a bus voltage wire, a ground wire, and a twisted differential pair wire (D+ and D-) for communication, with cable length not exceeding 5m. The communication system uses a non-return-to-zero inverted (NRZI) encoding with bit stuffing to ensure no long periods without signal edges that could impact clock synchronisation. Since it uses a differential signal, there are two possible configurations for one line being high, and the other low, called J and K states, which have opposite functions based on the speed of communication being used. These speeds are low-speed (1.5Mbps) and high-speed (12Mbps) and are determined by pullup resistors on the host side of the differential that pull one line up to 3.3V through a high resistance. To transmit information, the communication follows a series of packets containing start-of-packet and end-of-packet signals, as well as error detection and packet information. In addition, USB protocol is designed to be fully compatible, meaning USB 3.0 devices can be used in USB 2.0 contexts, and similarly for USB 2.0 with USB 1.0.

In the context of digital communication systems, latency is a crucial consideration when it comes to creating a user-friendly design. Other the past 50 years, many guidelines for application latency have been developed and proposed, with various studies summarised concisely in a conference paper by C. Attig et al [5]. System response times (SRT or latency) of 100ms were historically regarded as a maximum for which SRTs below this value would not affect users significantly, however this is shown to be outdated. Latency thresholds are summarised for various applications where input appears simultaneous to output, from visual at 30ms to audio at 20ms and tactile at 5ms. It is also concluded that latency starts to impair operation after 16ms for both zero-order tasks such as mice and keyboards, and more complex second-order tasks. In another study focusing on second order tasks, this latency threshold is concluded to be very similar at 14ms, providing a clear threshold for latency impacts to become apparent [6]. These conclusions will be relevant to the implementation of USB communication in the 2-way free-space optical communication system.

When considering physical interfaces for USB communication, the USB hardware and PCB guidelines publication by STMicroelectronics NV [7] provide an important baseline for design work. It outlines that protection against Electro-static Discharge (ESD) and Electro-magnetic Interference (EMI) is a requirement by JESD22-A114D and IEC 61000-4-2 standards and suggest that to abide by the standards and increase protection against ESD surges, an ESD protection (such as USBLC6-2SC6 for a full-speed USB) must be placed as close as possible to the USB receptacle. It is also clearly explained that a USB must have a VBUS sensing mechanism that allows it to connect its pull-up resistor to either D+ or D- data signal when the host is detected, allowing the host to then detect the device presence on the bus. It is recommended to use an external low-dropout regulator (LDO) to lower the input supply of the MCU [7].

A guide by Silicon Labs [8], looks at design considerations that should be considered when creating a USB driver interface, stating that "designing USB communications into an application enables a system to communicate with a variety of USB host devices and provides a convenient power option through the USB connection." [8]. A USB MCU can address both scenarios. This source compares several USB connectivity options, including fixed-function virtual COM port bridge, fixed-function HID bridge, HID USB MCU, and custom USB MCU. Fixed-function USB communication bridges are the simplest solution to implementing USB communication to a new design but offer the least flexibility. USB expertise is not required, as firmware and driver development are not required. The USB interface is not directly connected to the target system – instead, a bridge device interface (e.g. UART), serial peripheral interface (SPI), or inter-integrated circuit directly connects to the target application. According to Silicon Labs, USB MCUs offer the most flexibility and control over the USB communication interface but have the highest design complexity, with USB experience required. Since with this method all the MCU firmware is customisable, the USB MCU can perform additional tasks that are not available with a communication bridge. A USB MCU system allows flexibility in changing aspects of the design to fit the best USB solution as needed. A trade-off exists within the USB MCU method between high flexibility and USB expertise/possible driver development. Due to the complexity and nature of the requirements of this project, a USB MCU has been selected for the USB communication method [8].

The literature explored in this section provides guidelines for designing an effective 2-way free-space optical communication system that also satisfies standard USB protocol and regulations, as well as providing a quantitative reference for latency which will allow the system to function as intended.

### 4.3 Laser Diode, Driver & Receiver

The inception of the laser is often correlated with the rise of transistor and computer technologies beginning in the mid-20$^{th}$ century, and since then further developments and evolution in laser technology came about due to economic and functional needs. Various laser designs have been developed, however most modern quality lasers are built upon semiconductor technology such as GaAs or GaInP diodes, with wavelengths commonly ranging from 350 to 1400 nm. In addition to this, research into IR lasers with wavelengths longer than 1400 nm have become of interest due to not penetrating the human retina [9].

In free-space laser applications, it is also important to understand the wavelengths and effects of external lighting sources. Solar irradiance spans a wide range of wavelengths from 250 nm to 2500nm, and while it is not equally distributed due to atmospheric attenuation, numerical methods exist to calculate irradiance at different latitudes and times [10], and irradiance tends to fall from the max of just over 1 W/m$^2$ at 550nm to approximately 0.4W/m$^2$ at 1200nm [11, 12]. In addition to this, typical indoor ambient lighting has peak irradiance between 450 nm and 700 nm up to 1 W/m$^2$, with incandescent and halogen lighting also reaching up to between 0.5 and 1 W/m$^2$ for wavelengths between 700 nm and 900 nm [12]. While sunlight has been shown to not normally affect typical laser operation, measures can be taken to mitigate unwanted effects, through the use of monitor photodiodes in the transmitter [13], optical bandpass filters [10], and utilising receivers with narrow absorption bands [12].

Vertical-Cavity Surface-Emitting Lasers (VCSELs) are a type of laser diode (LD) useful for optical communication, widely used for their high speed, low power and low cost applications, with almost 95% of short range optical networking systems utilising GaAs based VCSELs at 850nm in the infrared (IR) wavelength [14]. Many designs implementing VCSEL have also been shown to be effective for gigabit communication with non-return to zero (NRZ) communication.

This makes VCSELs not only useful for USB 2.0 communication but also gives them the capability to support faster speeds. While beyond the scope of this project, these lasers also can be incorporated into dense monolithic multi-wavelength arrays, as well as the potential to be integrated directly into silicon photonic integrated circuits [14]. These lasers diodes are commercially available in IR wavelengths, making them a good choice to avoid typical sunlight and ambient lighting wavelengths.

According to AS/NZS IEC 60825:1, a continuous wave laser is Class 1M only if its accessible emission remains below the applicable AEL. For an 850nm laser, this limit is 0.78mW [15]. Accordingly, the laser diode driver (LDD) shall ensure the chosen laser's emission levels does not exceed this limit in all operating conditions.

Effective LDD design begins with a clear understanding of the LD's I-V behaviour, threshold, dynamics, and safe operating area. Since LDs are fragile and temperature shifts their electrical characteristics, the driver must regulate current tightly, incorporate ESD protection, and adequate thermal management for the intended application [16].

In its normal operating region, a LD's voltage barely changes, so a small voltage error can cause a current surge. Therefore, it must be driven by a constant current source to keep the current stable. The driver must keep current within limits and guard against forward over-current and reverse over-voltage. Hence implementing a current clamp and ESD protection is required to prevent these undesired results. Additionally, LD's are negative temperature coefficient devices, meaning heat lowers the LD's voltage and results in thermal runaway. A passive heatsink is required and is often sufficient for low-power LDs [16]. This literature suggests a high-frequency switch-mode driver over a linear topology because it delivers higher efficiency and enables a smaller, lighter design. The main trade-off is switching losses and related EMI, but they can be mitigated with careful layout and appropriate snubber and damping networks.

For the laser receiver, high speed photodiodes such as PIN, uni-travelling-carrier (UTC), and avalanche (APD) have been shown to be effective [17]. This paper highlights each photodiode's material choice, responsivity to bandwidth trade-off, and Semiconductor Optical Amplifier (SOA) integration. SOA is also important in maintaining Class 1M compliance, so this is a very useful guide for the selection of a high-speed, high-responsivity photodiode optimised for low-latency USB transfer in a Class 1M-compliant free-space optical.

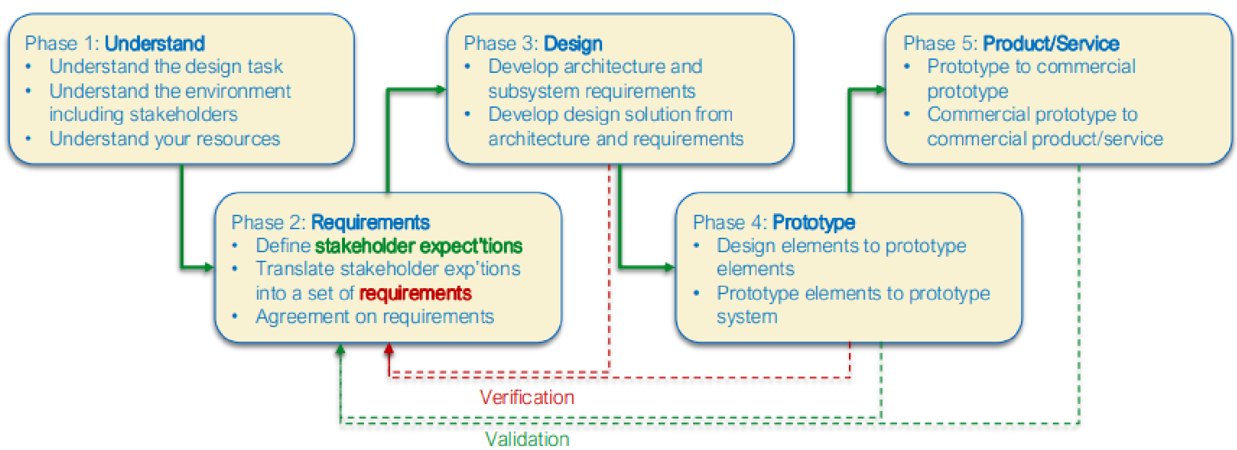
Graphical methods to balance feedback resistance, op-amp gain–bandwidth product, and photodiode capacitance for target noise and bandwidth are well detailed in the literature [18]. These provide a structured approach to trans-impedance amplifier (TIA) design, enabling stable, low-noise photocurrent-to-voltage conversion, and also helps in designing a stable transimpedance amplifier for laser receiver circuits.

## 4.4 Requirements Framework & Stakeholder Context

Requirements play a critical role in ensuring the design process delivers a solution that meets stakeholder expectations. The design process consists of five phases as shown in Figure 2. In Phase 1 ("Understand") and Phase 2 ("Requirements"), identifying stakeholders establishes the foundation for translating relevant stakeholder needs, goals, and objectives (NGO) into clear, actionable requirements [19].

Requirements define the scope, performance criteria, and constraints such as budget, regulatory compliance and operational limitations. This guides all subsequent design decisions to ensure that requirements are maintained in the end product. Without well-defined requirements, the project risks misalignment between client intent and user needs, alongside non-compliance with standards and potential cost or time overruns. The process can be iterative as it often requires clarification and validation to ensure all parties agree before progressing to the design stage. Well defined requirements provide a measurable baseline for verification and validation and also reduce the likelihood of late-stage changes. Overall, they serve as the bridge between stakeholder expectations and the final design.

*Figure 2: Design Process*




The client, the Australian National Fabrication Facility (ANFF) is a national infrastructure network established in 2007 under the Commonwealth's National Collaborative Research Infrastructure Strategy (NCRIS) [20]. It operates through eight university-based nodes offering researchers and industry open access to micro- and nanofabrication tools, technical expertise, and cleanroom facilities across Australia [20].
ANFF's interest in sponsoring the two-way laser communication system is to support translational research and product development, helping bridge laboratory innovation with real-world applications.

## 5. Top 20 Requirements

The tables below compile all the requirements that align with the project's purpose and will act as a guide in the system's design. The requirements were based on the stakeholder's needs from the project design brief, Technical Queries (TQ), derived from other features and allocated based on the team's direction. Once all the requirements identified, they were prioritised based on the following:

- Criticality - How important the requirement and does it align with the goals and objectives.
- Complexity - How much complexity will it add to the design.
- Cost - How much cost will it add to the design.
- Testability - How easy it is to test the requirement.

This ensures that the design addresses the most important requirements and stay within the scope of the project. Table 2 represents the description for each rating used to prioritise the requirements. Since the criticality was considered the main aspect, a weightage approach was used to give higher significant to criticality. Consequently, the equation below was used to calculate the ranking. This is not primarily a ranking of the importance of each requirement, but rather determines which requirements need to be focused on more due to the four factors.

$$Total\ points = 0.7(Criticality) + 0.1(Complexity) + 0.1(Cost) + 0.1(Testability)$$

*Table 2: Ratings description.*

| Ratings | Description | Criticality | Complexity | Cost | Testability |
|---|---|---|---|---|---|
| 1 | Worst | Not Critical | Trivial | Free | Trivial |
| 2 | Bad | Less Critical | Doable | \$0-10 | Doable |
| 3 | Neutral | Neutral | Neutral | \$10-25 | Neutral |
| 4 | Good | Important | Hard | \$25-50 | Hard |
| 5 | Best | Critical | Very Hard | >\$50 | Very Hard |

Note that the convention in the 'Source' column of Table 3 below relates 'Design Brief' D2 to the second numbered item in the design brief. Traces and TQ Sources contain hyperlinks, but TQ links must be opened in the browser to navigate to the correct cell.

*Table 3: Top 10 Requirements.*

| ID | Traced | Level | Requirement | Source | Delivery Method | Constraints | Criticality | Complexity | Cost | Testability | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **RQ0.02** | O1.2.1 | System | The optical communication system SHALL be Class 1M or below according to AS/NZS IEC 60825. | Design Brief (D2)<br><br>AS/NZS IEC 60825 | A laser diode capable of emitting at Class 1M and below at the designed circuit ratings will be used in the designing. The laser diode driver should clamp the laser's current flow to prevent the output power from breaching Class 1M. | Must comply with AS/NZS IEC 60825 standards. There should be enough current to flow through the diode on top of the MCU from the USB port. | 5 | 4 | 4 | 2 | **4.5** |
| **RQ0.03** | O1.3.2 | System | The system's power SHALL be provided through the host device USB connection on one end, and a power bank on the other end. | Design Brief<br><br>[Class TQ ID 104] | The PCB will be designed with connections from V+ and GND of the input type A cable to provide power to the PCB. The same design will be used on both ends for supply, although power will be supplied from a different port depending on if a host or device is connected. | Since a mouse/keyboard will be used, a second port is inevitable to supply power. The mouse and keyboard will need to be powered on top of the MCU and the laser. | 5 | 4 | 4 | 2 | **4.5** |
| **RQ1.05** | RQ0.04 | Subsystem | The implemented laser diode driver SHALL have a rise and fall time no more than 5ns | Allocated | In order to support 24Mbps, which is double the full speed communication due to a single communication line with 3 different states, the laser diode driver should rise and fall within 5ns to high or low for at least 30ns between switching. The quick fall and rise time will be achieved through a fast-switching MOSFET and VCSEL which will be controlled directly from the controller. | Switching speed will depend on the characteristics of MOSFETs on the market. The fast switching may also give rise to interference. Testing the driver at such a small window would require a good oscilloscope. | 5 | 3 | 4 | 3 | **4.5** |
| **RQ0.11** | O1.1.2 | System | The system SHALL use only individual components and bare integrated circuits (ICs), including bare microcontroller units (MCUs) | Design Brief (D3, 7) | The PCB will be designed from scratch, starting from the selected MCU module. Only bare ICs and discrete components will be used. Custom circuits will be designed to ensure these components operate safely. | No commercial driver board for the laser or receiver will be allowed. Completed kits such as the Arduino boards for ESP32 Dev Kit will not be used on the PCB. | 5 | 4 | 4 | 1 | **4.4** |
| **RQ0.14** | O1.1.3 | System | The system SHALL be compatible with USB Type A 2.0 cable at a minimum from the host. | [Class TQ ID 130] | As per the TQ, the system will be designed with USB Type A 2.0 port for the host. The four pins will be enough for the PCB to be powered and transfer data. | USB Type A 2.0 is limited to 500mA after enumeration. The PCB will need to operate under this current limit. | 5 | 4 | 2 | 3 | **4.4** |

| ID | Traced | Level | Requirement | Source | Delivery Method | Constraints | Criticality | Complexity | Cost | Testability | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **RQ1.03** | RQ0.02 | Subsystem | The system SHALL have an adjustable current clamp to limit the laser power. | Design Brief (D2) | In order to control the current being clamped, a potentiometer will be used in series with the laser diode so that the maximum current and voltage possible does not exceed the Class 1M rating. | If the laser diode temperature increases, the power consumption will increase, and the potentiometer might need some adjustments after long period of use. | 5 | 4 | 2 | 3 | **4.4** |
| **RQ0.13** | O1.1.3 | Subsystem | The system SHALL support communication through USB 2.0 Protocol | Team decision Minimum for Design Brief (D5) | A USB compatible MCU with clock speed greater than 200MHz will be used to facilitate bi-directional communication on the D+ and D- lines. | Even though the data communication between USB is fast, the MCU will need to process information from the receiver with error detection and correction for reliable data transfer. | 5 | 4 | 2 | 2 | **4.3** |
| **RQ0.07** | O1.3.1 | System | The system SHALL operate reliably in the artificial indoor lighting conditions of UWA's MILC Room, with no direct sunlight. | Class TQ ID 4 | If required, polarising filters will be use in front of the receiver to only allow light in one direction to go through and the existing light differential will be included as a global variable in the software to be tuned based on the environment being used. Lastly, an 850nm IR wavelength laser will be used to reduce external interference. | The laser light reaching the receiver should be strong enough to stand out against all their other lights in the region, else it will be harder to tune and filter out. | 5 | 3 | 2 | 2 | **4.2** |
| **RQ0.20** | O1.1.1 | System | Each side of the system SHALL not recognise reflected light from its own laser source | Design Brief (D 4) | The laser and receiver will be spaced enough to prevent any divergent light from reaching it. Moreover, added optical filters will be added to focus the light to only cover the receiver's detection area. | If a window/glass is used in between to which the light is reflected back, the light could be strong enough to still impact the receiver. | 5 | 2 | 2 | 3 | **4.2** |
| **RQ0.15** | O1.1.1; RQ0.12 | System | Once the system is set up, the lasers SHALL remain pointed at the receivers for the duration of operation. | Team decision + Logical option | To confirm that the system is aligned, LED lights on both ends will be used to confirm calibration and alignment. Tight adjustable laser mounts will be used to ensure lasers stay stationary. The system will have a high friction base to prevent slipping. | Testing might include blocking the laser for a short time before allowing it to communicate again. A recovery protocol should be considered in the system. | 5 | 2 | 2 | 2 | **4.1** |

| ID | Traced | Level | Requirement | Source | Delivery Method | Constraints | Criticality | Complexity | Cost | Testability | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **RQ0.10** | O1.1.2 | System | All project materials and documentation SHALL be released under an open-source license and delivered via a shared git repository. | Design Brief (Deliverables) | A public GitHub repository will be created for the purpose of the project, containing a README file detailing all contents, and the open-source documentation for all project materials. | There may be delays associated with uploading project files to the GitHub repository if collaborators want to make edits, they may need to wait on pull requests. | 5 | 2 | 1 | 2 | **4.0** |
| **RQ0.12** | O1.1.1 | System | The host and device modules SHALL be physically separated from each other. | TQ Information Session (Verbal) | An optical laser communication system will be designed as two separate modules. Laser calibration will be done manually with LEDs. | It may be difficult to align the transmitter and receiver modules for operation. Issues may arise with environmental disturbances. | 5 | 3 | 1 | 1 | **4.0** |
| **RQ0.16** | O1.4.1 | System | The system SHALL be completed and approved for use by the 27th Oct 2025 | ELEC5550 Unit Schedule | A comprehensive Gantt chart and team coordination methods have been implemented to ensure the deadline is met. Weekly check ins on progress against project goals will be performed. | Limited time to complete project may lead to time crunches, especially if other units or life events take priority. | 5 | 3 | 1 | 1 | **4.0** |
| **RQ0.09** | O1.4.1 | System | The cost of all components used in the final design, or purchased and reimbursed for the purpose of achieving the final design SHALL NOT exceed $500 | Design Brief (Budget) | A budget register is being maintained, with group discussion before agreeing on any purchases. The budget is aimed to be undershot so that replacement parts can be purchased if needed. | Risk of budget overrun increases if purchased parts are unavoidably damaged or inappropriate for the device. | 5 | 2 | 1 | 1 | **3.9** |
| **RQ1.04** | RQ0.04 | Subsystem | The system SHALL allow both power and device connections on either side. | Team decision | Two individual USB-A ports will be installed on each module to power the PCB and the other one for a device connection. | Needs to function safely if a power bank is also connected on the host side. Could consider a multiplexor. | 5 | 1 | 2 | 1 | **3.9** |
| **RQ3.01** | RQ0.02 | Subsyste | The system SHALL include warnings against laser magnification | Team decision | Written warnings against laser magnification will be applied to the device where power is supplied such that they are seen before the laser | None. | 5 | 1 | 2 | 1 | **3.9** |

| ID | Traced | Level | Requirement | Source | Delivery Method | Constraints | Criticality | Complexity | Cost | Testability | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | clearly visible adjacent to each power input. | | can operate. | | | | | | |
| **RQ0.04** | O1.3.1 | System | The system SHALL support communication speeds up to Full-Speed | Team decision | The laser's rise and fall times and the MCU's clock speed will be chosen specifically to allow for full-speed communication. | None. | 4 | 4 | 2 | 2 | **3.6** |
| **RQ3.03** | RQ0.15 | Subsystem | The laser mounts SHALL be tight and precisely adjustable | Team decision | The selected laser mount will be sturdily mounted onto the module, with a sensitive adjustment mechanism for accurate laser positioning. | Need a mount that will fit the laser choice. May be large. Adjustment needs to be accessible, and system must not move after adjusting. | 4 | 4 | 3 | 1 | **3.6** |
| **RQ0.01** | O1.1.1 | System | The optical communication system SHALL operate over a distance of at least 2m. | Class TQ ID 3 | The chosen laser will have a small enough divergence over 2 metres to ensure signals can be received properly. The system will have a built-in calibration sequence to confirm that the transmitter and receiver are aligned and communicating, with manual adjustments possible. | Collimator may be needed to keep the laser divergence low enough for the receiver. | 4 | 3 | 2 | 2 | **3.5** |
| **RQ1.06** | RQ0.01 | System | The laser SHALL have adequate power and divergence such that the receiver can function at minimum 2 meters distance | Allocated | The chosen laser will be powerful enough, with a small enough divergence to allow reliable communication with the receiver. Additionally, a laser collimator may be applied if required. | Collimator may be hard to implement along with adjustable laser mount. | 4 | 3 | 2 | 2 | **3.5** |

## 6. Other Requirements

In addition to the top twenty prioritised requirements, further requirements have been identified. These requirements were left out of the top twenty based on ranking lower in total points. Table 4 summarises these additional requirements alongside their associated delivery methods, constraint, traces and ranking points.

*Table 4: Other Requirements*

| ID | Traced | Level | Other Requirements | Source | Delivery Method | Constraints | Criticality | Complexity | Cost | Testability | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **RQ0.06** | O1.3.2 | System | The system SHALL operate for at least 2 hours without power external to the host and power bank. | Class TQ ID 44 | The system will be designed with a low power MCU, efficient laser driver circuitry, and optimised firmware to minimise idle consumption. Power drawn from system will be tested under full load to ensure the total consumption allows continuous operation for 2+ hours from the specified power bank source. | Duration of operation is constrained by USB port current limits (500mA for USB 2.0) and battery capacity of power bank. | 4 | 2 | 1 | 3 | **3.4** |
| **RQ2.01** | RQ0.02 | Subsystem | The system SHALL communicate USB 2.0 Protocol J-States as a non-emitting laser | Team decision | USB 2.0 uses differential signalling on the D+ and D- lines to transmit data. J state represents the idle state of the communication system, and will programmed to be sent as two bits of unpowered laser to minimise power usage. | Relies on determination of USB speed (full vs low speed) | 4 | 1 | 1 | 3 | **3.3** |
| **RQ1.01** | RQ0.04 | System | The MCU SHALL have a clock rate of at least 200MHz. | Allocated | An MCU with at least 200MHz clock rate specified in the datasheet will be selected to handle USB 2.0 protocol timing. Clock frequency will be verified to sustain maximum data rate | Clock signal needs to be aligned with transmitted signal. | 4 | 1 | 2 | 1 | **3.2** |
| **RQ0.19** | O1.3.1 | System | The system SHALL have a latency of less than 5ms | Class TQ ID 25 | low latency communication protocols (ie minimal packet buffering) will be programmed to ensure latency remains under 5ms. | Latency must account for both hardware and software delays. | 3 | 3 | 2 | 4 | **3.0** |
| **RQ0.18** | O1.3.1 | System | The system SHALL support use with hosts and devices on either side. | Design Brief | MCUs will be able to detect the device's pull up resistor, and the hosts enumeration signals, to determine what has been plugged in. System will be tested by switching the host and devices around on either side. This ensures operation works on both sides prioritising plug-and-play convenience. | Ensure protection against multiple hosts or devices plugged in | 3 | 3 | 1 | 2 | **2.7** |

| ID | Traced | Level | Other Requirements | Source | Delivery Method | Constraints | Criticality | Complexity | Cost | Testability | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **RQ1.02** | RQ0.03 | System | The system on each side SHALL require less than 100mA before USB enumeration, and less than 500mA after USB enumeration, from the power source at each end. | Allocated | The power architecture will be designed so that total draw after USB enumeration stays within the 500MA USB 2.0 limit (and 100mA pre-enumeration). Smart design architecture by placing bypass capacitors in certain locations will effectively limit current surges. Temporary full speed enumeration will happen on the host side to permit 500mA for laser initialisation | Must comply with USB 2.0 current limits while powering the MCU, laser diode driver & receiver. Any current surges during operation must be mitigated. | 3 | 1 | 1 | 1 | **2.4** |
| **RQ3.02** | RQ0.12; RQ0.18 | Subsystem | The system SHALL be two physically identical and separated module on the host and device side. | ELEC5550 Info Session 01: ANFF Stakeholder | Both ends will be created identically. Mode selection will be handled via software configuration. | Identical hardware must support both roles without compromising performance. Alignment must be maintained in both units for reliable communication. | 3 | 1 | 1 | 1 | **2.4** |
| **RQ0.17** | O1.2.2 | System | The system SHALL be portable by hand | Team decision | Design the system to be lightweight and compact. Internal components will be mounted securely to withstand movement without system failure. | Size and weight must remain small enough to be portable by handle while still provided thermal management (eg heat sinks are heavy). Component placement is constrained by optical alignment requirements. | 2 | 3 | 2 | 1 | **2.0** |
| **RQ0.08** | O1.2.2 | System | The system SHALL not contain stripped or exposed wires | [Class TQ ID 37]() | Ensure all wiring and terminations are fully enclosed within the housing. The PCB design will eliminate most of the wiring. This will help meet safety and aesthetic requirements. | internal layout must allow useful test points without exposing live connections during operation. | 2 | 2 | 2 | 1 | **1.9** |
| **RQ2.02** | RQ0.10 | Subsystem | The software SHALL be programmed in C | Team decision | Software design is entirely created in C to leverage team expertise. The code will contain thorough commenting. | Code must adhere to universal C practices/structure. | 2 | 2 | 1 | 1 | **1.8** |

## 7. Conclusion

This report analyses the need of the client to operate USB devices on a machine in which the USB device must be physically separate from the machine, to be implemented through the use of an optical laser communication system. This report drills down into the specific goals and objectives regarding laser safety, functionality, and specific use cases, with a thorough analysis of the relevant stakeholders, and their influence on the project. Major stakeholders include the design team (Team 26), the client, the teaching team (supervisors and coordinators), and third-party suppliers. From here, many areas of required research became apparent, such as previous laser communication designs, laser module details including wavelength considerations, and USB communication, providing important information for both determining requirements, and providing brief delivery plans.

This analysis has highlighted the higher criticality requirements that must be closely monitored due to complexity, cost, and/or testability, which will be crucial for efficiently producing a functional and compliant product. These priority requirements, typically the ones that are very complex to implement, include the Class 1M limitation, meeting full-speed USB data rates, power consumption, and laser calibration. Although delivery plans have been described for each requirement, each demand significant attention during the design phase due to their priority. Current delivery methods involve careful consideration of module datasheets, with potential extra components such as collimators, laser mounts, filters, and circuit elements. The analysis also highlights the need for a sound logical design framework to bring all the components and functionality together. From the outputs of this document, there is a clear basis from which the design and implementation of this project can be effectively carried out.

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