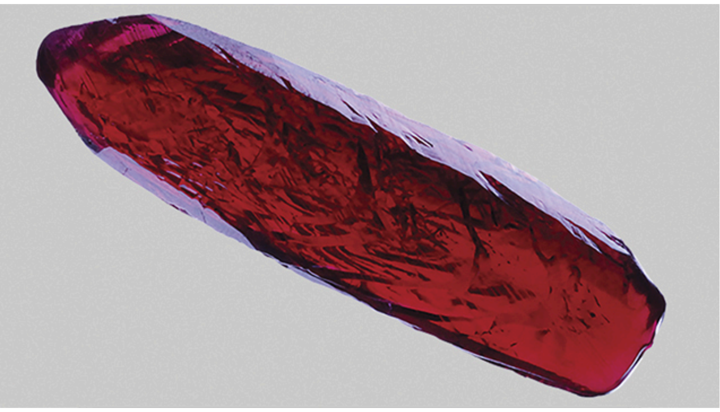
University of Central Florida
Senior Design II



Ruby Analysis via Spectroscopy Systems (RASS)

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Senior Design 2

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1 Executive Summary

As materials science continues to get both more advanced and accessible to the general public, gem fakes and shameful imitations are only becoming more prevalent and harder to distinguish. Many people take their expensive jewels to experts only for them to be imposters. Crystallography, the science of crystal structures and properties, is done primarily using optical instruments. However, rather than uploading images or spectra of the gems into a program and having more reliable conclusions, the most popular gemology methods are done purely by the expert's best judgment. A loupe is essentially a magnifying glass that looks for inclusions, but has no ability to record data. The dichroscope is very similar, however it separates out different polarized rays at different wavelengths. The difference between these wavelengths is up to the human eye alone. The dichroscope is often used in conjunction with a polarimeter, which determines crystalline structures of the ruby using two rotating polarizers. In addition, many novices simply shine a light at gems to see if they fluoresce. Our design seeks to focus on rubies and to make a multi-faceted testing system.

RASS aims to remove the objectiveness of gem characterization through a proof-of-concept technological approach. It will combine the most popular forms of ruby identification tests, fluorescence and dichroism, and unify them into one system that will test specifically rubies and be able to tell whether its real (whether that be synthetic or natural) or fake (made of garnet, dyed quartz, etc.). This document has been written to delineate the process of creating this system. Other relevant existing designs was described and compared to RASS's approach. Once this has been discussed, then the relevant technologies that are or could be involved in RASS's design was explored in excruciating detail. Post research, the parts was chosen based on the relevant knowledge we have at our disposal. Design constraints as well as the standards of this project was outlined towards the end, which will include the optical, electrical, hardware, and software components. All copyright permissions and sources was listed at the very end after the final conclusions of this project.

2 Project Description

There are many methods for crystallography in the world today. Due to advancements in optical technology as well as knowledge of materials, there are many experienced crystallographers who can spot a fake with a simple UV light and a loupe. However, as fake and synthetic gems are becoming more prevalent and harder to distinguish, it is imperative that distinction methods become more precise and reliable. To amend these concerns, we propose a multipurpose system that will combine these sporadic methods into a unified system that will remove any personal bias or human error on the inspectors' part. We designed a proof-of-concept system that will have the goal of distinguishing real rubies, whether that be synthetic or natural, from fake (imitation) ones. The fluorescence spectra of the ruby was captured via a spectrometer housed within an enclosed system, as well as verifying true trigonal crystal structures with the use of a dichroscope that was implemented into the spectrometer. The live results of these tests was displayed onto an external monitor and the overall prognosis was given. Once we prove that this can be done, more tests can be implemented into the system that will both enhance the results for ruby, but can be applied to other gems.

2.1 Motivation

Much of the current crystal characterization methods require years, even decades of experience to have trustworthy conclusions. With every type of gem, there are several methods crystallographers must choose from that all require different equipment and levels of expertise. This project seeks to prove that an all-in-one system can be created, with ruby chosen as our sample gem. With every ruby that can be found online, implementing a certified test that this system produces will ensure authentication of any highly priced “ruby” on the internet. It will remove the chances of any ruby being dyed quartz or garnet, provided that this test is conducted. Gem collectors as well as smaller businesses getting into the gem cutting industry was able to rely on this system to ensure that they aren’t getting scammed. In addition, if this device is made available at any reputable jeweler, it will ensure normal people can use this system at a cheaper cost than taking it to an expert to have it reviewed. Collectors was able to purchase this device and not get scammed by many of the workarounds that exist today.

2.2 Goals and Objectives

Goals

- Build a spectrometer that tests for the correct ruby fluorescence wavelength.
- Implement a dichroscope into the system to ensure proper pleochroism properties.

Stretch Goals

- Include a magnification system with a camera to image the impurities and detect them in software to enable distinctions between real and synthetic rubies.

Advanced Goals

- Implement other common gemology tests into the system such as a refractive index meter.
- Study other gem properties and implement tests for them into the system to enable multiple gem distinction.

Objectives

- Build a spectrometer that operates within the visible range.
    - Will read fluorescence and impurity spectra.
- Develop a dichroscope that will measure the crystalline properties of the ruby and implement the results into the spectrometer.
- Design a system that will orient the ruby in three different directions while illuminating the sample with an LED.
- Develop software that will analyze the data provided by the above tests and display the results to the user.

2.2.1 Function of Project

The function of this project is to be able to determine the spectra of a ruby given different tests. It was in an enclosed system to avoid any external influences. It will read the data from the spectrometer after the fluorescence and dichroism tests and display it to the user, while saying whether the sample passed or failed the tests. This will allow users to determine whether the ruby is real, that is, made of aluminum doped with chromium to make red corundum, in order to avoid fake imitations of garnet or dyed quartz and to know whether the money they're spending on the gem is going towards what they think it is.

2.2.2 Requirements

Our project combines electrical, optical, and software systems to create a multi-functional characterization system within an enclosed system. The first part of the optical design will use a spectrometer comprising 2 mirrors, a diffraction grating, a fiber, and a photodetector. A spectrometer is able to give a much more accurate reading of emission wavelength than the objective analysis of the human eye. The lens at the input end of the fiber was of a much higher power than the ones in the system in order to minimize the beam size that enters the fiber to ensure minimal light losses. A fiber was implemented rather than free space propagation to ensure minimal light loss as well as flexibility in where the optical system is located. The implementation of these separate optical components will ensure as accurate of readings as possible. Once analysis of the fluorescence test occurs, the peaks in the spectra was assessed to determine whether it passes the test.

The second part of the design was the dichroscope and the collimating system to implement the output into the spectrometer. It will consist of two glass prisms, a calcite rhombus, four lenses, two mirrors, and a beam splitter. The glass prisms exist to ensure that light is guided into and out of the calcite most effectively. The calcite itself exhibits birefringence, and thus is used to separate out the different polarizations of incoming light for our analysis. These polarizations was of different wavelengths, thus was collimated via the lens system and directed to the spectrometer using the two mirrors. The beam splitter was used to guide the light into the fiber that is used by the spectrometer while not interfering with the initial setup. Upon analysis of this spectrum, the different peaks was reviewed to determine whether the test passes.

The second optical component requires readings from different angles, thus a rotation stage was implemented. Three random orientations of the gem was chosen to have the maximum chance of receiving accurate results. The results from this portion was tested individually, and the individual successes or failures was displayed rather than a single pass or fail. In addition, a minimum ruby size will need to be established to ensure maximum reliability in this optical system.

Two LEDs, one white and one green, was implemented into the housing to enable the two optical components. The green LED was to ensure the ruby fluoresces at the right spectra for the first test, while the white LED was purely for illumination of the sample for the second test. These LEDs will not move and was soldered into an in-house circuit that was protected from both the internal components and external (ambient) conditions of the system.

The primary programming language this project will involve is Python, its considerable amount of search libraries as well as the presence of third-party modules allows it to be flexible and an ideal option. It's ideal for prototypes due to its user-friendly data structures and thus a fit for this proof-of-concept design that ideally be expanded upon in the future. It's portable across operating systems, which is incredibly handy for getting this system out to a diverse array of users.

The housing of the system was 3D printed and coated with a minimally-reflective paint to ensure the light from the LEDs has minimal impact on the spectrometer readings. This will impact the intensity of our readings, thus strong illuminators was needed. The dimensions for the different components that was exposed to the ruby was considered and implemented into the system to ensure maximum tolerance (minimal wiggling) of the chosen components. The internal housing was purely for the ruby exposure and data collection, and a second layer was implemented to make room for both the optical and electrical components. It will need to have proper support within to ensure that any bumping or movement of the system will not impact the components within it. The supports will need to be removable so that proper design can be achieved within the housing without jeopardizing the structure and having minimal interference with the alignment of the optical setup or touching the electrical components.

In essence, the requirements of this project will give proper exposure to all of the aspects of being an engineer in today's world. It is essential for most devices today to have electrical, software, and optical components to ensure usability for as many people as possible and further integration as technology develops. Working on a team with diverse skills and backgrounds will give the slightest hint into what being an engineer in the modern world really entails.

2.3 Marketing Requirements

When designing technology of any kind, it's important to have a discussion about the marketability of that product. What goes into this is safety, the cost of production, the cost of the components, the time it takes to make the product, how easy it is to transport, and many other factors. We as engineers need to take all of these factors into consideration when making a product. The most important one is making the project as cost-effective as possible in every aspect while not jeopardizing reliability. The goal of this system is to make it available to collectors, artisans, or anyone who would want to ensure that their ruby is what they think, or were told, it is.

The usability of a product is imperative to its success on the market. It should be simple so that both expert and novice alike can utilize it with minimal troubleshooting. As this is meant to be placed in gem shops and available for public use, a necessary assumption is that the consumer will have little to no technical background and will not be able to understand the science behind the system. In addition, it will have to be easily transportable so that collectors can take it with them to auctions or suspicious jewelers. With this in mind, the most difficult part of the system was placing the intended sample in the receptacle and understanding the required sample size. A simple sticker detailing these specifications can be used, and thus will enable a larger consumer base and encourage widespread use of the system.

In order to advertise this, we will have to choose an audience to market to and ensure we are catering our promotions to the best of our ability. Our intended client base are jewelers who may not have time to characterize every ruby that comes into their shop as well as collectors, who often get scammed at auctions. We will have to ensure that the general public can use this system for a small price and it can be a passive income for shop owners. People who own this product personally will want it to fit somewhere convenient and without much hassle in transportation so that they can take it to auctions. We plan to design this product on as small of a scale as possible while ensuring stability. Of course, the user cannot drop the system, but small jostles should not affect any components within. In addition, the form of media this is featured on will need to be considered to reach these audiences. Potential options are printed media, specialized browser ads, social media, sponsorships, partnerships, and many more. When considering this, the affordability and amount of reach of each advertisement will need to be analyzed and potentially tested to ensure optimal interest and purchases.

It goes without saying that a major objective is to make this system as cost effective as possible. Thus, methods such as Raman spectroscopy and X-Ray crystallography were avoided due to their large price points and potentially unsafe wavelengths. Visible wavelengths was used due to the availability of economical components, such as the diffraction grating for visible wavelengths, less risk of eye damage should improper use of the system occur, and the lack of need of UV or IR filtering coatings on the optical components. LEDs are optimal light sources due to their low-cost and reliability in the modern world. It was decided to use a calcite dichroscope as opposed to a simple polarizing one because the price difference is not major and the calcite variant produces much more reliable results. The housing was 3D printed due to its availability and cheap material.

2.4 Specifications

Table 1: RASS Specifications List

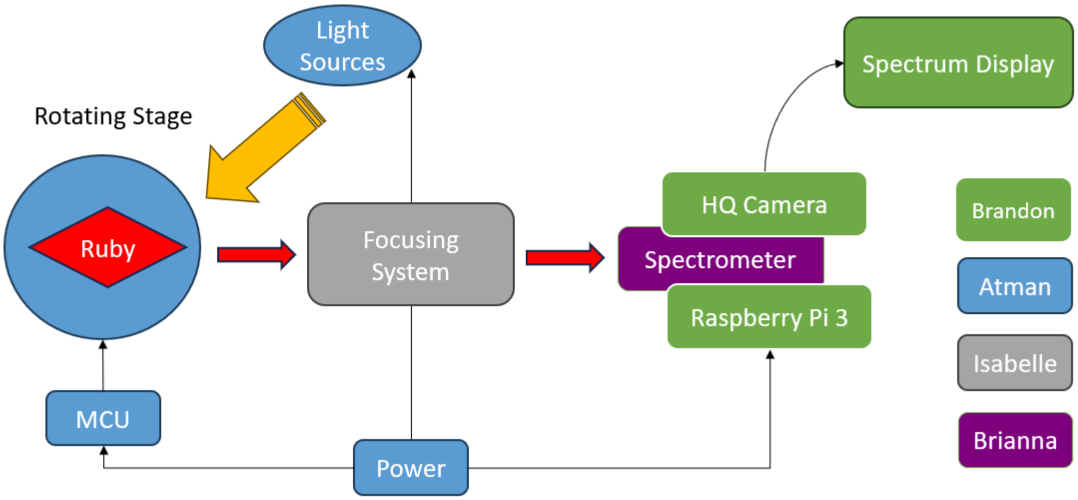
Component	Parameter	Specification
Rotating Stage	Controllable Angle	45°/90°/180°/360° Circulation
Ruby	Test Subject	Synthetic
Fiber	Light Propagation	MMF
Diffraction Grating	Wavelength Dispersion	300 groove/mm Plane ruled reflective
Pi Camera	Spectrum Imaging	12.3 MP
Green LED	Fluorescent Wavelength	550 nm
Mirrors	Reflection	$R_{avg} \geq 95\%$
Beamsplitter	Reflection/Transmission	R/T: 50/50
Calcite	Pleochroism	Optical Grade (High clarity)
Prisms	Light Guidance	Right Angle
White LED	Illumination	400-700 nm

These specifications were determined from the final part list and their intended implementation into the system. Given the requirements of RASS and the goals it sets to achieve, each specification listed is an integral feature of our system. The sample of the ruby will need to be rotated at specified angles, the tested ruby was synthetic, the fiber is integral to ensuring the maximum amount of light will reach the spectrometer, the diffraction grating dictates what wavelength range RASS will operate in, the Pi Camera was a cheaper alternative to a photodiode and achieves the same goal, the green LED fluoresces the ruby, the mirrors guide the light into the beamsplitter, the calcite enables the pleochroism test, the prisms guide the light through the calcite, and the white LED was used for the pleochroism test.

2.5 Hardware Block Diagram

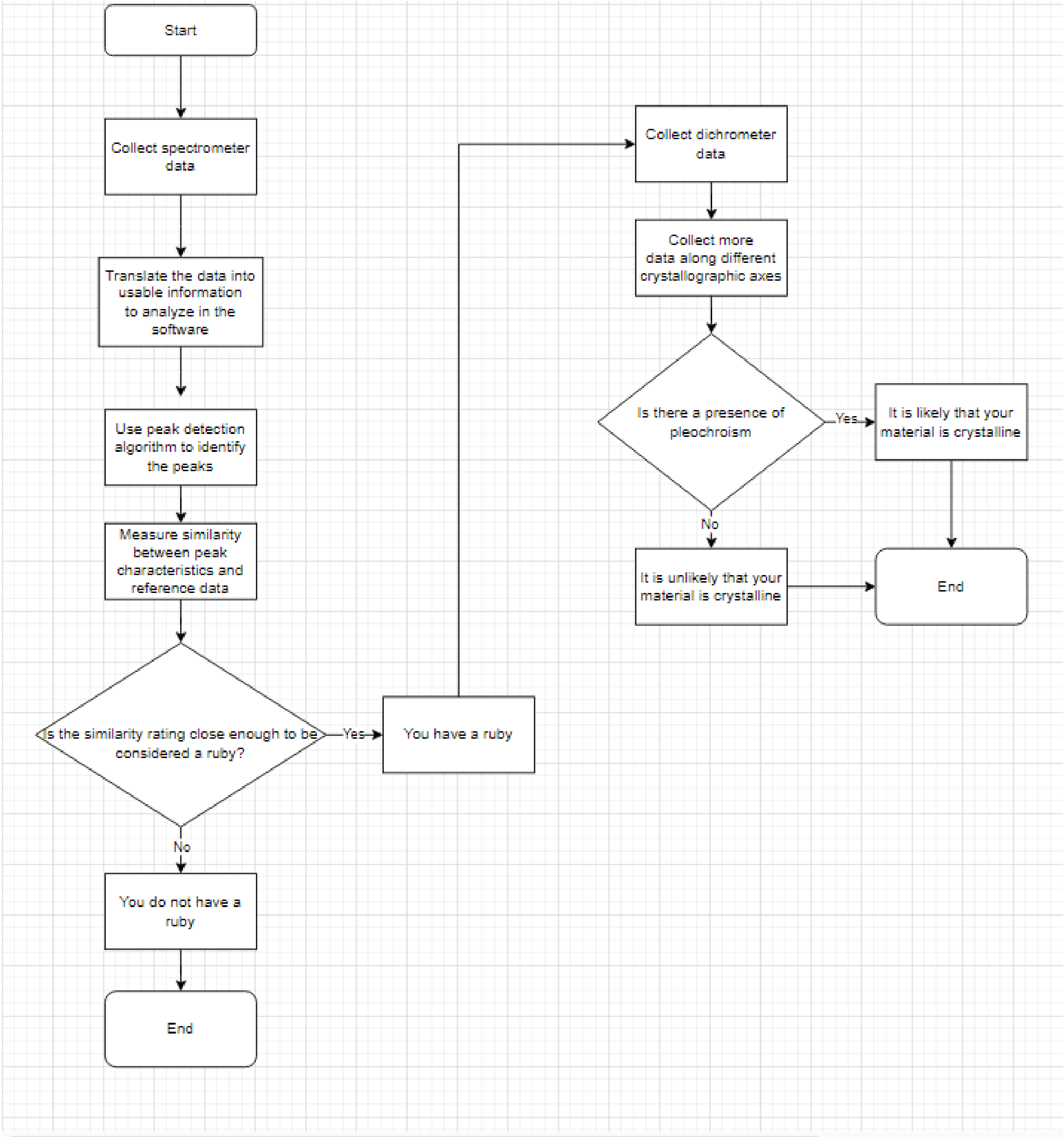
Block Status as of September 15th, 2023:

- Each block is currently being researched/designed.
- No blocks have been purchased or acquired.
- No blocks have been completed.
- No prototypes have been made.



The light source (either the green or white LED, depending on the test that is running) will illuminate the ruby held within the rotating stage. The output light from the green LED test was focused into the spectrometer. The light from the white LED pleochroism test (the dichroscope) will also be focused into the spectrometer. The results of each test was analyzed and displayed on an external monitor.

2.6 Software Flowchart

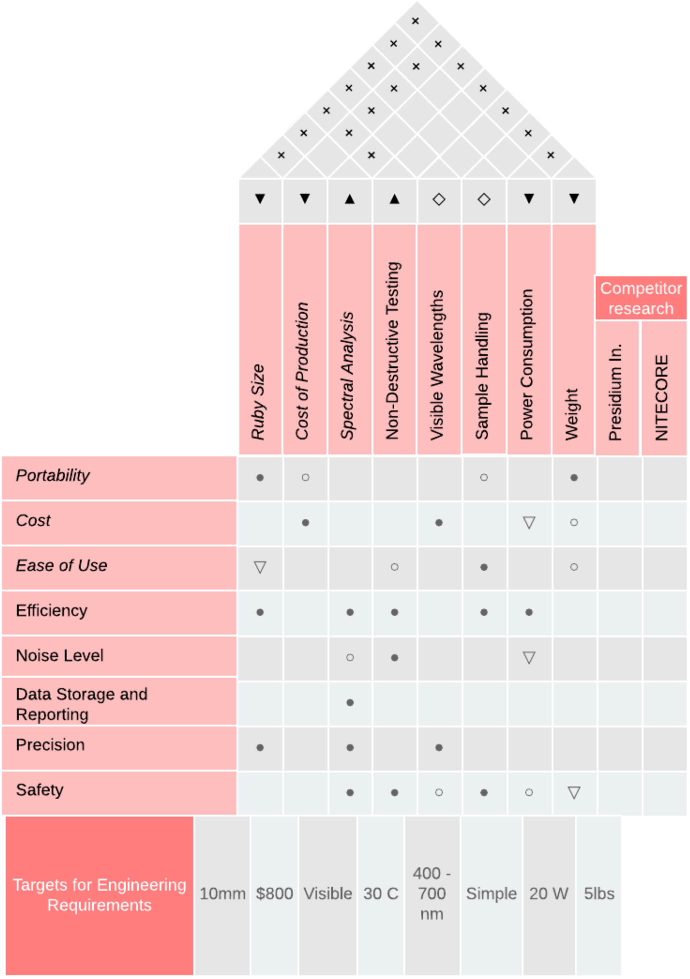


The software analysis will primarily consist of the spectrometer readings. Once the incident light on the diffraction grating is split and displayed onto the Pi Camera, an image was taken. This image was analyzed to determine the peaks in the intensity of each wavelength via a peak detection algorithm. The ruby spectrum will need to have peaks at specific wavelengths, and thus the predetermined wavelength was analyzed to ensure fluorescence. If the ruby does not pass this test, the ruby is determined to be fake and the process ends. Should the ruby pass this test, the dichroscope test wasgin. The spectrum will once again be collected and the difference in peaks was analyzed. Should these peaks be sufficiently different wavelengths, the ruby passes the test and is determined to be real.

2.7 Quality of House Analysis

Correlation matrix	
+ +	Strong positive
+	Positive
–	Negative
– –	Strong negative
	Not correlated

Relationship matrix		
⊙	Strong	9
○	Medium	3
△	Weak	1
	No assignment	0



									Competitor research	
	▼	▼	▲	▲	◇	◇	▼	▼		
	Ruby Size	*Cost of Production*	*Spectral Analysis*	Non-Destructive Testing	Visible Wavelengths	Sample Handling	Power Consumption	Weight	Presidium In.	NITECORE
Portability	●	○				○		●		
Cost		●			●		▽	○		
Ease of Use	▽			○		●		○		
Efficiency	●		●	●		●	●			
Noise Level			○	●			▽			
Data Storage and Reporting			●							
Precision	●		●		●					
Safety			●	●	○	●	○	▽		
Targets for Engineering Requirements	10mm	$800	Visible	30 C	400 - 700 nm	Simple	20 W	5lbs		

3 Related Technologies

When developing any product, the existing market must be analyzed. Things to consider when researching this is methodology versus other existing methods, price points, and consumer accessibility for their intended purpose. It was found that many products aim to achieve a similar goal to RASS, but take a far more barebones approach to gem analysis through the use of only one test. Specifically, the thermal conductivity test seems to be a popular approach despite its ability to be bypassed becoming more widespread. In addition, many gem analysis methods on the market are mainly used by gemologists and not intended for the general, untrained public.

3.1 Existing Similar Projects and Products

The current relevant technologies that exist for gem characterization typically serve one purpose or are complex and expensive. Those options was explored as well as the single system that exists that can characterize whether a gem is real or not, but are not similar to this project. There are not many previous designs that exist that aim to achieve what this project will do.

3.1.1 Dichroscope Alternatives

London Dichroscope

There are two types of dichroscopes, one that uses calcite and another that uses simple polarizing filters, called the "London dichroscope". Both will produce a split image that represents any pleochroic colors that are present. When researching this, it was found that the simple polarizing method only allows for only one pleochroic color to be seen at a time. This is not optimal for this project's desired setup and would require more components that would consume more time and make results more difficult to achieve. In contrast, the calcite variant allows both colors to be viewed at the same time, hence the choice to implement this method that can easily be distinguished via spectroscopy[63].

Refractometer

The refractometer is another method that confirms the doubly refractive property of ruby. Rubies have a very specific refractive index that can be tested with this device, but requires a well-polished and flat facet to place on the surface of a prism in addition to a contact liquid between the respective refractive indices of the prism and the gem. Rubies are not always perfectly polished, and this would cause further limitations in the design of this product. In addition, the contact liquid would need to be constantly applied, and novices may damage optical components if the proper amount of liquid is not used or applied properly. Given all of these conditions, implementing a refractometer into this system would cause it to be less attractive to users without a fundamental understanding of the system. The dichroscope, in contrast, is a much simpler device to use with more straightforward and easily-understandable results[50].

Polarimeter

Similar to the London dichroscope, the polarimeter utilizes two polarizing lenses to analyze the internal structure of rubies. It requires the gem to be analyzed at various angles and positions. It's vertically oriented, with the two polarizers placed on either side of the sample. Beneath the lower polarizer is an achromatic light source that enables linearly polarized light to enter the sample and to shine upwards into the second polarizer. This top polarizer is rotated 90° in either direction, and upon light output it can be determined whether the ruby exhibits pleochroism. However, without a side-by-side comparison, it can be difficult to determine whether the gem actually exhibits pleochroism, hence the popularity of the dichroscope. In addition, this system would require more hardware in the system than what's already planned. Many times the polarimeter is used in conjunction with the dichroscope for further validation of the test. However, because of the lack of reliability in the human eye to tell separate wavelengths, with the implementation of more advanced optical analysis that our project aims to achieve, the use of the polarimeter can be wholly eliminated without compromising reliability[63].

3.1.2 Spectrometer Alternatives

Spectrophotometers

Spectrophotometers are optical tools made for measuring the amount of light a sample transmits or absorbs at various wavelengths. Their main objective is to measure how much light a substance absorbs or transmits, and this measurement is useful for many different purposes. Spectrophotometers can measure light from a variety of spectral ranges, including ultraviolet (UV), visible (Vis), and infrared (IR) light, depending on the model and the sample's absorption properties. These tools are necessary in many domains of science and industry where the quantitative examination of chemical compounds is crucial.

In disciplines like chemistry, biology, environmental science, and pharmaceuticals, spectrophotometers are widely used. They are used in molecular biology to quantify DNA and proteins, allowing for quick and accurate measurement of nucleic acid and protein quantities. Spectrophotometers are essential for quality control and research in many sectors because they are used in analytical chemistry to calculate the solute concentration in solutions. Additionally, environmental scientists frequently employ spectrophotometry to monitor water quality, gauge pollutant levels, and examine the chemical make-up of environmental samples. Spectrophotometers are tools used in pharmaceutical laboratories to assist in the formulation and quality control of pharmaceuticals and treatments, assuring uniformity and adherence to legal requirements. In many scientific and industrial applications, spectrophotometers are essential tools for quantitative analysis and quality assurance.

The optical instruments spectrometers and spectrophotometers are related yet have different uses and applications. Spectrometers are versatile instruments made to study the full electromagnetic spectrum and break it down into its individual wavelengths. They are commonly used to detect elements, compounds, and analyze the spectral characteristics of light sources in disciplines like astronomy, material science, and chemical analysis. Spectrophotometers, on the other hand, are specialist tools designed for measuring the absorption or transmission of light by a sample at particular wavelengths. They are essential for applications including DNA and protein quantification, environmental monitoring, and chemical concentration measurements in a variety of sectors because their main function is quantitative analysis. While both tools are used to study light and how it interacts with matter, spectrophotometers offer precise, quantitative data at particular wavelengths, whereas spectrometers give a comprehensive view of the spectrum. This allows for accurate concentration determination and quality control in analytical and biological assays.

Spectroradiometers

Spectroradiometers are specialized optical devices made for taking accurate readings of the spectral radiance, also known as irradiance, of light sources over a range of wavelengths. They are indispensable instruments for a variety of applications that call for precise characterization of light sources because their main function is to quantify the intensity of light at each wavelength in the spectrum. In areas like lighting design, remote sensing, and calibration, comprehensive spectral information from spectroradiometers is essential for comprehending and managing the spectral properties of light.

Spectroradiometers are used in many different fields where precise spectrum data is required. These tools are used in lighting design to gauge and assess the spectrum power distribution of man-made light sources, assisting in the development of excellent, cost-effective lighting systems for both indoor and outdoor settings. In order to quantify the spectral reflectance of surfaces on Earth or other planets and enable the study of vegetation, water bodies, and atmospheric conditions, spectroradiometers are also essential in remote sensing. Additionally, these tools are employed in the calibration and quality control of light sources, such as LEDs, lasers, and displays, to guarantee that they work consistently and dependably and adhere to predetermined industry standards. Overall, spectroradiometers are essential in applications that depend on precise spectral data to produce the best outcomes and scientific revelations.

Spectrometers and Spectroradiometers are optical devices with distinct but connected uses. Spectrometers are useful for detecting elements and compounds as well as for examining the spectral characteristics of light sources since they are made to examine and separate electromagnetic energy into its component wavelengths. The spectral brightness or irradiance of light sources across a range of wavelengths is carefully measured using spectroradiometers, which are specialist instruments. Spectrometers are frequently employed in disciplines like chemistry, astronomy, and material science because they provide qualitative information on the composition and features of substances. Contrarily, because spectroradiometers concentrate on quantitative information, they are essential for tasks like lighting design, remote sensing, and the calibration and quality control of light sources. While spectrometers and spectroradiometers both entail the study of light, they serve different purposes in different scientific and industrial contexts. Spectrometers provide a more comprehensive qualitative perspective of the spectrum, whereas spectroradiometers provide exact quantitative data.

Spectroscopes

Spectroscopes are straightforward optical instruments, frequently handheld, that are used for qualitative spectral analysis. Their main objective is to graphically represent the light spectrum so that observers may recognize the presence of particular spectral lines or bands in a sample. Spectroscopes are convenient tools for quick and basic qualitative analyses of the spectrum properties of diverse light sources because of their portability, affordability, and ease of use. Spectroscopes are useful teaching tools and can be useful for amateur astronomers, hobbyists, and basic science investigations even though they lack the precision and quantitative capabilities of more sophisticated spectrometers or spectrophotometers.

In order to introduce students and enthusiasts to the idea of spectroscopy and the behavior of light, spectroscopes are frequently employed in educational settings. They offer a quick and easy way to see the distinctive spectral lines or bands created by various light sources. The spectra of stars and other celestial objects can be observed and identified using spectroscopes by amateur astronomers and stargazers. Despite having fewer uses than more advanced spectroscopic instruments, spectroscopes are essential for promoting an awareness of spectral analysis and acting as a starting point for people who are curious about the intriguing field of spectroscopy.

While both spectrometers and spectroscopes are used to examine the spectral characteristics of light, their complexity, accuracy, and uses are very different. The intensity of light at various wavelengths can be precisely measured by spectrometers, which are sophisticated analytical equipment. For activities like identifying elements, compounds, and assessing spectrum properties, they are utilized in scientific research, industry, and fields including chemistry, astronomy, and material science. In contrast, spectroscopes are simpler, qualitative instruments that visually display spectra, primarily serving instructional and introductory purposes. While they lack the precision and quantitative capabilities of spectrometers, spectroscopes are important for exposing students and enthusiasts to the fundamental ideas of spectroscopy and are widely used by amateur astronomers to detect and identify celestial spectra.

Gas Chromatography-Mass Spectrometers (GC-MS)

Powerful analytical tools called gas chromatography-mass spectrometers (GC-MS) combine two different techniques to separate and identify the constituents of a complicated mixture. In the first step, gas chromatography (GC), the sample is vaporized and sent through a chromatographic column to separate it into its constituent parts. Based on their chemical characteristics and interactions with the column material, the mixture's components separate while being carried by a carrier gas. The separated chemicals are ionized by the eluted substances and measured by the mass-to-charge ratio of the resultant ions in the mass spectrometer (MS). The GC-MS system is an invaluable tool in areas including analytical chemistry, forensics, environmental investigation, and pharmaceutical research since it may enable extremely specific identification of particular compounds in a sample.

Forensic scientists frequently utilize GC-MS to analyze drugs, explosives, and trace evidence discovered at crime scenes. It is used in environmental research to monitor pesticide residues in food, analyze soil contamination, and detect and quantify pollutants in air and water. For drug analysis, quality assurance, and the identification of active ingredients in pharmaceuticals, the pharmaceutical sector relies on GC-MS. Analyzing food product composition and finding pollutants are both utilized in food safety. The identification of volatile organic compounds is aided in research and development by GC-MS, making it an essential tool in fields like organic synthesis and natural product analysis. In many different domains where precise and highly specific compound identification is crucial, GC-MS is unavoidable.

Both spectrometers and GC-MS devices are essential in analytical chemistry, although their capabilities and main uses are different. Spectrometers are adaptable instruments made to evaluate the full electromagnetic spectrum. They are frequently used to detect elements and compounds as well as to investigate the spectral characteristics of light. They offer qualitative data, providing perceptions on the make-up and traits of substances. The exact and extremely specific component identification in complicated mixtures is provided by GC-MS devices, which combine gas chromatography and mass spectrometry. They provide quantitative data and are highly effective in industries that require precise compound identification, including forensic investigations, environmental monitoring, and pharmaceutical research. GC-MS instruments are crucial for applications requiring precise compound identification and concentration determination since they are specialized for quantitative and particular analysis, in contrast to spectrometers, which have a broader, qualitative focus.

Spectrometers are adaptable instruments that have significantly altered our understanding of the physical and chemical properties of the universe. They are used in a variety of fields, including chemistry, astronomy, and environmental science. Understanding the basics regulating spectrometer operation, their wide range of applications, and the essential components involved in their manufacture can help us appreciate the critical role these devices play in advancing scientific knowledge.

3.1.3 General Alternatives

Gem Testers

There is a singular device that claims to be the industry's most trusted colored gemstone tester. The Gem Tester II differs from this project in that it tests more than one gem type, ranging from glass to diamond, rubies, emeralds, and many more imitations. It's compact and portable. It doesn't involve any optical components and solely uses thermal conductivity to determine the gemstone's quality. The company that makes it is called Presidium, and they have made two versions of this type of test. However, the thermal conductivity test has been shown to have workarounds that have even been done during live gem shows or auctions. This renders this system, with only one function, unreliable. They also feature a handheld version, which can also be bypassed[49].

The Presidium Multi Tester III is a device that is closer to what our project aims to achieve, however it only identifies colorless diamonds and moissanites. It does not aim to achieve the same with rubies. It does both thermal and electrical conductivity tests, however it cannot be applied to rubies. It is similar to this project only in that it is multifunctional[49].

With all alternative options considered, it has been deemed that this project is the first of its kind in the gemology of rubies. The dichroscope is the most cost-effective, layman friendly, and reliable method of determining the pleochroic properties of rubies. In addition, fluorescence tests are incredibly difficult to bypass and thus has been chosen as another primary test in this project design.

3.2 Relevant Technologies

The technologies used in RASS was outlined and discussed in the following chapter. More specifically, the consideration process when choosing components and software was detailed so that future engineers was able to understand the thought process behind this product and better replicate it.

3.2.1 Software

As RASS implements a Raspberry Pi, an Arduino, and a spectrometer that all require some form of software component, the following options were considered. The pros and cons of each option are considered and the final reasonings of why these methods were chosen are analyzed and explored.

3.2.1.1 Microcontroller/Arduino Software

General Use

The use of microcontroller devices such as Arduino and Raspberry Pi's are often used when creating a spectrometer, with good reason too. Arduino and Raspberry Pi code can be crucial in managing many aspects which include light sources, diffraction gratings, and detectors. If these systems are used the software would be beneficial and essential for tasks such as taking measurements, handling any of the signals from the device, or transmitting the data to another device for further analysis.

Effectiveness for Gemstone Analysis

The suitability of this software for gemstone analysis hinges on the finer details of the project's requirements. When it comes to basic spectrometer operations, this software is a reliable option, adequately serving the purpose. The software efficiently handles straightforward tasks such as capturing simple absorption spectra, this makes it a valuable tool for routine gemstone analysis. However, for more demanding and advanced gemstone analysis techniques, which require the identification of distinct gemstone types based on intricate spectral signatures and extracting highly detailed information from the sample, it may be necessary to enhance the capabilities of the software by integrating advanced data processing tools when computing this information.

In these more complex cases, advanced data processing tools can significantly enhance the depth and precision of your gemstone analysis. These supplementary software options are more adept at handling complex data manipulation, spectral deconvolution, and multivariate analysis, allowing you to extract more detailed information from the spectra. These tools also allow users to perform sophisticated pattern recognition and statistical analyses, which would be vital when trying to identify and characterize gemstone materials with precision.

Moreover, the incorporation of advanced data processing tools can open the door to in-depth research and comprehensive gemological studies, enabling you to explore intricate gemstone properties, trace their origins, detect treatments or enhancements, and gain a comprehensive understanding of the gemological world. While the basic spectrometer software remains essential for routine tasks, the integration of advanced data processing tools broadens your capabilities and enables you to delve deeper into the multifaceted realm of gemstone analysis[70].

3.2.1.2 LabVIEW

General Use

LabVIEW is a versatile graphical programming environment designed for the precise control of instruments and the acquisition of data.

One of the standout features of LabVIEW lies in its remarkable adaptability and compatibility with an extensive array of hardware components. This inherent versatility means that LabVIEW is exceptionally well-suited for the development of spectrometer setups that can be customized to meet even the most intricate and specialized requirements. This broad hardware support not only ensures that a diverse range of sensors, detectors, light sources, and other spectrometer components can be seamlessly integrated but also enables the creation of spectrometer systems that can address the unique needs of specific applications.

LabVIEW extends its capabilities into the realm of user interface design. With its innate support for creating tailored graphical user interfaces (GUIs), it becomes possible to craft user-friendly and highly intuitive front-end applications. These GUIs serve as the connecting tool through which operators can interact with the spectrometer, offering a rich and catered user experience that enhances the control, monitoring, and analysis of the spectrometric data.

LabVIEW is a software platform that can be utilized by those working on the development of custom spectrometers. The unique blend of visual programming, hardware compatibility, and user interface design capabilities allows engineers, researchers, and scientists to create spectrometer solutions that are both functional and accessible. In the evolving landscape of spectrometry, LabVIEW can be a valuable tool when aiming for accurate and insightful data analysis.

Effectiveness for Gemstone Analysis

LabVIEW excels when you want to create a user-friendly interface for your spectrometer. Its graphical nature simplifies the creation of control interfaces and data visualization tools. For gemstone analysis, where precise control and real-time data presentation are vital, LabVIEW can be highly effective. You can develop custom GUIs that allow users to control the spectrometer, select gemstone types, and view spectral data in real-time. Moreover, LabVIEW offers advanced data analysis capabilities, including Fourier transformation, peak identification, and spectral comparison, which are useful for gemstone analysis.

LabVIEW emerges as an outstanding choice when your objective is to craft an interface for your spectrometer that melds user-friendliness with functionality. At its core, LabVIEW embraces a graphical programming system, making the process of constructing control interfaces and developing data visualization tools a more simplified experience[71].

In terms of gemstone analysis, where precision and real-time data presentation are important when trying to determine success, LabVIEW performs well as a software tool. Its ability to facilitate the design of custom GUIs introduces many possibilities. These tailor-made GUIs serve as the basis in which users can have control over the spectrometer, allowing them to make selections such as identifying specific gemstone types and viewing the spectral data in real-time. The real-time data presentation becomes a valuable asset in the gemstone analysis process, allowing gemologists and researchers to assess gemstone properties quickly.

3.2.1.3 Python with Libraries

General Use

Python stands as an incredibly powerful and adaptable programming language, known for its widespread utilization across many scientific and engineering domains. Its full capabilities are realized when utilizing many of its specialized libraries, including but not limited to numpy, matplotlib, and scipy[73]. All of the tools and libraries in addition to the base version of Python make it into an all-encompassing toolkit, perfect for taking the reins of numerous projects including DIY spectrometers, enabling the acquisition of spectral data, and masterfully conducting in-depth data analysis and visualization.

Python and its extensive libraries form the backbone of a versatile and highly customizable solution for spectrometer control and data management. In the realm of DIY spectrometry, the ability to utilize Python's programming capabilities brings forth numerous possibilities. By leveraging this language in along with the aforementioned libraries, users can design and implement control systems that govern the spectrometer's various components, whether it be the illumination source, grating, or detector, all with the ability to tailor the controls to the specific needs of the project.

One of Python's standout qualities is its aptitude for data handling and analysis, and this is where the numpy and scipy libraries step in. These libraries provide a wide set of functions and tools for numerical and scientific computing. The numpy library offers a robust framework for efficient handling of multi-dimensional arrays and matrices, this is essential for storing and manipulating spectral data. Meanwhile, scipy enhances Python's capabilities by providing a wide array of specialized functions that makes it an ideal tool for many scientific and engineering applications. It has capabilities for signal processing, optimization, statistics, and more, allowing users to have most, if not all, that they may need to process and analyze spectral data with precision.

In addition, another library, matplotlib, adds more capabilities in terms of data visualization. It has many options of plotting tools and functions and allows users to craft captivating and informative graphical representations of the spectral data. This feature is significant for analyzing the actual spectra and also for conveying results to peers, students, or stakeholders in a well displayed format.

Using an overall view on spectrometry, Python, in tandem with libraries like numpy, matplotlib, and scipy, assumes the role of a powerful and versatile tool that's indispensable. Its ability to facilitate DIY spectrometer control, data collection, analysis, and visualization will most likely provide all that is needed for any scientific or engineering purpose.

Effectiveness for Gemstone Analysis

One of Python's standout qualities is its adaptability. Because it is so open-ended and customizable, users are able to create tailored scripts and applications that should be able to work through the entire gemstone analysis process very efficiently. The first step of this whole process would be the acquisition of spectral data. Python excels in enabling users to design scripts that can efficiently collect and store this valuable data for further use in the process.

Python's power is way more than just data collection. Preprocessing, another crucial step in gemstone analysis, can be conducted through the use of Python scripts. We was able to implement preprocessing algorithms, refining and conditioning spectral data to create a more accurate analysis.

Because of Python's capabilities and ability to be versatile we can continue to use it for even more than data preparation. We can also work with advanced analysis techniques and be able to implement algorithms that cater to the unique demands of gemstone analysis[74]. Users can harness the libraries available in Python's ecosystem to create algorithms that precisely match acquired spectra with established reference data, further helping in the authentication and classification of gemstones.

Furthermore, Python can efficiently take on the challenging task of absorption peak identification, where it enables the development of algorithms that pinpoint characteristic features within the spectra. This capability is crucial for gemstone analysis, as these readings are some of the most important information when trying to read the data and it aids in the differentiation of gem types based on their distinctive spectral signatures.

In conclusion, Python emerges as an excellent choice for gemstone analysis when considering a DIY spectrometer. Its multifaceted capabilities, rich ecosystem of scientific libraries, and adaptability ensure that it makes the data acquisition and preprocessing phases as easy and streamlined as they could be and also offers an expansive toolkit for advanced analysis techniques. The language's capabilities elevate it to the forefront of gemstone analysis, enabling enthusiasts, gemologists, and researchers to further their studies with enhanced precision, efficiency, and depth.

3.2.1.4 Custom Software

General Use

Custom software development involves creating software from the ground up, tailored specifically to your spectrometer's design and gemstone analysis requirements. This approach offers maximum flexibility but requires significant programming expertise and time.

Effectiveness for Gemstone Analysis

Custom software can be highly effective for gemstone analysis, especially when you have precise control requirements or need to implement unique analysis algorithms. You have full control over software functionality, enabling you to design workflows that match your specific gemstone analysis needs. For instance, you can develop algorithms for identifying gem types based on spectral fingerprints, integrating external databases, and performing statistical analysis. However, this approach demands a substantial development effort and expertise in areas like signal processing and data analysis.

3.2.1.5 Spectroscopy Software Libraries

General Use

Spectroscopy libraries, such as `python-seabreeze` and `SpectraGryph`, provide pre-built tools for spectrometer control and spectral data analysis. These libraries simplify the software development process by offering standardized functions and classes for spectrometer communication and data processing.

Effectiveness for Gemstone Analysis

Using spectroscopy libraries can be highly effective. They offer a balance between flexibility and ease of use, making them suitable for various spectrometer setups and gemstone analysis tasks. You can leverage these libraries to quickly build software for acquiring and preprocessing spectral data[75]. For gemstone analysis, you may use spectral libraries to implement methods like peak identification, absorbance calculation, and gemstone identification based on known spectral signatures.

3.2.1.6 GUI Frameworks

General Use

GUI frameworks like PyQt, Tkinter, and others allow you to create user-friendly interfaces for controlling the spectrometer and visualizing spectral data. These interfaces enhance the user experience by providing intuitive control and real-time data presentation.

Effectiveness for Gemstone Analysis

GUI frameworks are effective when you want to provide a user-friendly interface for your spectrometer, which is valuable in gemstone analysis applications. You can design interfaces that allow users to select gemstone types, initiate measurements, and view spectral data in a user-friendly format. These interfaces can also include features like real-time plotting, data export, and integration with external databases for gemstone identification. The choice of GUI framework depends on your programming skills and platform preferences.

3.2.1.7 Open-source Spectrometer Software

General Use

Open-source spectrometer software projects are often developed collaboratively by the scientific community. They may provide complete or partial solutions for spectrometer control and data analysis. These projects can serve as valuable resources for DIY spectrometer builders.

Effectiveness for Gemstone Analysis

If you find an open-source project that aligns with your DIY spectrometer's design and objectives, it can be highly effective. Open-source solutions can save you substantial development time and provide well-tested and optimized code for spectrometer control and data analysis. You may need to customize the software to meet specific gemstone analysis requirements, such as integrating spectral databases or implementing custom analysis algorithms.

In conclusion, the choice of software for your DIY spectrometer for gemstone analysis should align with your specific goals, programming skills, and project complexity. Python offers a versatile and accessible option with a wide range of libraries. LabVIEW is excellent for creating user-friendly interfaces. Custom software provides maximum flexibility but requires significant effort. Spectroscopy libraries and open-source projects offer a balance between ease of use and flexibility, making them suitable for various spectrometer setups and gemstone analysis tasks. GUI frameworks enhance user interactions, which can be valuable in gemstone analysis applications. Consider your priorities and constraints when selecting the best software for your DIY gemstone analysis spectrometer.

3.2.2 Spectrometer

Spectrometers are essential tools in various scientific disciplines, enabling us to analyze and understand the properties of light and matter. This paper explores the working principles, applications, construction, and a comparison with similar tools to shed light on the significance of spectrometers in modern science.

Spectrometers are tools used to separate and then measure the different properties of light, allowing us to obtain valuable information about the structure, properties and composition of various substances. With the assistance of spectrometers, scientists from several disciplines may examine how light interacts with different matters to determine the composition and characteristics of that material. In order to obtain useful information about the sample being investigated, they function according to the fundamental principles of light dispersion and a number of measurement techniques.

How Spectrometers Work

Spectrometers are an essential tool for various scientific studies and a variety of sectors because they make it possible to characterize light and analyze a considerable amount of detail of each material. They work by utilizing several measurement techniques and the laws of light dispersion, giving researchers insight into the make-up, structure, and characteristics of substances.

Spectra

Spectroscopy is a scientific tool that is used for understanding the properties of different materials and electromagnetic radiation. The three primary forms of a spectra that have been researched extensively and used often are the Emission spectra, absorption spectra and the continuous spectra. Each spectra has a specific use and provides unique information on the makeup of atoms, molecules and celestial objects. These spectras can be seen in Figure 1.

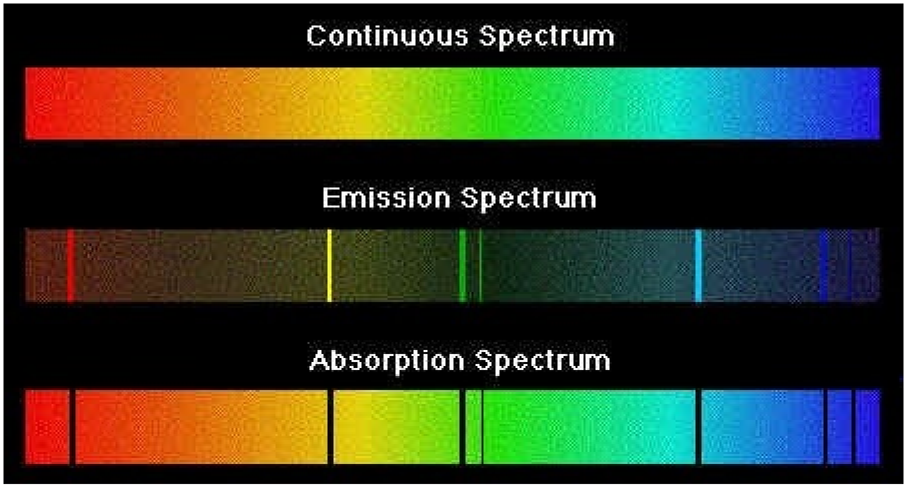


Figure 1: Three spectrums, Continuous, Emission, and Absorptions

The emission spectra is produced when atoms or molecules release energy in the form of electromagnetic radiation. This occurs when an excited electron in an atom or molecule reverts to a lower energy state, this is called energy release. The light that is illuminated has distinct sharp lines at the different wavelengths that are particular to the element or molecule that is being presented. Various applications like chemical analysis and the elemental makeup of stars and other celestial bodies utilities the emission spectra.[76]

With respect to the emission spectra, the absorption spectra are produced when atoms or molecules absorb specific wavelengths of electromagnetic radiation. This absorption occurs as photons with specific energies are absorbed, advancing electrons in the ground state to higher energy levels. Where the absorbed wavelengths are not present, the spectrum as a result shows dark lines or bands. The study of the interstellar medium and estimating the concentration of specific elements or compounds both benefit from the use of absorption spectra to determine the make-up of substances in a sample.[76]

Lastly, for the continuous spectra, the electromagnetic radiation is distributed uniformly and smoothly throughout a wide range of wavelengths. They don't have any distinct bands or lines that are shown in the emission and the absorption spectra. Blackbody radiation is commonly connected to the continuous spectra, this is when all potential wavelengths are present due to the thermal motion of particles. This is used to comprehend the temperature and make-up of astronomical objects, such as stars and galaxies, they are crucial.

The continuous spectrum results from the interaction of heat radiation with matter. While emission and absorption spectrums are created by interactions between matter and electromagnetic radiation. The absorption spectrum shows dark lines or bands at the same wavelengths, whereas the emission spectrum shows recognizable lines or bands that correspond to particular elements or molecules. The continuous spectrum lacks these particular characteristics. While the continuous spectrum is used to estimate temperature and composition, emission and absorption spectra are used to identify different elements, compounds, and even analyze celestial objects. The continuous spectrum offers details on temperature and composition, while the emission spectra illustrates the energy transitions of excited electrons, absorption spectra display the wavelengths that are absorbed.[76]

For scientists in many different fields, continuous, emission, and absorption spectra are invaluable tools. While the continuous spectrum reveals information about temperature and composition, emission and absorption spectra provide insights into the energy levels of atoms and molecules. It improves our knowledge on the physical cosmos and beyond to comprehend the principles and uses of these three spectrums.

Dispersion of Light

In spectrometry, light dispersion is a crucial phenomenon. For the examination of spectral data, it involves the division of light into its individual colors or wavelengths. This dispersion happens when distinct wavelengths of light travel through a material, usually a prism or a diffraction grating, with varying refractive indices.

White light, which is made up of all the hues that are visible, enters a spectrometer and undergoes dispersion, which causes a continuous spectrum from red to violet to form. This spectrum, which includes each of the many colors that make up white light, is frequently referred to as a "rainbow" spectrum. The wavelength of each hue determines how much it bends (or disperses), with shorter wavelengths bending more than longer ones. Numerous spectrometric measurement techniques are built on this dispersion.

Measurement Techniques

Spectrometers use a variety of measurement methods to learn more about a sample. The technique picked depends on the analysis's particular goals. Here are a few typical measurement methods for spectrometers:

1. Emission Spectroscopy: Emission spectroscopy is examining the light wavelengths released by an energized sample. The investigation of atomic and molecular species makes use of this technology particularly well. An atom or molecule passes through electronic transitions and emits recognizable light wavelengths when it absorbs energy. Emission spectroscopy is frequently used in flame testing, element identification, and chemical reaction monitoring.[76]
2. Absorption Spectroscopy: A spectrometer is used to gauge how much light is absorbed by a sample at particular wavelengths. The spectrometer measures the intensity of transmitted light after exposing the sample to a variety of light wavelengths. The composition and concentration of the sample can be inferred from variations in intensity at particular wavelengths.[76]
3. Fluorescence Spectroscopy: When a sample is exposed to light, fluorescence spectroscopy is used to examine the fluorescence that is produced. Fluorophores

are molecules that absorb light at one wavelength and then emit it at a longer wavelength. Environmental monitoring, drug discovery, and medicinal research all frequently employ this method.

4. Raman spectroscopy is a non-destructive method for gathering data on the rotations and vibrations of molecules. It entails examining the variations in frequency between the incident and dispersed light. In forensic science, pharmacological research, and material analysis, Raman spectroscopy is used.[77]
5. Mass Spectrometry is a potent method that includes ionizing molecules and determining the mass-to-charge ratios of the ions. This technique is commonly used in chemistry, proteomics, and environmental investigation to ascertain the molecular weight, structure, and content of molecules.[78]

In order to collect data about a sample, spectrometers split light into its individual hues and perform several measuring processes. Scientists use spectrometers to examine the composition, structure, and properties of materials in a non-destructive and highly informative way, whether by absorption, emission, fluorescence, or Raman techniques. These devices offer priceless insights into the universe of matter and are essential tools in domains ranging from chemistry and physics to environmental research and astronomy.

Applications

Spectrometers are versatile tools with uses in a variety of scientific disciplines. Spectrometers are utilized in three important disciplines: chemical analysis, astronomy, and environmental monitoring. Multiple applications show the instrument's value in advancing knowledge and solving pressing problems in various fields.

Chemical Analysis

Spectrometers are widely used in chemistry to identify and quantify the composition of substances. Techniques like UV-Vis spectroscopy and infrared spectroscopy are invaluable in this regard. In order to identify unidentified substances, spectrometers like infrared (IR) and mass spectrometers are essential. While IR spectrometers offer details about the functional groups found in organic molecules, mass spectrometry is utilized to ascertain the molecular weight and chemical structure of compounds. Quantitative analysis uses spectrometers to estimate the concentration of particular chemicals in a sample. For example, UV-Vis spectrophotometry is frequently used to calculate the concentration of ions, molecules, or other substances in solution. This has uses in food testing, environmental analysis, and pharmaceuticals. Chemical professionals can comprehend the three-dimensional structure of molecules with the aid of Nuclear Magnetic Resonance (NMR) spectrometers. NMR is essential for studying the characteristics and behavior of various molecules, which enables research into drug discovery, materials science, and biochemistry.[78]

Astronomy

In astronomy, spectrometers help scientists determine the composition, temperature, and motion of celestial objects. Tools like spectrographs are essential for studying the light emitted or absorbed by stars, galaxies, and other cosmic entities. Astronomers use spectroscopy to examine the light that stars and other celestial bodies release.

Astronomers are able to determine the chemical makeup, temperature, and radial velocity of stars and galaxies using spectrometers, such as the spectrographs on board the Hubble Space Telescope. One important tool for describing exoplanets is spectroscopy. It aids in the detection of specific compounds, such methane or water, in the atmospheres of exoplanets.[78] The knowledge acquired aids in the search for planets that may support life. The redshift of distant galaxies may only be ascertained with the aid of spectrometers. Understanding the universe's expansion and the development of celestial objects depends on this.

Environmental Monitoring

Spectrometers play a crucial role in environmental science by analyzing pollutants, monitoring atmospheric composition, and studying climate change through tools like spectroradiometers and lidar systems. Spectrometers, in particular infrared gas analyzers, are used in environmental monitoring to quantify the concentration of pollutants in the atmosphere. These tools are used in climate research because they can identify greenhouse gasses like carbon dioxide and methane. Water quality is evaluated using UV-Vis spectrophotometry and fluorescence spectrometry to measure factors including chemical oxygen demand (COD), turbidity, and the presence of contaminants such as heavy metals and organic pollutants. NIR spectrometers are used to examine the content and quality of soil. Spectrometers help to optimize agricultural methods and manage soil resources by measuring variables including nutrient content, pH, and organic matter.[78]

Ruby Fluorescence Spectra

Ruby exhibits a red (694 nm) fluorescence spectra under long wavelengths. Specifically, ruby is excited within three absorption bands: 250, 410, and 550 nm. The pumping wavelengths excite the chromium ions and cause them to fluoresce. The lifetime of this excitation is short, only up to 50 ns. The ion then relaxes and makes its transition back to its stable state. This short excitation period is enough to allow for detection of this fluorescence spectra, thus the spectrometer was implemented.

3.2.3 Dichroscope

When investigating methods of gem characterization, the dichroscope was one of the main tools in a gemologist’s arsenal. In order to verify the quintessential trigonal crystal structure of ruby, versus the hexagonal structure of quartz or cube-based garnet that do not exhibit pleochroism, this device may be used[63].

Dichroscopes operate on the concept of pleochroism, the general term for dichroism and trichroism, and it can only be observed in colored and doubly refracting crystals. Different crystal structures will exhibit different absorption and reflection wavelengths that are imperative in deciphering whether the crystal is real or fake. The readings of a dichroscope show these differing wavelengths plainly, and thus make it easy to determine to a novice gemologist or otherwise inexperienced layman whether the ruby has the proper qualities. The fundamentals of birefringence are essential in understanding why the dichroscope is so effective[44].

The dichroscope is a small instrument, able to fit into one's pocket. It can be used to test transparent crystals when used with a light source. The gem is first illuminated with an incoherent, achromatic light source and the viewing end of the dichroscope is placed as close as possible to the gem's surface. From there, the light enters the first aperture (a pinhole), is guided through a glass prism into calcite where the two wavelengths are separated, leaves the calcite and is once again guided by a glass prism into another pinhole, focused through a lens, and shone through two polarizers of opposing orientations. The two polarizing lenses will show the colors of the two wavelengths, and thus the structure of the crystal can be determined[64].

Birefringence and Calcite

When investigating the dichroscope, the reason as to why the inclusion of calcite ($CaCO_3$) makes the dichroscope more effective was explored. Calcite, in this application, is colorless or white when pure. It is number 3 on the Mohs hardness scale, thus can be scratched by a knife. When light passes through this mineral, it splits into two rays that travel at different speeds in different directions with different polarizations. This is called birefringence, and oftentimes can be observed with the naked eye[65].

Calcite has a rhombohedral structure and often shows hexagonal crystals. It is an anisotropic material, meaning different values are obtained when probing specimens from several directions despite it being the same material. Because it is anisotropic, it has a non-equivalent crystallographic axis and electromagnetic waves (light) that enter the crystal experience different refractive indices in different directions. EM waves first enter with the same velocity, but when interacting with the optical axis they are separated into two distinct rays[55].

Electromagnetic waves propagate through space with oscillating electrical and magnetic components that are oriented perpendicularly to each other and to the direction of propagation. Visible light is composed of both of these components, thus when interacting with a material the velocity of these waves is highly dependent on the electrical conductivity of the material. When traveling through the crystal, EM waves must interact with the electric fields of the atoms within the material, thus their speed is impacted[55].

The ordinary ray is the ray that follows the typical laws of refraction; it travels with the same velocity in all orientations through the crystal. The extraordinary ray travels with a velocity that is highly dependent on the direction it travels through the crystal, thus the need of the sample being observed from different angles. If incident light is parallel to the optical axis, it is not separated into individual components and the light rays exiting the crystal have the same optical path lengths. If it is perpendicular, the ordinary and extraordinary rays still occur and experience different optical path lengths, but emerge from the same location[55].

Crystal Structures and Pleochroism

Pleochroism is the effect of variations in color that is dependent on the polarization direction of incident light. The polarization direction is dependent on the orientation of a material in the incident light path and is only possible to be viewed via anisotropic materials[60].

For a mineral to exhibit pleochroism, it must have a specific crystal structure in which different wavelengths of light are absorbed. The angle at which it is viewed will show these different colors. Recall that as in anisotropic materials, refractive index changes with direction. Because the refractive index is wavelength dependent, different wavelengths was absorbed at different angles. Thus, pleochroism is able to be viewed. Tetragonal, trigonal, and hexagonal minerals exhibit what is known as dichroic properties, where they show two colors. Orthorhombic, monoclinic, and triclinic crystals are trichroic. Isometric minerals do not exhibit pleochroism[60].

Ruby Optical/Structural Properties

Rubies are a natural, inorganic mineral that have trigonal crystal structures. It ranges from orange-red to pink-ish or purplish red in color, and is a variety of corundum. In this specific case, ruby is red because the corundum is doped with chromium. It ranks 9.0 on the Mohs scale, second only to diamond and moissanite[61].

Corundum, the main component of ruby, is the crystalline form of aluminum oxide and can contain different traces of choice materials. These materials can come in the form of inclusions or dopants that change the color of the corundum. It typically comes in the more well-known forms of ruby or sapphire. It depends on the dopants[62].

Corundum has a trigonal crystal structure, its lattice containing oxygen atoms that form an imperfect hexagonal close packaging. Two thirds of the octahedral spots between these oxygen ions are inhabited by aluminum ions. This structure is often described as pseudohexagonal[62].

Trigonal crystal structures, also known as rhombohedral systems, are defined by a three-fold rotation axis; they're often generated by stretching a cube along its diagonal and forming the cubic crystal system. These components are located in reference to four axes, three of them are equal length with 120° intersections, the remaining one is perpendicular to the plane the other three are located on. The structure can be rotated 120° about the rotation axis and each face presented was identical to the starting face. Minerals with trigonal crystal structures exhibit double refraction and have two different refractive indices for light of two different colors[62].

3.2.4 Light Emitting Diode

Light emitting diodes, otherwise known as LEDs, consist of a single p-n junction diode. The main driving force behind LEDs is electroluminescence. The simplified explanation of this phenomena is the process in which current flows through a semiconductor and light is emitted[66].

A semiconductor is made of a base material with an unoccupied conduction band/full valence band (e.g. Si, GaAs) that is doped with impurities (e.g. As, B) to create free electrons (n) or holes (p). When a voltage is applied, it allows these free electrons and holes to move and meet at where the p-type and n-type materials are connected, called a junction. When these electrons and holes combine, light is generated. When free electrons in the conduction band drop to the lower energy level of holes to fill these gaps, the excess energy is released in the form of a photon. The difference in the energy levels of the electron and lower energy level will determine the energy of the photon. The higher the energy of the photon, the greater the frequency of light (shorter wavelengths). Most semiconductors have a low band gap energy level, thus don't generate much light. LEDs have semiconductors specifically chosen so that the energy drop is much higher and the photon is able to be viewed. To achieve the right wavelength of light for different applications, the proper energy gap has to be chosen[62].

Illumination Spectrum and Intensity

For the purposes of this project a green and white LED will need to be used. Due to ruby excitation properties, an LED that emits at a wavelength of 550 nm was selected. It will need to be of a high enough intensity to cause the ruby to fluoresce, and this quality was experimented with or calculated. For the dichroscope measurements, a white light LED with no predetermined wavelength was needed, as its main purpose is to simply generate reflections from the internal crystal structures of the ruby.

3.2.5 Beamsplitters

A beamsplitter is an optical component that splits the incident light into two separate beams, hence the term. The ratio between these two beams is predetermined depending on their application. There are many different types of beamsplitters, which was explored further.

Beamsplitters come in the forms of cubes or plates. Cubes are formed using two right angle prisms, one of which has its hypotenuse coated according to the application, then they are cemented together along their respective hypotenuses. Plate beamsplitters are flat glass plates that are coated on the first side of the substrate and designed for a 45° angle of incidence. Most of these components have an anti-reflection coating on the opposite side to remove Fresnel reflections. There are several advantages and disadvantages to using cube or plate beamsplitters, detailed in the table below[67].

Table 2: Beamsplitter Comparison

Type	Advantages	Disadvantages
Cube	● Simple 0° AOI Integration ● No beam shift ● Equal reflection and transmission optical path lengths ● Optical system path lengths shortened	● Heavy glass construction ● More material ● Difficult and more expensive to manufacture in larger sizes ● Difficult to mount into a 3D printed system
Plate	● Lightweight ● Inexpensive	● Reflection and transmission optical path lengths are

	- Easily able to be scaled in the manufacturing process - Easily mounted in a 3D printed system	different - Transmitted light experiences a beam shift - 45° AOI will require additional alignment time

In addition to the forms, there are different coating options for beam splitters. Standard beamsplitters are best for a versatile range of applications where unpolarized light and polychromatic light sources are in play. They're very flexible in how they're used and would be ideal in applications such as this project[67].

Polarizing beamsplitters are used to split incident light into s and p-polarized beams. The reflected beam would be s-polarized and the transmitted beam would be p-polarized. It is possible for both beams to have an equal ratio, despite the often occurrence of weaker p-polarized light. This is useful for polarization separation applications[67].

Dichroic (not in relation to ruby crystalline properties) beamsplitters split light by wavelength. They are often used for laser beam combiners designed for pre-designated wavelengths or hot and cold mirror applications. This is the type of beamsplitter often used in fluorescence applications. However, it will not be necessary here as hot and cold mirrors are used for separating visible and infrared light, this project utilizes spectra entirely in the visible region[67].

Some beamsplitters have an extinction ratio, where the p-polarized light is not effectively prevented from reflecting back and light loss occurs. Beamsplitters are typically good at reflecting s-polarization but are not good at preventing p-polarization reflections. When s-polarized light interacts with the reflection surface, the electric field and the surface share the same plane. However, when p-polarized light hits this surface, it has components both in the surface plane and perpendicular to the surface. Thus, the reflected light is not free of p-polarization whereas the transmitted light was[67].

For the purposes of this project, the ideal beamsplitter would have an equal ratio between reflection and transmission to account for both the fluorescence and pleochroic spectra that this project requires. Different variations of both cube and plate beamsplitters was considered in the part selections portion of this paper.

3.2.6 Lenses

The operating principle of a lens is refraction, which can be described as when light passes through a material it changes direction based on both the constituent wavelengths of the light and the properties of the material. They are made of transparent substrates such as silica or BK7 that are optimized for minimal absorption at different wavelengths and typically have at least one curved surface. There are two main types of lenses that was considered for this project, named convex and concave lenses. When looking for the lenses the F/#, effective focal length, and curvature all must match[59].

Convex lenses get their name from the outward curve of the external surface. They can also be called positive lenses or converging lenses. This shape enables incoming parallel or collimated rays to be focused onto a single point, called the focal point. This focal point varies based on the severity of the curvature of both sides of the lens as well as the thickness. When diverging rays enter a convex lens that is placed to maximize light input and optimize focal length, the rays become collimated. These lenses are typically used in microscopes or telescopes[59].

Concave lenses are the opposite of convex lenses, they are designed to cause rays to diverge after passing through them. Their surfaces are curved inwards, and they are often called diverging lenses. These lenses have an odd way of calculating the focal point, as one would have to calculate this value on the input side of the lens. They can be used in reverse to magnify an image but are typically used in making small, high resolution images larger for projection purposes[59].

Pertaining to this project, magnification of the input light was needed in order to focus properly into the fiber and thus into the spectrometer. Thus, convex lenses will primarily be used and was selected in later portions of this paper.

3.2.7 Prisms

Prisms are optical components that are cut with precise angles and plane faces in order to effectively analyze, reflect, or refract light. Ordinary prisms can be used to separate light into its constituent wavelengths. Prisms are useful in their ability to be modeled as a system of plane mirrors, as they can bend or fold light to change image parity. Multiple mirrors would need to be used to accomplish the same output of a single prism[52].

Prisms achieve what mirrors aim to accomplish through a principle called internal reflection, where light that enters this element is reflected internally and exits through the other side of the prism. There are two main types of prisms, and each was detailed and considered for this project[51].

The first type is dispersion prisms, whose primary goal is to split light into its constituent wavelengths. This property of prisms is dependent on the geometry, the angles at which the prism is cut, and the index dispersion curve, which is based on the index of refraction of the substrate. Different wavelengths will deviate at varying angles and thus was split[51].

Deviation prisms are self-explanatory, they change the beam path in order to rotate the output image or displace it from its original axis. These deviations are usually done at pre-designated angles and will change based on desired applications[51].

For the purposes of this project, two deviation prisms was used in order to help guide the light through a calcite rhombus. They was selected later in the parts selection portion of this paper.

3.2.8 Mirrors

Optical mirrors are used to reflect light in order to “steer” the incoming beam in the desired direction. They can be curved or flat depending on whether the beam size will need to be maintained, expanded, or minimized. Curved mirrors act as “reflecting lenses”, as they too have a focal point that can be used for different applications. Mirrors can be coated with different materials in order to specialize them for different wavelength ranges and absorption parameters. Flat mirrors was used for this project due to their ease of acquiring and simple implementation. Mirror selection was done later in this paper[68].

3.2.9 Optical Fiber

For this project the utilization of an optical fiber is to transport the light that fluorescences from the ruby to the spectrometer. To select this fiber a few things need to be considered; it should minimize signal loss as well as maintain the spectral characteristics of the light transporting from the ruby to the spectrometer. To meet these requirements we need to look at the attenuation, numerical aperture, core diameter, wavelength range, dispersion as well as make sure it is compatible with our system.

Inorder to reduce the intensity and spectral content lost of the fluorescent light coming from the ruby we need a fiber with low attenuation. Generally, single-mode fibers are a better option for low attenuation compared to a multimode fiber. This is due to the way a single-mode fiber propagates light. Single-mode fibers only allow one mode of light to travel through the fiber core which reduces scattering and modal dispersion. This allows for single mode fibers to transmit signals over longer distances with minimal signal loss. In multimode fibers the fiber core is larger and allows multiple modes to propagate within it which can cause modal dispersion and signal degradation over a shorter distance.

The Numerical Aperture (NA) of the fiber determines its capacity to collect light and at which angle it collects light. For our system we want a higher numerical aperture to ensure the light is fully captured and that it maintains its characteristics. Generally a single-mode fiber has a lower numerical aperture compared to a multimode fiber. Due to the single-mode fiber having a smaller NA it is a more focused and narrower acceptance angle for the light which causes for a limited range of angle allowing more efficient and higher spatial resolution. Whereas Multimode fibers often have a higher numerical aperture. This allows them to accept the light from a higher range of angles which is beneficial for short-distances. The numerical aperture can vary within our project.

The core diameter of the fiber affects the efficiency at receiving light and the spatial resolution. In various applications surrounding spectroscopy a smaller core diameter is usually preferred as it collects light better and provides a higher spatial resolution. The smaller core diameter allows the fiber to transmit one mode of light minimizing modal dispersion and allowing a long travel distance with a low attenuation. The larger core diameter promotes multimode light propagation, which can ultimately cause modal dispersion over shorter distances. When looking at the various core diameters of fibers, single-mode fibers are considerably smaller than multimode fibers. Typically single-mode fibers range from a core diameter of 8-10 micrometers whereas multimode fibers typically range from 50 to 63 micrometers.

In order to maintain the characteristics of light it is important to select a fiber that has dispersion. This becomes especially crucial when dealing with lines in a spectrometer. Single mode fibers typically have dispersion compared to multimode fibers. Dispersion refers to the spreading out of signals over time. Plays a major role in determining signal transmission quality. Single mode fibers have dispersion, chromatic dispersion, which occurs when different wavelengths of light travel at different speeds within the fiber. This feature enables single mode fibers to transmit signals over distances with distortion making them suitable for high speed and long distance communication applications. On the hand multimode fibers are more prone to dispersion due to the presence of multiple modes of light within their larger core. Consequently they are better suited for shorter distance applications where signal quality is less critical such as area networks (LANs) or shorter point to point connections.

The last two conditions to keep in mind are the wavelength range and the compatibility to our system. When looking through various optical fibers we need to ensure that the fiber can transmit light in the 300 nanometer to 800 nanometer wavelengths range. It will also have to be implemented into our system, therefore it will need to be flexible and be able to be mounted on either side of the fiber.

Within spectrometer applications generally a single-mode fiber is preferred as it allows for less modal dispersion, and has a lower attenuation. Although we are only transmitting light along a short distance we want as little signal loss as possible to ensure that we are collecting all the different fluorescent excitations from the ruby.

Throughout testing and finalization of the RASS, we found that we experienced too much light loss to couple our light output into an optical fiber. Due to the light loss we had to rearrange our project and take the optical fiber out of the design and have the lens setup directly in front of the spectrometer.

3.2.10 Slit

Once the excitation source has interacted with the ruby and fluorescence excitation occurs, it will travel through the fiber and the light exits through a narrow vertical slit. The width of the slit is an important factor when designing the resolution of the RASS. A larger width means more optical power which can reduce the amount of time required to obtain an accurate reading. However, the smaller the slit, the wider the resolvable bandwidth of the absorption spectrum. When selecting the width size there are sizes ranging from anywhere between 5 micrometers to 800 micrometers. In order to calculate the width desired for the RASS equation one was used.

$$t = 1.9\sqrt{d} \times \lambda \qquad (1)$$

In equation one, d represents the distance between the slit to the image, λ represents the maximum transmittance wavelength. For the RASS λ=694 nm and d = 25mm This means we need a slit width of 250 µm. We were able to order the 250 µm slit as it is commercially available.

3.2.11 Grating

There are two dispersion optics that are often considered for the analysis of a fluorescent spectrum, a diffraction grating or a prism. To determine the type of dispersion element to use we mainly need to look at the desired resolution of at least 5 nanometers. Prisms can be hard to buy commercially for small projects as prisms are made custom to fit the various factors for its desired application, because of this prisms are more expensive and harder to obtain. Due to these constraints the RASS will utilize a diffraction grating.

Diffraction gratings are optical devices that enable the separation and analysis of light into its constituent wavelengths. Diffraction gratings allow scientists to study unique spectral fingers of various objects ranging from many different distances. In this section, we have investigated the inner workings of diffraction gratings, the role they play in spectrometers, the two main types of gratings, the calculation of groove spacing, and the key concepts of order of diffraction and incidence angle.[78]

How Diffraction Gratings Work

Diffraction gratings work on the principles of wave interference. When a light source hits a diffraction grating it interacts with the parallel lines or grooves that are closely spaced. This interaction causes the light to be dispersed into its individual component wavelengths forming a spectral pattern. This occurs due to the superposition of the light waves that pass through the gratings.

Each line in the diffraction grating acts as a separate source of secondary waves. Diffraction orders are created by the constructive and destructive interference between the light waves and the secondary waves. The central order, $m=0$, relates to the undeviated direct beam of light. Higher orders, $m = <1$, then are formed on each side of the undeviated beam; these represent diffractive light from various angles and correspond to different wavelengths.[78]

Use of Diffraction Gratings in Spectrometers

For a spectrometer the diffraction grating is one of the most important components. The main role for the diffraction grating is to disperse light according to its wavelength. This allows the user to measure and analyze the intensity of each wavelength separately. In a standard spectrometer light is collimated from a source and directed into a diffraction grating. The grating then disperses the light at different wavelengths, and focuses into a detector that is positioned at a specific angle from the grating in order to collect the diffracted light. The angle of the grating and the detector is important as the change in the angle can vary the different wavelengths that are collected. We need to ensure that we are focusing the light to ensure the detector collects all various wavelengths. By doing this it will provide valuable information about the ruby being tested.

Two Different Types of Diffraction Gratings

There are two primary types of diffraction gratings: ruled gratings and holographic gratings. Each has their own benefits and applications, which was discussed as follows.

A ruled grating is produced by physically engraving closely spaced grooves onto the surface of a substrate, typically using a diamond-tipped tool. Ruled gratings are known for their durability and can be customized with specific groove densities for specific applications. They are commonly used in spectrometers that require high-resolution and accuracy.

Holographic gratings are created through a more intricate process. A holographic interference pattern is exposed onto a photoresist-coated substrate, and after development, this pattern becomes the grating. Holographic gratings offer several advantages, including excellent optical quality, low stray light, and the ability to produce gratings optimized for a wide range of wavelengths. These gratings are often preferred for spectrometers that cover a broad spectral range.[78]

Calculating Groove Spacing

Groove spacing, also known to be line density, is a key specification for a diffraction grating. This will determine the dispersion and the range of wavelengths of light that was separated by the grating. The formula to calculate line density (d) is given as:

$$d = \frac{\lambda}{m sin(\theta)} \tag{2}$$

Where λ is the wavelength of light, m is the diffraction order and θ is the angle of diffraction. For RASS we was utilizing a 300 grooves/mm diffraction grating.

Diffraction Angle and Blazed Angle

The diffraction angle (θ) is the angle at which the diffracted light hits the detector. The diffraction angle is essential to determine the spatial separation of the different spectral components. The diffraction angle is a function of both the wavelength (λ) and the groove spacing (d), as described in the groove spacing calculation.

The blazed angle (θ_B) is the angle the grating is oriented to achieve the highest efficiency at any specific wavelength, known as the blaze wavelength (λ_b). When designing a spectrometer, it is important to keep the blaze angle in mind. Blazed diffraction gratings eliminate all of the diffraction orders except one that includes the zeroth order if it is not selected, this is to optimize the grating efficiency, which can be found by quotient of the diffracted power and the incident power of the light. Due to the fact that gratings are not lossless tools, a high grating efficiency is needed so the system can achieve a maximum signal throughput. The blaze angle is calculated by the following equation:

$$\theta_B = sin^{-1}(\frac{m\lambda_B}{2d}) \tag{3}$$

The blazed angle is essential for maximizing the efficiency of the grating at the desired wavelength and ensuring that the desired order of diffraction is enhanced. Where m is the diffraction order, λ_B is the blaze wavelength and d is the groove spacing.

The grating should be blazed at the angle of maximum efficiency for a ruby. To find this, use Equation 3 with the parameters $m = 1$ and $\lambda = 694$ nanometers. Since d is typically a standardized number, this can be varied with those known quantities to produce a blaze angle that matches the m and λ values.

There are generally three main groove spacing available for commercial use, 300 gr/mm (3.33µm spacing), 600 gr/mm (1.66µm spacing), and 900 gr/mm (1111nm). With this in mind customizing a slit is expensive and can take many weeks. For the RASS we decided to use a 300 groove/mm grating. Using equation 4 we can calculate the diffraction angles, a being the spacing of the grating, λ= 694 nm, m=1. Table 3 shows the 600 grooves/mm and 900 grooves/mm are not an ideal grating for our set up as some of the diffraction angles are not obtainable.

$$sin(\theta_m) = \frac{m\lambda}{a} + sin(\theta_i) \qquad (4)$$

Table 3: Incident angle vs. Diffraction angle

θ_m when θ_i =	300 grooves/mm	600 grooves/mm	900 grooves/mm
$\theta_i = 15°$	27.85°	42.60°	62.07°
$\theta_i = 30°$	45.11°	66.65°	Out of Range
$\theta_i = 45°$	66.28°	Out of Range	Out of Range

Diffraction gratings are vital tools that enable the separation and analysis of light by its constituent wavelengths, making them indispensable in spectrometers. Ruled and holographic gratings are the two primary categories, each offering specific advantages. Parameters such as groove spacing, diffraction angle, and blazed angle are critical for designing and using spectrometers effectively. These versatile optical components empower scientists and researchers to unravel the secrets of the universe, one spectral line at a time.

3.2.12 Electrical Components

For RASS our electrical components consist of a transformer, Bridge Rectifier, Linear Voltage Regulator, Capacitors, Low Dropout Voltage Regulator, USB 2.0 type A connector, Resistors, Light Emitting Diodes, and the Arduino Mega 2560 Microcontroller Rotation Sub-System. In this section we will dive into the research behind each component.

Transformer

In order for the power in our system to be electrically integrated various specifications have to be taken into account. This includes the specifications of the parts and how they may be configured with each other for optimal performance. The reader may already note that in order for parts in the system to function energy must be carried to them. In our power supply system energy is introduced by the mains and then to a transformer with an output of 12 V DC at 4.17 A and maximum power of 50VA.

A transformer is a crucial component in power supply circuits, playing a fundamental role in the generation, transmission, and distribution of electrical energy. Its primary function is to transfer electrical energy between two or more circuits through electromagnetic induction. This key device facilitates voltage transformation, isolation, and impedance matching, ensuring efficient and safe power delivery across various applications.

The transformer's core principle is based on Faraday's law of electromagnetic induction, which states that a changing magnetic field induces an electromotive force (EMF) in a nearby conductor. In a transformer, this is achieved by using two coils, known as the primary and secondary windings, wound around a common magnetic core. When an alternating current (AC) flows through the primary winding, it generates a changing magnetic field, which, in turn, induces a voltage in the secondary winding.

One primary role of a transformer in a power supply circuit is voltage transformation. This capability allows power to be efficiently transmitted over long distances. High voltage in the primary winding can be transformed into a lower voltage in the secondary winding for safer and more practical distribution. Conversely, transformers can step up the voltage when needed, such as in power generation to transmit electricity over long distances with reduced energy losses. In our case, we seek to step down the voltage.

Isolation is another critical function of transformers. The physical separation of the primary and secondary windings by the transformer's insulating core prevents direct electrical connection between input and output. This isolation ensures safety by minimizing the risk of electric shock and protects sensitive electronic devices from potential voltage fluctuations or noise in the power grid.

Impedance matching is essential in power supply circuits to optimize power transfer between different components. Transformers help achieve impedance matching by adjusting the turns ratio between the primary and secondary windings. This ensures that maximum power is transferred from the source to the load, minimizing signal reflections and enhancing overall system efficiency.

In addition to these primary functions, transformers contribute to power quality by regulating voltage levels and minimizing voltage fluctuations. Voltage regulation is particularly crucial in sensitive electronic equipment, as it helps maintain a stable power supply, preventing potential damage or malfunction.

Transformers also play a vital role in power conversion, as they are integral components in various types of power supplies. In AC-to-DC power supplies, transformers are often used to step down the voltage before rectification and smoothing processes. This makes the power supply more adaptable to the specific voltage requirements of electronic devices. Furthermore, transformers contribute to energy efficiency by reducing power losses during transmission and distribution. Higher voltage transmission lines experience lower resistive losses, and transformers enable efficient voltage stepping for long-distance power transmission, reducing energy waste in the form of heat.

Since our application is what is considered "low-power" and low voltage, the above-mentioned transformer is more efficient. Step-down transformers play a crucial role in power supplies, especially in low-power applications where voltage reduction is necessary for safe and efficient operation. These transformers are designed to convert high-voltage, low-current AC (alternating current) power into low-voltage, high-current power, matching the requirements of various electronic devices. In the realm of low-power power supplies, such as those used in electronic gadgets, sensors, and small appliances, different types of step-down transformers find utility.

One common type of step-down transformer is the linear transformer. Linear transformers are characterized by their simple design and reliability. They operate on the principle of electromagnetic induction, where a changing magnetic field induces a voltage in a coil. In a linear transformer, there are primary and secondary coils wound around a common magnetic core. The ratio of turns between the primary and secondary coils determines the voltage transformation.

In low-power applications, linear transformers are preferred for their ability to provide a stable output voltage with minimal distortion. They are commonly found in linear power supplies, which are known for their low noise and high regulation. However, linear transformers tend to be less energy-efficient compared to other types, as they may dissipate some power as heat.

Switched-mode power supplies (SMPS) represent another category of step-down transformers widely used in low-power applications. SMPS transformers operate by rapidly switching the input voltage on and off. This switching is typically performed at high frequencies, allowing for smaller and lighter transformers. The efficiency of SMPS transformers is higher than that of linear transformers, making them suitable for low-power devices where minimizing energy consumption is crucial.

SMPS transformers are further classified into several types, including flyback, forward, and push-pull transformers. Each type has its advantages and is chosen based on specific design requirements. For instance, flyback transformers are commonly used in low-power applications due to their simplicity and cost-effectiveness. They are often found in devices like USB chargers and small power adapters. In contrast, forward transformers are employed in applications demanding higher power levels and better efficiency. Push-pull transformers, with their ability to handle moderate power levels and provide good efficiency, are also utilized in certain low-power scenarios. The versatility of SMPS transformers makes them an integral component in the design of modern, compact electronic devices.

Another noteworthy type of step-down transformer is the autotransformer. Autotransformers differ from traditional transformers in that they share a common winding between the primary and secondary circuits. This results in a more compact design and potentially lower cost. Autotransformers are often used in low-power applications where size and weight constraints are critical factors.

In low-power power supplies, the choice of step-down transformer depends on various factors, including the application's power requirements, size constraints, cost considerations, and efficiency goals. Linear transformers are favored for their simplicity and stability, while SMPS transformers, with their high efficiency, are essential in energy-conscious designs. Autotransformers offer a compact solution for certain applications.

Bridge Rectifier

The relationship between a step-down transformer and a bridge rectifier lies at the heart of power supply systems, playing a crucial role in converting alternating current (AC) to direct current (DC). To understand this relationship, it's essential to delve into the functions and characteristics of each component.

A step-down transformer is a device designed to reduce the voltage from its primary winding to its secondary winding. This reduction in voltage is achieved through electromagnetic induction, where the primary winding, connected to the AC source, induces a magnetic field in the transformer core. This magnetic field, in turn, induces a voltage in the secondary winding, which is typically at a lower voltage level compared to the primary winding. The ratio of the number of turns in the primary and secondary windings determines the voltage transformation.

On the other hand, a bridge rectifier is a circuit that converts AC to DC by rectifying the voltage. It uses diodes arranged in a bridge configuration to rectify the entire waveform, allowing only one direction of current flow. This rectification process eliminates the negative half-cycles of the AC waveform, resulting in a pulsating DC output. The bridge rectifier is a crucial component in the conversion of AC power to a form that can be utilized by various electronic devices. The bridge rectifier, connected to the secondary winding of the transformer, rectifies the AC voltage. During the positive half-cycle of the AC waveform, two diodes conduct, allowing current to flow through the load. In the negative half-cycle, the other two diodes conduct, maintaining the direction of the current flow. This rectification process is essential for converting AC to a unidirectional flow of current.

In our case, if the step-down transformer outputs 4 amps, it implies that at the lower voltage level, the power remains the same but the current has increased. This 4-amp output is a crucial parameter to consider when designing subsequent components in the system, such as the bridge rectifier. The bridge rectifier is responsible for converting alternating current (AC) into direct current (DC). It utilizes a set of diodes to rectify the alternating voltage by allowing the current to flow in one direction. When choosing or designing a bridge rectifier for a particular application, it is imperative to consider the current requirements.

The output current from the step-down transformer is a key determinant in sizing the bridge rectifier. The bridge rectifier should be designed to handle, at a minimum, the same current as the transformer output. However, to ensure a margin of safety and account for potential fluctuations or variations in the system, it's advisable to choose a bridge rectifier with a slightly higher current rating. In this case, if the step-down transformer outputs 4 amps, a bridge rectifier designed for, say, 5 or 6 amps would be a prudent choice. This additional capacity provides a safety margin and ensures that the bridge rectifier can effectively handle the current flowing through it without the risk of overheating or other adverse effects.

Additionally, it's crucial to consider the type of load connected to the bridge rectifier. Different loads may have varying current requirements, and the bridge rectifier should be selected or designed to accommodate the maximum expected load current. In our case, the current requirements of the load is at most 2.54 A. This includes the two LEDs and the Raspberry Pi 3 B.

Linear Voltage Regulator

The relationship between a step-down transformer and a linear voltage regulator is crucial in power supply systems, providing a systematic approach to control and stabilize voltage levels for various electronic devices. Understanding the nature of this relationship requires delving into the functions of each component and how they complement each other.

A step-down transformer serves as the initial stage in the power supply chain, tasked with reducing the input voltage to a level suitable for the subsequent electronic circuits. Transformers operate on the principle of electromagnetic induction, wherein a changing magnetic field induces a voltage in a nearby coil. In the case of a step-down transformer, the primary coil, connected to the input power source, has more turns than the secondary coil, which is linked to the output. This discrepancy in turns results in a voltage reduction across the secondary coil compared to the primary coil.

The primary function of the step-down transformer is to match the electrical requirements of the load by converting high-voltage, low-current AC power from the source into low-voltage, high-current AC power for the device. This transformation minimizes energy loss during transmission and ensures that the voltage supplied to the load falls within the desired range. However, transformers alone cannot guarantee a constant and regulated output voltage.

This is where the linear voltage regulator comes into play. Its primary purpose is to stabilize the voltage at the output of the transformer, compensating for fluctuations in the input voltage and variations in the load. Linear voltage regulators accomplish this by employing feedback mechanisms to compare the actual output voltage with a reference voltage and adjusting the output accordingly.

In the context of a step-down transformer, the linear voltage regulator plays a critical role in maintaining a steady output voltage. As the transformer can only provide a reduction in voltage but lacks the ability to ensure a precise and constant output, the linear voltage regulator steps in to refine the voltage levels. This is particularly crucial for sensitive electronic components that require a stable power supply to function optimally.

The relationship between the step-down transformer and the linear voltage regulator is symbiotic. The transformer sets the stage by reducing the voltage to a manageable level, while the regulator fine-tunes and stabilizes the output voltage. Together, they form a reliable system that addresses the inherent challenges in power distribution, ensuring that the voltage reaching the electronic device remains consistent. Moreover, the linear voltage regulator enhances the overall efficiency of the system by dissipating excess energy as heat. By doing so, it prevents voltage spikes and fluctuations that could potentially damage or disrupt the operation of connected devices. This collaborative effort between the transformer and the voltage regulator is particularly evident in scenarios where precision and stability are paramount, such as in electronic equipment used in medical devices, communication systems, and laboratory instruments.

However, it's crucial to acknowledge that the linear voltage regulator has its limitations. One significant drawback is its inefficiency in dissipating excess energy as heat, especially when dealing with high voltage differentials. This inefficiency can lead to thermal issues and energy wastage. As a result, in some applications where energy efficiency is a priority, alternative voltage regulation methods, such as switching regulators, might be preferred. In our case, we use a fixed output linear voltage regulator rated at 5 V, 3 A output.

The output current of the transformer is given as about 4 amps. However, it's essential to recognize that the transformer does not amplify current; instead, it redistributes power while maintaining the principle of conservation. Therefore, the output current of the transformer is the same as the input current, neglecting losses.

When integrating a linear voltage regulator into the circuit, its purpose is to stabilize the voltage supplied to downstream components. Linear voltage regulators maintain a constant output voltage regardless of changes in the input voltage or load conditions. In this context, the current rating of the linear voltage regulator should be chosen to handle the maximum expected load current. The load current is the current drawn by the connected devices or components downstream of the voltage regulator. To ensure stable operation, the linear voltage regulator should be designed to handle at least the maximum load current. In our case, the maximum load current is about 2.54 amps.

When selecting a linear voltage regulator, it's also essential to consider its dropout voltage. Dropout voltage is the minimum voltage difference between the input and output of the regulator for it to maintain regulation. In our case this is between 1.6 V and 1.8 V. Choosing a regulator with an appropriate dropout voltage ensures stable operation even when the input voltage is close to the desired output voltage. In practical applications, it's advisable to select a linear voltage regulator with a current rating slightly higher than the calculated total load current. This provides a margin of safety and ensures the regulator operates within its specified limits, preventing overheating and potential damage. The current rating selected for the linear voltage regulator in our case is 3A.

Capacitors

Capacitors play a pivotal role in direct current (DC) power supply circuits, serving a variety of functions that contribute to the stability, filtering, and efficiency of the system. In this discussion, we'll explore the significance of capacitors in DC power supplies, delving into their various roles and the impact they have on the performance of electronic devices.

At its core, a DC power supply circuit converts alternating current (AC) to direct current, ensuring a steady and consistent flow of electrical energy to power electronic devices. Capacitors in this context act as essential components, offering several key functions that enhance the overall functionality and reliability of the power supply. One primary role of capacitors in DC power supplies is smoothing or filtering. As the DC power supply rectifies AC voltage, the resulting signal may exhibit ripple—small fluctuations or variations in voltage. These ripples can introduce unwanted noise and interference in electronic circuits. Capacitors are employed to smooth out these variations by storing electrical energy during periods of higher voltage and releasing it when the voltage drops. This smoothing action results in a more stable DC output, reducing the impact of ripple and ensuring a constant and reliable power supply to connected devices.

Furthermore, capacitors contribute to voltage regulation within DC power supplies. Voltage regulation is crucial to maintaining a consistent output voltage irrespective of changes in the input voltage or load conditions. Capacitors assist in this process by storing excess charge when the output voltage is higher than the desired level and releasing charge when the voltage falls below the set threshold. This dynamic response helps stabilize the output voltage, preventing fluctuations and ensuring that the connected devices receive a steady and regulated power supply.

In addition to smoothing and voltage regulation, capacitors also play a vital role in energy storage. They act as reservoirs of electrical energy, providing additional power when there is a sudden demand or a transient load. This feature is particularly beneficial in electronic devices where quick bursts of energy may be required, such as in power amplifiers or devices with rapidly changing power requirements. The capacitor's ability to discharge rapidly makes it a valuable component for meeting sudden spikes in power demand, enhancing the overall efficiency and performance of the power supply system.

Capacitors also contribute to the reduction of electromagnetic interference (EMI) and radio frequency interference (RFI) in DC power supplies. As electrical currents flow through the circuit, they can generate electromagnetic fields that may interfere with nearby electronic components or external devices. Capacitors act as effective filters, attenuating high-frequency noise and minimizing the potential for interference. This not only ensures the proper functioning of the device powered by the DC supply but also prevents unwanted electromagnetic radiation that could disrupt other nearby electronic systems.

It's important to note that different types of capacitors may be used in DC power supply circuits, each with its own characteristics and suitability for specific applications. Electrolytic capacitors, for instance, are often employed for their high capacitance and ability to handle higher voltage levels, while ceramic capacitors are valued for their low equivalent series resistance (ESR) and suitability for high-frequency applications.

In many cases, a combination of electrolytic and ceramic capacitors is employed. Electrolytic capacitors, with higher capacitance values, are effective for filtering lower-frequency variations, while ceramic capacitors, with lower equivalent series resistance (ESR) and high-frequency filtering capabilities, address higher-frequency noise. In certain applications with stringent requirements for output voltage stability and transient response, additional capacitors might be employed. This can include supplementary electrolytic or tantalum capacitors strategically placed to address specific aspects of the circuit's performance.

It's essential to note that while capacitors are crucial for stabilizing a linear regulator's output, an excessive number of capacitors can lead to issues such as overshoot, ringing, or instability. Therefore, the capacitor selection and placement should align with the regulator's datasheet recommendations and the specific characteristics of the application. In our case, tantalum capacitors are recommended by the datasheet of the LM323K linear voltage regulator.
So far, I calculate that only one electrolytic capacitor and one ceramic capacitor was at the input of the linear voltage regulator.

Low Dropout Voltage Regulator
Low Dropout Voltage Regulators (LDOs) play a crucial role in DC power supply circuits by maintaining a stable output voltage even when the input voltage is close to the desired output voltage. To ensure optimal performance and reliability in such circuits, the choice of capacitors is essential. The capacitors used with LDOs serve various purposes, including filtering, stability enhancement, and transient response improvement. This article explores the types of capacitors necessary for use with LDOs in a DC power supply circuit.
One of the primary considerations when selecting capacitors for LDOs is the output capacitor, which is typically placed at the regulator's output terminal. The output capacitor is crucial for filtering and stabilizing the output voltage, especially in low-frequency applications. Electrolytic capacitors are commonly used for this purpose due to their high capacitance values and reasonable cost. However, tantalum capacitors are also suitable for applications with tighter space constraints.

The capacitance value of the output capacitor affects the LDO's transient response and overall performance. A higher capacitance value helps to reduce output voltage variations in response to load changes or transient events. However, it is essential to strike a balance, as excessive capacitance may lead to stability issues, especially in circuits with low ESR (Equivalent Series Resistance) LDOs. Therefore, it is crucial to refer to the LDO's datasheet for recommended output capacitance values and ESR limits.

In addition to the output capacitor, the input capacitor is another critical component in a DC power supply circuit with an LDO. Placed at the input terminal of the regulator, this capacitor helps filter high-frequency noise and provides transient response support during sudden changes in the input voltage. Ceramic capacitors, with their low ESR and ESL (Equivalent Series Inductance), are commonly used as input capacitors. They are effective in handling high-frequency noise and offering quick response times. The input capacitor's capacitance value is determined by factors such as the input voltage ripple, load transient response requirements, and the LDO's specifications. It is essential to consider the minimum and maximum recommended input capacitance values provided in the LDO datasheet. A well-chosen input capacitor ensures stability and prevents voltage drops during transient events, thereby enhancing the overall performance of the DC power supply circuit.

Beyond the input and output capacitors, another crucial capacitor in LDO applications is the bypass or "ceramic" capacitor. Placed close to the LDO's output pin, the bypass capacitor helps improve high-frequency noise filtering and transient response. Ceramic capacitors, particularly those with low ESR, are ideal for this role. The bypass capacitor provides a low-impedance path for high-frequency noise, preventing it from affecting the LDO's regulation performance. The ESR of the bypass capacitor is a crucial parameter, as a lower ESR value enhances the capacitor's effectiveness in filtering high-frequency noise. However, care must be taken not to use an excessively low ESR capacitor, as it may lead to stability issues in some LDO designs. Consulting the LDO datasheet is essential to ensure compatibility and optimal performance. In our case, 1µF or greater capacitance is required between the LDO and ground. At output current values < 10mA this can be reduced to 0.33µF, or 0.1µF for currents below 1.0mA.

USB 2.0 type A connector

In our project there is only one USB 2.0 type A receptacle being designed in the power supply. This connector will supply 5V to the Raspberry Pi 3 B device at a maximum of 2.5A.

The USB 2.0 Type A connector is a standardized interface designed for connecting various devices, such as computers, smartphones, and peripherals. Known for its widespread use, this connector has four pins: two for power supply (VCC and GND) and two for data transfer (D+ and D-). Voltage regulators are essential components in electronic circuits, ensuring that the voltage supplied to the system remains within specified limits. In the context of USB 2.0 Type A connectors, voltage regulators play a crucial role in stabilizing the power supply. These regulators maintain a consistent output voltage regardless of fluctuations in the input voltage, ensuring that the connected devices receive a reliable and regulated power supply.

USB 2.0 Type A connectors are designed to handle a standard voltage of 5 volts. However, the actual voltage supplied by different sources may vary. Voltage regulators act as guardians against overvoltage and undervoltage conditions. In a USB power supply scenario, unexpected spikes or drops in voltage could potentially damage connected devices. Voltage regulators ensure that the voltage remains within safe operating limits, protecting both the device and the USB port.

While the primary role of USB 2.0 Type A connectors is data transfer, the stability of the power supply also affects the signal integrity. Fluctuations in voltage can introduce noise and interference, impacting data transmission. Voltage regulators contribute to maintaining a clean power supply, thereby supporting reliable data communication. USB connectors are extensively used for charging various devices. Voltage regulators play a role in adhering to charging standards, such as USB Power Delivery (PD). They ensure that the voltage supplied through the USB connector aligns with the charging requirements of the connected device, facilitating safe and efficient charging.

When a USB 2.0 Type A connector is plugged into a port, it establishes a connection with the power supply of the host device. The +5V pin in the USB 2.0 Type A connector is responsible for delivering power to the connected device. Capacitors, strategically placed within the power supply circuitry, play a crucial role in maintaining the stability of this 5V power supply.

One primary function of capacitors is to filter out high-frequency noise and voltage ripples from the power supply. Electronic devices often generate noise during operation, and this noise can introduce instability in the power supply. Capacitors act as a buffer, absorbing these fluctuations and ensuring that the connected device receives a clean and stable 5V supply. This is particularly important for devices that require precise and stable power, such as microcontrollers, sensors, and other integrated circuits.

Furthermore, capacitors contribute to the overall efficiency of the power supply by mitigating voltage spikes and drops. When there is a sudden increase or decrease in power demand from the connected device, capacitors release or store energy to compensate for these fluctuations. This dynamic response helps in preventing voltage spikes that could potentially damage sensitive electronic components. In the context of data transfer, USB 2.0 Type A connectors not only deliver power but also facilitate communication between devices. Capacitors indirectly play a role in ensuring the reliability of data transfer by stabilizing the power supply. A fluctuating power supply can lead to data corruption and communication errors. By maintaining a steady voltage level, capacitors contribute to the integrity of the data transmission process. In our case, there is no capacitor designed to be across the USB connector. However, at the prototyping stage this option was thoroughly tested.

Resistors and Light Emitting Diodes

In our power supply system there are 2 LEDs. These LEDs perform the functions mentioned in previous chapters of this document. One white LED requires about 3.3 V at 20mA and one green LED requires about 3.3 V at 20 mA. There is also another green LED on order that requires about 2.2 V at 20 mA. At the prototyping stage, we have inspected whether or not it would be more efficient to put resistors in parallel or series with each LED. This will depend on whether or not we want to reduce voltage or current on that particular branch. This in turn depends on the overall system response.

Arduino Mega 2560 Microcontroller Rotation Sub-System

As mentioned previously in this document the ruby of interest is placed on a stage that will rotate at angles of interest. The stage is connected to a stepper motor and its rotation was managed by the Arduino Mega 2560.

The Arduino Mega 2560 is a versatile microcontroller board that serves as an integral part of the Arduino ecosystem. Developed by Arduino SRL, it represents an evolution from the earlier Arduino boards and is designed to cater to projects requiring a larger number of input and output pins, more memory, and increased computational power. The Mega 2560 is a popular choice among hobbyists, students, and professionals alike due to its extended capabilities and compatibility with a wide range of sensors, actuators, and other electronic components.

Key Specifications:

1. Microcontroller: The heart of the Arduino Mega 2560 is its microcontroller. It features an ATmega2560 chip, an 8-bit AVR microcontroller clocked at 16 MHz. This microcontroller is the brain behind the board, responsible for executing the instructions provided by the user's program.
2. Memory: One of the significant improvements over its predecessors is the increased memory. The Mega 2560 comes with 256 KB of flash memory for storing the user's program, 8 KB of SRAM for variables, and 4 KB of EEPROM for non-volatile data storage.
3. Digital I/O Pins: One of the standout features of the Mega 2560 is its extensive array of digital I/O pins. It boasts 54 digital input/output pins, of which 15 can be used as pulse-width modulation (PWM) outputs. This abundance of pins makes it suitable for complex projects that involve a multitude of sensors, actuators, and other peripherals.
4. Analog Input Pins: In addition to the digital pins, the Mega 2560 has 16 analog input pins. These pins are essential for interfacing with analog sensors, such as temperature sensors, light sensors, and potentiometers.
5. Communication Ports: The board supports various communication protocols, including UART, SPI, and I2C. This flexibility allows the Mega 2560 to communicate with a wide range of devices, from simple displays to advanced sensors and communication modules.
6. USB Interface: The Mega 2560 includes a USB interface for programming the board and serial communication with a computer. It uses the standard Type-B USB connector, and users can program the board using the Arduino Integrated Development Environment (IDE) via USB.
7. Voltage Regulator: The board is equipped with a voltage regulator that allows it to be powered with an external power supply ranging from 7 to 12 volts. This makes it compatible with a variety of power sources, including batteries and external adapters.
8. Clock Speed: Running at a clock speed of 16 MHz, the Mega 2560 provides sufficient processing power for a wide range of applications, from simple LED

Operating a stepper motor using an Arduino Mega 2560 involves understanding the basics of stepper motors, the specifications of the Arduino Mega 2560, and programming to control the stepper motor effectively. Stepper motors are widely used in various applications where precise control of rotation is required. Unlike regular DC motors, stepper motors move in discrete steps, making them suitable for tasks like positioning, robotics, and 3D printing. They consist of multiple coils and a rotor, and by energizing these coils in a specific sequence, the motor moves in precise steps.

To operate a stepper motor with the Arduino Mega 2560, you need to establish the appropriate connections. Typically, a stepper motor has four or more wires, and you need an H-bridge driver or a stepper motor driver module to control it. First, Stepper motors require an external power supply. Connect the positive and negative terminals of the power supply to the respective terminals on the stepper motor driver. Second, Connect the wires of the stepper motor to the appropriate terminals on the stepper motor driver. The order of the wires may vary, but it's commonly labeled as A, A', B, B', or similar. Third, Connect the control pins of the stepper motor driver to the Arduino Mega 2560. Fourth, Connect the ground (GND) of the Arduino Mega 2560 to the ground of the stepper motor driver. Fifth, Ensure that the Arduino Mega 2560 is powered. In our case, this is done via an external power supply connected to the power jack.

After the wiring is set up, we will program the Arduino Mega 2560 to control the stepper motor. We will want to set the stepper motors maximum speed and acceleration. We will want it to move the stepper motor about 500 steps in one direction, wait for a second, then move it back to the starting position, and wait again. The values and sequence was adjusted according to our specific requirements.

The use of a stepper motor has several advantages.

1. Precise Positioning and Control: Stepper motors move in discrete steps, allowing for precise control over their position. Each step corresponds to a specific angle of rotation, making them ideal for applications where accurate positioning is essential. This characteristic is particularly advantageous in tasks such as CNC machines, 3D printers, and robotic systems, where precise control over movement is critical.
2. Open-Loop Operation: Stepper motors operate in an open-loop system, meaning they don't require feedback devices like encoders for position sensing. The controller sends a sequence of pulses to the motor, and the motor moves accordingly. This simplifies the control system, reduces costs, and makes stepper motors easier to implement in various applications.
3. No Servo Tuning Required: Unlike servo motors, stepper motors don't require tuning of feedback loops and PID (Proportional, Integral, Derivative) parameters. This simplifies the setup process and eliminates the need for complex calibration procedures. This plug-and-play characteristic makes stepper motors more accessible for users without advanced control system knowledge.
4. Cost-Effective: Stepper motors are generally more cost-effective than servo motors. Since they operate in an open-loop system and do not require additional feedback devices, the overall system cost is reduced. This affordability is a significant factor, especially in applications where cost considerations play a crucial role, such as in consumer electronics and hobbyist projects.

5. High Torque at Low Speeds: Stepper motors provide high torque even at low speeds, making them suitable for applications that require precise control and substantial holding torque. This characteristic is valuable in scenarios where the motor needs to hold a position without external force acting against it, as is often the case in robotics and manufacturing.
6. Simple Control Interface: Controlling a stepper motor is relatively straightforward. By sending a sequence of pulses to the motor driver, the motor moves in discrete steps. This simplicity in control interfaces simplifies the integration of stepper motors into various projects and systems. It also makes them a suitable choice for educational purposes, allowing beginners to learn about motor control without dealing with the complexities of closed-loop systems.
7. Reliability and Durability: Stepper motors are known for their reliability and durability. The absence of brushes, as seen in brushed DC motors, contributes to a longer lifespan with minimal wear and tear. This makes stepper motors a robust choice in applications that demand continuous and reliable operation, such as in industrial automation and machinery.
8. High Resolution and Accuracy: Stepper motors offer high resolution due to their ability to move in precise steps. This high resolution translates to accurate positioning and control, making stepper motors suitable for applications where fine movements are essential. In applications like 3D printing and CNC machining, the high resolution of stepper motors contributes to the quality and precision of the final output.
9. Low Power Consumption at Standstill: Stepper motors consume relatively low power when at a standstill. This is because the motor only draws current when a step is taken, reducing power consumption during periods of inactivity. In applications where energy efficiency is a concern, stepper motors provide an advantage by minimizing power consumption during idle times.
10. Operational Simplicity: Stepper motors offer operational simplicity in terms of control and maintenance. Their open-loop nature simplifies the control algorithm, and their robust construction minimizes the need for frequent maintenance. This operational simplicity makes stepper motors a preferred choice in applications where ease of use and minimal upkeep are crucial.

3.2.13 Sensor System

The sensor is arguably the most important part of a spectrometer, without it all the rest of the set up would be useless. When researching what type of detector to use we were trying to utilize the detectors that are easily compatible with familiar software programs and its ability to obtain a good resolution for the incident beam of light ranging from 600 nanometers to 700 nanometers waveband[33][35].

Raspberry Pi Cameras

When looking through various sensor systems, the main two options for the RASS were a CCD sensor and Raspberry Pi Cameras. This is because of the knowledge base of our group members. Due to the working knowledge of our group we thought it would be best with what we have a stronger understanding of, that being the Raspberry Pi Cameras.

Camera Module v1

The Camera Module v1, for Raspberry Pi is one of the camera modules specifically designed for this board. It offers an affordable solution for photography and video capture needs. Equipped with a 5 megapixel resolution and the OmniVision OV5647 sensor it serves as a camera module for projects that don't require high image quality. However it's important to note that the lens on this module is fixed and cannot be changed which limits its versatility when compared to camera modules. Despite its limitations in low light conditions and lack of image quality and flexibility found in Raspberry Pi camera modules, its affordability makes it an ideal choice for beginners who want to explore photography and video projects using their Raspberry Pi.

Camera Module 3

The Camera Module 3 represents an upgrade over its predecessor, the v1 module offering a solution for Raspberry Pi enthusiasts. With its 5 megapixel resolution and Sony IMX219 sensor it delivers improved image quality along with performance, under lighting conditions. One of its standout features is the ability to use lenses giving users flexibility to pursue various photography and videography projects. It strikes a balance between affordability and image quality making it popular and versatile for applications. Whether you're into DIY photography, video streaming or surveillance this module can meet your needs effectively.

HQ Camera

The Raspberry Pi HQ Camera is an imaging tool that offers high quality photography and video capture capabilities for Raspberry Pi boards. With its Sony IMX477 sensor and the ability to use lenses it delivers outstanding image quality suitable for both hobbyists and professionals. Its strong performance in low light conditions and the availability of a range of lenses empower users to tackle projects with precision and creativity. From astrophotography to macro photography or high quality video recording the HQ Camera provides the flexibility and top notch imaging capabilities needed to elevate Raspberry Pi based projects.

GS Camera

The Raspberry Pi GS Camera is an imaging solution designed for industrial and professional applications. It offers versatility along with performance, in demanding environments. It offers support for a variety of high quality Sony sensors, such as the IMX477 IMX290 and IMX462. This makes it an excellent choice for projects that demand image quality and precision. With the option to use lenses this camera module provides flexibility allowing users to adapt it to different applications and needs. Its robust performance in challenging conditions and compliance with standards make it a top tier option for machine vision, sensing and high performance imaging tasks where image quality and customization are crucial.

Raspberry Pi 4 Emission Acquisition Sub-System

The reader will note that there are multiple ways to acquire the type of spectral emissions we are interested in for this project. Among these, microcontrollers and single-board computers (SBCs) are both essential components in the world of spectral analysis, embedded systems and the internet of things (IoT)[29]. They both play significant roles in various applications, but they differ in terms of their capabilities, use cases, and design. A microcontroller is a compact integrated circuit designed for specific tasks, typically within embedded systems. Key characteristics of microcontrollers include: Low power consumption; Specialized for dedicated tasks; Limited computational power and memory; Often used for real-time applications; Typically include input/output pins for interfacing with the external world; Minimal operating system or no operating system. Some popular microcontroller families include: Arduino (ATmega series); Raspberry Pi Pico (RP2040); STM32 (ARM Cortex-M series); PIC (PIC16, PIC18, PIC32)[31].

SBCs possess the following characteristics: More processing power and memory than microcontrollers; Typically run a full operating system (Linux, Windows); Suitable for general-purpose computing; Provide various connectivity options (USB, Ethernet, Wi-Fi); Used for both prototyping and production. Applications for SBCs range from Education and prototyping (learning to program, experimenting with hardware) to Media centers and entertainment (e.g., Raspberry Pi running Kodi) and IoT gateways (handling data aggregation and communication) all the way to Industrial applications (data acquisition, control systems). Some popular SBCs include: Raspberry Pi (various models); BeagleBone; Odroid (various models); Intel NUC (Next Unit of Computing); NVIDIA Jetson series[31].

While both types of platforms are quite similar in what they can accomplish, there are distinct differences. Microcontrollers are designed for low-power, specific tasks with limited computational power and memory. In contrast, SBCs offer significantly more processing power and memory, making them suitable for a wide range of applications. Microcontrollers often run minimal or no operating system, while SBCs run full-fledged operating systems like Linux. This difference allows SBCs to handle multitasking and diverse software. SBCs typically come with various connectivity options, including USB, Ethernet, and Wi-Fi, making them versatile for different applications. Microcontrollers often require additional components to achieve similar connectivity. Microcontrollers are generally more cost-effective and are preferred for low-budget projects, while SBCs tend to be more expensive due to their enhanced capabilities. Microcontrollers are best suited for dedicated, real-time, and power-efficient tasks, while SBCs excel in applications that require general-purpose computing, multitasking, and connectivity.

The reader may recall that Spectroscopy operates on the fundamental principle that different materials absorb, emit, or scatter light in distinct ways. By examining the resulting spectral patterns, scientists can deduce valuable information about the substances under investigation. Spectroscopy is also a non-destructive technique, making it suitable for a wide range of applications[34]. In our setup, our useful information is generated starting with emissions from the ruby. Ultimately, the emissions are read through the spectrometer which in turn starts the characterization process. In conjunction with the spectrometer we have devised a sub-system. This subsystem involves the use of the Raspberry Pi single-board computer (SBC). Our reasoning behind using this particular SBC is based on multiple factors including power consumption, useful utilities, cost, adaptability, among other things. Our sub-system components include the following:

Raspberry Pi 4, Pi camera, diffraction grating spectroscope, CCTV lens, green LED, and white LED. This sub-system can be seen as a system for "emission data acquisition."

The Raspberry Pi is a series of small, affordable, single-board computers designed for educational and hobbyist purposes[30]. Developed by the Raspberry Pi Foundation, these credit-card-sized computers offer significant computing power in a compact form factor. They are equipped with various hardware interfaces, including USB, HDMI, GPIO pins, and Wi-Fi, making them highly versatile.

Raspberry Pi computers run on the Raspbian operating system, a Linux-based distribution optimized for the Pi's hardware. These devices are known for their ease of use, low power consumption, and extensive community support. Raspberry Pi has gained popularity as a platform for numerous applications, including robotics, home automation, and, increasingly, scientific experimentation[30].

To be clear there are different models of Raspberry Pi available:

- Raspberry Pi 1 Model A and Model B:
  - These were the first Raspberry Pi models, with limited processing power and memory.
- Raspberry Pi 2 Model B:
  - An improvement over the first generation, offering better performance and more memory.
- Raspberry Pi 3 Model B:
  - Quad-core processor and integrated Wi-Fi and Bluetooth, the Raspberry Pi 3 was a significant upgrade.
- Raspberry Pi 4 Model B:
  - Quad-core ARM Cortex-A72 CPU and support for up to 8GB of RAM. It offers USB 3.0 ports and dual HDMI outputs.
- Raspberry Pi Zero and Zero W:
  - Compact and affordable models designed for embedded and IoT projects.

The model of interest in our case is the Raspberry Pi 4 Model B. With each model there is hardware that must be used. This of course may change according to the model. In our case for spectroscopy, these are the basic requirements:

- Raspberry Pi: (this is the actual SBC mentioned above)
- MicroSD Card: A microSD card (16GB or larger) is used to store the Raspberry Pi's operating system and your spectroscopy software.
- Power Supply:
- Display and Input: You can use a monitor with HDMI input for displaying the Raspberry Pi's desktop environment. Additionally, you'll need a USB keyboard and mouse for interaction.
- Internet Connection: For software installation and updates, it's advisable to connect your Raspberry Pi to the internet. You can use an Ethernet cable or Wi-Fi, depending on your model.

- Spectroscope Kit: The key components of a spectroscope include a diffraction grating, a slit, and a sensor (e.g., a camera).
- Additional Peripherals: You might require other peripherals such as breadboards, sensors, and LED lights, depending on your project's complexity.

It might not yet be apparent to the reader why our selection of this Raspberry Pi model is appropriate for this project. By way of comparison, we can make the following observation with various microcontroller type platforms. One of the key advantages of Raspberry Pi is its ability to run a full-fledged operating system (OS) like Raspberry Pi OS, based on Linux. This enables it to perform a wide range of tasks, from serving as a basic desktop computer to running web servers and media centers. Raspberry Pi also features built-in support for wireless connectivity via Wi-Fi and Bluetooth. Arduino, on the other hand, is a brand of microcontrollers rather than single-board computers. Arduino boards are equipped with microcontrollers from the Atmel/Microchip family, such as the ATmega series, which are known for their low power consumption and simplicity. These boards consist of digital and analog input/output pins that can be easily programmed to interact with various electronic components. Arduino boards are designed to be embedded into specific projects and are not intended to run full operating systems. They rely on a sketch-based programming environment that simplifies the process of writing code to control attached hardware. Arduino boards usually lack features like HDMI output, Ethernet, or native Wi-Fi/Bluetooth support, which are common in Raspberry Pi boards.

Raspberry Pi runs a full-fledged operating system, typically a variant of the Linux kernel. This allows it to support a wide range of programming languages and software development tools. Python, in particular, is the de facto programming language for Raspberry Pi, making it an excellent choice for both beginners and experienced developers. It can run web servers, databases, and other software applications. The ability to run a full operating system also enables multitasking and the use of graphical user interfaces, making Raspberry Pi suitable for projects that require user interaction. Additionally, you can install various Linux-based software packages, which opens up opportunities for diverse applications[27].

Arduino's software environment is more specialized. It uses a simplified version of C/C++ for programming, making it accessible to beginners. The Arduino Integrated Development Environment (IDE) is user-friendly, with a straightforward code editor and a library of pre-written code snippets. However, Arduino lacks the capability to run a full operating system, limiting it to a single, dedicated program[27]. This simplicity is advantageous in terms of low latency and real-time control, making Arduino suitable for projects that require precise timing and responsiveness, such as robotics, automation, and sensor data acquisition.

Both Raspberry Pi and Arduino serve as powerful tools in the world of electronics and DIY projects, but they cater to different needs and preferences. Raspberry Pi, with its full operating system and robust software support, is suitable for a broad range of projects, including those that require web connectivity and user interfaces. Arduino, with its real-time control capabilities and extensive hardware compatibility, is ideal for embedded systems and applications that require precise timing and interaction with sensors.

Another comparison can be made with NanoPi, which is another type of SBC. NanoPi is a series of SBCs developed by FriendlyELEC. These SBCs are designed to cater to the growing demand for small, cost-effective computing solutions for various applications. The NanoPi series has been competing with Raspberry Pi, offering alternative choices for SBC users. NanoPi SBCs typically offer 1GB to 4GB of RAM. The exact RAM size may differ between different NanoPi models. In addition, NanoPi boards usually use microSD cards for storage, similar to Raspberry Pi. Some NanoPi models include eMMC storage options for faster and more reliable storage. Similar to Raspberry Pi, NanoPi boards feature USB ports, Ethernet, and some models include Wi-Fi and Bluetooth capabilities[28][31].

In terms of graphics, NanoPi SBCs use Mali GPUs, typically Mali-450 or Mali-400. The GPU performance may differ depending on the specific NanoPi model. Also similar to Raspberry Pi, NanoPi supports popular Linux distributions such as Armbian, Ubuntu, and FriendlyCore. A distinction can be made between the two platforms in this regard. Whereas, Raspberry Pi benefits from its wide user base, making it compatible with a broad range of applications and software and many software packages are optimized for Raspberry Pi, NanoPi may require more effort to find compatible software for specific models due to its smaller user base.

In terms of performance, NanoPi models vary in CPU performance, but most quad-core options offer reasonable performance for a wide range of tasks. NanoPi models with Mali GPUs offer good graphics performance, making them suitable for multimedia applications. NanoPi models typically have 1GB to 4GB of RAM, making them suitable for lighter tasks and embedded systems. Some NanoPi models feature eMMC storage options, offering faster and more reliable storage performance.

Of particular interest in the emission acquisition is the use of a camera in the Raspberry Pi 4 sub-system. The Raspberry Pi Camera is a compact and lightweight camera accessory specifically designed for Raspberry Pi boards. It connects to the Raspberry Pi's dedicated CSI (Camera Serial Interface) connector, making it easy to integrate with the board. The camera module is typically a small, rectangular device that can be mounted on the Raspberry Pi.

3.3 Strategic Components and Part Selections

For the RASS we made choices for each component based on our research. We outline why we chose these components and compared them to similar products.

3.3.1 Optical Components

LEDs

The green and white LEDs for this project will need to be of a high intensity to ensure the ruby is properly illuminated in the system. The green LED will need to have an emission wavelength of 550 nm in order to properly fluoresce the ruby. The white LED can be incoherent as it is a simple illumination source.

Table 4: Green LED Part Selection

Specification			
Manufacturer	Lumileds	Wurth Elektronik	Lumex
Model	L128-PCG20L3500000	156125M173000	SML-LX1206UWW-TR
Power Rating	726 mW	78 mW	70 mW
Luminous Flux/Intensity	145 lm	28 mcd to 280 mcd	90 mcd
Forward Voltage	36.7 V	2 V, 3.3 V	3.5 V
Price (1)	$0.41	$1.25	$1.23

With the given specifications above, the Wurth Elektronik LED at 550 nm was decided to be the best option for RASS.

Table 5: White LED Part Selection

Specification			
Manufacturer	Cree LED	Lumileds	Cree LED
Model	XPGEWT-01-0000-000000RE2	L2C5-40901208H1500	XHP50D-H0-0000-0D0ZF440G
Forward Current	700 mA	900 mA	6 A
Luminous Flux/Intensity	382 lm	4894 lm	808 lm
Forward Voltage	2.8 V	34.2 V	11.2 V
Price (1)	$1.62	$11.80	$6.72

From the given specifications, it has been determined that the first Cree LED option was the best component for the project.

Beamsplitter

When considering what type of beam splitter to integrate into our system, various specifications need to be considered. The size of the component must not be too large as to add unnecessary expense to the project as well as not too small where not enough input light was transmitted or reflected. In addition, whether to use a plate or cube beamsplitter will also need to be considered. The wavelength range this project will operate in was entirely visible, so beamsplitters within 400-700 nm was the sole consideration. This component will need to have an equal reflection to transmission ratio to optimize the output of both optical systems and ensure no unnecessary losses occur.

Table 6: Beamsplitter Part Selection

Specification				
Manufacturer	Edmund Optics	Edmund Optics	Thorlabs	Thorlabs
Construction	Plate	Cube	Plate	Cube
Model	#45-313	#32-600	BSW04	BS007
Diameter (mm)	12.50	5.00±0.10	12.70	5.00
Thickness (mm)	1.00	5.00±0.10	3.00	5.00
Substrate	Float Glass	N-BK7	Fused Silica	N-BK7
Reflection/Transmission Ratio	50/50	50/50	50/50	50/50
Wavelength Range (nm)	400-700	400-700	400-700	400-700
Price	$46.00	$177.00	$104.81	$174.70

From this table, we can conclude that the Edmund Optics plate beamsplitter will achieve what this project needs for the cheapest price.

Prisms

The right angle glass prisms in this application will need to match the size of the calcite rhombus, have no coatings, and be of a price within a college student's budget. There will need to be two of them, but they was identical as they serve the same purpose of guiding the light in and out of the calcite block.

Table 7: Prism Part Selection

Specification			
Manufacturer	Labnique	StayMax	NYJLGD
Model	MT-RAP-25	SMax-00015	ZJGJ-30
Substrate	K9 Optical Glass	N-BK7	K9 Optical Glass
Dimensions	25 mm x 25 mm x 25 mm	30 mm x 30 mm x 30 mm	30 mm x 30 mm x 30 mm
Price (1)	$16.95	$18.99	$9.99

While the third option seems very cheap for a similar product to the first option, Labnique has a more reputable consumer base. While a cheaper price would be nice, the Labnique prism would be the best choice.

Mirrors

The mirrors to be considered would need to have a coating that reflects the wavelength range that RASS will operate in with high reflectivity. They will need to be cost-efficient and easily mounted within the system. There will need to be two of them for adjustment of the optical axis.

Table 8: Mirror Part Selection

Specifications			
Manufacturer	Edmund Optics	Thorlabs	Edmund Optics
Model	#32-940	PF05-03-G01	#43-866
Reflectivity	$R_{avg} \geq 95\%$	$R_{avg} > 90\%$	$R_{avg} \geq 95\%$
Wavelength	450 - 650 nm	450 nm - 2 µm	450 - 650 nm
Diameter	5.00 ± 0.25 mm	0.5 in	6 x 6 mm
Price (1)	$23.00	$39.03	$23.00

For RASS, a square mirror would be more easily mountable into a 3D printed system. Because the two mirrors are the same price, the optimal option would be the second Edmund Optics mirror.

Calcite

For the RASS the calcite will need to be as clear as possible while remaining within budget constraints. There are treated calcite specimens where they're made to be more clear, however this can drive up the price of them fairly quickly. In addition, many samples are charged per gram in addition to the clarity, so size was considered. Smaller samples may be better for maintaining the desired portability of the system but may not be optimal for maximum light collection.

Table 9: Calcite Part Selection

Specification			
Brand	3B Scientific	Earth Gems	jjlminerals
Size	22 mm x 16 mm x 12 mm	70 mm x 50 mm x 23 mm	3.5 cm x 3.5 cm x 2.5 cm
Clarity (by personal judgment)	Good	Good	Excellent
Weight	0.03 lb	226 g	77 g
Price	$38.00	$27.93	$60.00

From the above table, we can concur that the Earth Gems calcite was the most cost effective option. While splurging on the highest quality calcite would be nice, it would not be within our budget constraints.

Optical Fiber

Due to the conditions of our project the RASS was using a multimode fiber. A multimode fiber can be used in this setup due to the short distance it is traveling, and the ease of utilization of a multimode fiber. As stated it is easier to align a multimode fiber into an optical setup due to the increase in core diameter size compared to a single mode fiber.

Table 10: Fiber Parts Selection

	OM1 ST ST Duplex Fiber Patch Cable	OM2 ST-ST Duplex Fiber Patch Cable	ST/UPC to ST/UPC Fiber Optic Patch Cable
Wavelength Range	300 - 1800 nm	300 - 1800 nm	300 - 1800 nm
Attenuation	0.50 dB	0.50 dB	0.30 dB
Numerical Aperture	0.275	0.2	0.275
Core Diameter	62.5 µm	50 µm	62.6 µm

As seen above in Table 10 the ST/UPC to ST/UPC Fiber Optic Patch Cable, Simplex, with a 62.5/125µm core-cladding diameter and OM1 multimode fiber was selected. This is because of its low attenuation compared to the other fibers.

Diffraction Grating

For the RASS during our research process we found that a 300 grooves/mm reflective diffraction grating that works within the visible light range was needed. Below we compared three diffraction gratings from big well known companies.

Table 11: Diffraction Grating Selection

	MKS Newport	Thorlabs	Edmund Optics	Thorlabs
Type	Ruled	Ruled	Ruled	Transmission
Size (mm)	12.5 x 12.5	12.7 x12.7 x 6	12.7 x 12.7	12.7 x 12.7
Groove Density (grooves/mm)	300	300	300	600
Blaze Angle	4.3°	4.18°	4.3°	28.7

For the RASS we only compared 300 grooves/mm ruled reflective diffraction gratings. Out of the three you can see there is not a big difference. For the RASS the Thorlabs GR13-0305 - Ruled Reflective Diffraction Grating, 300/mm, 500 nm Blaze, 12.7 x 12.7 x 6 mm was chosen due to the lower price.

Sensor

Table 12: Sensor Selection

	Camera Module v1	**Camera Module 3**	**HQ Camera**	**GS Camera**
Image sensor	OmniVision OV5647	Sony IMX219	Sony IMX477	Sony IMX477
Resolution	5 Megapixels	8 Megapixels	12.3 Megapixels	12.3 Megapixels
Pixel Size	1.4 µm	1.12 µm	1.55 µm	1.55 µm
Aperture	f/2.9	f/2.0	Adjustable	Adjustable
Field of View	54° x 41°	62.2° x 48.8°	Depends on lens	Depends on lens
Focus Type	Fixed	Fixed or Manual	Manual	Fixed or Manual

For the RASS we decided to go with the Raspberry pi HQ Camera. As shown in Table 12 the HQ camera has an adjustable aperture and we can change the field of view by getting various lenses to attach to the camera. The resolution is also higher and does not have a fixed focus type.

Electrical Supply/Components

The electrical set up and power requirements of this project is as follows. For each component in our set up there does not appear to be many variations in terms of the type of power needed for the devices. The main components that was of interest are the spectrometer, photodetector, rotating stage, dichroscope, the display, and lamp source.

Note that the spectrometer is available as one unit in which case the power supply is the standard 120 VAC. If we decide on using each of these as a separate unit, their respective power sources may differ. For example, a handheld model for the spectrometer will come with a 120 VAC adapter. As a variation, the spectrometer can also be powered through USB by using either the Arduino or the Raspberry Pi architectures. In these cases, the power supply can be as low as 9 VDC.

Assuming that the photodetector (photodiode) was a separate unit, the photodiode uses the photovoltaic effect. This uses the creation of a voltage across a p-n junction of a semiconductor when the junction is exposed to light. The simplest form of the photodetectors is a p-n junction device operated under reverse bias condition. Thus, the requirement of a power supply source is essential for the operation of photodetectors. Typically, the photodetector would be used with a battery.

An alternative to the battery operated photodetector is the self-powered photodetectors. These are a class of devices which requires no external power supply for their operation. The working of self-powered photodetectors is closely related to that of the photovoltaic devices operated under short-circuited mode or open-circuited mode. The self-powered photodetectors can be classified into two types. The first type of self-powered photodetectors independently generates sufficient power on their own and they do not require any external power supply or a separate energy harvesting unit for their operation. The second type of self-powered photodetectors is the integration of the conventional photodetectors with a separate energy harvesting unit which supplies energy required for the operation of the photodetectors connected to it.

The rotating stage is powered by standard 120 VAC. The dichroscope has no external power source. The display was on a computer screen or a monitor through USB or HDMI compatibility. The laptop will require a power supply of either 12 VDC battery or 120 VAC. The monitor will require 120 VAC.

3.3.2 Electrical Components

There are several types of versions of cameras. The original Raspberry Pi Camera Module features a 5-megapixel sensor and is capable of capturing 1080p video at 30 frames per second. It's a cost-effective option for basic photography and video projects. Next, an improved version, Raspberry Pi Camera Module (v2.1), comes with an 8-megapixel sensor and better image quality. It supports 1080p video at 30fps and 720p video at 60fps. The Raspberry Pi NoIR Camera Module (v2.1) (No Infrared) version is identical to the regular v2.1 camera but lacks the IR filter, making it suitable for low-light and night-vision applications when used with IR lighting[27]. Finally, Raspberry Pi High-Quality Camera features a 12.3-megapixel Sony IMX477 sensor and interchangeable lenses. This one offers exceptional image quality and is ideal for professional photography and video projects.

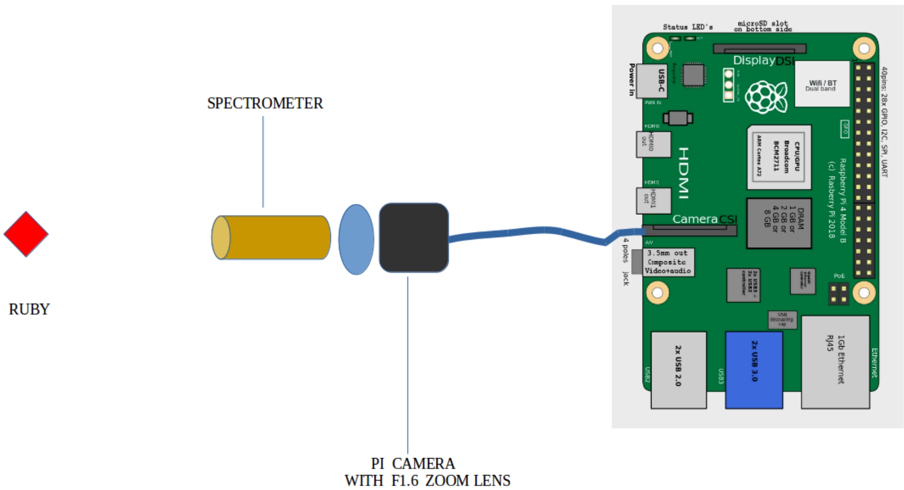


Figure 4: Emission Data Acquisition Subsystem Including Raspberry Pi 4B (cf. Appendix A)

3.3.2.1 Raspberry Pi 4 B, Basic Features / Accessories

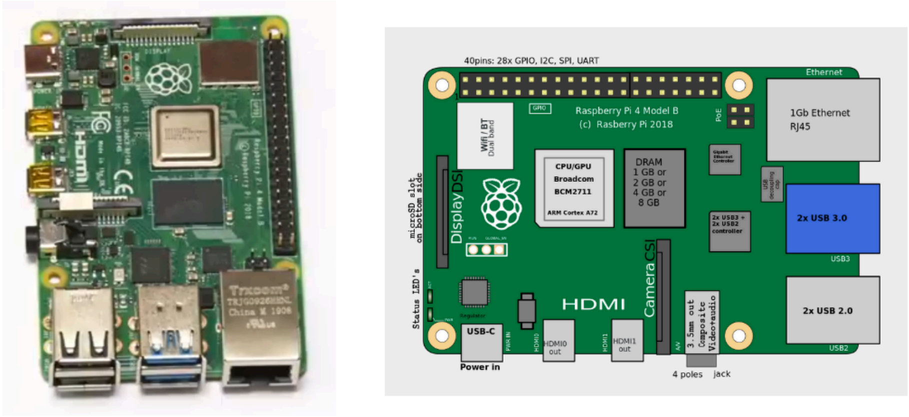


Figure 5: Raspberry Pi 4B (cf. Appendix A)

This version of the Raspberry Pi SBC follows the IEEE 802.11b/g/n/ac wireless protocol and Bluetooth 5.0. As the reader will note in the images above, there is a USB 2.0 connector (two ports), a USB 3.0 connector (two ports), and a gigabit ethernet connector. We may also note the USB-C port for the power supply (5 V, ~ 3 A), two 4K (resolution) micro HDMI ports, one 3.5mm stereo audio and composite video connector. There is also the 40-pin GPIO and below it is the 4-pin power-over-ethernet (PoE) connector. This version uses Broadcom BCM2711 system-on-chip (SoC) with 64-bit, quad core ARM Cortex-A72 CPU at 1.5GHz.

In the image below, we can see on the right side the slot where the micro-SD card may be inserted after the appropriate software has been imaged on it.

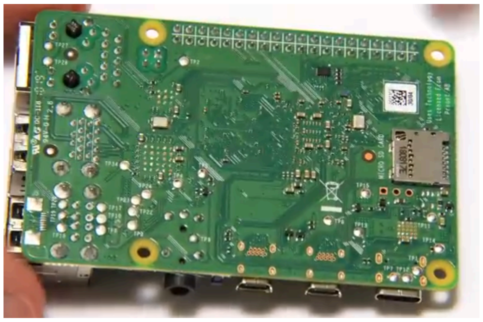


Figure 6: Raspberry Pi 4B (cf. Appendix A)

Typical accessories that come with this SBC include the following: USB-C power supply (5V, 3A), 2 HDMI to micro-HDMI cables, case, mouse, keyboard (with 3 internal USB ports). Not included are the following: micro-SD card, SD card reader, USB-C to micro-SD card adapter, camera.These last three are critical in order to set up the software appropriately.

3.4 Parts Selection Summary

Table 13: Overall Part Selection

System	**Part**	**Acquisition**	**Cost Per Unit**	**Purchase/Fabrication Status**
Housing	Rotating Stage	Purchase	$17.99	No
Housing	Shield	3D Printing	$0.00	No
Testing	Synthetic Ruby	Purchase	$20.00	Yes
Spectrometer	Mirrors	Purchase	$64.94	No
Spectrometer	Fiber	Purchase	$9.49	No
Spectrometer	Diffraction Grating	Purchase	$76.58	No
Spectrometer	Pi Camera	Purchase	$50.00	Yes
Spectrometer	Pi Module	Purchase	$19.99	Yes
Spectrometer	550 nm LED	Purchase	$2.04	Yes
Dichroscope	Mirrors	Purchase	$23.00	No

Table 13: Overall Part Selection

System	Part	Acquisition	Cost Per Unit	Purchase/Fabrication Status
Dichroscope	Beamsplitter	Purchase	$46.00	Yes
Dichroscope	Calcite	Purchase	$38.00	Yes
Dichroscope	Apertures	3D Printing	$0.00	No
Dichroscope	Prisms	Purchase	$57.00	No
Dichroscope	Lenses	Purchase	–	No
Dichroscope	White LED	Purchase	$1.56	Yes

4 Related Standards & Real World Design Constraints

The standards that will pertain to RASS were analyzed in depth and taken into consideration when designing the device. If this product ever reaches the market, a more in-depth guidebook that details the specific standards of the device was made.

4.1 Related Standards

ANSI Z535: This is a series of standards that is primarily focused on safety signs, labels, and symbols. It defines the specific colors and designs used for signs and labels and provides guidelines for choosing them in order to convey the desired safety message. As the RASS has electrical components that when mistreated could result in an accident, these standards will need to be considered and the appropriate signs made[69].·

ANSI Z10: This set of standards outlines manufacturing workplace guidelines, including safety objectives and targets, leadership and employee commitment, audits, documentation and record keeping, and legal workplace safety requirements that ensure the continuous improvement of safety performance is achieved and implemented within a potentially dangerous workplace. It’s applicable to a great range of industries and organizations, and can improve reputation among the workforce for its demonstration of a company’s commitment to safety[69].

ASME Y14: Schematics are a necessary tool for any product design, and this set of standards details exactly how those should be done. There is a wide range of what is defined in this set, which includes but is not limited to: decimal inch drawing sheet size, format, line conventions and lettering, multi and sectional view drawings, dimensioning and tolerancing, screw thread representation, types of engineering drawings and their applications, drawing practices, and digital product definition data (DPD) practices[69].

ANSI/ESD S20.20: With electronic components comes the need for proper precautions to prevent the discharge of static electricity causing damage to sensitive electronic components and assemblies. These standards detail things such as personnel grounding using wrist straps or other ESP protective equipment, regular compliance verification activities, protective packaging and labeling, protective requirements for workstations, audits and evaluations, and a formal written plan to assist designated ESD control coordinators[69].

ASTM D4169: As the RASS will have optical components with only a certain amount of tolerance, proper packaging was needed. This standard provides guidelines for the quality of shipping containers as well as procedures on how to test them. These can include shock, compression, drop, incline impact, and loose load tests and are typically done in a lab setting. There is a performance criteria that must be met for each specific packaged product and the environment in which it was distributed in[69].

ISO 9001: This is an internationally recognized standard for quality management. It's based on a set of principles that detail customer focus, leadership, engagement, process approach, improvement, decision making based on evidence, and customer satisfaction. These standards implement risk-based thinking, which is identifying risks and opportunities that can impact achievement and quality objectives. Every process must be monitored, measured, and analyzed to ensure products always meet customer requirements. In addition, these processes must always be analyzed for improvement to enhance their performance and effectiveness. To demonstrate compliance with these standards, audits must be conducted by accredited certification people and thus a certification was obtained[69].

IEC 60130-10: This standard details the multiple types of connectors that can be used in a very wide range of applications. It describes qualities such as dimensions, mechanical properties, electrical properties, and environmental considerations. Based on these specifications, it details the performance of each of these connectors to ensure compatibility, reliability, and their suitability for the intended applications. It is an older set of standards, and revolves around DC power connectors that operate below 3 MHz. This can be used to connect a power source to a PCB and thus to the rest of the device while ensuring all components receive the right electrical values and don't get burnt, which could pose a hazard to the user and ruin the device as a whole[69].

Universal Serial Bus (USB): The USB is an industry standard for digital data communications that operate within short distances. It allows data exchange as well as power delivery between numerous amounts of electronics. It's used all over the world and is the main choice when communicating between devices, as it is versatile and excellent at transmitting signals no matter the device type. Due to its wide use, it was a primary choice for the RASS to ensure compatibility across as many devices users may have as possible[69].

Ruby Standards: Before describing some of the different standards or techniques used in characterization, the reader should note that characterizing rubies is a multifaceted process that involves assessing their physical, chemical, and optical properties, as well as their geographic origin. These properties are crucial for both gemological and mineralogical purposes, including gem identification, valuation, and determining geographic origins. Physical characterization of a ruby can be done in five different ways: crystallography, density, hardness, cleavage and fracture, or refractive index. Each of the properties associated with this type of characterization has its own merit. To provide crystallography data, for example, X-ray diffraction (XRD) is a fundamental technique used to determine the crystallographic structure of rubies. By analyzing the diffraction pattern produced when X-rays interact with the crystal lattice, scientists can precisely determine the unit cell dimensions, symmetry, and orientation of the crystal. Measuring the density of a ruby can provide insights as well into its composition and potential treatments. Density determination involves comparing the gem's weight in air and in a liquid medium of known density, typically using a hydrostatic balance. The density of rubies typically falls within the range of 3.97 to 4.05 g/cm^3. Variations in density can indicate the presence of fillers or synthetic components.

In addition to the previous physical properties, the hardness of a ruby is a key characteristic that contributes to its durability and wear resistance. Rubies are one of the hardest natural gemstones, ranking 9 on the Mohs scale. To assess hardness, gemologists use the Mohs scale and perform scratch tests, comparing the ruby's resistance to scratching with various reference minerals. The extent to which hardness becomes a point of interest for a researcher has an impact in determining a ruby's cleavage and fracture characteristics is important in assessing its durability and value. Rubies often exhibit no cleavage, which means they lack natural planes of weakness where the gem could break. Instead, they typically display a conchoidal fracture, characterized by smoothly curved surfaces when fractured. By contrast, the refractive index (RI) of a ruby, a measure of how much light is bent as it passes through the gem, is essential for evaluating its brilliance and transparency. Gemologists employ refractometers to measure the RI of rubies accurately. The RI for ruby typically ranges from 1.762 to 1.770, with higher values indicating a greater dispersion of light and potential heat treatment.

The chemical properties and associated techniques also provide a unique set of data. The techniques associated with these properties typically include elemental composition, inclusions, spectroscopy, and trace elements. Understanding the elemental composition of a ruby is vital for identifying its authenticity and potential treatments. X-ray fluorescence (XRF) is a common technique used to determine the elemental composition of rubies. By irradiating the gem with X-rays, scientists can measure the characteristic X-ray emissions, which correspond to the elements present. Rubies are primarily composed of aluminum and oxygen, with the red color resulting from trace amounts of chromium. By contrast, inclusions, tiny mineral or fluid-filled cavities within a ruby, can reveal important information about its geological history. Microscopy, particularly high-resolution techniques like scanning electron microscopy (SEM) and transmission electron microscopy (TEM), allows for the examination of inclusions at a microscopic level. These inclusions can help identify the ruby's origin and any heat treatment or filling processes it may have undergone.

The use of the inclusions technique may also involve other techniques such as Spectroscopy. Spectroscopy techniques, including UV-Vis spectroscopy and Raman spectroscopy, play a crucial role in characterizing rubies. UV-Vis spectroscopy measures the absorption and transmission of light in the ultraviolet and visible spectrum, providing information about the ruby's color and potential treatments. Raman spectroscopy, on the other hand, is used to identify the mineral composition and any inclusions within the ruby by analyzing the scattering of light. This technique in turn is related to another called Spectrometry. This latter pertains to investigating the trace elements of a ruby. The presence of trace elements, such as iron and titanium, can influence the color and optical properties of rubies. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), for example, is a powerful technique for detecting and quantifying trace elements. By analyzing the concentrations of these elements, scientists can gain insights into the ruby's geological history and determine its origin.

GIA: The reader may at this point be assessing how exactly one goes about grading or reporting on the authentication of any of the above standards. Currently, there are a list of institutes, both national and international that manage this process. The Gemological Institute of America (GIA) is one of the most renowned gemological institutes globally and has set the benchmark for gemstone authentication. The GIA developed the "Four Cs" system, which assesses gemstones based on carat weight, cut, color, and clarity. This system is widely used for grading diamonds and colored gemstones, including rubies. The Cs are: carat weight, cut, color, clarity. Carat weight is a measure of a gemstone's size. One carat is equivalent to 0.2 grams. The carat weight of a gem is an essential factor in its valuation, but it should be considered in conjunction with other characteristics. The cut of a gemstone refers to its proportions, symmetry, and finish. The quality of the cut can significantly impact a gem's brilliance and overall appearance. For colored gemstones like rubies, color is one of the most critical factors. The GIA grades the color based on hue, tone, and saturation. In the case of rubies, the presence of red with a hint of blue is highly desirable. Clarity refers to the presence of internal and external imperfections or inclusions in the gemstone. The GIA provides clarity grades to assess the extent of these imperfections. The GIA issues gemological grading reports that detail the Four Cs and other relevant information for individual gemstones. These reports provide essential data for buyers and sellers and are trusted worldwide for gemstone authentication.

IGI: The International Gemological Institute (IGI) is another institute that offers grading and certification services for gemstones. IGI certificates are widely recognized and provide information about the quality and authenticity of gemstones. In addition, the American Gem Society (AGS) is an organization dedicated to consumer protection and ethical business practices in the jewelry industry. AGS has its own grading standards for diamonds and colored gemstones, emphasizing cut quality and providing detailed reports. There are various other international gemological organizations and laboratories who set standards for gemstone authentication. These include the European Gemological Laboratory (EGL), Asian Institute of Gemological Sciences (AIGS), and the Swiss Gemological Institute (SSEF). While standards may vary among these organizations, they all share a commitment to providing reliable gemstone authentication. Obtaining a certification from a reputable gemological laboratory, such as the Gemological Institute of America (GIA) or the International Gemological Institute (IGI), is often the most reliable way to confirm the authenticity of a ruby. These organizations employ advanced equipment and experts to perform comprehensive analyses. The identification of a real ruby involves a combination of visual inspection, laboratory testing, and the use of specialized instruments to assess various physical and optical properties. A trained gemologist or jeweler with access to the appropriate instruments is crucial for accurately determining the authenticity of a ruby.

4.2 Economic Constraints

When developing any product or device for commercial or personal use, the cost of each component and cost of development must be considered. In this portion, as the team members producing this are all unpaid, only the components was discussed as well as different contributing factors to the device's price point.

The development of the RASS was entirely self-funded by the members of the team. For this reason, each part was chosen based on getting the maximum quality for a cheaper price. The members of the team are all in college and thus are on a college budget, making it difficult to properly pick parts and ensure maximum quality of the project. Despite this, the RASS needs to be a reliable device with parts that will not break down as the device is used. With greater quality comes larger price tags, however this design ensures that each test is able to be fully and accurately accomplished while finding a medium between expensive parts and not jeopardizing quality.

The components of the RASS was purchased singly or in smaller quantities, as opposed to buying them in bulk. This contrasts with the manufacturing process. Components are cheaper per unit when they're bought in bulk rather than on an individual basis, which will add to our design process price tag but was beneficial for when this product is made on a larger scale. This quality of bulk part buying is also beneficial in the scaling up of this project, as the cost per device will go down and it was cheaper to produce if we produce more. The overall purchasing price of the RASS will need to be adjusted.

In addition to part quality, the size of the system was designed in accordance with parts rather than the other way around. This is because the system can be 3D-printed for a much cheaper price than purchasing a custom housing. This enables us to have a diverse array of options in terms of part sizes, which is important for any device as prices tend to increase with larger sizes. In addition, keeping things on a smaller scale will encourage less light loss throughout the system so we don't need to buy larger components to have more light throughput in the system.

Optical components can be a coin flip on price points in relation to their quality. Larger optics as well as certain components on a smaller scale can be incredibly expensive due to manufacturing complexities. Coatings on the optical apparatus are another factor to be considered, as they would be beneficial in reducing certain optical aberrations or effects that would impede the output quality of the project. To avoid the need for coatings, the RASS utilizes only visible wavelengths. This quality was chosen carefully so as to not make the project more expensive and out of scope for our budget.

Overall, the RASS is a system that is intended to be a proof-of-concept, thus is minimal in its budget while ensuring its intended goal is accomplished. Now that the world is thankfully out of the COVID-19 pandemic, ordering parts is much easier. Additionally, the widespread use of Amazon or larger shipping companies such as USPS or UPS has made it so shipping prices are not outrageous and are mostly trustworthy at protecting the integrity of parts.

4.3 Time Constraints

Considering that this product is being designed in a two-semester college course, the team is kept on a consistent schedule by personal, group, and academic deadlines. This means that we have our own personal goals of what to achieve in a given day or week, group-enforced objectives that are accomplished at a minimum of a biweekly basis, and the monthly course deadlines.

In the context of the RASS, the first four months was spent understanding the physics behind this project, picking our components based on this knowledge, and purchasing the major components and testing them in order to ensure we can compile the parts in time for next semester. These months was the timeframe in which our budget and planned amount to spend is finalized, in addition to maintaining a weekly plan to build the system up to our standards. Writing this paper was done as the group members learn more about the project and what other factors to consider in the making of the device. Schematics was loosely drawn, as final measurements and dimensions of the project was finalized upon building the system.

The next five months, including the winter break, will involve ordering all the parts of the system and implementing them into a unified product. This was where the optical alignment was done and distances altered in the paper, the electrical components was acquired, tested, and implemented into the system, and the software was developed and finalized. The paper was updated during this time to detail any unforeseen happenstances in the building of the device.

A large factor to be considered is lead times on acquiring parts for the system. Some components can have as large of lead times as six weeks, which is not beneficial for the short time frame of the design of this project. With such long lead times, if there is a delay in the shipping of any important components, such as the PCB or optical parts, then that presents a very large problem for this project. All parts need to be ordered well in advance for testing, setup, and final implementation into the system. Lead times for al components will need to be analyzed and planned for.

The team making this idea a reality is fortunate enough to have several committee members with extensive background and knowledge of the different fields included in the design of the RASS. The expertise of these generous experts will help pave the way for the success of this project and potentially save us more time in the development portion. In addition, the past professors who passed their knowledge down onto the team have enabled this project to be a reality. The education garnered from them will make the design of the RASS much easier.

The RASS will have a shorter time constraint than what's typically seen in industry, as the time frame is less than a year. It was a collaborative effort, and with enough hard work and knowledge the system was fully realized within the time constraints given.

4.4 Equipment Constraints

Rubies come in many shapes and forms that will have to be considered within this project. A minimum and maximum ruby size will need to be determined as well as whether the RASS was able to function properly with common jewelry constraints, such as reflection or absorption of different wavelengths within different materials typically used in gem decoration. The dimensional limits of the ruby will need to be calculated and will heavily depend on the dichroscope's capabilities within an optical system. The fluorescence spectra will not depend heavily on the size of the ruby.

Python was the primary language used in this project. Due to this, the RASS was limited to Python's packages and will have to determine how to integrate them into the different requirements of the system. The package needed for the spectrometer will need to be determined, as well as for the rotating stage. The list of commands each of these components supports will determine what packages was used in the RASS.

RASS will not be able to connect to the internet or upload information to a cloud storage. In addition, it will not have bluetooth capabilities. For these reasons, the software and hardware will have to work entirely offline and be stored within a hardware system. Hardware systems are limited by storage and the type of storage system used, this will include options such as a flash drive, hard drive, and solid state drive. Information from the system will have to be transferred to the selected drive via a USB cord due to the lack of wireless capabilities.

3D printers was used to create the housing for this system. After analyzing the sizes of the 3D printers available, it has been determined that the containment parts of this system will have to be small in scale yet hardy. This will require filament and thorough designing of the optical system as well as electrical component considerations. The housing will need to hold each optical component in place and be heat resistant enough to not melt or be damaged by the LEDs or electrical components. While this may seem like a limitation, the RASS is meant to be portable so this will work more to our favor than be a detriment.

Due to the system's requirement for optical alignment, proper equipment that is designed to handle optical components was necessary. They will need to have a high amount of precision and accuracy in order to ensure proper alignment of the system. While the housing of the system was custom printed, the tolerance of the slots should be sufficient to properly hold the part and not allow it to wiggle out of place.

The potential for automating the manufacturing of this device and implementing robotics should be reflected on. This would be beneficial to minimize labor costs and ensure more consistency in the output product. The equipment should be energy efficient and meet compliance and safety standards. It will need to be maintained on a regular basis to ensure the longevity of the equipment and lower costs in the long run. Using machines rather than manpower would also benefit the scalability of this product, as it would be less expensive to keep machines running for longer than to have more workers working longer hours.

4.5 Safety Constraints

There are many methods in crystallography that analyze gem qualities, the more precise ones require wavelengths within ranges that are unsafe the the human eye (IR) or have the potential for the user to develop cancer later in life (X-Rays). As this device is meant to be portable and widely available to layman use, it was determined that for the safety of all, visible wavelengths must be used. This enables a much safer user experience as well as more design safety. Safety glasses will not need to be used, much to the benefit of the RASS. In addition, high optical powers, such as those utilized by high power lasers, will not need to be used. Finally, no dangerous chemicals was used in this system so there is no need for containment.

The electrical power requirements of this system was kept at a minimum to ensure that no parts was affected by any heat. This has to be considered because the housing of the system was 3D printed and not made of metal. In addition, at high heats the optical components might be affected. The PCB and wiring within the system was fully enclosed to ensure that there is no risk of electrocution should someone not know to touch any wiring or sensitive parts within the system. All components was enclosed to ensure no layman persons will touch any delicate parts.

A concern with 3D printing are volatile emissions that originate from melting down filament. However, with proper planning and a good ethical conscience these emissions for the most part can be avoided. In addition, once recyclable and more advanced filament is developed then it can allow for more sustainable creation of parts as well as safer conditions for printing.

Emergency procedures for this product would most likely come into play should the internal electrical components be exposed or the product is destroyed in such a way that the glass of the optical components is shattered. A safety procedure should either of these events happen will need to be written. This would entail operations such as ensuring the device is unplugged and given time to discharge any remaining voltage, and wearing protective gloves should anything shatter for cleanup.

Due to the inclusion of a rotation stage, noise and vibration constraints will need to be considered. Because the stage is small, there are no major threats to getting something stuck in it other than a few stray hairs or string, and they should be able to be easily cleaned out given the proper tools and procedures. The rotation stage will need to have longevity without the motor getting too noisy, as noise pollution will need to be minimized. If any vibrations occur, it would not be in contact with any operator of the system and thus intense vibrations that could harm the user would not need to be considered.

4.6 Environmental Constraints

Upon first glance, a ruby characterization may not have direct environmental impact (other than manufacturing processes). However, after deep thought into the broader scopes of gemology and its importance, the impact of developing accurate systems to analyze gems becomes apparent.

Consumer awareness when purchasing precious gemstones can help to make more informed and responsible choices. When this long-term effect takes place, then it will force the gemstone industry to incorporate more environmentally friendly and ethical practices into their mining to meet consumer demands. This demand for environmental considerations will force the industry to have more sustainable mining, processing, and transportation methods. These changes will reduce the carbon footprint these practices have as well as diminish the large impacts on local ecosystems, such as deforestation, habitat destruction, and ecosystem disruption. Distinguishing rubies may even prevent unethical mining as a whole. Supporting synthetic rubies, which do not require mining or unethical sourcing practices, can help to prevent the unsustainable mining practices that harm local communities as well as the environment.

Developing this technology will also drive advancements in this type of system that even scientists can use. The need to accurately determine real from fake rubies can lead to even broader applications in scientific research, which can eventually lead to environmental conservation practices and the study of geology that will only benefit sustainability. Once more accurate and non-arguable identification can be achieved, it will reduce mining pressure and thus reduce environmental pressure that is associated with ruby acquisition.

Choosing to 3D print the system has its benefits and negative impacts. On the one hand, it allows for the reduction of waste due to it being an additive process and is energy efficient. In addition, localized production is an amazing benefit to 3D printing parts and parts can be optimized with minimal material usage. However, much of the material used in 3D printing is plastic and thus not sustainable. There is the option of using recycled materials but that comes with its own difficulties. Some 3D printers used in industrial applications have a high energy consumption rate, thus the desire for RASS to be as small as possible. Recycling 3D printer materials can be challenging due to the diverse compounds within filament, as well as some of these filaments having the potential for dangerous emissions. As more eco-friendly filaments are developed some of these issues can be mitigated greatly.

4.7 Manufacturability Constraints

The manufacturing of the RASS will mostly be inhibited by cost, assembly difficulties, and part availability. Because this product operates in the visible wavelength range, it will make the optical components much easier to acquire and more economically viable. The other components are not specialized or complex, so this enables even more manufacturing availability.

Sourcing the components has multiple factors to consider. Lead times on ordering parts will need to be considered as well as supply chain options and availability. The price of the product could go up or down depending on the current state of available parts, as well as what's available in the workforce.

The optical alignment of the system was simple once the 3D printed housing is developed and parts can be inserted into slots. The alignment will need to be verified due to anomalies in manufacturing processes, however this should be simple as long as output requirements are specified and able to be tested for. If machines assemble this optical system, then it will remove the potential of smudging the components or otherwise damaging them.

The housing was 3D printed, however if created on a larger scale a higher quality housing may be used for a more marketable, sleek design. Cushioned slots for the optical components to allow for vibrations or other mechanical stresses would be ideal. In addition, it could allow for more efficient implementation of the electrical components that fit into the housing better and could downsize the product. However, this would require more precise tooling and equipment on the part of the manufacturer. This might not be a problem for companies that specialize in optics, however for companies that specialize in gemology products this could raise an issue. Tolerances for each optical component would need to be considered, as changes in the optical alignment will have an impact on the output of the system.

The software for the RASS would have to be developed to be usable across multiple operating systems, such as Linux, Ubuntu, Mac, and Windows. As RASS was originally coded using Python, the operating system should be able to be checked and accounted for. This might put more strain on the hardware storage for the system, but installation directions for specific software, say that comes on a USB with the product or available from a commercial website with a verified purchase, would simplify this requirement tremendously.

Manpower in developing any product has to be considered. For the RASS, not much physical labor was required and the majority of testing the device was testing the optical alignment. However, this would require access to a somewhat skilled workforce. Guidelines on testing will have to be written that is layman friendly so that proper testing can be accomplished without necessitating a whole team of expensive engineers. This will add to the cost of development, but can be downsized should the proper guidelines be put in place.

Transporting this product will need to be considered, as if the product is too large or fragile it will drive up transportation costs. The RASS was done on as small of a scale as possible, with a modular design that can be locked in place. This will ensure stability of the product and lower these costs. Due to the lack of advanced coatings on the optics as well as other design decisions, storing RASS will not pose a large issue should the storage be handled properly.

This product, as it is for a specialized audience and not generally for everyone to own one in their home, will not need to have an incredibly large production volume. Should demand rise then the production of RASS should be able to be scaled to match what is required, as many of the components aren’t specialized.

4.8 Ethical Constraints

In large, the RASS is a safe system that should be made with ethical methods. This can include inclusion in the production of the system and ensuring everyone is welcome to use or purchase it. Environmental impact and sustainability has already been discussed, so other portions of ethical considerations was discussed.

During the manufacturing process of this product, should a company be started around it, fair labor practices as well as inclusivity and accessibility will need to be given priority to the work force operating in the process. Fair wages, safe working conditions, and rights for workers will all need to be considered to ensure a healthy workplace environment. The price of the RASS will need to be adjusted so that all workers are paid a living wage. Health and safety risks in all aspects of productions will need to be closely documented and accounted for to ensure worker knowledge and proper procedures in the event of an emergency. Rigorous testing and risk assessment of all machinery and development processes will need to take place.

RASS stores data after a run, and no personal information was required in the user interface portion of the software development. This will ensure privacy of all users. At most, the date and test number was recorded for record keeping purposes of the device to ensure quality across all tests and maintenance consistency. Anyone implementing this device into their company or storefront was discouraged from asking for personal data from users.

Being transparent in a device’s capabilities should be at the forefront of ethical considerations. Engineers should not lie about what their product does in order to get more consumer purchases. The features, limitations, and benefits of RASS was clearly labeled and openly discussed with purchasers in order to properly market the product and ensure what is being purchased is as expected. Deceptive marketing practices will never be encouraged.

In order to constantly improve the product and ensure long-term marketability, RASS should have a user forum for feedback, questions, and concerns pertaining to the product. This will ensure both customer loyalty and accountability on the part of the manufacturer. In addition, any product will always be able to be improved and user feedback will only help to realize those goals even faster.

4.9 Sustainability Constraints

When considering sustainability of any product, there are many factors to consider. A large part of this is material selection and the efficiency of what’s chosen in many aspects. Environmental impact has already been discussed, so other considerations was discussed.

Choosing materials that are recycled, biodegradable, or renewable should be prioritized when making a product. 3D printing materials that fit this requirement to the best of technology that exists now should be used. Thankfully 3D printing is known for minimizing the amount of resources used, however energy consumption of 3D printers needs to be improved. Gas emissions from this portion of the production will also need to be considered and minimized. In addition, ensuring that the utilization of resources such as water and energy outside of 3D printing will need to be accounted for and implemented.

When packaging RASS, environmentally friendly yet sturdy packaging will need to be used. As the environmentalist movement is making great strides in this regard, sourcing packaging that meets this requirement should not be an issue. It will need to be recyclable and biodegradable, as well as ensuring what is used is efficient enough that the amount used can be minimized to reduce packaging waste.

Sourcing from manufacturers that practice sustainability and good ethics was prioritized. These sources will need to have a good history of transparency with consumers and good record keeping for traceability of every product we procure from them.

Planning for the long-life of any product should be a designer's goal. Single-use products are incredibly wasteful and should be avoided if possible. Life cycle assessments should be conducted in order to properly assess the impact of a product throughout its entire lifecycle, which includes the raw material extraction to disposal of the product. Toxic substances should be avoided that can release harmful chemicals into the environment once the product is disposed of. The end-of-life of the product will need to be accounted for, as it should be recyclable or have a proper disposal process. If any of the parts can be reused, all the better.

Educating the user on the specifications of the device was needed. This includes its energy efficiency, recyclability, and proper usage to ensure as long as a life as possible for the product. In addition, providing the forum that was discussed earlier for constant improvement of the product can contribute to its longevity and sustainability.

If the product is advertised as sustainable, third-party certifications should be sought out and placed on marketing in order to validate any claims the company makes. This will ensure trust in the product and will provide the designers with better guidelines to making sustainable products.

5 Comparison of ChatGPT with other Similar Platforms

ChatGPT Analysis

When comparing something to its similar competitors, an analysis of the original must be done. ChatGPT is an amazing natural language processing tool that is driven by AI. It is better than most chatbots available and enables the user to have human-like interactions. It can answer questions and assist with basic language-based tasks, such as composing emails or resumes. It can answer questions related to code, science, and mathematics but has been unreliable in doing so. Its last information update was in January 2022, and thus does not have any updated information on world events past that point.

The technology behind ChatGPT is Large Language Model (LLM) technology. LLMs have proved that they play an important part in Artificial Intelligence-based technologies. Many LLM's are used for their capabilities in language processing and vast amounts of data that they can use to formulate a well written, human-like, response. The version of the model ChatGPT uses was developed by OpenAI, and is labeled as GPT-3.5. OpenAI has since stopped updating the model of its free version supposedly in order to turn profit, and an updated GPT-4 is used commonly in paid versions of alternative AI conversation bots. The GPT-3 model is seen rarely and is typically used in tandem with other AI tools or search engines.

At the base of an LLM is a neural network. A neural network is a machine learning model composed of many interconnected neurons, each of these being simple mathematical functions that process input data. The strength of connections between neurons is represented by numerical weights, determining how the output of one neuron can be determined as the input to another. Neural networks can vary in size, in the case of LLMs, the network would be very large containing millions of neurons and billions of connections, each with its own weight.

With the LLMs the program can perform calculations on the input to decide the output. Instead of having the instructions set in stone for the model to use, an algorithm is used to review the large volume of existing data to then actually define the model. As such, the human programmers are not the actual ones building the model, instead they build the algorithm that then builds the model.

When analyzing an LLM, programmers define the model's architecture and construction rules, but the model itself generates neurons, their connections, and the weight assigned to these connections during a process called "training".

During training the model follows the instructions to then define these itself. The training involves feeding the model large amounts of text data, and over time, through trial and error and constant comparison of the output to its input, the model is able to continually improve its text generation. With sufficient computing resources and data, the model can produce text that is near indistinguishable from human writing.

ChatGPT is a language learning model, and thus has features that reflect that. It can solve problems it's not explicitly trained on, hence the mathematical and coding capabilities. This ability is called zero-shot learning. In addition to this, if the AI doesn't know how to solve a problem, it can work out a solution to it based on a few examples. This mostly pertains to the language learning portion of the processing tool, as it bases the next words based on the previous examples it's given. This is a large part of the language learning model and has been essential in the success ChatGPT faces today.

The question answering feature of ChatGPT has been notably better than simply searching a question in a search engine. It produces well-tailored responses to questions and enables the user to not search the internet for the same question that has been reworded several times. Many people have turned to it for retrieving faster answers to more complex questions that would take longer to search themselves in the more common search engines.

The code generation of ChatGPT has surprised computer scientists and researchers alike. While it is very good and can provide working code for many languages for basic applications or problems, it is notoriously not to be relied on and meant to be an assistive tool.

As has been hinted at above, ChatGPT has its limitations. Even when asked questions it cannot possibly know the answer to, it gives its best attempt at providing a response, whether it be fake or simply wrong. For this reason, many people have gotten into scandals for relying on ChatGPT for answers that were supposedly true but upon simple search engine verification did not track.

The responses that are provided by ChatGPT are responses that sound right and are right a lot of the time, but there is no guarantee that the answer will actually be correct. No predetermined responses are used, instead the responses are created at the time of generation for each response. However, the information within LLMs is confined to their training data, which may be incomplete, incorrect, or outdated. For instance, ChatGPT's knowledge is limited to data available until January 2022, as it states itself, and it cannot access private or non-public documents, which can be crucial for many business applications. Many users may not know this and create a query requesting a response that would utilize information that is after the available data date. So the model can provide information that would have been the best response before or during the available data date but is outdated now.

Google Bard

Another LLM that has come out in recent times is Google Bard. Google Bard is an AI chatbot designed to mimic human conversations using natural language processing and machine learning. When the model originally came out it utilized Google LaMDA. LaMDA, which stands for Language Model for Dialogue Applications, is a family of conversational LLMs developed by Google AI. LaMDA is trained on a massive dataset of not only text but code as well. It can be used to complete many of the same tasks that ChatGPT is capable of accomplishing.

Unlike its initial use of Lambda, Bard has since upgraded to Google's advanced Palm 2 language model, which excels in common-sense reasoning, logic, and speed when compared to previous models.

PaLM 2

PaLM 2 is the next-generation LLM developed by Google AI. As a LLM successor it is significantly more powerful and capable. PaLM 2 was trained in similar manners to its predecessors including training with scientific and mathematical data, as well as text in over 100 languages. This gives PaLM 2 a wide range of knowledge and abilities. Google is currently working to make PaLM 2 more accessible to researchers and developers. The PaLM API is a cloud-based service that allows developers to access the power of PaLM 2 through a simple programming interface.

As we have discussed, it is known that ChatGPT's access to information is limited to the dataset it was trained on, which was last updated in 2021. This means that ChatGPT may not be able to provide accurate or up-to-date information on topics that have changed since then. Bard, on the other hand, has access to the real-time internet, which means that it can provide more up-to-date information on a wider range of topics. Bard can also access and process information from a variety of sources, including news articles, academic papers, and social media.

HuggingChat

Another AI chatbot is HuggingChat which utilizes the BLOOM LLM. BLOOM is an advanced language model with 176 billion parameters. It's trained on a vast dataset of text and code and is one of the world's largest and most powerful models. BLOOM can generate text, translate languages, create creative content, and provide informative answers like many other LLM based chatbots. It's multilingual, trained in 46 languages and 13 programming languages making it one of the most multilingual and versatile LLMs in the world. It continuously updates its knowledge, ensuring the latest information for up-to-date answers. Additionally, BLOOM is open source, offering its code freely for anyone to use and modify, promoting transparency and accessibility compared to proprietary models.

WriteSonic

WriteSonic is an AI tool that specializes in its marketing applications, a common use of ChatGPT. It produces optimized search engine content for blogs and webpages in addition to writing ads, emails, product descriptions, and posts for social media. It’s known for its long-form content creation that is high quality and akin to ChatGPT, as it uses models that were later developed by OpenAI. However, it is known to forget its tonal queues that users give it as well as not properly utilize previous instructions it’s been given when generating new content. In addition, it has an odd pricing plan that is required after a certain word count. While it is cheaper than other AI writing tools, it cannot compare to the free, unlimited writing feature that ChatGPT offers[52].

Bing AI

BingAI is an interesting platform because it incorporates images into its AI chat features. It utilizes OpenAI’s GPT-4 to power its AI search engine capabilities, which is considered a next generation LLM that is more powerful than ChatGPT’s GPT-3.5. In addition to this, it uses Dall-E 2, which gives it its text to image capabilities. This gives it the unique multimodality that isn’t involved in many AI search engines to date. On top of all of this it provides up to date results and includes cited sources to ensure credibility in its answers while remaining an entirely free platform. To its detriment, there is a limited number of prompts a user can make per session and the responses may be slow. Despite offering citations for its sources, it can still provide inaccurate information just like any other AI search engines[52].

Claude

Anthropic, a company supported by Google, has developed an AI called Claude that was designed using AI principles to ensure it provides honest and harmless answers while remaining helpful. It has two versions, called Claude Instant and Claude 2. Claude 2 is, obviously, more powerful and excels at a wide range of tasks. These can include dialogue as well as "creative" content generation and detailed instructions. Clause Instant, as named, is faster and cheaper. It excels in casual dialogue, text analysis, summaries, and document analysis and comprehension. If a user is skilled at prompting each model can still be used well to satisfy their individual needs. Additionally, it can be used to create downstream applications through its API. Claude is recommended over ChatGPT for specific applications, including deep understanding of technical content and generating optimized code. However, ChatGPT is still more reputable at most other tasks that the majority of the population requires with its language model[52].

Perplexity

Also utilizing OpenAI's already generated models, Perplexity AI is reputed as a ChatGPT alternative. Its free versions are powered by GPT-3, ChatGPT's older model. While ChatGPT's UI is very basic and somewhat clean, Perplexity boasts a minimalist, dark-themed interface that is desirable to most computer users today. Perplexity was created in order to solve the notorious problems of ChatGPT, namely its authenticity complications and copyright problems. It also cites its sources like Bing's AI chatbot and allows the user to fine-tune their searches by narrowing down these sources. The alternative to its free version is the Pro version that is powered by GPT-4. This version comes with a "copilot" that asks clarifying questions to guide the AI in its search for answers and find the best one for the user[52].

ChatSonic

Similar to most of the AI bots listed above, ChatSonic is branded as an alternative to ChatGpt and is geared towards content creation and creative tasks. The latest version is powered by GPT-4 as well as Google's search engine. Due to this, it can give you up-to-date information unlike ChatGPT's need to have knowledge updates. ChatSonic gives conversational, multi-moded replies and customized answers based on avatars. Some have reviewed the UI of this tool as complex and saturated, unlike ChatGPT's simple and straightforward approach. The conversations have been deemed to be quite slow and the AI can lose its focus on the topic after enough prompting. While it is branded to be a free alternative to ChatGPT, it has a limit of ten thousand words per month. To remove this limit, the price of a subscription must be paid[52].

Poe

Poe was created as an all-encompassing AI chatbot. It incorporates many large language models such as GPT-3.5-Turbo, GPT-4, Claude +, LlaMA 2, PaLM, and more. It was developed by Quora, and the goal for it was to have the benefits of most existing chatbots today in one system. It is notably fast with an easily understandable UI that can provide quick, accurate answers to questions. The idea behind this is that questions are passed through multiple LLMs and answers are given back from each one. A curious feature of Poe is that it allows the user to create personalized chatbots simply through initial prompts. Like many other AI software, there is a free version with notably less features than the premium version. The premium offers accessibility to all the available AI models without word or question limits[52].

Pi

Pi, which cleverly stands for "Personal Intelligence", is an AI assistant that was designed by Inflection AI. Its goal is to cater itself towards each user's unique interest and is branded as supportive, smart, and always available. It's oriented towards smartphone usage and is available on many of the most popular social media platforms, such as Instagram, Facebook, and WhatsApp. It even went the extra mile to develop its own iOS app while still being available on its website. Akin to virtual assistants such as Google or Siri, it features comforting voices to allow users to interact with it verbally. Despite all of these features, it is known to "hallucinate" and can have difficulty correctly answering complex questions. It has other languages available, but struggles with anything that isn't English. Like ChatGPT, it has knowledge updates and is even more up to date than its comparison counterpart, having knowledge from events before November 2022. Much to its detriment, Pi is only available to Apple users and the inferior phone users must wait until a new app is developed[52].

Amazon CodeWhisperer

Branded as a coding assistant, Amazon CodeWhisperer has extensive training in the art of open-source code as well as code hosted in Amazon servers. It helps with applications such as coding recommendations and security checks. Amazon CodeWhisperer is more geared towards users who work with Amazon services, but it can also be used in IDEs such as JupyterLab and VS Code. It is reputed to work exceedingly well with more popular codes such as Python, Java, and JavaScript. It is a free, internationally available platform. It also provides citations for its generated code suggestions in order to enhance security[52].

Jasper AI

Jasper AI is geared towards marketing, SEO applications, and related fields. It's designed by the company Jasper and is an AI platform for businesses that is conversational. It assists in content creation tasks, varying from writing blog articles to writing love letters to that special someone. It's powered by multiple LLM models, such as OpenAI's GPT-4, Claude, and Google's models. It claims to learn and adapt to the user's voice to maintain tone consistency across their brand. It operates using templates that are designed for 50 different use cases and can help quickly generate complete, presentable content for a diverse array of applications. It can understand more than 30 languages, to allow for marketing campaigns in multiple countries. As it is geared towards content creation and not technical questions, it struggles with higher order concepts. Its replies require fact-checking and have been reviewed to be generic and repetitive, which is a concern with a template-based platform. There is no free version of this AI, which lowers it on the scale of usable LLM-based search engine chatbots[52].

6 Hardware Design

This section will dive deeper into the setup of RASS. It talks about the layout of the overall system, spectrometer, dichroscope and how they will both connect. As well as the subsystem block diagram.

6.1 Overall System

The overall system was a top-down design. The top of the box will open to reveal an adjustable receptacle that will hold the ruby in place. This is to account for jewelry but it was up to the user to properly place the sample into the chamber. The receptacle is attached to the rotating stage so that the ruby can be properly rotated without impacting the optical components. The LEDs was placed at an off-angle with respect to the ruby to minimize surface reflections that will directly enter the lens. The lenses are simplifications of focusing/collimating systems that was designed to minimize the beam size for optimal fiber alignment. The dichroscope is also placed at an angle that will have minimal interference from the white LED light and will allow for adequate room for the rotation stage and ruby. A beam splitter was utilized to simplify the optical system and implement the dichroscope into the spectrometer without jeopardizing the focusing lens that will directly view the ruby. The spectrometer will have an input fiber that will take both the fluorescence and dichroscope light for measurement.

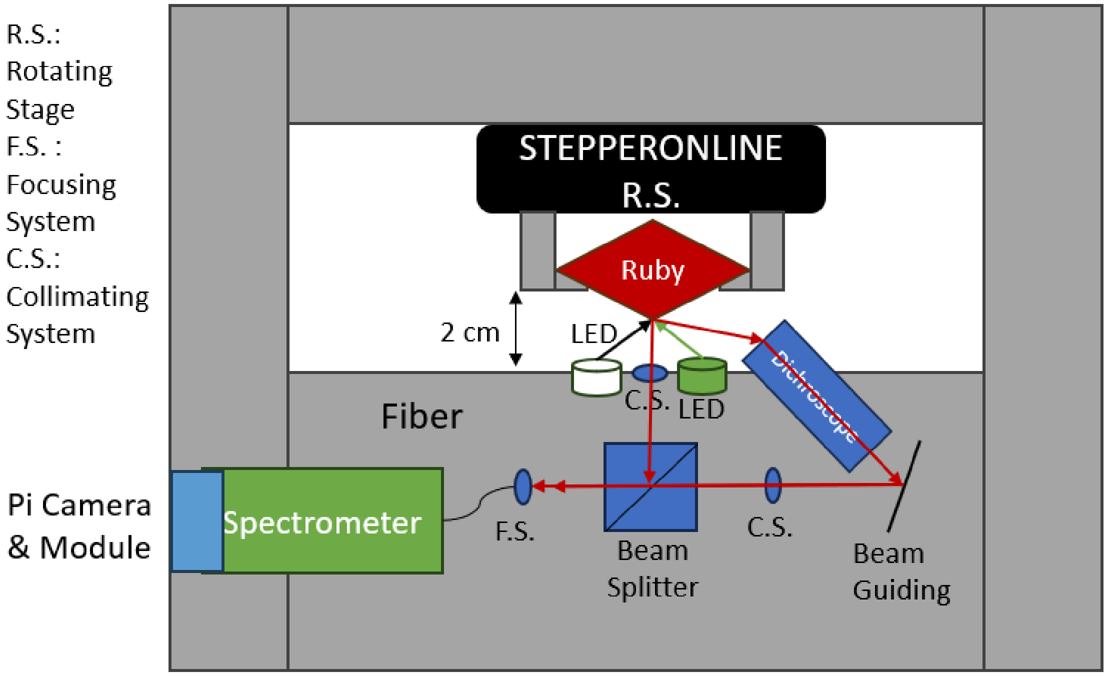


Figure 7: Overall system layout

It is worth noting that this housing was not achieved in the final design due to time, financial, and material constraints.

6.2 Lens System

The system was simplified from the previous dichroscope design, as there was too much light loss from each optical component. The system was reduced one component at a time, starting with the beamsplitter which was replaced with a mirror, then one of the 40 mm lenses were removed, then the entire lens system replaced with the mirror also removed. The system starts

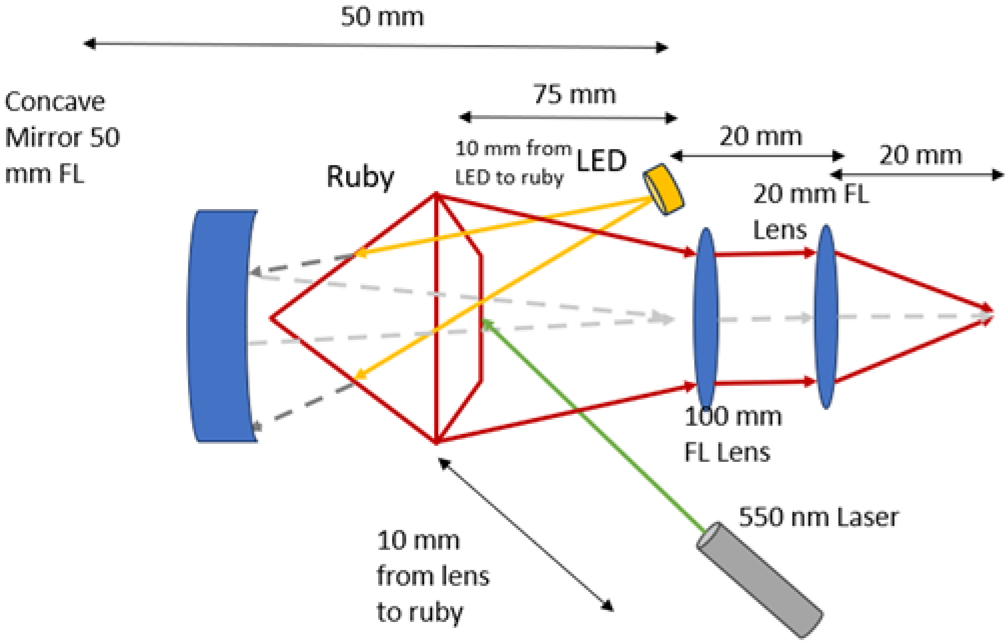


Figure 8: Lens optical setup

6.2.1 Addendum: Redesign Explanation

When executing the system, several problems were encountered. The first, and most notable, one was the severe losses from the calcite. As the sample did not have amazing clarity, it had to be removed from the system. However, during this paper the importance of calcite was emphasized due to its ability to separate out the separate wavelengths due to them being different polarizations. However, upon both further thought and testing there was a revelation that polarization was not needed in this setup and was redundant, as the light was refocused back into the system anyway unlike a true dichroscope.

After removing the calcite, the need for a beam splitter was also eliminated thus reducing the setup to one lens system rather than two. At this point 20 mm diameter lenses of varying focal lengths were being used. While results were able to be achieved after precise alignment, after each sample change it was required that the system be realigned.

A discovery was made that much of the light being shone onto the ruby was transmitting through and being lost. The back of the mount was hollow, so a concave mirror was purchased and used to have as much light as possible enter the system. At this point the system was composed of a concave mirror, four lenses, and a flat mirror.

The dichroism output from the white LED was difficult to align and the fluorescence output from the green LED was simply not bright enough to be read by the Pi camera in the spectrometer. Testing continued on for quite some time, with less than stellar results.

Acceptable alignment was achieved with the dichroism measurements after some time, but fluorescence output was still nonexistent with the green LED in use. At this point, deadlines were approaching quickly and a solution was needed. A laser whose bandwidth included 550 nm was implemented into the system instead of the green LED. The increase in intensity yielded much better results with the fluorescence output, however both the fluorescence output and dichroism outputs would not focus to the same point.This was due to the white LED output essentially consisting of reflections of light from the inner back facets of the ruby, and thus not an even distribution of colors, more so small images of the back facets that appeared at random depending on how the ruby was positioned. The fluorescence of the ruby caused the emission photons to travel in any direction, and thus could not focus the same way the already directed reflections from the ruby did.

The theory that may explain why there was so much difficulty in aligning the two outputs is that the white LED provides uncollimated light that is reflected back from the ruby, and wants to focus very quickly. When the ruby fluoresces the output light does not focus nearly as fast as the dichroic output, as fluorescence cannot have focused direction. It was recommended that a fast-focusing lens be put in front of the laser so that the spot size would match that of the size of the ruby and thus fluoresce more of it, however this yielded results similar to the LED and its issues.

Much time was spent testing and pondering why good results were hard to achieve during this design. After much consideration and gradually removing more and more optical components at a time, it was realized that the LED light was reflecting off the back facets of the ruby and diverging incredibly quickly from the optical path, so much so that the small 20 mm diameter lenses couldn’t possibly catch enough of the light for the spectrometer to read consistently. Ruby facets, while there are standards, are cut at imperfect angles and thus enter the optical system at different angles. Smaller lenses would restrict how large the ruby could be by a tremendous amount. In this case, the larger the initial lens the better.

Implementing the large first lens created a need for a second lens that could match the large image plane of the first lens. Thus, a second lens that was fairly large was also introduced. Having these large lenses, in tandem with the concave mirror, allowed both the dichroism and fluorescence outputs to focus to the same focal point, and enter the spectrometer adequately to achieve results. This resulted in the final optical design of the RASS, as seen above.

Another note to add would be that it was realized that rotating the ruby was not wholly needed. The nature of true dichroscopes is for them to be held as close to the ruby as possible to capture as much light from it as possible. They have an incredibly small field of view and thus rotation is needed. However, the RASS scenario was different. In using a lens system it is effectively equal to taking an image of the entire ruby, magnifying it, and taking its spectrum. The entire image of the ruby is taken into account in this design, not just small sample spot sizes.

6.3 Spectrometer

For the spectrometer two mirrors are utilized, along with a diffraction grating and a PI camera accompanied with a module. The first mirror was used to collimate the light from the slit, and it was separated into its constituent wavelengths via a reflective diffraction grating. The beam will then be focused onto a screen that will then be read by the detector.

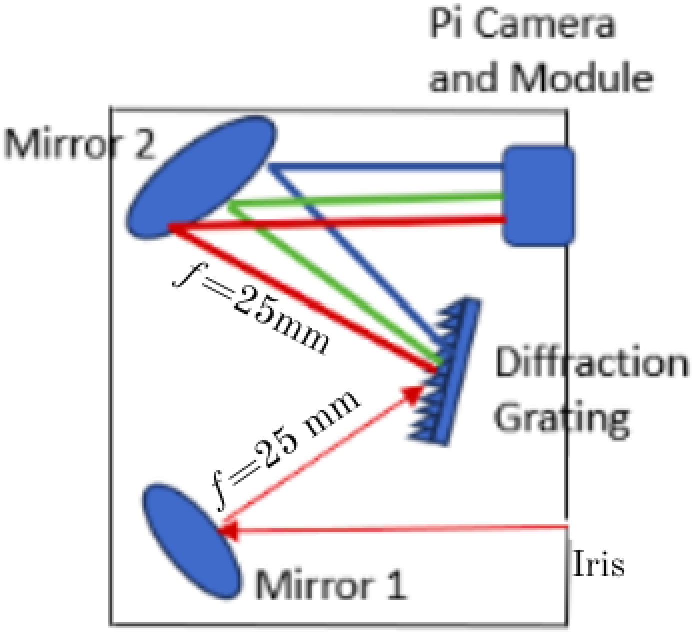


Figure 9: Czerny- Turner spectrometer optical setup.

6.4 Primary Optical System

This is a simplified diagram of the ray tracing of the optical setup. The green LED will fluoresce the ruby and the light will directly enter the beam splitter and get focused into the fiber. The dichroscope is pictured in the lower right. The emitted light from the ruby will enter the calcite and be split into its separately polarized rays. These beams was focused and redirected via mirrors onto the beam splitter and into the fiber. Any light entering the fiber will enter the spectrometer for analysis.

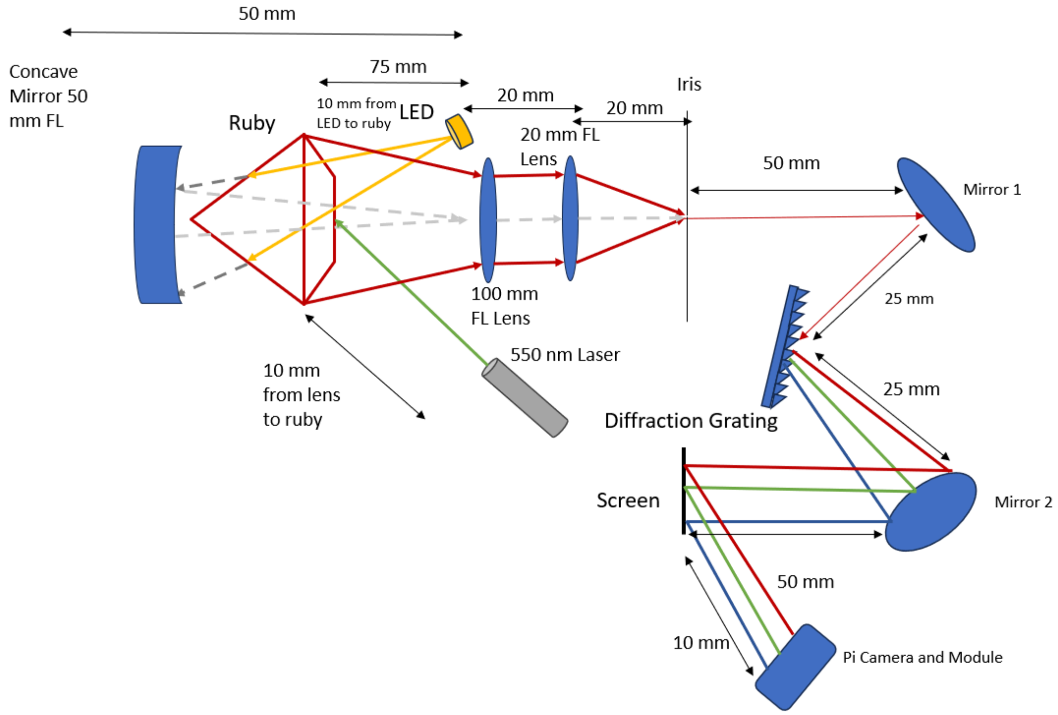


Figure 10: Combined optical setup

6.5 Electrical

Brief Description of Power Supply Configurations

As a preliminary step towards an efficient power supply an assessment must be made as to the appropriate combination of the components. The significance of its configuration lies in the precise arrangement and characteristics of its components, which collectively determine the performance, efficiency, and reliability of the power supply. The reader will note also that this arrangement comes with certain constraints on the power supply system simply because of what our intentions are for the components on the PCB. As explained in previous chapters LEDs was used to analyze the rubies of interest. Because of the different wavelengths of light emitted by the LEDs their proximity to one another must be taken into account so as to not create a situation in which their respective energies (wavelengths) will interfere with their functions. Other factors taken into account in the design configuration include power usage, thermal conditions, response to any anomalies, preventing potential damage, heat sink placement, component longevity, and consistent performance.

The circuit behavior and energy supply needs was provided in the following ways. First, there 120 VAC supplied to the transformer which is then stepped down to around 12 VDC. This 12 VDC is carried to a bridge rectifier which produces what is known as ripple voltage. Ripple voltage refers to the small, periodic variations in the direct current voltage within a circuit that is supposed to provide a constant voltage output. This phenomenon commonly occurs in electronic devices and power supply systems that use rectifiers to convert alternating current to direct current. The ripple voltage is a result of incomplete smoothing of the rectified waveform.

Because of this ripple phenomenon, a filter capacitor is used right after the bridge rectifier along with a bypass capacitor. As explained previously, the filter capacitor acts as storage and the bypass capacitor filters any oscillating signal. Now, once this rectified and filtered direct current arrives at the 5V linear regulator, it is then redistributed at the output of this regulator with a potential of 5V. And at this point, as seen in all three configurations, current continues to be distributed to the LDOs or the USB connector.

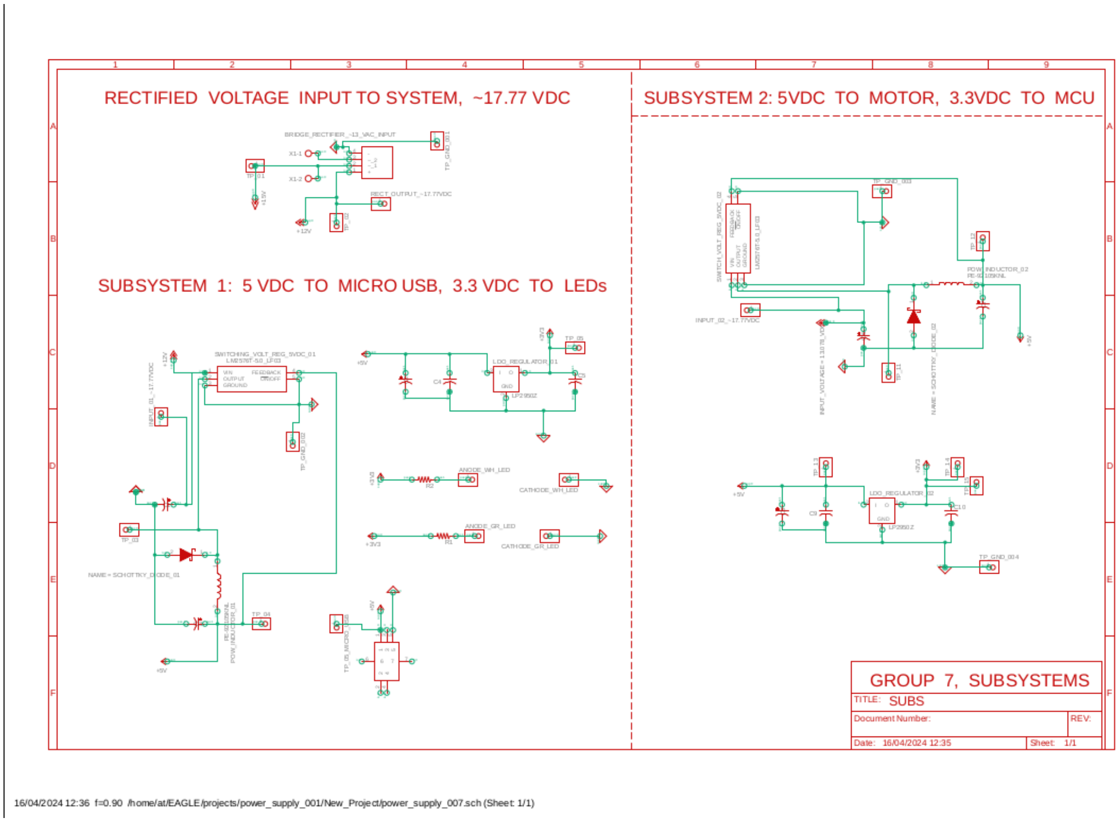


Figure 11: PSU Schematics (two subsystems)

PSU Subsystem 1

The reader may note that the power supply unit (PSU) is split into two subsystems.
Subsystem 1 is the PCB that receives alternating current from a wall outlet. It rectifies this AC voltage to approximately 17.77 VDC. Note that this 17.77 VDC is supplied to both subsystem 1 and subsystem 2 at the same time. With respect to subsystem 1, this rectified DC voltage is then regulated to 5 volts by the LM2576 switching voltage

(Buck) regulator. This 5V output is supplied at the same time to both the input of the low-dropout (LDO) voltage regulator and to the micro-USB type B receptacle. This receptacle is connected to the Raspberry Pi 3.

The reader will note that the two LED branches have their own voltage regulator that is in parallel with the USB type B connector. Here, after the 5 volts is regulated to 3.3 V, this 3.3 V is supplied to the LEDs. This was done to facilitate experimentation of LEDs requiring different current values. The reader may also note in this configuration that the transformer is not placed on the PCB. This is because we foresee that the PCB may be handled in a way that requires a less heavy object to move or maneuver. Also note that subsystem 1 is designed to facilitate maneuverability of the LEDs. As such, headers are placed on this board that will connect to jumper wires that was attached to the LEDs of interest. Something that should be mentioned is that this configuration may be the most difficult one design on the PCB. Note that the voltage regulator of the LED branches is a low-dropout (LDO) voltage regulator. Only one LDO is used to regulate both LEDs. This configuration facilitates more flexibility when maneuvering the PCB. It also makes manufacturing the PCB clearer. This configuration also excludes the transformer accounting for the increased maneuverability.

PSU Subsystem 2

Subsystem 2 is the PCB that supplies energy to the servo motor and the microcontroller unit (MCU). Similar to subsystem 1, it also has a Buck regulator and a LDO regulator. 5V is supplied to a servo motor (used as rotation stage) and 3.3V supplied to a potentiometer (used to actuate the motor). Note that the MCU and the potentiometer require the same amount of energy. Three headers are designed attached to the leads of the potentiometer. This is done to facilitate the use of a different potentiometer a distance from the board in case the PCBs need to be enclosed and the onboard potentiometer cannot be accessed. It should be mentioned that even though the rotation stage was designed and built, its use was not implemented. This is because its use would cause light to be redirected outside the system.

Brief Description of Microcontroller Unit (MCU) Configuration

Our MCU is designed for simplicity as our application does not require many features. The reader will note from Figure 12 that we designed this MCU without any emulation capabilities. Our reference MCU is the Texas Instruments MSP430G2 family of microcontroller. The typical configuration of this family allows users to efficiently program, deprogram, place, or relocate signal pins. In our case, with the aid of the corresponding CCStudio program, we use bits 3 and 6 to communicate with the MCU. Note that this board is the same board the potentiometer is placed on, therefore the potentiometer selected was also based on the similarity of its energy needs with that of the MCU. Both require approximately 3.3V to operate.

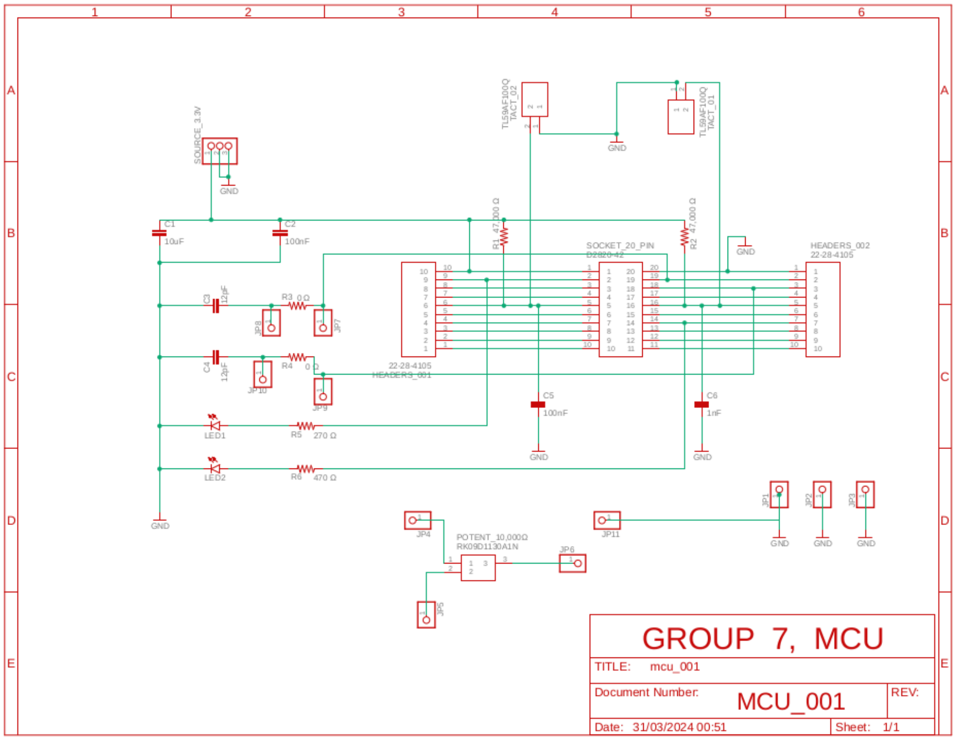


Figure 12: MCU Schematic

7 Software Design

Python libraries used and their effectiveness:

Numpy stands out for its ability in handling arrays and math tasks efficiently within Python. Its robust framework supports large, multi-dimensional arrays and matrices, along with a suite of advanced math tools for manipulating these arrays. At its core lies the nd-array, a high-performing multi-dimensional array that hosts a plethora of optimized operations and functions for numerical tasks. Its ability to execute vectorized operations significantly enhances speed compared to standard Python lists, making it a cornerstone in scientific computing, data analysis, machine learning, and other fields where swift and effective calculations matter. Moreover, Numpy smoothly integrates with various libraries and tools, serving as a fundamental building block for numerous Python packages focused on science and data tasks.

Matplotlib.pyplot is an essential tool in Python for creating high quality visualizations. Its adaptability and user-friendly approach make it the preferred choice for crafting an array of plots—from line plots, histograms, scatter plots, to bar charts, and beyond. With an interface similar to MATLAB, it allows for swift creation of plots, offering customization options for colors, labels, annotations, and titles. Whether it's data exploration, sharing insights, or presenting discoveries, Matplotlib.pyplot contains a vast array of features and configurations, allowing users to tailor their plot. Its seamless integration with other Python libraries like NumPy further shows off how it excels at handling numerical data with ease.

The cv2 library, or OpenCV, stands as a powerful tool for Python-based computer vision tasks. Its arsenal includes a vast array of functions and algorithms designed for in-depth analysis, processing, and manipulation of images and videos. With OpenCV, users can utilize an extensive toolkit capable of executing tasks such as image filtering, object detection, facial recognition, feature extraction, and geometric transformations. Its strength includes complex operations like image stitching, background subtraction, optical flow analysis, and machine learning-powered image recognition. OpenCV's adaptability and effectiveness make it a dominating resource in fields spanning robotics, augmented reality, healthcare imaging, security systems, and various industries related to image analysis. This framework allows developers to apply vision-centric applications and solutions.

Scipy is a great additional library for scientific and technical computing tasks, serving as a valuable extension to NumPy. It goes beyond by delivering a wide array of advanced functions and algorithms essential for numerical integration, optimization, signal processing, linear algebra, statistics, and more. Within its submodules there are tools for interpolation, solving differential equations, Fourier transforms, and specialized mathematical functions important in scientific research, engineering simulations, and data analysis. The ease of integration with other scientific libraries makes it a preferred choice for complex mathematical operations.

Main body code:
This code captures the image from the webcam and then displays it in a figure window. The numpy and matplotlib.pyplot libraries are used to display the image, and the cv2 library is used to capture the image from the webcam.

1. These first lines are importing the necessary libraries. numpy is used for numerical operations, matplotlib.pyplot is used for plotting, and cv2 is used for computer vision.
2. This line creates a VideoCapture object to capture video from the webcam. The 1 argument specifies that we want to capture video from the first webcam.
3. This line calls the read() method on the VideoCapture object to capture a frame from the webcam. The ret variable was True if the frame was captured successfully, and False if it was not. The frame variable will contain the captured frame.
4. This line prints the shape of the frame to the console. This is useful for debugging purposes.
5. This line creates a new figure window.
6. This line displays the captured frame in the figure window.
7. This line blocks the execution of the script until the figure window is closed.

Flowchart

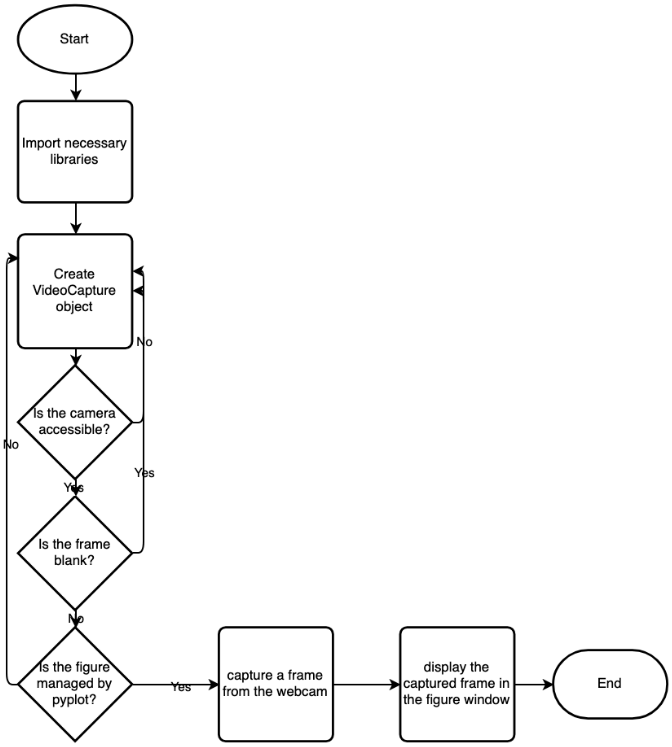


Figure 13: Software flowchart

Figure 14 contains the software flowchart for the portion of the product that is responsible for capturing and storing the diffraction grating.

This code captures a frame from the webcam and then plots the intensity of the pixels in row 255 of the image.

1. These first lines are importing the necessary libraries. numpy is used for numerical operations, matplotlib.pyplot is used for plotting, and cv2 is used for computer vision.
2. This line creates a VideoCapture object to capture video from the webcam. The 1 argument specifies that we want to capture video from the first webcam.
3. This line calls the read() method on the VideoCapture object to capture a frame from the webcam. The ret variable was True if the frame was captured successfully, and False if it was not. The frame variable will contain the captured frame.
4. This line creates an empty NumPy array to store the intensity of the pixels in row 255 of the image.
5. This loop will loop over the x range.
6. This will capture the red, green, and blue values of the pixel at position (x, 255). The 255 value may be adjusted depending on the positioning of the diffraction grating.
7. The intensity value is captured by adding the values of the red, green, and blue colors and dividing the value by 3

8. The intensity is then added to the NumPy array
9. The minimum value of the spectrum is subtracted from all of the values in the spectrum array in order to normalize the spectrum values
10. The Spectrum is plotted
11. This line blocks the execution of the script until the figure window is closed

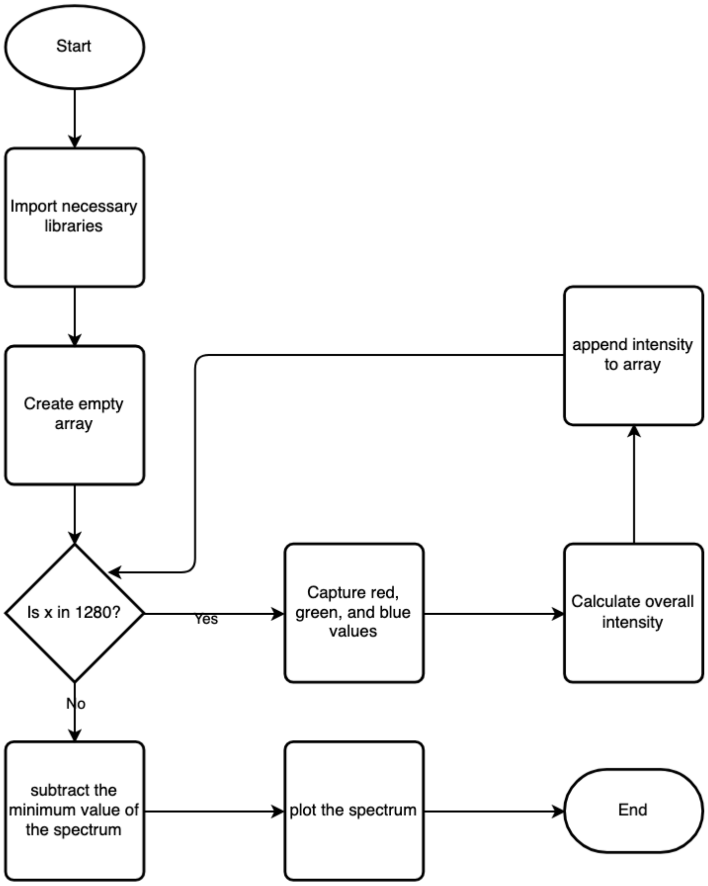


Figure 14: Software flowchart

Figure 15 contains the software flowchart for the portion of the product that is responsible for converting the captured diffraction grating into a plot of the spectrum.

The goal of this code is to identify peaks within specific ranges of data and make a determination based on the presence of these peaks as to whether or not the material is a Ruby.

1. These first lines are importing the necessary libraries. numpy is used for numerical operations and the scipy.signal library imports the find_peaks function for peak detection
2. A list of ranges is defined for use, however in this case, only a single range is used from 690 to 700

3. The next line will take three arguments: x_vals (x-axis data), y_vals (y-axis data), and ranges (ranges to search within) for the find_peaks_in_ranges function and it will iterate through each specified range.
4. The function finds indices of elements within each range in the x-axis data and selects corresponding y-axis values
5. In the function, find_peaks from SciPy is used to identify peaks within each range
6. Retrieves x and y values of the peaks using the peak indices
7. A list of indices of peaks found within the specified ranges is returned
8. The condition checks if there are any peaks found within the specified ranges for the given x and y data. If peaks are found, it returns True, indicating it is a "Ruby"; otherwise, it returns False, suggesting it's not a "Ruby."

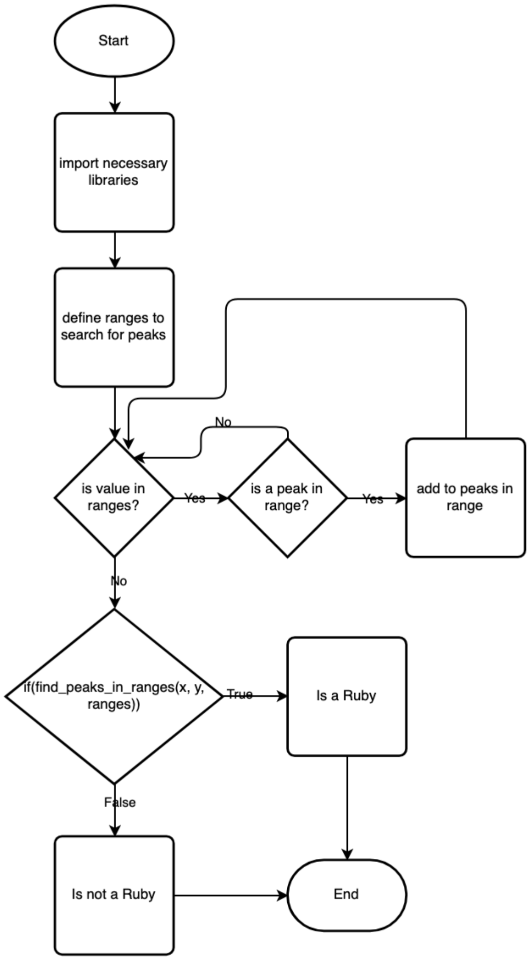


Figure 15: Software flowchart

Figure 16 contains the software flowchart for the portion of the product that is responsible for analyzing the information captured from the spectrum to identify characteristics of the material we are looking for.

Case Diagram

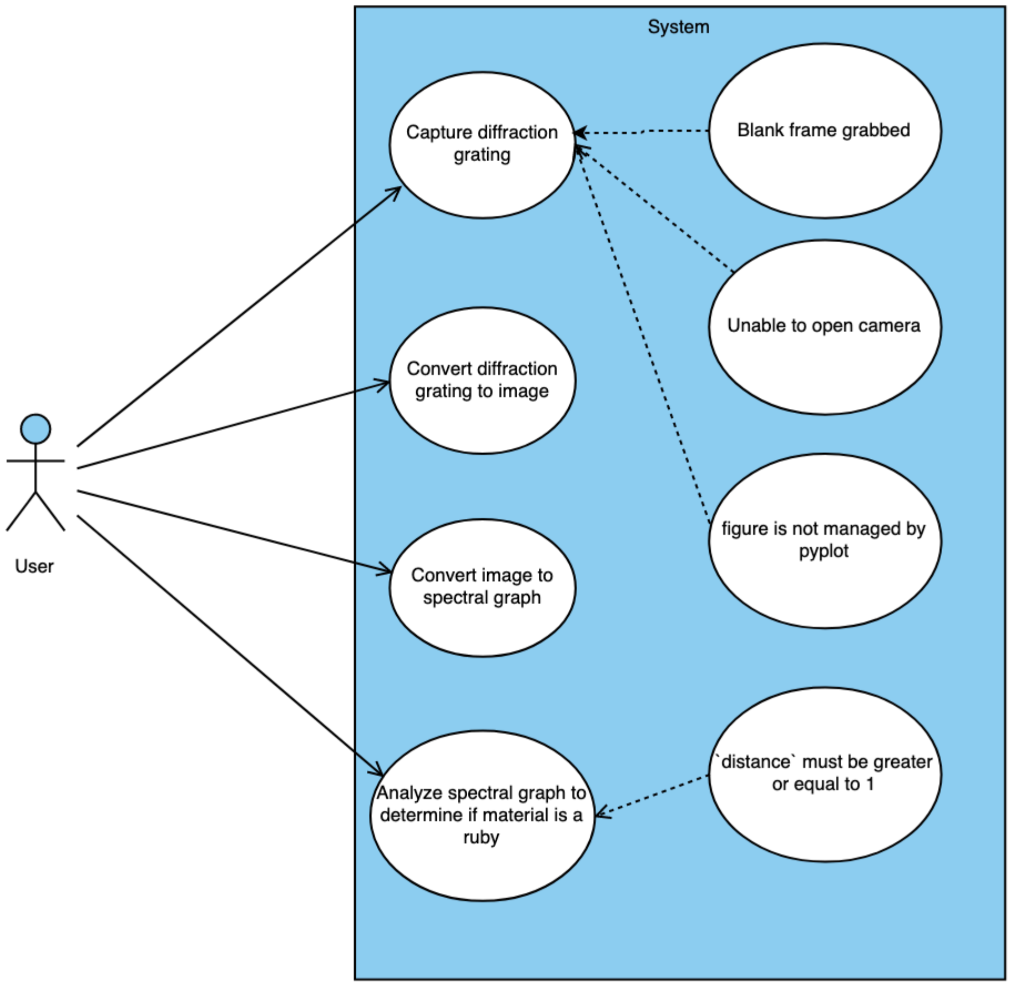


Figure 16: Case Diagram

Figure 17 contains the case diagram for all portions of the product.

Class Diagram

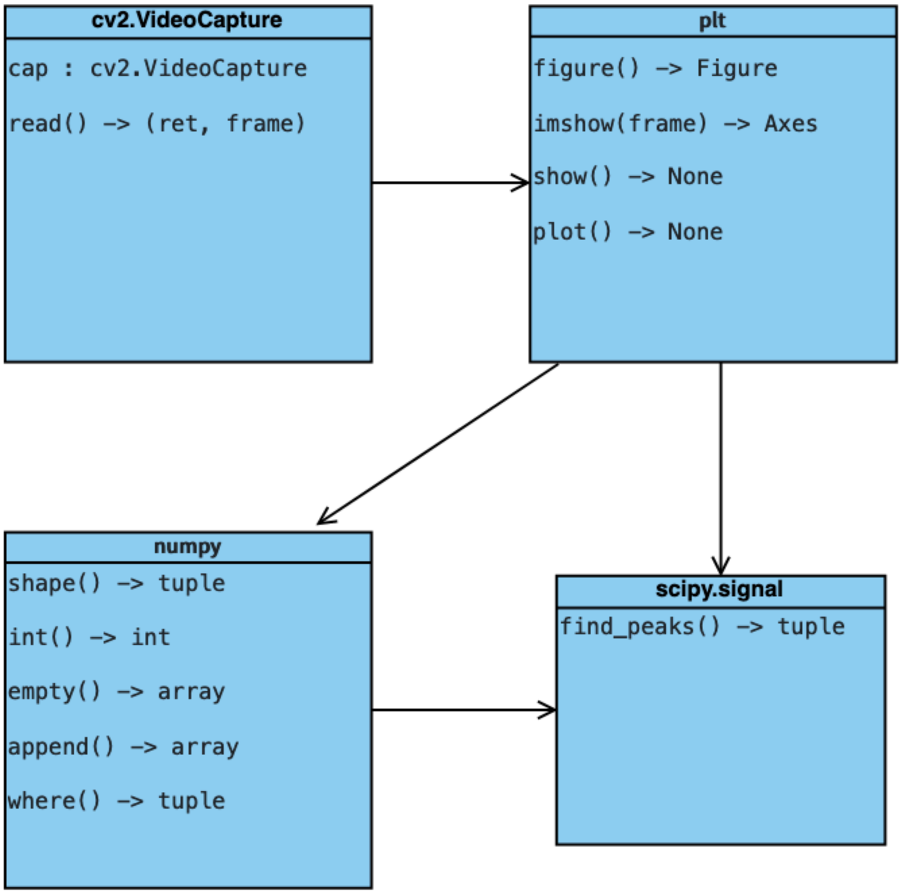
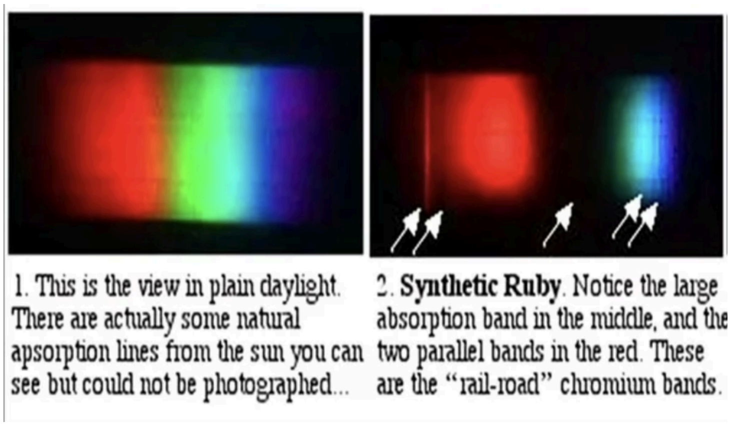


Figure 17: Class diagram

Figure 18 contains the *Class diagram* for all portions of the product and takes into consideration the attributes for the classes that are required in for the second and third portions of the software.

User Interface



1. This is the view in plain daylight. There are actually some natural apsorption lines from the sun you can see but could not be photographed...

2. **Synthetic Ruby**. Notice the large absorption band in the middle, and the two parallel bands in the red. These are the "rail-road" chromium bands.

Figure 18:

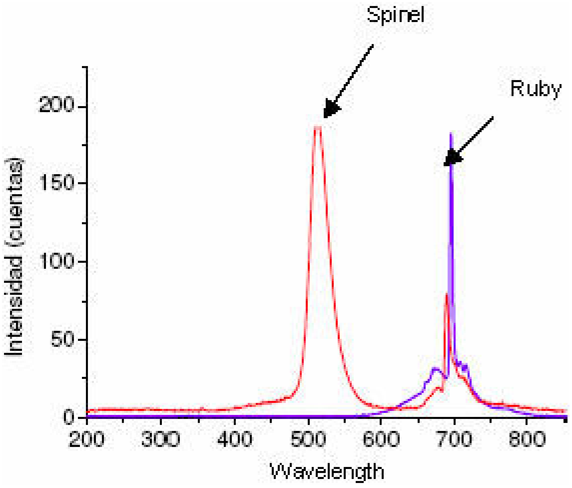


Figure 19: Spectral graph of ruby light

When Considering the UI for the System the diffraction grating (Figure 19) and spectral graph (Figure 20) will remain shown so they can be referenced for the specific material currently under review. The results of the status of the material being a ruby or not will also be clearly displayed.

8 System Fabrication/Prototype Construction

The details of the electrical components of RASS are explored below. The implementation of the rotating stage, the LEDs, the Raspberry Pi, and the Arduino will all be explained.

8.1 Circuit Board Design and Preparation

Printed Circuit Boards (PCBs) play a crucial role in electronic devices by providing a platform for connecting and supporting various electronic components. In a nutshell, PCBs serve the following key functions. PCBs offer a stable and rigid platform for mounting electronic components. The board provides mechanical support, holding the components in place and preventing them from moving or vibrating excessively. In addition, The most fundamental function of a PCB is to provide electrical connections between different electronic components. Conductive pathways, typically made of copper traces, are etched onto the surface of the board to establish these connections. These traces ensure the flow of electric current between different parts of the circuit.

PCBs provide a physical structure for electronic components. Before the advent of PCBs, electronic circuits were assembled using point-to-point wiring, a method that was not only time-consuming but also prone to errors and inefficiencies. PCBs revolutionized this process by offering a standardized and efficient way to arrange components in a compact space. The board acts as a canvas on which various electronic components, such as resistors, capacitors, and integrated circuits, are securely mounted. This organized arrangement not only saves space but also enhances the overall durability and reliability of electronic devices.

In so far as the use of energy is of interest, PCBs facilitate the mounting of electronic components such as resistors, capacitors, integrated circuits, and other devices. These components are soldered onto the surface of the PCB, creating a compact and organized arrangement. The copper traces on the PCB serve as pathways for electrical signals to travel between components. This is essential for the proper functioning of the electronic circuit. Signal integrity and the prevention of signal interference are crucial aspects of PCB design. Furthermore, PCBs often include features like heat sinks and copper planes to help dissipate heat generated by electronic components. Efficient heat dissipation is vital for preventing overheating and ensuring the longevity and reliability of the electronic device.

PCBs enable the miniaturization of electronic circuits by providing a compact arrangement of components and connections. This is especially important in modern electronics where devices are becoming increasingly smaller and more portable. The ability to densely pack components on a small, flat surface is a key advantage of PCB technology. As electronic devices continue to shrink in size while increasing in functionality, the role of PCBs becomes even more crucial. They enable the creation of compact and lightweight gadgets, making portable devices, such as smartphones and laptops, possible. The miniaturization also contributes to energy efficiency, as shorter electrical pathways reduce signal loss and power consumption. This speaks to the fact that, economically, PCBs are manufactured through standardized processes, making mass production of electronic devices more cost-effective and efficient. This standardization also ensures consistency and reliability in the production of electronic components and devices.

There are a few steps in creating printed circuit boards which may involve different techniques:

1. *Design Phase:*

The journey begins with the design phase. Engineers use computer-aided design (CAD) software to layout the circuit, define the components, and plan the connections. This step is crucial as it sets the foundation for the entire PCB creation process.

2. *Subtractive Methods:*

Chemical Etching: One of the traditional methods involves using a copper-clad substrate. A mask, usually made of photoresist, is applied, and then the board is exposed to UV light through the designed pattern. After developing the image, the board undergoes chemical etching, where an acid removes the unprotected copper, leaving behind the desired traces.

Milling: CNC (Computer Numerical Control) milling is another subtractive method. A milling machine precisely removes copper from the substrate according to the design. This method is often used for prototypes and small production runs.

3. *Additive Methods:*

Inkjet Printing: Inkjet printing technology has been adapted for PCB fabrication. Conductive ink is deposited onto the substrate, creating the circuit pattern. While this method is relatively fast, it may not be as precise as traditional methods.

3D Printing: Advancements in 3D printing have paved the way for additive PCB manufacturing. Specialized 3D printers deposit conductive materials layer by layer to build up the circuit. This method allows for intricate designs and is particularly useful for rapid prototyping.

4. *Semi-Additive Methods:*

Electroless Plating: Electroless plating is a semi-additive method where a thin layer of conductive material is deposited onto a substrate without the need for an electrical current. This plated layer serves as the base for subsequent processes in building the circuit.

Screen Printing: Screen printing involves applying a conductive paste through a stencil onto the substrate. This method is suitable for low-volume production and prototyping.

5. *Advanced Techniques:*

Laser Direct Imaging (LDI): LDI is a precise method where a laser is used to directly expose the PCB substrate, eliminating the need for a physical mask. This technology enables finer features and is commonly used in high-density interconnect (HDI) PCBs.

Plasma Etching: Plasma etching, a dry etching technique, uses ionized gas to selectively remove materials from the substrate. This method offers high precision and is used for intricate designs, especially in semiconductor manufacturing.

Rapid PCB Prototyping Machines: Dedicated machines for rapid PCB prototyping can transform a design into a functional prototype within hours. These machines often combine various techniques like milling, drilling, and solder paste dispensing to streamline the process.

6. *Surface Finishes:*

Hot Air Solder Levelling (HASL): After the circuit is defined, the board undergoes surface finishing processes. HASL involves coating the PCB with molten solder and then leveling it with hot air. This provides a protective layer and facilitates soldering of components.

Electroless Nickel Immersion Gold (ENIG): ENIG is a popular surface finish for its flatness and corrosion resistance. It involves depositing a thin layer of nickel followed by a layer of gold onto the copper traces.

7. *Assembly:*

Once the PCB is fabricated, it goes through the assembly phase. Surface mount devices (SMDs) and through-hole components are soldered onto the board. Automated pick-and-place machines ensure precise component placement.

8. *Testing and Inspection:*

Automated Optical Inspection (AOI): AOI systems use cameras and image processing algorithms to inspect PCBs for defects, ensuring the quality and functionality of the final product.

9. *Quality Control:*

Rigorous quality control measures are implemented to identify and rectify any manufacturing defects. This includes functional testing, electrical testing, and often, X-ray inspection for hidden issues.

As a first step, an important part of the power supply configuration is efficiency of the printed circuit board (PCB) design and fabrication. As seen above, there are multiple levels to PCB creation. The power supply configuration journey begins with the design phase of the PCB. This is the starting point of PCB fabrication and therefore of circuit design and fabrication itself. Engineers use computer-aided design (CAD) software to layout the circuit, define the components, and plan the connections. This step is crucial as it sets the foundation for the entire PCB creation process.

There are many variants of software applications that can be used for this process. For example, one of the prominent PCB design tools is Autodesk Eagle, known for its user-friendly interface and extensive component libraries. Eagle allows engineers to create schematics, design PCB layouts, and perform simulations. Its seamless integration with Autodesk Fusion 360 enhances collaboration between electrical and mechanical design teams. Altium Designer is another comprehensive PCB design software widely utilized in the industry. It offers a unified environment for schematic capture, PCB layout, and component management. Altium Designer's advanced features include 3D visualization, signal integrity analysis, and interactive routing, providing a holistic solution for complex designs.

Other software include KiCad which stands out as an open-source PCB design tool, making it accessible to a broad user base. It includes a schematic editor, PCB layout module, and a 3D viewer. KiCad's community-driven development model ensures regular updates and a rich set of libraries. The software's flexibility and cost-effectiveness make it particularly attractive for small and medium-sized projects. For high-frequency and high-speed designs, Cadence Allegro and OrCAD PCB Designer are go-to choices. These tools offer advanced features like constraint-driven design and real-time collaboration.

Cadence tools excel in managing complex layouts, ensuring signal integrity, and optimizing designs for manufacturing.

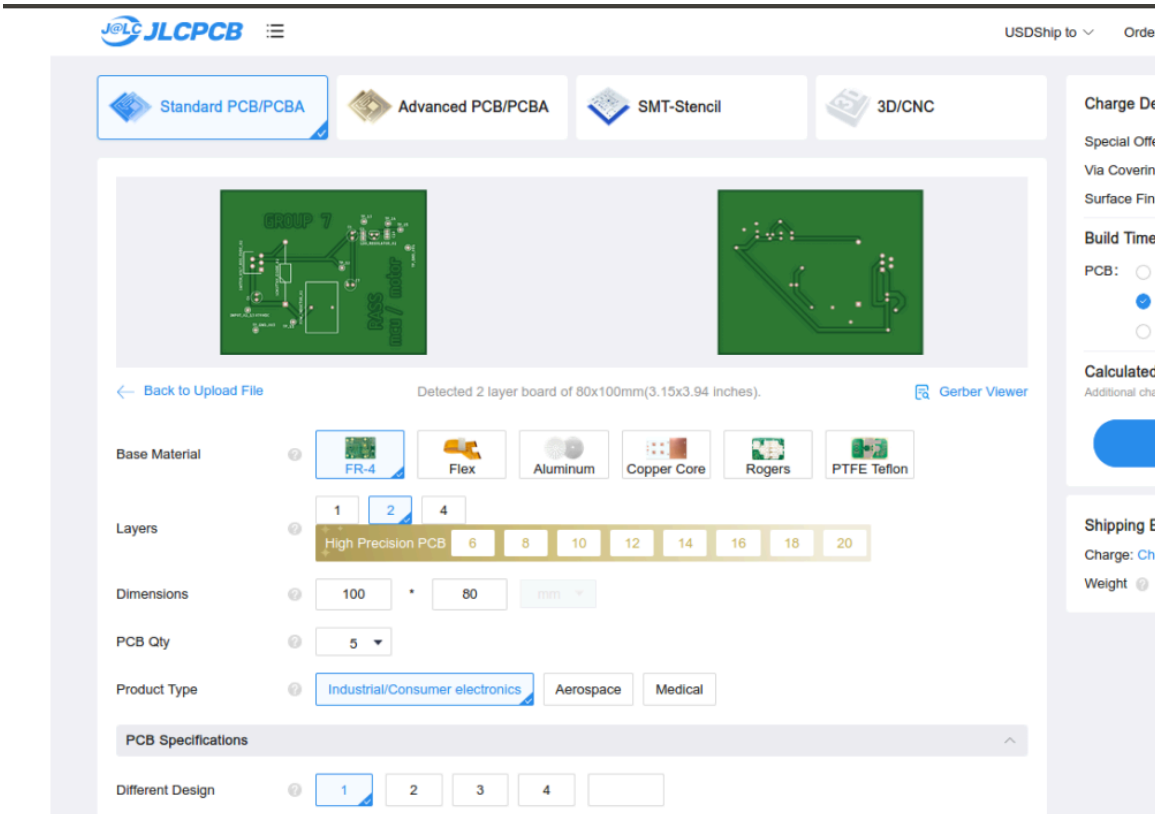
In addition to software already mentioned, there is also PADS by Siemens which is a comprehensive PCB design suite suitable for a wide range of applications. It provides tools for schematic capture, layout, and simulation. PADS is known for its scalability, making it suitable for both simple and complex designs. Its integration with other Siemens tools enhances the overall product development workflow. In recent years, cloud-based PCB design tools like Upverter have gained popularity. Upverter allows collaborative design in real-time, enabling teams distributed across the globe to work seamlessly on a project. Its cloud-based nature ensures that designers always access the latest version of the project, fostering efficient collaboration.

For those focusing on rapid prototyping and quick iterations, EasyEDA offers an online platform for schematic capture and PCB layout. EasyEDA's simplicity and low learning curve make it an attractive option for hobbyists and small-scale projects. It also provides a community platform for sharing designs and collaborating with other users. Simulation is a crucial aspect of PCB design, and tools like SPICE (Simulation Program with Integrated Circuit Emphasis) and LTspice are widely used for electronic circuit simulation. These tools help designers analyze the behavior of circuits, optimize performance, and identify potential issues before the physical prototype stage. For this project the Eagle scriptable electronic design automation (EDA) application is used.

The reader should note that the ultimate point of using the software is to provide a well-defined and well-documented engineering and scientific basis to develop a final product using what the PCB is actually made on or from, otherwise known as a PCB laminate or just laminate. A PCB laminate is a fundamental component in the construction of electronic devices, serving as the substrate that supports and connects various electronic components. It plays a crucial role in providing a stable and reliable platform for the intricate network of conductive pathways that form the circuits of electronic devices. At its core, a PCB laminate is a *composite* material that typically consists of layers of fiberglass cloth impregnated with epoxy resin. The fiberglass provides mechanical strength and rigidity to the laminate, while the epoxy resin serves as an insulating material. This combination of materials creates a sturdy yet lightweight foundation for the intricate web of copper traces that make up the circuitry.

The manufacturing process of a PCB laminate itself involves a series of meticulous steps beyond what we need to do in this project as they are commercially available. Initially, thin sheets of fiberglass cloth are layered together, and the entire stack is coated with epoxy resin. This forms a substrate that, when cured, becomes a solid and rigid material. The next step involves the creation of copper layers. Thin sheets of copper foil are then bonded to the substrate using heat and pressure. The excess copper is etched away, leaving behind the desired circuit pattern. PCB laminates come in various types, each tailored to specific applications and performance requirements. One common classification is based on the number of layers, ranging from single-sided PCBs, double-side PCBs, to complex multilayer boards. Single-sided boards have circuitry on only one side, while multilayer boards incorporate multiple layers of conductive material separated by insulating layers. The latter allows for more complex and compact circuit designs, making them suitable for advanced electronic devices. We will attempt to use a single-sided board in this project.

The choice of PCB laminate material is critical, as it directly influences the board's electrical and mechanical characteristics. FR-4, a flame-retardant epoxy glass composite, is one of the most widely used materials due to its excellent electrical insulating properties, mechanical strength, and cost-effectiveness. Initially, we thought to produce the PCBs ourselves, but ultimately we chose the FR-4 laminate material when ordering our PCBs from JLCPCB (located in Hong Kong, China) after designing them using Autodesk Eagle. Once the appropriate Gerber files were created, the orders were placed. Note that it took two iterations since the first design had a flaw in the PCB layout of PSU 1.



Detected 2 layer board of 80x100mm(3.15x3.94 inches).

Base Material: FR-4

Layers: 2

Dimensions: 100 * 80

PCB Qty: 5

Product Type: Industrial/Consumer electronics

Different Design: 1

Figure 20: JLCPCB ordering website

8.2 PCB Layout and Specifications for PSU and MCU

Below are Autodesk Eagle images of the PCB layout for the schematics mentioned above. The editor view shows the proximity of the components and the paths and distances of the traces in real terms. The widths of the traces can be adjusted if either the pads or the current values need to be adjusted. The top view only shows the components on the top of the PCB. The bottom view shows the traces going to and from the leads of the components on the bottom surface of the PCB. Finally, the needed specifications / properties and bill of materials are shown.

PCB Layout Editor view

In this view we can see the original traces on the PCB in their original state as they are being translated geometrically from the schematic into an actual final product. Here, many physical adjustments can be made before a final product is depicted. This is perhaps the most intricate part of the PCB design process. The first layout design of this board was flawed because there was a short-circuit designed between two of the rectifier leads.

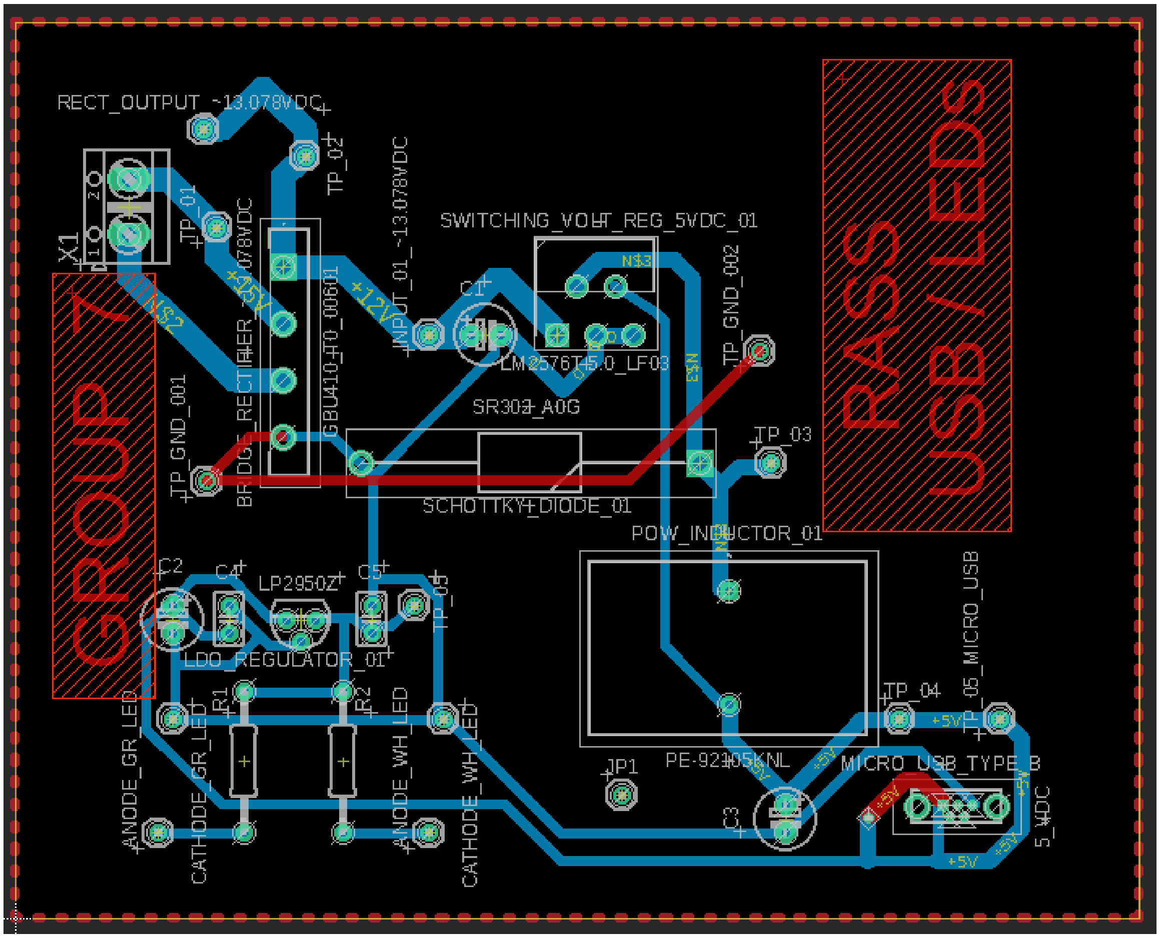


Figure 21: Layout Editor view of PSU 1

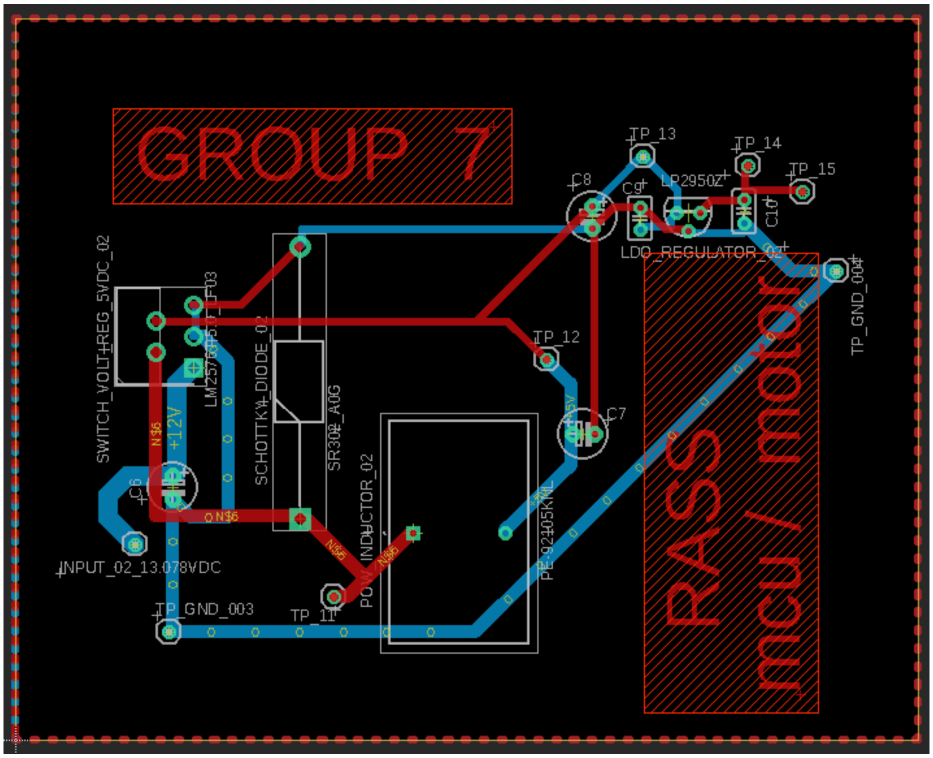


Figure 22: Layout Editor view of PSU 2

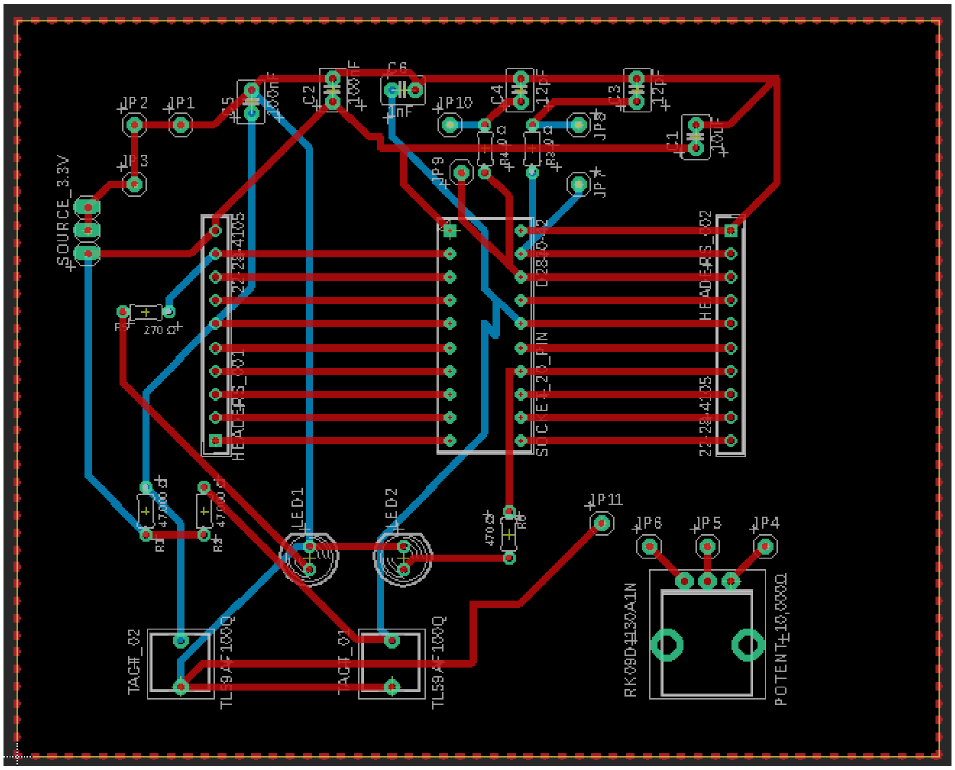


Figure 23: Layout Editor view of MCU

Manufacturer Top View

This view depicts the actual final layout of the components on the PCB itself. It also depicts the final appearance of the PCB.

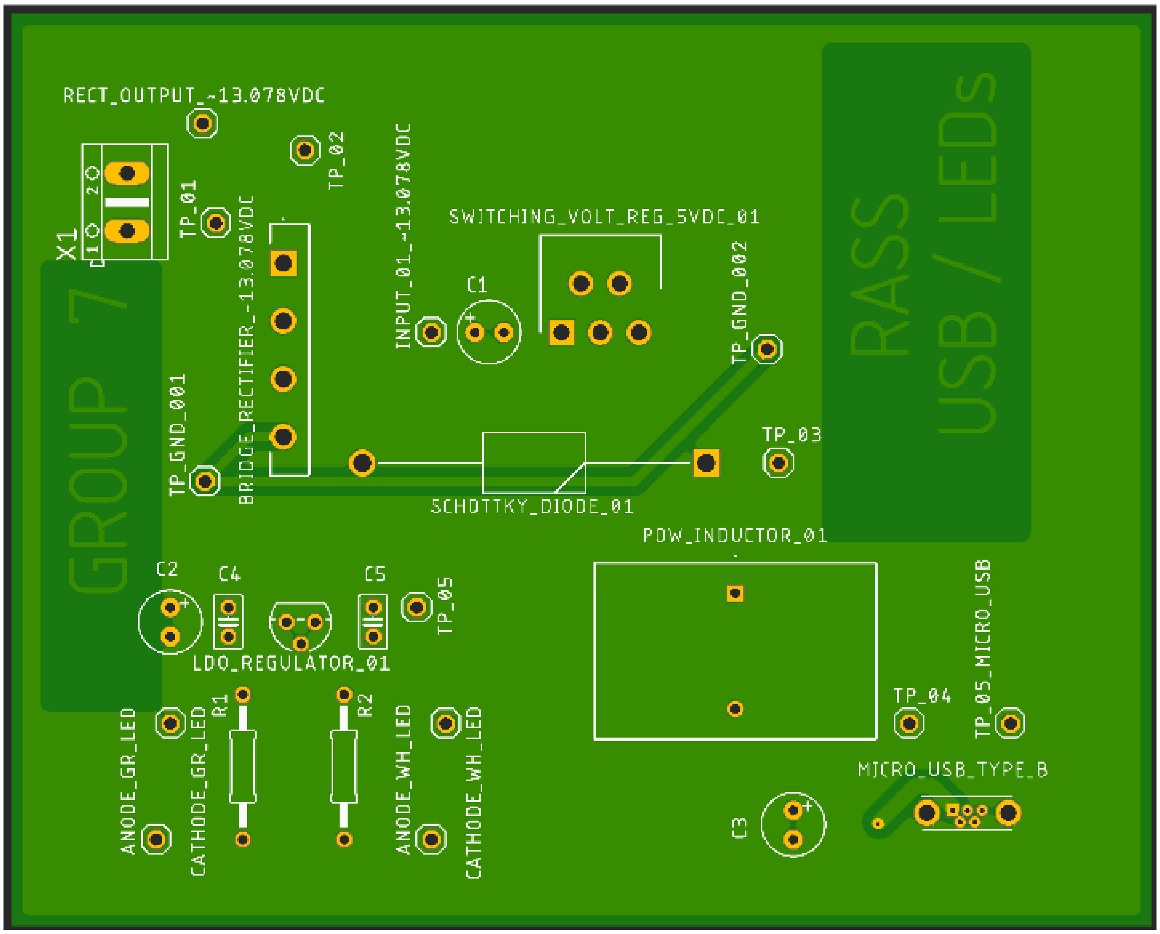


Figure 24: Manufacturer Top View PSU 1

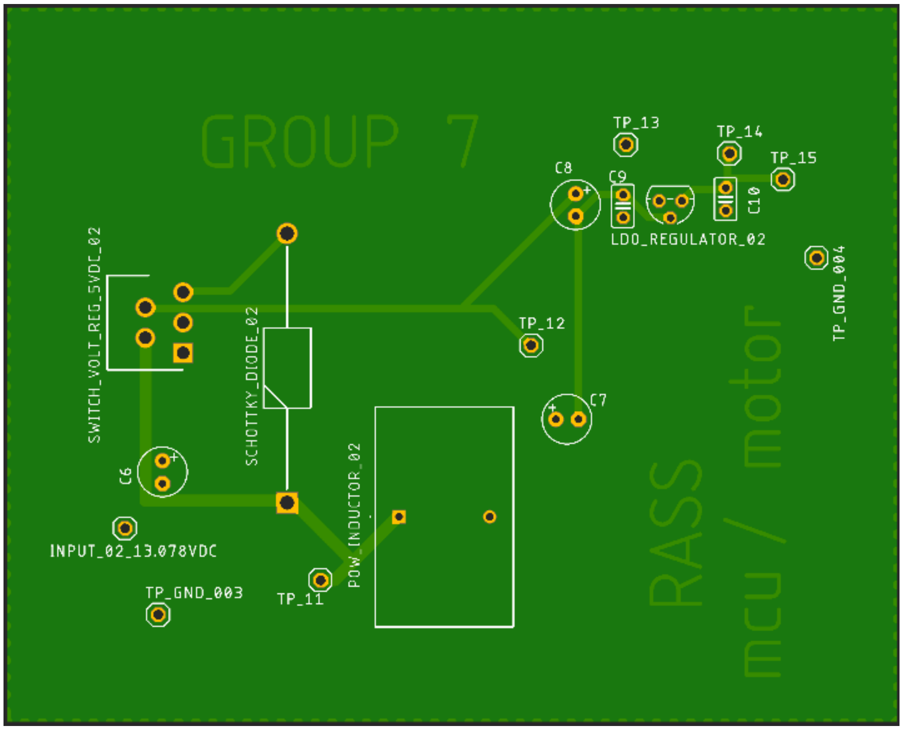


Figure 25: Manufacturer Top View PSU 2

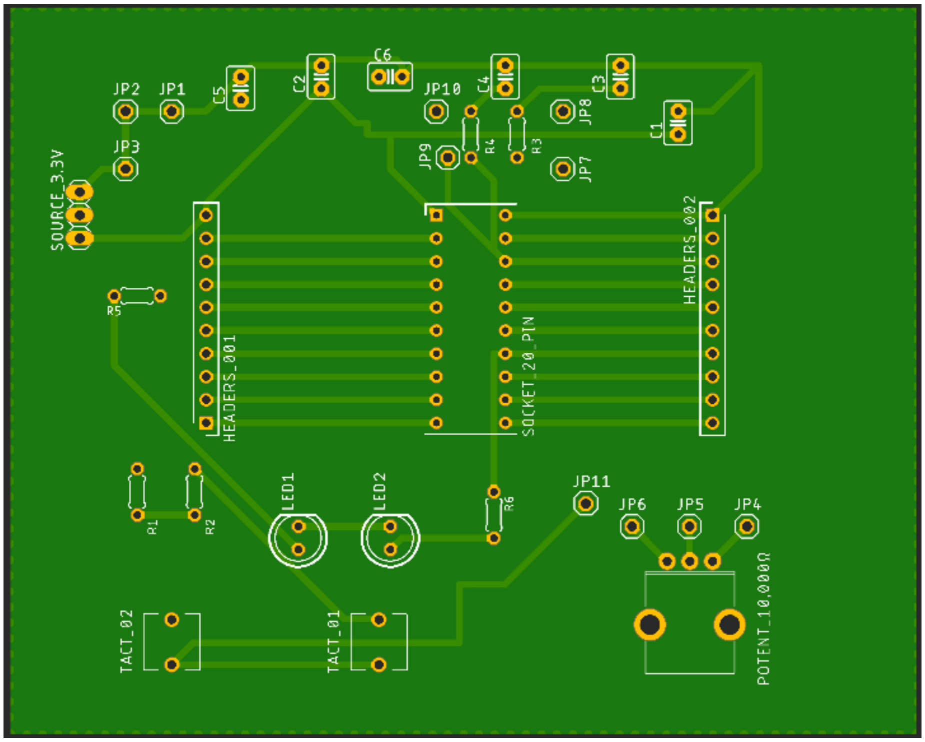
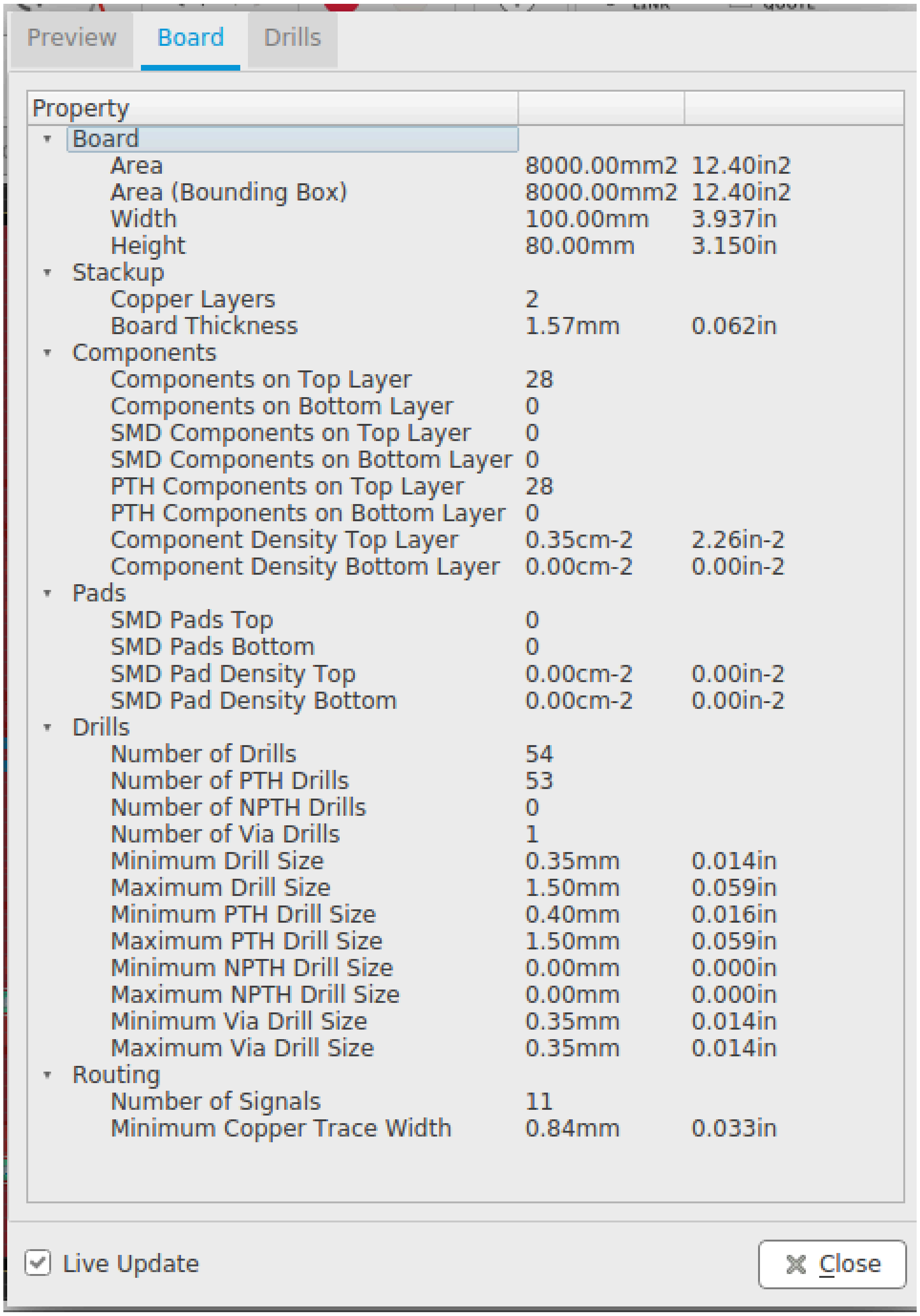


Figure 26: Manufacturer Top View MCU

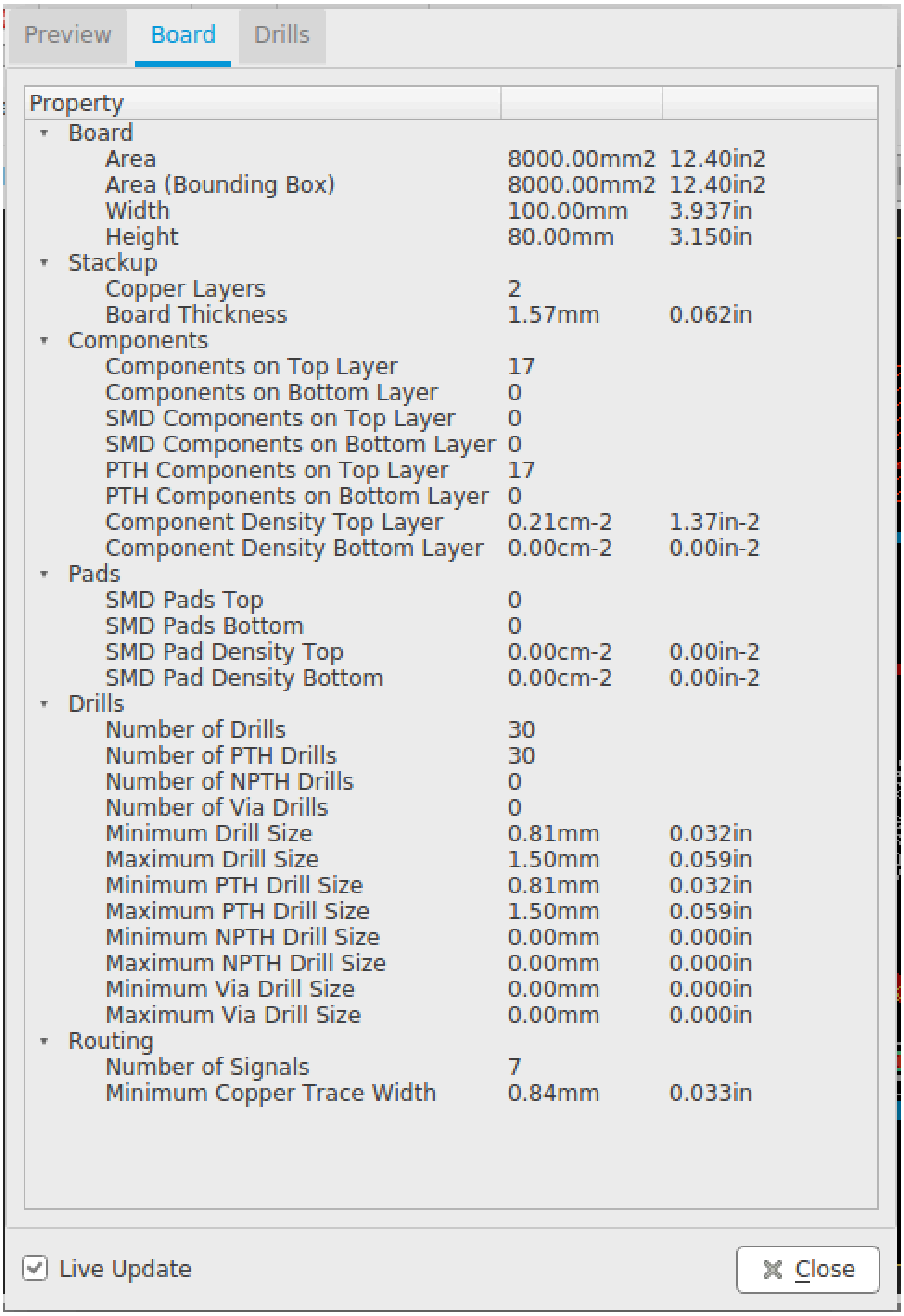
PCB Specifications (properties) and Bill of Materials (BOM)

Below is the Autodesk Eagle list of the physical artifacts of the PCB. These artifacts are articulated by and through the PCB properties and the BOM. The physical nature of the PCB and its component placement is enumerated here. This information is useful to confirm or correct any anomaly associated with the assembly of the final product. Note that the BOM is a confirmation of the total component number on the list of properties.



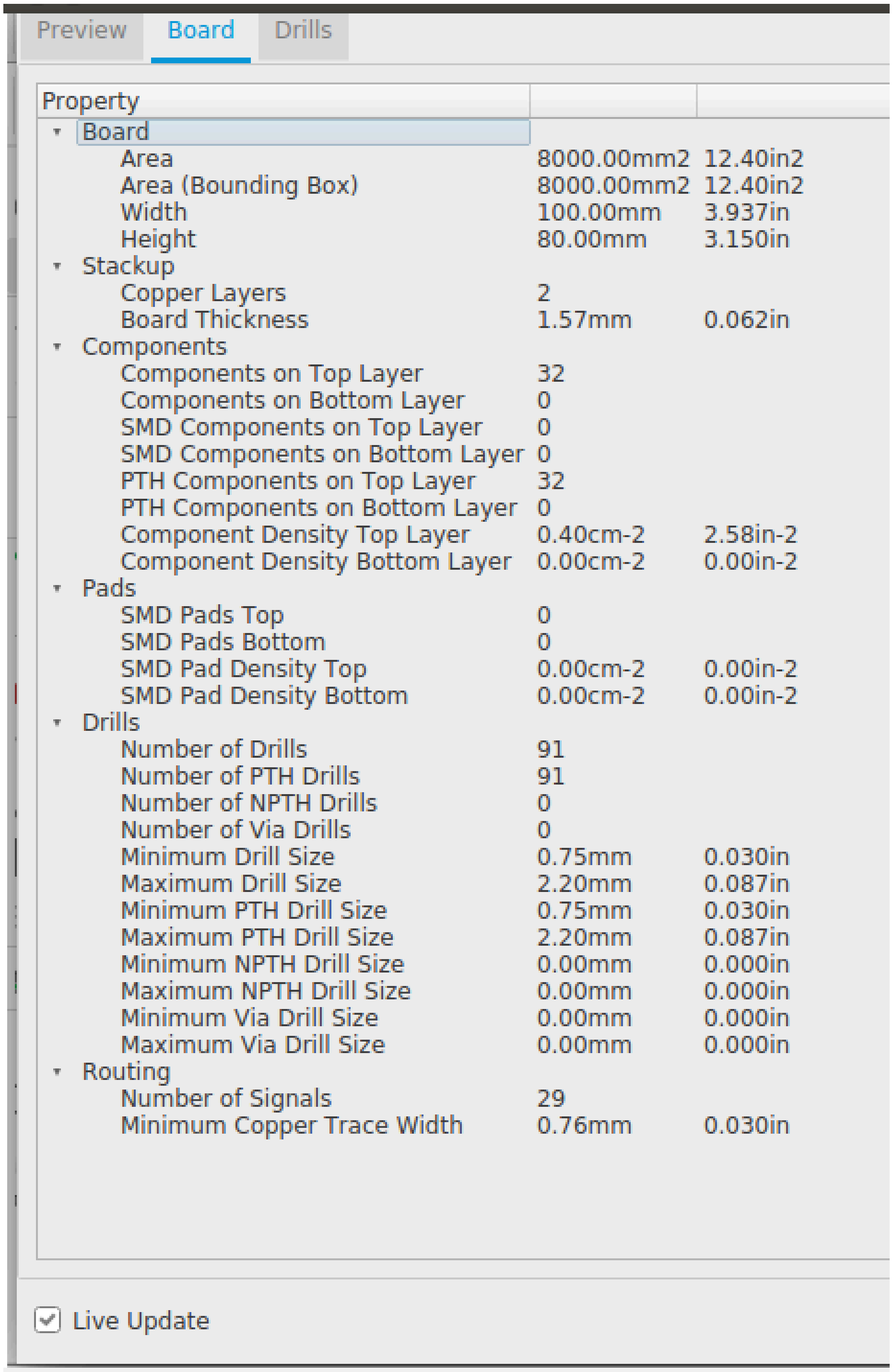
Property		
Board		
Area	8000.00mm2	12.40in2
Area (Bounding Box)	8000.00mm2	12.40in2
Width	100.00mm	3.937in
Height	80.00mm	3.150in
Stackup		
Copper Layers	2	
Board Thickness	1.57mm	0.062in
Components		
Components on Top Layer	28	
Components on Bottom Layer	0	
SMD Components on Top Layer	0	
SMD Components on Bottom Layer	0	
PTH Components on Top Layer	28	
PTH Components on Bottom Layer	0	
Component Density Top Layer	0.35cm-2	2.26in-2
Component Density Bottom Layer	0.00cm-2	0.00in-2
Pads		
SMD Pads Top	0	
SMD Pads Bottom	0	
SMD Pad Density Top	0.00cm-2	0.00in-2
SMD Pad Density Bottom	0.00cm-2	0.00in-2
Drills		
Number of Drills	54	
Number of PTH Drills	53	
Number of NPTH Drills	0	
Number of Via Drills	1	
Minimum Drill Size	0.35mm	0.014in
Maximum Drill Size	1.50mm	0.059in
Minimum PTH Drill Size	0.40mm	0.016in
Maximum PTH Drill Size	1.50mm	0.059in
Minimum NPTH Drill Size	0.00mm	0.000in
Maximum NPTH Drill Size	0.00mm	0.000in
Minimum Via Drill Size	0.35mm	0.014in
Maximum Via Drill Size	0.35mm	0.014in
Routing		
Number of Signals	11	
Minimum Copper Trace Width	0.84mm	0.033in

Figure 27: PSU 1 Properties



Property		
Board		
Area	8000.00mm2	12.40in2
Area (Bounding Box)	8000.00mm2	12.40in2
Width	100.00mm	3.937in
Height	80.00mm	3.150in
Stackup		
Copper Layers	2	
Board Thickness	1.57mm	0.062in
Components		
Components on Top Layer	17	
Components on Bottom Layer	0	
SMD Components on Top Layer	0	
SMD Components on Bottom Layer	0	
PTH Components on Top Layer	17	
PTH Components on Bottom Layer	0	
Component Density Top Layer	0.21cm-2	1.37in-2
Component Density Bottom Layer	0.00cm-2	0.00in-2
Pads		
SMD Pads Top	0	
SMD Pads Bottom	0	
SMD Pad Density Top	0.00cm-2	0.00in-2
SMD Pad Density Bottom	0.00cm-2	0.00in-2
Drills		
Number of Drills	30	
Number of PTH Drills	30	
Number of NPTH Drills	0	
Number of Via Drills	0	
Minimum Drill Size	0.81mm	0.032in
Maximum Drill Size	1.50mm	0.059in
Minimum PTH Drill Size	0.81mm	0.032in
Maximum PTH Drill Size	1.50mm	0.059in
Minimum NPTH Drill Size	0.00mm	0.000in
Maximum NPTH Drill Size	0.00mm	0.000in
Minimum Via Drill Size	0.00mm	0.000in
Maximum Via Drill Size	0.00mm	0.000in
Routing		
Number of Signals	7	
Minimum Copper Trace Width	0.84mm	0.033in

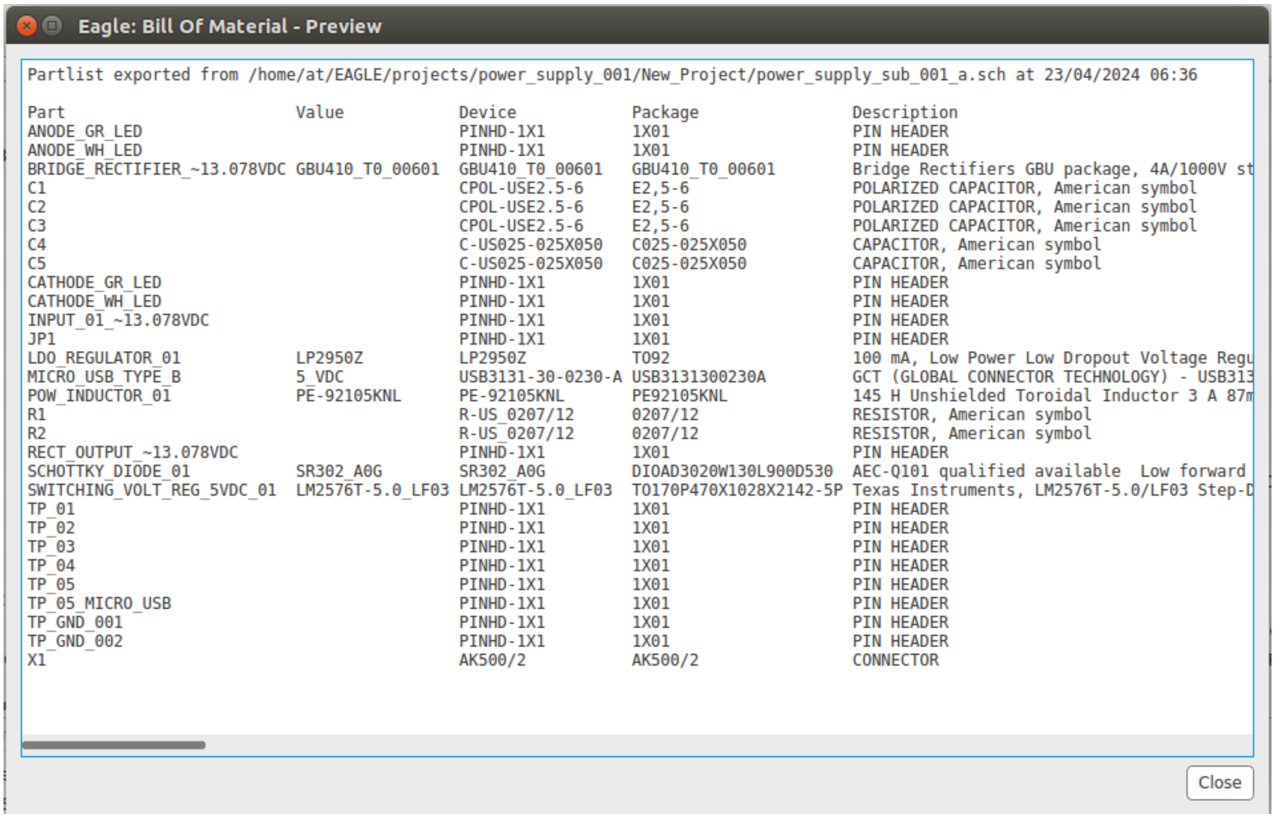
Figure 28: PSU 2 Properties



Property		
▾ Board		
Area	8000.00mm2	12.40in2
Area (Bounding Box)	8000.00mm2	12.40in2
Width	100.00mm	3.937in
Height	80.00mm	3.150in
▾ Stackup		
Copper Layers	2	
Board Thickness	1.57mm	0.062in
▾ Components		
Components on Top Layer	32	
Components on Bottom Layer	0	
SMD Components on Top Layer	0	
SMD Components on Bottom Layer	0	
PTH Components on Top Layer	32	
PTH Components on Bottom Layer	0	
Component Density Top Layer	0.40cm-2	2.58in-2
Component Density Bottom Layer	0.00cm-2	0.00in-2
▾ Pads		
SMD Pads Top	0	
SMD Pads Bottom	0	
SMD Pad Density Top	0.00cm-2	0.00in-2
SMD Pad Density Bottom	0.00cm-2	0.00in-2
▾ Drills		
Number of Drills	91	
Number of PTH Drills	91	
Number of NPTH Drills	0	
Number of Via Drills	0	
Minimum Drill Size	0.75mm	0.030in
Maximum Drill Size	2.20mm	0.087in
Minimum PTH Drill Size	0.75mm	0.030in
Maximum PTH Drill Size	2.20mm	0.087in
Minimum NPTH Drill Size	0.00mm	0.000in
Maximum NPTH Drill Size	0.00mm	0.000in
Minimum Via Drill Size	0.00mm	0.000in
Maximum Via Drill Size	0.00mm	0.000in
▾ Routing		
Number of Signals	29	
Minimum Copper Trace Width	0.76mm	0.030in

☑ Live Update

Figure 29: MCU Properties



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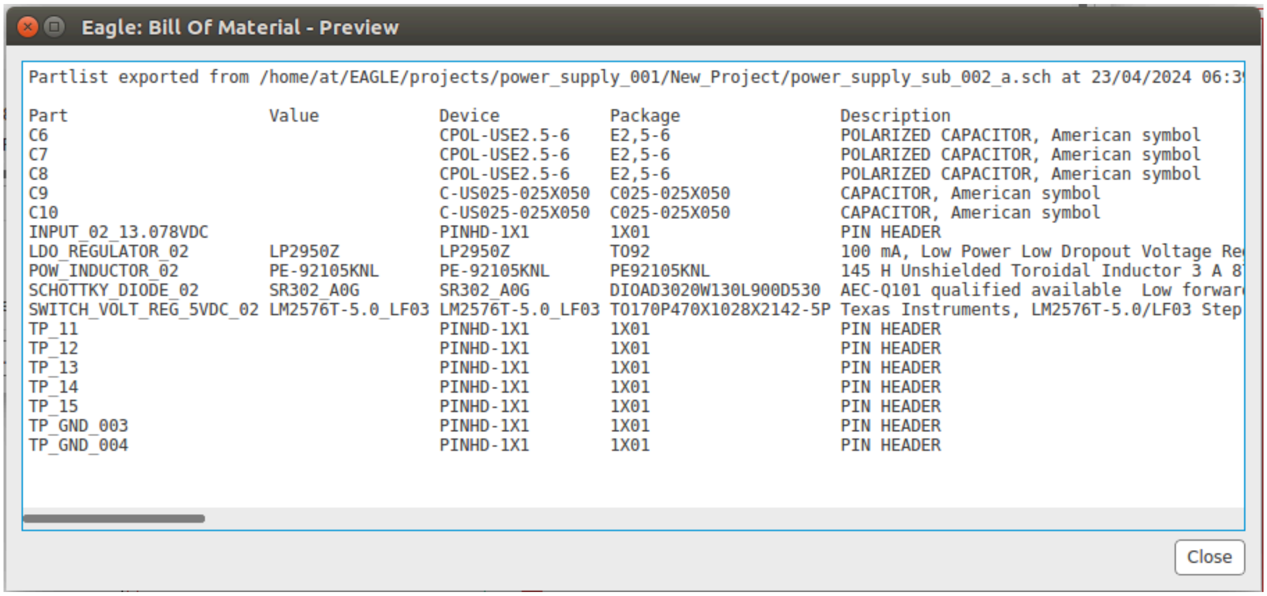
Partlist exported from /home/at/EAGLE/projects/power_supply_001/New_Project/power_supply_sub_001_a.sch at 23/04/2024 06:36

Part                        Value            Device            Package                Description
ANODE_GR_LED                                 PINHD-1X1         1X01                   PIN HEADER
ANODE_WH_LED                                 PINHD-1X1         1X01                   PIN HEADER
BRIDGE_RECTIFIER_~13.078VDC GBU410_T0_00601  GBU410_T0_00601   GBU410_T0_00601        Bridge Rectifiers GBU package, 4A/1000V st
C1                                           CPOL-USE2.5-6     E2,5-6                 POLARIZED CAPACITOR, American symbol
C2                                           CPOL-USE2.5-6     E2,5-6                 POLARIZED CAPACITOR, American symbol
C3                                           CPOL-USE2.5-6     E2,5-6                 POLARIZED CAPACITOR, American symbol
C4                                           C-US025-025X050   C025-025X050           CAPACITOR, American symbol
C5                                           C-US025-025X050   C025-025X050           CAPACITOR, American symbol
CATHODE_GR_LED                               PINHD-1X1         1X01                   PIN HEADER
CATHODE_WH_LED                               PINHD-1X1         1X01                   PIN HEADER
INPUT_01_~13.078VDC                          PINHD-1X1         1X01                   PIN HEADER
JP1                                          PINHD-1X1         1X01                   PIN HEADER
LDO_REGULATOR_01            LP2950Z          LP2950Z           T092                   100 mA, Low Power Low Dropout Voltage Regu
MICRO_USB_TYPE_B            5_VDC            USB3131-30-0230-A USB3131300230A         GCT (GLOBAL CONNECTOR TECHNOLOGY) - USB313
POW_INDUCTOR_01             PE-92105KNL      PE-92105KNL       PE92105KNL             145 H Unshielded Toroidal Inductor 3 A 87m
R1                                           R-US_0207/12      0207/12                RESISTOR, American symbol
R2                                           R-US_0207/12      0207/12                RESISTOR, American symbol
RECT_OUTPUT_~13.078VDC                       PINHD-1X1         1X01                   PIN HEADER
SCHOTTKY_DIODE_01           SR302_A0G        SR302_A0G         DIOAD3020W130L900D530  AEC-Q101 qualified available  Low forward
SWITCHING_VOLT_REG_5VDC_01  LM2576T-5.0_LF03 LM2576T-5.0_LF03  T0170P470X1028X2142-5P Texas Instruments, LM2576T-5.0/LF03 Step-D
TP_01                                        PINHD-1X1         1X01                   PIN HEADER
TP_02                                        PINHD-1X1         1X01                   PIN HEADER
TP_03                                        PINHD-1X1         1X01                   PIN HEADER
TP_04                                        PINHD-1X1         1X01                   PIN HEADER
TP_05                                        PINHD-1X1         1X01                   PIN HEADER
TP_05_MICRO_USB                              PINHD-1X1         1X01                   PIN HEADER
TP_GND_001                                   PINHD-1X1         1X01                   PIN HEADER
TP_GND_002                                   PINHD-1X1         1X01                   PIN HEADER
X1                                           AK500/2           AK500/2                CONNECTOR
```

Figure 30: PSU 1 BOM



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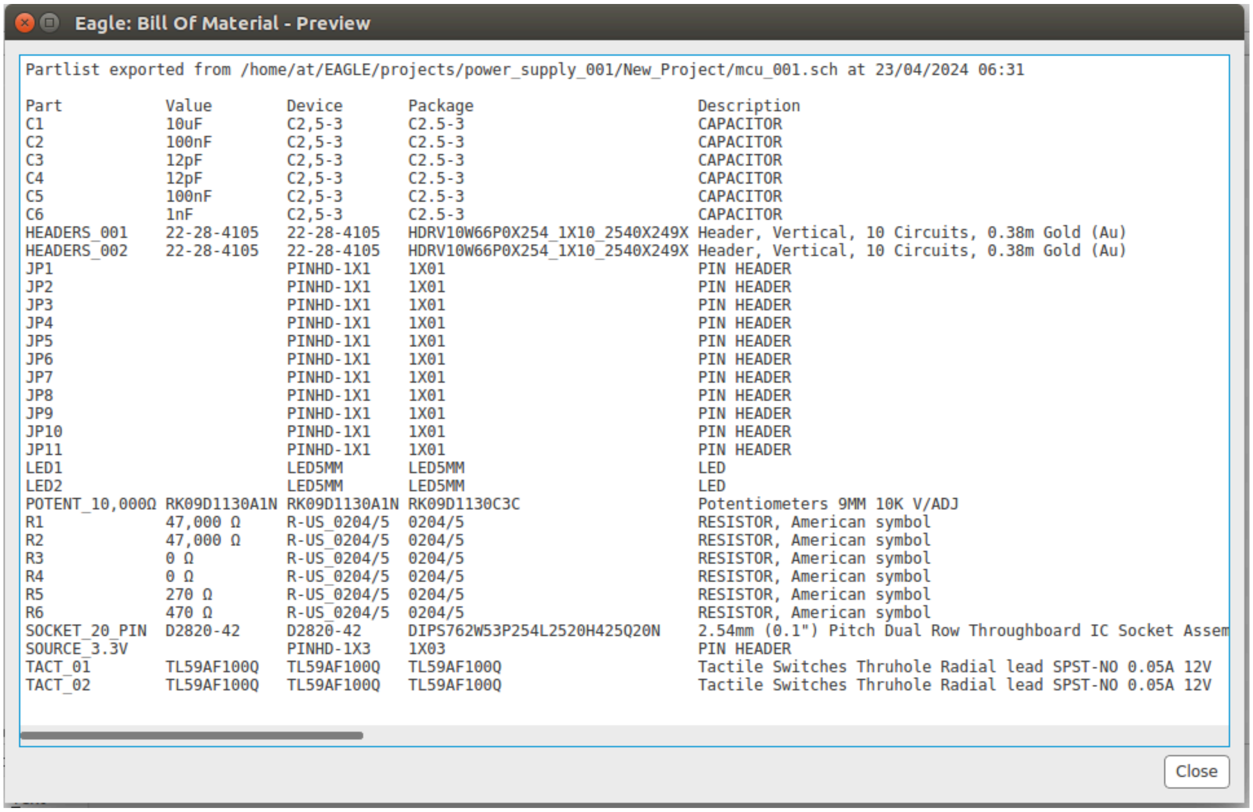
Partlist exported from /home/at/EAGLE/projects/power_supply_001/New_Project/power_supply_sub_002_a.sch at 23/04/2024 06:3

Part                    Value            Device           Package                Description
C6                                       CPOL-USE2.5-6    E2,5-6                 POLARIZED CAPACITOR, American symbol
C7                                       CPOL-USE2.5-6    E2,5-6                 POLARIZED CAPACITOR, American symbol
C8                                       CPOL-USE2.5-6    E2,5-6                 POLARIZED CAPACITOR, American symbol
C9                                       C-US025-025X050  C025-025X050           CAPACITOR, American symbol
C10                                      C-US025-025X050  C025-025X050           CAPACITOR, American symbol
INPUT_02_13.078VDC                       PINHD-1X1        1X01                   PIN HEADER
LDO_REGULATOR_02        LP2950Z          LP2950Z          T092                   100 mA, Low Power Low Dropout Voltage Re
POW_INDUCTOR_02         PE-92105KNL      PE-92105KNL      PE92105KNL             145 H Unshielded Toroidal Inductor 3 A 8
SCHOTTKY_DIODE_02       SR302_A0G        SR302_A0G        DIOAD3020W130L900D530  AEC-Q101 qualified available  Low forwar
SWITCH_VOLT_REG_5VDC_02 LM2576T-5.0_LF03 LM2576T-5.0_LF03 T0170P470X1028X2142-5P Texas Instruments, LM2576T-5.0/LF03 Step
TP_11                                    PINHD-1X1        1X01                   PIN HEADER
TP_12                                    PINHD-1X1        1X01                   PIN HEADER
TP_13                                    PINHD-1X1        1X01                   PIN HEADER
TP_14                                    PINHD-1X1        1X01                   PIN HEADER
TP_15                                    PINHD-1X1        1X01                   PIN HEADER
TP_GND_003                               PINHD-1X1        1X01                   PIN HEADER
TP_GND_004                               PINHD-1X1        1X01                   PIN HEADER
```

Figure 31: PSU 2 BOM



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Partlist exported from /home/at/EAGLE/projects/power_supply_001/New_Project/mcu_001.sch at 23/04/2024 06:31

Part           Value        Device       Package                        Description
C1             10uF         C2,5-3       C2.5-3                         CAPACITOR
C2             100nF        C2,5-3       C2.5-3                         CAPACITOR
C3             12pF         C2,5-3       C2.5-3                         CAPACITOR
C4             12pF         C2,5-3       C2.5-3                         CAPACITOR
C5             100nF        C2,5-3       C2.5-3                         CAPACITOR
C6             1nF          C2,5-3       C2.5-3                         CAPACITOR
HEADERS_001    22-28-4105   22-28-4105   HDRV10W66P0X254_1X10_2540X249X Header, Vertical, 10 Circuits, 0.38m Gold (Au)
HEADERS_002    22-28-4105   22-28-4105   HDRV10W66P0X254_1X10_2540X249X Header, Vertical, 10 Circuits, 0.38m Gold (Au)
JP1                         PINHD-1X1    1X01                           PIN HEADER
JP2                         PINHD-1X1    1X01                           PIN HEADER
JP3                         PINHD-1X1    1X01                           PIN HEADER
JP4                         PINHD-1X1    1X01                           PIN HEADER
JP5                         PINHD-1X1    1X01                           PIN HEADER
JP6                         PINHD-1X1    1X01                           PIN HEADER
JP7                         PINHD-1X1    1X01                           PIN HEADER
JP8                         PINHD-1X1    1X01                           PIN HEADER
JP9                         PINHD-1X1    1X01                           PIN HEADER
JP10                        PINHD-1X1    1X01                           PIN HEADER
JP11                        PINHD-1X1    1X01                           PIN HEADER
LED1                        LED5MM       LED5MM                         LED
LED2                        LED5MM       LED5MM                         LED
POTENT_10,000Ω RK09D1130A1N RK09D1130A1N RK09D1130C3C                   Potentiometers 9MM 10K V/ADJ
R1             47,000 Ω     R-US_0204/5  0204/5                         RESISTOR, American symbol
R2             47,000 Ω     R-US_0204/5  0204/5                         RESISTOR, American symbol
R3             0 Ω          R-US_0204/5  0204/5                         RESISTOR, American symbol
R4             0 Ω          R-US_0204/5  0204/5                         RESISTOR, American symbol
R5             270 Ω        R-US_0204/5  0204/5                         RESISTOR, American symbol
R6             470 Ω        R-US_0204/5  0204/5                         RESISTOR, American symbol
SOCKET_20_PIN  D2820-42     D2820-42     DIPS762W53P254L2520H425Q20N    2.54mm (0.1") Pitch Dual Row Throughboard IC Socket Assem
SOURCE_3.3V                 PINHD-1X3    1X03                           PIN HEADER
TACT_01        TL59AF100Q   TL59AF100Q   TL59AF100Q                     Tactile Switches Thruhole Radial lead SPST-NO 0.05A 12V
TACT_02        TL59AF100Q   TL59AF100Q   TL59AF100Q                     Tactile Switches Thruhole Radial lead SPST-NO 0.05A 12V
```

Figure 32: MCU   BOM

9 System Testing

The RASS aims to be as precise as possible. In order to ensure that everything works according to plan, testing of each component needs to occur. By ensuring that each individual component is working on its own prior to putting everything together will limit the amount of possible errors.

9.1 Spectrometer

The spectrometer, in the RASS, main goal is to capture the light from the ruby and analyze the different wavelengths. If there is any light leakage, noise, or any other possible flaws within the components it could throw the entire spectrum off.

9.1.1 Optical Fiber

Optical fibers are crucial components in the RASS, if the fiber is not working properly the light going through the spectrometer will not be accurate. To ensure the optimal performance of an optical fiber, it's essential to conduct thorough testing. This testing involves assessing various aspects of the fiber, from physical inspection to measuring signal quality.

Firstly, we begin with visually inspecting the fiber connectors and ends. Look for any signs of dirt, scratches, or damage. We perform a continuity test using a visual fault locator (VFL). The VFL emits visible light into the fiber, allowing you to identify breaks or bends in the fiber easily. Check for any light leakage along the length of the fiber.

Next we do quantitative testing, this includes Power Meter Testing, a Light Source Test, and Insertion Loss and Return Loss Measurement. To do the power meter test by measuring the optical signal using an optical power meter and connecting the meter to the fiber and ensuring that the signal power meets the specifications for RASS. This test helps verify that the signal is strong enough for reliable data transmission. The Light Source Test uses an optical light source to send a fixed amount of light into the fiber. You then measure the received light using a power meter. This test confirms the integrity of the fiber link and ensures that the light signal is consistent and within acceptable limits. The Insertion Loss and Return Loss Measurements measure the loss of signal power as light travels through the fiber. Additionally, measure return loss, which indicates the amount of light reflected back toward the source.

Thoroughly testing our optical fibers is a critical step in maintaining the reliability and efficiency of RASS. By combining visual inspections and power meter measurements, it allows us to ensure that the light being carried from the ruby to the spectrometer is not being compromised by insufficient optical fibers.

9.1.2 Slits

Testing a slit is essential to ensure its precision, accuracy, and overall performance of the RASS spectrometer. Due to the slit size being a crucial role in the spectrometer, because of its effect on diffraction grating spacing, it is important to ensure it is working properly. For the RASS we was 3D-printing our slit. To test we will do 4 tests, a visual inspection, Dimensional Measurement, a light transmission test, and a camera test.

Firstly, we looked at the slit to ensure there were no visible defects. We checked for irregularities in its shape, cleanliness, and alignment and made sure there were not foreign particles that got into it during the 3D process. To measure the dimensions of the slit we have to use precision measuring tools. For the RASS the only dimension that is important is the width. We have to ensure it is 250µm. For optical slits, perform a light transmission test. Use a light source and detector to measure how much light passes through the slit. This test ensures that the slit allows the desired amount of light to pass through. Lastly, a functionality test, this includes aligning the slit in the optical set up and ensuring it works well with the diffraction grating. This test was conducted in the following months.

Testing a slit is a critical step in ensuring that it meets design specifications and functions as intended. Whether used in optical instruments, mechanical systems, or other applications, a well-tested slit contributes to the overall precision and reliability of the system it is a part of. By combining visual inspections, dimensional measurements, and functional tests, one can ascertain the quality and performance of a slit, ultimately contributing to the success of the larger system it serves.

9.1.3 Concave Mirrors

An optical grade mirror plays a pivotal role in RASS spectrometers. Testing its quality and performance is essential to guarantee accurate reflection and maintain the integrity of optical systems. For the mirrors we will do 4 tests, a visual inspection, curvature measurement, reflectivity measurement, and an angle of incidence test.

For the visual inspection test we looked for any scratches, stains, or possible defects that may affect the reflection of light. The curvature measurement is taken by using an Ophthalmic lens clock. For the reflectivity test we utilize a reflectometer or a spectrophotometer to measure the reflectivity of the mirror. This test assesses how efficiently the mirror reflects light at specific wavelengths. Lastly, the angle of incidence test, we measure the mirror’s reflectivity at different angles of incidence. This test will ensure that the mirror performs consistently across a range of incident angles.

Testing an optical grade mirror is a meticulous process that ensures its precision and reliability in optical systems. By combining visual inspections, surface measurements, and reflective property assessments, one can confidently verify the mirror's quality. A well-tested optical grade mirror contributes to the efficiency and accuracy of the RASS.

9.1.4 HQ Raspberry Pi Camera

The High-Quality Raspberry Pi Camera module brings advanced imaging capabilities to the RASS, offering high-resolution still photography to measure the various wavelengths. Making sure the camera is working properly is extremely important.

We began by visually inspecting the HQ Raspberry Pi Camera module, this includes checking for any visible damage, loose connections, or foreign particles on the lens. Ensure that the camera module is securely attached to the Raspberry Pi board. Then we verified the connection between the HQ Camera module and the Raspberry Pi board was good. Making sure you have secure connections are vital for reliable data transfer between the camera and the Raspberry Pi.

Once we have looked at the physical aspects of the camera we have to look at the software side of things. We utilized the official Raspberry Pi camera software to capture images. The raspistill command is used for capturing images. We tested various settings such as resolution, exposure, and white balance to ensure flexibility in imaging. We then had to test the camera's performance in low-light conditions. Assess the quality of images captured in various lighting environments. The HQ Camera module, with its larger sensor, is designed to perform well in low-light conditions. Finally we monitored the HQ Camera module's temperature during prolonged use. Excessive heat can impact performance, so we need to ensure proper ventilation or consider adding heat sinks if needed.

Testing the HQ Raspberry Pi Camera is a comprehensive process that involves both hardware and software considerations. When doing this we ensure that the HQ Camera module meets the requirements for RASS.

9.2 Dichroscope

The main goal of the dichroscope is to assess the trigonal crystal structure that is characteristic of ruby and is not found in its imitations, namely dyed quartz and garnet. Enacting these necessary tests will ensure RASS works properly and each test result is reliable.

9.2.1 Calcite

The calcite is the defining component of the dichroscope. If this component does not have the necessary clarity and size required for the optical setup, it will drastically reduce the output power of the beam and it may be undetectable by the time it reaches the fiber for the spectrometer.

Qualitative analysis will first be conducted to simplify the testing process. Calcite samples was visually inspected to look for imperfections in the stone that would contribute to light scattering and thus losses in the optical output. While the calcite does not need to be perfectly clear, imperfections should be minimal as to reduce output losses without driving up the cost of materials for the final product. In addition, it does not need to be excessively large, as calcite is often priced based on clarity and weight.

To quantitatively test the calcite, the power of the input light from the sample ruby was measured initially and recorded. Then, the beam was passed through the calcite and refocused onto the same detector to get the difference in power readings. Ideally the output power should be around 70% of what was initially put through, as the power was further reduced by the beamsplitter. This will help to verify that the calcite is up to standard for RASS and at least meets the minimum power requirements to be read by the spectrometer. The image quality of the calcite can also be assessed after the focusing system, if the image of the ruby at the focal point is reproduced with decent intensity then it may also pass the test.

As the calcite is the pivotal component of the dichroscope, its quality must be maximized while keeping price options relatively low. This can prove difficult, as many clear calcite options are lab treated and can be expensive. However, smaller sizes of calcite can help to mitigate this detail.

9.2.2 Mirrors

The mirrors used for the guiding of light outside of the dichroscope are simple, and should not need excessive testing. They will need to be large enough to sufficiently capture and reflect the beam profile while not increasing the size of the system. In addition, the coating on the mirrors will have to be selected for the desired wavelength range of the system.

When selecting the mirrors, circular mirrors with an aluminum coating (operating at least within the 400-700 nm range) will need to be selected. The beam size should be kept minimal throughout the system, thus the mirrors should not need to be larger than 20 mm. Proper mounts can be purchased as well for optical alignment testing purposes, but if the housing is sufficiently designed this may not be necessary.

To test the mirrors, simply shine a flashlight upon one and ensure that all wavelengths are reflected and minimal chromatic aberrations occur. Inspect the mirror and ensure no debris is present, such as dust or fingerprints from improper handling. Should any of these be present, use optical grade cleaning solutions and wipes to clean the surface gently and with a method that leaves minimal smudges behind. After this step, shine a laser (it can be as simple as a HeNe) onto the mirror and ensure the mirror reflects it properly at a 45° angle, as most mirrors are designed to be optimized at this angle. Power readings can be taken before and after the mirror reflection to ensure minimal light scattering is occurring.

The mirrors are not pivotal in a way that the lenses are in the optical beam path, but improperly coated or dirtied mirrors can introduce light scattering or unwanted reflections that will contribute to the overall losses of the system. The above steps should be enacted to ensure the mirrors are up to the quality required for RASS.

9.2.3 Lenses

Lens testing is straightforward, as RASS has no need for specialized coatings in wavelengths such as UV or IR. The lenses will need to focus the beam to a small focal point to ensure maximum light propagation into the fiber. The lenses will need to be somewhat powerful, as the system was minimally sized and will not have a lot of room for large, high curvature lenses.

To select the lenses, focal lengths of less than 40 mm were considered for RASS's requirements. They were all uncoated and the lens sizes were 20 mm or less. The smaller sized mirrors were used later in the system, as the beam size decreased with each additional pair of lenses implemented.

To test the lenses, the focal lengths on the packaging were read and tested for. A simple way to do this is to hold the lens beneath a light source and above a flat, dark surface and test for where the light comes into focus. On an optical breadboard, this same effect can be achieved more accurately using an uncollimated light source and moving the lens towards or away from the light source until the image was reproduced or focused onto a point. The distance in which this measurement occurred was recorded and compared with the given specifications on the lens packaging from the manufacturer.

In addition to the quantitative testing above, the lenses were inspected similarly to the mirrors for imperfections in the substrate or unwanted contaminations on the lens surfaces. If imperfections were present within the substrate, the location of the imperfection was assessed and it was determined whether the lens was still usable or needed to be replaced. If the lens was dirty, the same method of cleaning from the mirrors was applied. Optical grade cleaning solutions with wipes were used. When handling lenses, gloves should be worn at all times so as to not dirty the surface and alter the images.

In any optical alignment or collimation system, the quality of the lenses are imperative to the success of the output. Any imperfections can result in scattering of the light that will reduce output power and affect the readings from the spectrometer. Thus, quality lenses must be used and well maintained for the success of any optical system.

9.2.4 Beamsplitter

The beamsplitter can be tricky to test, especially if one is using a beamsplitter with coatings. In this application, however, it should be simplified as there are no coatings present and RASS will operate in the visible range.

The beamsplitter should be first inspected for any contaminants or imperfections in the substrate. Should imperfections be present, it will need to be determined whether the imperfections are located in such a way that the component is still usable or needs to be replaced. If contaminants are present on the surface, the simple cleaning with optical grade solution and wipes can be utilized. Beamsplitters should be used with gloves at all times.

To test the beamsplitter, one laser was needed. The initial output power of the laser will need to be measured. Then, the laser must be aligned to be incident on the first face of the beamsplitter at a 45° angle (in the case of a plate beamsplitter, if using a cube the it must be normal to the first face of the cube, not the inner joint). The laser should split into two paths once it is passed through the beamsplitter. Measure the output power of both output beams and ensure they are relatively equal if using a 50-50 beamsplitter. Other beamsplitters must be analyzed according to the package specifications. Test the beamsplitter using the other side to ensure that the split is still present.

The beamsplitter in this application was imperative in focusing the beams from both tests into the spectrometer. A large amount of the power was lost, so precise optical alignment will need to be necessary to achieve the best results. In addition, the component must be sufficiently clean to minimize light loss as it passes through the material.

9.2.5 Iris

The iris in this case was 3D printed and will have minimal effect on the system. The main purpose of it is to block out any light not emitted from the ruby. The testing was simple, as the size of the iris will need to be determined through trial and error of different rubies to ensure maximal ruby light enters the optical system while minimizing noise from the green and white LEDs.

To test the iris, illuminate the ruby and visually assess the light that is able to pass through. Determine if enough red light is going through and whether any white or green light is allowed to enter. You can use different sizes of paper to simulate the increase or decrease in iris size, and finally settle on a choice that optimizes the system.

To quantitatively test the iris, grab an adjustable iris and a spectrometer with a few lenses or microscope objective. Illuminate the ruby with the white light and put the adjustable iris first in the system. Then, use a focusing lens system to focus the light into a fiber that leads to a spectrometer. Analyze the spectrum and see how much noise is being allowed into the system. Adjust the iris so that noise is minimized but the desired readings are of sufficient power. Then, once the desired output is achieved, take a sheet of paper and trace the circumference of the iris, being careful not to adjust it. Use this measurement to 3D print the actual iris for the system.

The implementation of the iris is necessary to minimize noise in the spectral readings. Not using this will allow white light into the system from the white LED that will impact readings negatively. RASS needs distinct peaks to be effective, and allowing noise into the readings will only jeopardize this quality. Tests for the iris aren’t exactly precise, so much trial and error is necessary in order to produce an iris of accurate circumference. In the end, it is important to note that the iris will greatly contribute to the limitations of the ruby size, and alterations to the system may need to be made to minimize the size of the ruby allowed (which is desirable) while allowing for more precise readings to be made. In addition, this will also heavily depend on the power of the white LED used in the system, so when implementing an LED the iris size must be adjusted in order to account for this change.

9.2.6 Prisms

The prisms are there to guide the light through the calcite. They are similar to the previous components in that they are uncoated and able to operate in the visible wavelength spectrum. They are an additive component that only enhances light travel through the system, but still should be chosen carefully. The ones used in this system are right angle prisms.

To properly assess the prisms, a visual test must be done. Look for imperfections in the substrate as well as any contaminants on the surface. Imperfections will need to be assessed and determined whether the light scattering they will cause is allowed to be included in the system. Any contaminants on the surface will need to be cleaned using optical grade solution and wipes.

To test the prism, shine a laser on one of the straight sides (not the hypotenuse) and study its travel through the material. Find the incident angle where back reflections are minimized and record it. Assess the angle where the laser light exits the prism and record it as well. This can be done on a piece of paper with the laser light mounted as low as possible to ensure more accurate readings. Otherwise, a rotating stage can also be employed. Either way, light travel through the prism will need to be assessed in order to effectively apply it to the calcite.

The cleanliness of the prisms as well as a good understanding of light propagation through the material are necessary for effective implementation into the optical system. The light will not be guided properly should these qualities not be assessed.

9.3 Electrical Components

A comprehensive approach to transformer testing involves the use of various instruments to assess electrical, mechanical, and insulation aspects. Laboratory 456 has various testing instruments for the above components. Various test instruments are employed to evaluate different aspects of transformers, ranging from their electrical characteristics to their insulation properties. The following are some key test instruments used in transformer testing:

1. Transformer Turns Ratio (TTR) Meter: This instrument measures the turns ratio of the transformer windings. It ensures that the transformer is designed and constructed correctly, as any deviation from the specified turns ratio can affect its performance.
2. Transformer Resistance Meter: This meter is used to measure the DC resistance of transformer windings. Deviations in resistance can indicate issues such as winding deformation or a poor connection, which may affect the transformer's efficiency.
3. Insulation Resistance Tester: Insulation resistance is a critical parameter for transformers. This tester applies a high DC voltage to the insulation system and measures the current flowing through it. A low insulation resistance may indicate the presence of moisture or contaminants, which can lead to insulation breakdown.
4. Power Factor/Tan Delta Test Set: This instrument assesses the dielectric losses in the insulation of a transformer. It helps identify any insulation aging or deterioration, which could lead to a reduction in the transformer's lifespan.
5. Partial Discharge (PD) Measurement System: Partial discharges are localized breakdowns within the insulation. PD measurement systems detect and measure

these discharges, helping to assess the overall condition of the transformer insulation and identify potential failure points.

6. Short Circuit Impedance and Load Loss Test: These tests involve applying a short circuit to the secondary winding while measuring the impedance and load loss. They help evaluate the transformer's ability to withstand short circuits and its overall efficiency.
7. Sweep Frequency Response Analysis (SFRA): SFRA is used to analyze the frequency response of a transformer to a swept sinusoidal input. Any deviations from the expected response can indicate mechanical issues, such as winding deformation or core movement.
8. Dissolved Gas Analysis (DGA): DGA is crucial for assessing the condition of the transformer oil. Gas levels and types present in the oil can provide insights into potential problems like overheating or insulation breakdown.
9. Buchholz Relay: While not a test instrument per se, the Buchholz relay is a protective device connected to the transformer. It detects faults such as internal short circuits or incipient faults by monitoring the oil flow.
10. Thermal Imaging Camera: Infrared thermography is used to detect abnormal temperature patterns in the transformer. Hotspots can indicate issues like loose connections or internal faults.
11. Voltage and Current Transformer (CT) Testers: These instruments verify the accuracy and performance of voltage and current transformers connected to the main transformer. Correct measurements are crucial for protective relay and metering accuracy.

9.3.1 Bridge Rectifier

Testing a bridge rectifier is a crucial step in ensuring the proper functioning of electronic circuits, especially in power supply applications. A bridge rectifier is a key component that converts alternating current (AC) into direct current (DC). Testing involves verifying its ability to rectify the AC signal and deliver a smooth DC output. Various test instruments are employed for this purpose, each serving a specific function in assessing the performance and reliability of the bridge rectifier.

1. Multimeter: The multimeter is a fundamental tool for assessing basic parameters of a bridge rectifier. It measures key electrical characteristics such as voltage, current, and resistance. By connecting the multimeter in different configurations across the rectifier, one can verify the correct voltage drop across diodes, ensuring they are not shorted or open.
2. Oscilloscope: An oscilloscope is essential for examining the waveform at various points in the rectification process. It allows visualization of the AC input waveform and the DC output waveform. Anomalies such as excessive ripple or distorted waveforms can be detected, indicating potential issues with the rectifier.
3. Function Generator: A function generator is used to provide an AC signal to the bridge rectifier during testing. By varying the frequency and amplitude of the input signal, one can evaluate the rectifier's performance under different operating conditions.
4. Load Bank: Applying a load to the bridge rectifier is crucial for assessing its capability to handle different levels of current. A load bank simulates real-world

conditions, helping to identify any issues related to overloading or insufficient current-carrying capacity.

5. Insulation Tester: An insulation tester is employed to check for electrical insulation integrity. It ensures that there are no short circuits or leakage paths between the AC and DC sides of the rectifier. This is particularly important for safety and to prevent damage to other components in the circuit.
6. Temperature Measurement Devices: Thermal performance is critical for the reliability of electronic components. Infrared thermometers or thermal imaging cameras can be used to assess the temperature of the bridge rectifier during operation. Overheating may indicate inefficiencies or impending failure.
7. Diode Tester: A dedicated diode tester, often included in a multimeter, can be used to individually check each diode within the bridge rectifier. This ensures that all diodes are functioning correctly and have the expected forward and reverse bias characteristics.
8. Voltage Regulator Tester: If the bridge rectifier is part of a voltage regulator circuit, a voltage regulator tester can be used to assess the stability and accuracy of the output voltage. This is crucial for applications where a stable DC voltage is required.
9. In-Circuit Testing: In-circuit testing involves assessing the bridge rectifier while it is still connected to the overall circuit. This helps identify issues related to the interaction of the rectifier with other components and ensures that it operates within the intended design parameters.

9.3.2 Linear Voltage Regulator / Switching Voltage Regulator

Testing a voltage regulator is crucial to ensure its proper functionality and adherence to specifications. Several test instruments play a vital role in evaluating the performance of a linear voltage regulator. These instruments help verify parameters such as output voltage accuracy, load regulation, line regulation, transient response, and overall stability.

1. Digital Multimeter (DMM): The Digital Multimeter is a fundamental tool for measuring voltage, current, and resistance. When testing a linear voltage regulator, a DMM is used to verify the output voltage accuracy. This involves connecting the DMM to the output terminals of the regulator and comparing the measured voltage with the specified value.
2. Oscilloscope: An oscilloscope is invaluable for assessing the transient response and overall stability of a linear voltage regulator. It helps visualize the regulator's output waveform under different operating conditions. Transient response is critical to ensure that the regulator can quickly recover from sudden changes in load or input voltage.
3. Electronic Load: An electronic load is used to simulate different load conditions on the regulator. This instrument helps evaluate the load regulation of the linear voltage regulator by varying the load current and observing how well the regulator maintains a stable output voltage.
4. Variable Power Supply: A variable power supply is employed to test the linear voltage regulator under different input voltage conditions. This is crucial for assessing the line regulation of the regulator, which measures its ability to maintain a consistent output voltage despite variations in the input voltage.

5. Frequency Counter: Some linear voltage regulators may have adjustable frequency operation, especially in switching regulators. A frequency counter is used to measure the output frequency and ensure that it aligns with the regulator's specifications.
6. Temperature Chamber: Temperature can significantly impact the performance of electronic components. A temperature chamber is used to test the linear voltage regulator's thermal characteristics. This involves subjecting the regulator to different temperature levels and assessing its ability to maintain stable operation.
7. Power Analyzer: A power analyzer is employed to measure the efficiency of the linear voltage regulator. Efficiency is a critical parameter, especially in applications where power consumption is a concern. The power analyzer helps identify any losses in the regulator and ensures it operates with optimal efficiency.
8. Voltage and Current Sources: Precision voltage and current sources are used to provide controlled inputs to the linear voltage regulator during testing. These sources help simulate various operating conditions, enabling a comprehensive evaluation of the regulator's performance.
9. Noise and Ripple Meter: Assessing the output noise and ripple of a linear voltage regulator is essential, especially in sensitive electronic circuits. A noise and ripple meter helps quantify the level of unwanted signals present in the regulator's output.
10. Logic Analyzer: In cases where the linear voltage regulator includes digital control features, a logic analyzer is employed to capture and analyze digital signals. This ensures that the digital control circuitry operates as intended.

9.3.3 Electrolytic Capacitors

Testing electrolytic capacitors is crucial to ensure their proper functioning in electronic circuits. These capacitors are commonly used for filtering, coupling, and energy storage in electronic devices. Several test instruments are employed to assess the health and performance of electrolytic capacitors.

1. Multimeter: The multimeter is a fundamental tool for testing electrolytic capacitors. It can measure capacitance, resistance, and voltage. To check the capacitance of an electrolytic capacitor, the multimeter is set to the capacitance measurement mode. It is essential to discharge the capacitor before testing to avoid inaccurate readings.
2. ESR Meter (Equivalent Series Resistance): ESR meters are specifically designed to measure the equivalent series resistance of capacitors. Electrolytic capacitors, over time, can develop increased internal resistance, affecting their performance. An ESR meter helps identify capacitors with high ESR, indicating potential issues. High ESR can lead to increased power dissipation and reduced capacitor efficiency.
3. LCR Meter: LCR meters are versatile instruments that measure inductance (L), capacitance (C), and resistance (R). When testing electrolytic capacitors, the LCR meter is used to measure capacitance and the dissipation factor ($\tan \delta$), providing information about the capacitor's dielectric losses. An abnormal $\tan \delta$ value may suggest a faulty capacitor.

4. Oscilloscope: Oscilloscopes are used to observe the voltage waveforms across capacitors. An electrolytic capacitor's voltage should exhibit a smooth and continuous charging and discharging curve. Any irregularities or unexpected behavior may indicate a faulty capacitor. Additionally, an oscilloscope helps in assessing the ripple voltage across capacitors in power supply circuits.
5. Leakage Current Tester: Electrolytic capacitors should have low leakage currents to function effectively. A leakage current tester applies a voltage to the capacitor and measures the resulting leakage current. Elevated leakage current may indicate capacitor degradation or failure. This test is particularly important for capacitors used in critical applications where low leakage is essential.
6. Reforming Power Supply: Reforming is a process used to restore the dielectric strength of electrolytic capacitors that have been unused for an extended period. A reforming power supply applies a gradually increasing voltage to the capacitor, allowing it to reform its dielectric layer. This process is crucial for capacitors that have been in storage to prevent damage during reactivation in a circuit.
7. Temperature and Humidity Chamber: Capacitor performance can be affected by environmental conditions. Testing electrolytic capacitors in a temperature and humidity chamber simulates real-world operating conditions. This testing helps assess the capacitor's stability and reliability across a range of temperatures and humidity levels.
8. Surge Current Tester: Electrolytic capacitors in power supply circuits are often subjected to surge currents during startup. A surge current tester applies high current pulses to the capacitor, simulating startup conditions. This test ensures that the capacitor can handle the transient surge currents without failure.

9.3.4 Ceramic Capacitors

Testing ceramic capacitors is a crucial step in ensuring their reliability and performance in electronic circuits. Various test instruments are employed to assess different aspects of these capacitors.

1. Capacitance Meters: One of the fundamental characteristics of a capacitor is its capacitance, which represents its ability to store electrical charge. Capacitance meters are used to measure the capacitance of ceramic capacitors accurately. These meters apply a known voltage to the capacitor and measure the resulting charge, allowing the calculation of capacitance.
2. Inductance Meters: While ceramic capacitors are primarily designed for capacitance, they may exhibit some level of inductance due to their construction and materials. Inductance meters help determine the inductance of a capacitor, which is essential for applications where inductance could impact performance.
3. Dielectric Absorption Measurement: Ceramic capacitors have a dielectric material between their plates, and dielectric absorption is a phenomenon where the capacitor retains a small amount of charge even after being discharged. This can affect the capacitor's performance in some applications. Instruments like dielectric absorption bridges are used to measure and evaluate this characteristic.
4. Insulation Resistance Testers: Insulation resistance is a crucial parameter to assess the reliability of a capacitor. Insulation resistance testers apply a high voltage to

the capacitor and measure the resistance between the capacitor terminals. This test helps identify any leakage currents or insulation breakdown issues.

5. Equivalent Series Resistance (ESR) Meters: The Equivalent Series Resistance of a ceramic capacitor includes the resistive components that contribute to power loss in the capacitor. ESR meters are employed to measure this resistance, providing insight into the capacitor's efficiency and performance in high-frequency applications.
6. Voltage and Current Testing: Ceramic capacitors operate under specified voltage and current ratings. Testing the capacitor under these conditions is essential to ensure it can withstand the expected electrical stresses. Instruments like voltage and current probes help verify if the capacitor meets the specified operational parameters.
7. Temperature Chamber: Ceramic capacitors can be sensitive to temperature variations. Temperature chambers are used to test capacitors under extreme temperature conditions, simulating the range of temperatures they might experience in real-world applications. This helps assess the capacitor's stability and performance across different temperature environments.
8. Cyclic Aging Testers: Cyclic aging tests involve subjecting the capacitor to repeated cycles of voltage and temperature stress. This helps simulate the long-term effects of operational conditions on the capacitor's performance. Cyclic aging testers are used to evaluate the capacitor's reliability over an extended period.
9. Dissipation Factor (DF) Measurement: The Dissipation Factor is a measure of energy losses in a capacitor and is crucial in applications where high efficiency is required. DF meters are used to measure this factor, providing insights into the capacitor's performance in terms of energy storage and release.
10. Failure Analysis Tools: In cases where a capacitor fails to meet specifications, various failure analysis tools such as scanning electron microscopes (SEM) and X-ray machines are employed. These tools help identify the root cause of failure, whether it be due to manufacturing defects, environmental stress, or other factors.

9.3.5 micro-USB 2.0 Type-B

Testing micro-USB 2.0 Type-B connectors is a critical step in ensuring the reliability and performance of USB devices. Various test instruments are employed to evaluate different aspects of these connectors, covering electrical, mechanical, and signal integrity parameters.

One of the fundamental electrical tests for micro-USB 2.0 Type-B connectors is the continuity test. This test ensures that the connector's pins are properly connected and that there are no short circuits. A multimeter is commonly used for this purpose. By probing the connector's pins, manufacturers can verify that each pin is correctly wired and that there is no unintended connection between adjacent pins.

To assess the electrical characteristics of micro-USB 2.0 Type-B connectors, impedance and capacitance measurements are crucial. Network analyzers and impedance meters come into play to measure the characteristic impedance of the connector and ensure it complies with USB 2.0 specifications. Capacitance meters are used to verify that the capacitance between adjacent pins is within acceptable limits, as excessive capacitance can degrade signal quality.

Signal integrity testing is paramount to evaluate the performance of micro-USB 2.0 Type-B connectors. Oscilloscopes are extensively utilized to analyze signal waveforms and check for issues such as overshoot, undershoot, and jitter. These instruments help identify signal distortions that may affect data transmission speed and reliability. Furthermore, Eye diagram analysis is another critical aspect of signal integrity testing. An oscilloscope is employed to generate eye diagrams, graphical representations of signal quality. By examining the eye opening, engineers can assess the quality of the signal and identify potential issues that may affect data integrity.

9.4 Software Testing

It was important to ensure that the software will interact in the expected manner. The three main phases that the software has been broken up into are: the collection of data, the translation of data, and the analysis of data. It is important to make sure each of these different phases are working as expected to the best of our ability.

Due to the collection of data is not purely a software aspect, communication must be made to ensure that the construction of the spectrometer is set up appropriately so that the diffraction grating can be properly received and saved by the camera lens attached to the Raspberry Pi.

The next aspect that will have to be tested is the translation of data from the captured image of the diffraction grating into a graph of the fluorescence spectra. The code will have to be slightly adjusted to capture the intensity values at the y axis that best expresses the fluorescence. To ensure that the data is being properly translated we can compare the created spectral graph with one created from previously utilized lab software to have control data as a baseline. It is important to ensure that the created graph and readings are as they should be. If not, the source of the error has to be tracked down and adjusted whether it be a physical error or a software error. As we was seeking out specific characteristics of the spectra we want to make sure that this is expressed accurately on the spectra so that when we make our judgment and take our readings we know we are using accurate information and can come to a proper conclusion. If the information is not translated properly and is shifted over then the specific characteristics that we are looking for may fall out of the expected range. There may be methods to still identify these characteristics by calculating the spacing between expected peaks however this may leave more room for error. This is because the peaks could have the same spread but be falling in color ranges that would not be associated with a ruby.

The final aspect we want to test is the analysis. If we have ensured that the previous steps have been completed without error then it was even easier to check that the analysis is working appropriately. With a properly graphed spectral diagram a conclusion can be initially made as to whether or not the material is a ruby. If the conclusion made by the system does not agree then it is important to identify if this is due to error, large or small, or if the judgment is actually accurate and is making a decision with precision that may not happen when just visually making an assumption.

Some of the error handling and checks within functions are as follows. Within the code for the cv2/OpenCV library there is built-in error handling to ensure the camera is working appropriately, specifically in the cv2.VideoCapture() code. There is error handling to ensure that the camera is actually being accessed and able to be opened. This allows you to know if there is either a physical or software issue with the actual connection to the camera.

9.5 Overall Integration

The RASS aims to analyze the fluorescent spectrum and the crystalline structure of various rubies. This process completes two tests, the spectrometer test and the dichroscope test, which both occur after the ruby is securely fastened in the ruby holder. The spectrometer test will run first then the dichroscope test will complete once the spectrometer test is fully completed. After the light travels through the dichroscope it will then be sent through a beam splitter and some collimating lenses to the spectrometer to make the dichroscope test quantitative.

The spectrometer test, the Green LED was turned on and travel though the ruby. The light will travel from the ruby through a lens and to an optical fiber to capture the light, sent through the slit to the first collimating mirror, then reflected off the diffraction grating to the focusing mirror and finally to the HQ Camera. This process will measure the fluorescent spectrum of the ruby being tested. If the Rubies peak wavelength is at 695 nm or within 2 nm of that it is a real ruby. If it is not within that range it is a fake ruby.

Once the spectrometer test is complete the dichroscope test will activate the white LED. The illuminated light is then sent through a slit, through a prism, through the calcite, through another prism and finally a focusing lens. Once it passes through that set of optics it was emitting two different wavelengths. Those beam paths was set through various optics to redirect the light to a beam splitter that will then focus it into the spectrometer fiber. From these two wavelengths we was able to tell if it has the correct crystalline structure. If there are two distinct wavelengths then it is the right crystalline structure. If it does not have two distinct wavelengths then the tested gem does not have the same crystalline structure as a ruby.

Once both tests are complete and the photos collected from the HQ Camera, it is processed through the selected software. The spectral graphs will then be analyzed for the peaks shown in the light spectrums. If the peaks match the specifications required for a ruby the system will notify you that the ruby is real, if the specifications do not match then the system will tell you if it is not a ruby.

9.6 Plan for Senior Design 2

Senior Design 2 is for the building portion of RASS. Preparations for Senior Design 2 will start during the break. We will start by ensuring all of the components are here and tested properly over winter break. We will all individually work on prototyping our own portions until January 26th, 2024. We will then work on testing each component individually, looking for anything that might need adjustments or improvements. Starting February 12th, 2024 the RASS was going through the revision portion and finalizing individual tests. Due to 3D printing taking quite a bit of time, we would like to start the creation of the files March 4th, 2024 and have everything printed and adjusted by March 22nd, 2024. That way the RASS was finalized the week of April 12th. Lastly, starting April 15th, 2024 we wasgin the edits of the final document and the final presentation. Table 15 highlights all these dates.

Table 15: Plan for SD2

#	Task	Start	End	Status	Responsible
1	Order Components	11/15/2023	12/03/2023	Completed	All
2	Testing Components	11/15/2023	12/05/2023	Completed	All
3	Meeting with Dr. Delfyett	01/08/2024	01/12/2024	Completed	Isabelle/ Brianna
4	Spectrometer Prototyping	01/15/2024	01/26/2024	Not Started	Brianna
5	Dichroscope Prototyping	01/15/2024	01/26/2024	Not Started	Isabelle
6	PCB Prototyping	01/15/2024	01/26/2024	Completed	Atman
7	Motorized Rotation Stage Prototyping	01/15/2024	01/26/2024	Completed	Atman
8	Design Spectral Graph Software	01/15/2024	02/16/2024	Not Started	Brandon
9	Initial Presentation	02/05/2024	02/09/2024	Not Started	All
10	Testing of Spectrometer Prototyping	02/05/2024	02/09/2024	Not Started	Brianna
11	Testing of Dichroscope Prototyping	02/05/2024	02/09/2024	Not Started	Isabelle
12	Testing of PCB	02/05/2024	02/09/2024	Completed	Atman
13	Testing of Motorized Rotation Stage	02/05/2024	02/09/2024	Completed	Atman
14	Testing of Software/ Bug Work Through	02/12/2024	03/01/2024	Not Started	Brandon
15	Revisions to Spectrometer Prototyping	02/12/2024	03/01/2024	Not Started	Brianna
16	Revisions to Dichroscope Prototyping	02/12/2024	03/01/2024	Not Started	Isabelle
17	Revisions to PCB	02/12/2024	03/01/2024	Completed	Atman
18	Revisions to Motorized Rotation Stage	02/12/2024	03/01/2024	Completed	Atman

Table 15: Plan for SD2

#	Task	Start	End	Status	Responsible
19	Meeting with Dr. Delfyett	03/04/2024	03/05/2024	Not Started	Isabelle/ Brianna
20	Create 3-D printing files	03/04/2024	03/15/2024	Not Started	All
21	Print all 3-D Printed Components	03/18/2024	03/22/2024	Not Started	Isabelle/ Brianna
22	Build Final System	03/22/2024	04/05/2024	Not Started	All
23	Test Final System	04/05/2024	04/12/2024	Not Started	All
24	Adjust Final Document	04/15/2024	04/19/2024	Not Started	All
25	Final Presentation	04/15/2024	04/19/2024	Not Started	All

10 Administrative Content

Administrative content to be considered includes the overall goal of the project and the technical processes that will occur in order to achieve it. Specifically, the process of the system, the necessary budget to purchase the components on a singular level, and the milestones for the timeline will all be explored.

10.1 Process

1. Open the housing lid.
   a. Ensure that little to no contaminants (dust, skin oils, etc.) are present on the sample stage.
   b. Clean the sample stage if contaminants are present.
2. Load the sample into the chamber by placing it into the center of the rotation stage and closing the lid to ensure ambient light will not interfere.
3. Initiate the test sequence by pressing a button on the outside of the housing.
4. The fluorescence process wasgin.
   a. The green LED will turn on and illuminate the sample, causing it to fluoresce if it’s a real ruby.
   b. The emitted light from the ruby will travel through the fiber and was analyzed via the spectrometer.
   c. Text was displayed on the screen that indicates whether the sample passes this phase of the characterization.
   d. Whether the sample passes this test or not, the procedure will continue.
5. The dichroscope test wasgin.
   a. The green LED will shut off and the white LED will turn on.
   b. The light reflected into the dichroscope would be focused onto the spectrometer, where if two distinct peaks are present then the sample passes the test.
   c. Repeat for three angles, labeled “Trial” and I, II, and III. If the ruby passes at least two of the three trials then it passes the whole test.
   d. Text was displayed on the screen that indicates whether the sample passes this phase of the characterization, with individual trials included.

    e. Whether the sample passes this test or not, the procedure will continue.
6. The individual test and trial results was displayed clearly on an external monitor. Specific data was available as well.
7. An overall consensus on whether the ruby is synthetic, natural, or fake was displayed in large letters.
8. The user was given an option to save the data to a folder.
9. The trial is complete and on-screen text will indicate that the user is able to remove the ruby from the housing.
    a. The data from the previous run will not clear until the user manually does so or a new run begins.
    b. If the previous run data was not saved, the user was prompted to save it before starting a new run. Nothing displays if the previous data was saved.

10.2 Budget

To complete this project it will cost approximately $545.61 as seen in Table 16. These prices are approximate as some of the specifications of the products might change. This project will have 4 main sections that was included into the budget. Including the Spectrometer, the Dichroscope, the electrical components and miscellaneous. For each component of the project there was different parts. The spectrometer will need a multimode fiber, two mirrors, a diffraction grating, and a detector. The Dichroscope will need a beamsplitter, calcite rhombus, glass prisms and mirrors. The electrical components include everything that was needed for the motorized rotation stage. Lastly, the miscellaneous section covers the rubies and the 3-D printing material.

Table 16: Overall Budget

Component	Manufacturer/ Model Number	Price
Spectrometer		
Multi-mode Fiber	Fiber Cable Direct FCDUS57v241	$9.49
Mirror (2x)	ThorLabs CM254-025-P01	$129.88
Grating	Thorlabs GR13-0305	$76.58
Pi Camera	DigiKey SC0818	$50.00
Raspberry Pi Module	DigiKey	$19.99
Dichroscope		
Beamsplitter	Edmund Optics #45-313	$46.00
Calcite Rhombus	Earth Gems	$38.00
Glass Prisms	Labnique MT-RAP-25	$57.00
Mirrors	Edmund Optics #43-866	
Electrical Components		Unit Price
Printed Circuit Board	Aoje- Link FR-4 Glass Fiber	$12.39

Table 16: Overall Budget		
Component	Manufacturer/ Model Number	Price
Transformer	Triad Magnetics TCT50-03E07K	$17.61
Bridge Rectifier	Diotec Semiconductor B250R	$0.72
Linear Voltage Regulator	Texas Instruments LM323K STEEL/NOPB	$65.71
Fixed Terminal Block	Altech AK500/2	$0.63
USB 2.0 Type A Connector	CUI Devices UJ2-AV-A-TH	$0.80
Green LED	Lumex SSL-LX5093PGD	$0.24
LDO Voltage Regulator	Onsemi LP2950CZ-3.3G	$0.49
White LED	Lumex SSL-LX5093XUWC	$1.19
Green LED (2)	Dialight 521-9251F	$0.68
Red/White/Green LED	Wurth Elektronik 156125M173000	$1.23
Miscellaneous		
Ruby 1	Amazon Gryrigns Synthetic Ruby	$16.98
Total		$545.61

10.3 Initial Project Milestones

These next two semesters we have a total of 7 big assignments. This semester was the design portion of our project and will have three major assignments. One being a divide and conquer assignment due on September 15th, and a halfway checkpoint on November 3rd to have 60 pages completed and finally a 120 page final report due December 5th. Throughout the process of getting this final report done we was meeting bi-weekly and occasionally more the closer we get to deadlines to ensure we are keeping our progress consistent. Our group was meeting various times for each big assignment. For the Divide and Conquer assignment we was meeting on September 14th to finalize our draft, on September 19th we will meet for the Divide and Conquer meeting that was held with our professors, on September 28th we will meet to finalize the publish to our website as well as discuss progress on overall research. Our next big assignment is the 60 page turn in, for this we will split it into two parts and meet on October 17th to compile a 30 page draft, then again on November 2nd to compile and finalize the 60 page draft, then we will have a meeting on October 7th with professors to discuss the feedback for the draft, and lastly for this assignment we will meet on October 14th to finalize publication to our website. For the final report we will meet on November 21st to compile a 90 page draft and then meet again on December 1st to compile the last 30 pages of the draft to finalize the report.

For the spring semester we will have 4 big assignments. This is the building portion of the project where we will put all the research together to build the 2-D ruby laser printer. This semester will consist of a Middle term demo, final presentation, showcase, final report. The showcase will also include a summary and video. The final report consists of a website, peer review and exit interview. During this semester we will meet weekly to discuss progress on individual sections. Starting in February we will start to combine the individual sections into a demo.

Table 17: Schedule for SD1

#	Task	Start	End	Status	Responsible
Senior Design I					
1	Ideas	08/21/2023	09/08/2023	Completed	Group
2	Project Selection and Role Assignments	08/21/2023	09/15/2023	Completed	Group
Project Report					
3	Divide and Conquer	08/28/2023	09/15/2023	Completed	Group
4	Table of Contents	09/18/2023	10/01/2023	Completed	Group
5	60 Page Document	09/18/2023	11/03/2023	Completed	Group
6	90 Page Document	09/18/2023	11/21/2023	Completed	Group
7	120 Page Document	09/18/2023	12/05/2023	In Progress	Group
8	Laser Acquisition	09/01/2023	09/22/2023	In Progress	Brianna/ Isabelle
9	Ruby Trigonal Structure	08/30/2023	09/22/2023	Completed	Isabelle
10	Ruby Fluorescence Spectra	08/30/2023	09/22/2023	Completed	Brianna
11	Spectrometer Schematic	09/18/2023	09/30/2023	Completed	Brianna
12	Dichroscope Schematic	09/18/2023	09/30/2023	Completed	Isabelle
14	PCB Layout	09/18/2023	09/22/2023	Completed	Atman
15	Recording & Data Abstraction	10/01/2023	11/01/2023	Researching	Group
16	Power Supply	10/01/2023	11/20/2023	Completed	Atman
18	Motorized Rotation Stage	10/01/2023	11/20/2023	Completed	Atman
19	Lens Design - Spectrometer	09/18/2023	11/20/2023	Completed	Brianna
20	Lens Design Dichroscope	09/18/2023	11/20/2023	Completed	Isabelle
21	Order & Test Parts	10/31/2023	12/01/2023	In Progress	Group

11 Conclusion

RASS began with a desire to quantify the objective methods that gemologists use to ensure proper gem structure and qualities to determine if a gem was real. The members of this team wanted to prove that a goal like this could be achieved for one of the most popular gems out there, ruby. In order to properly identify rubies, simplify the analysis process, and to produce reliable results, the idea of the RASS was created. Gemologists need years of training to produce reliable results using their separate tools, whereas through simple optical analysis these properties can be calibrated and discerned with ease and no training required. It would help the general public spend less exorbitant amounts of money that they already spent procuring the gem to get it analyzed and ensure it's real. In designing this system, the hope is that it simplifies the testing process of valuable gems and places less pressure on miners to procure more of them to compete with an ever growing market of fakes and imitations.

To achieve these goals, RASS utilizes simple spectroscopy to take advantage of several different gem properties. One of them is fluorescence, in which excitement at a certain wavelength causes the ruby to emit a different wavelength that can be tested for. If the wavelength detected is outside of this spectrum, it can be concluded that the ruby is not real. Another test that was implemented was a dichroic test, where the ruby is illuminated with incoherent white light and passed through a calcite rhombus to separate out its constituent rays. This test should have two peaks in the spectrum, each corresponding to a different color. These two colors will discern whether the ruby has a trigonal crystal structure or is an imitation, such as quartz and garnet not exhibiting any pleochroism.

The electronics within this system were selected in order to ensure the device would remain as compact as possible while not jeopardizing any of the optical components. A green LED is used that contains the necessary wavelength to cause the ruby to fluoresce, and is integrated within the viewing angle necessary for the light to properly hit the ruby. A white LED, primarily for the dichroic spectrum, is also implemented to ensure maximum illumination without interfering with the optical alignment. A Raspberry Pi module and a high quality camera was used to take an image of the spectrum that was analyzed via software to determine the different intensities of different wavelengths. In addition, the rotating stage was implemented with an adjoining Arduino board to control the rotation of the stage and ensure three different angles of incidence was achieved. Previous devices that achieve similar goals to ours were analyzed and concluded to have inferior analytical capabilities than our design, as well as being overly expensive considering the singularity in testing and the simplicity of the devices. The most notable ones on the market employed thermal conductivity tests, which can be easily bypassed and are more often recommended to be used in conjunction with other analyses, such as the ones used in RASS.

In terms of the optical components, a visual spectra was settled on being the most ideal due to safety requirements as well as power consumption. After careful study and fully considering the different avenues the RASS could embark on, it was concluded that working in the visual spectrum would be the most cost effective and beneficial wavelength range for the consumer. The dichroscope and fluorescence readings require different optical alignment systems, and thus are separated and focused into a beamsplitter that will allow for both of the readings to be fed into the spectrometer. These two separate systems operate on uncollimated light, and thus will need to be focused down into the fiber of the spectrometer after entering a beam splitter that will unify both systems.

The housing of this system was chosen to be 3D printed to ensure that the inner system can be analyzed should any faults occur, and to allow for simpler customization of the distances between optical systems as well as the electrical components. It will ensure the system is cheaper and uses less materials in the design process. Customization is imperative and should remain cost effective as it allows for the system to be expanded on in the future should more tests be included and the gem variety increased.

RASS was carefully designed with all of the key technologies necessary to carry out the intended goal of ruby analysis, and to pave the way for future technologies that can expand on this concept. The hope is that someday more tests was implemented that are calibrated to different gems. In this extensive documentation of the development process of RASS, future inventors have the capability to replicate this design as well as improve it. All references were carefully documented to ensure all information used has been kept transparent and readers can be assured that reliable sources were used in the research portion of the design process. RASS may not have a diverse selection of gems to choose from, but this proof-of-concept design is meant to be expanded upon in the future and to make the gem industry more reliable as a whole.

Appendix A Copyright Permission

Images provided in section 3.3.2 and section 3.3.3 Strategic Components and Part Selections are governed by one of the following:

- Raspberry Pi 4 B

Apache License 2.0 Version 2.0, January 2004 https://github.com/leswright1977/

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Images provided in section 6 Electrical Supply / Components are governed by one of the following:

- Diffraction grating spectroscope.

Apache License 2.0 Version 2.0, January 2004

https://github.com/leswright1977/PySpectrometer/tree/main/media

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