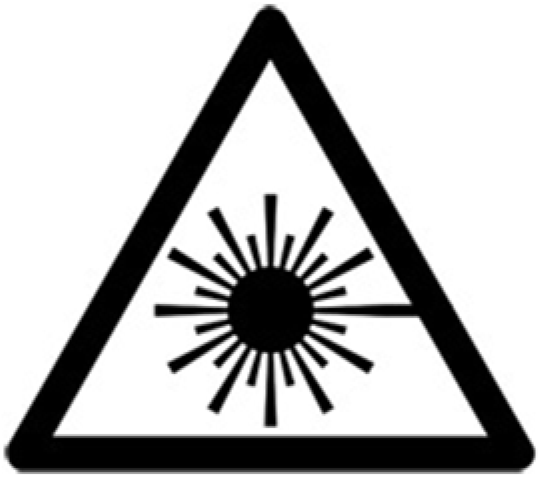

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Laser Skeet

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&
Department of Electrical and Computer Science

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1.0 Executive summary

Skeet is a sport that is modeled after fowl hunting. People participate to practice for hunting, for competition, or just for fun. During skeet shooting circular clay targets are thrown or launched into the air and the player attempts to hit the target using a shotgun. Skeet shotguns have a pellet radius of 30 inches at 21 yards. However, this pattern may be tighter or spread out more depending on player preference. Typical range for skeet is 62 yards, but can exceed 70 yards. Trap shooting is very similar but with different rules. Both Skeet and Trap are applicable to our project.

This project aims to take the worries of a firearm out of the sport of skeet and trap shooting. This will be done by replacing Lead pellets powered by gunpowder with a safe to user IR laser. The standard clay disk used as a target will be a re-usable puck with IR sensors that communicates with the shooter and indicate a hit along with some other functions to improve the overall experience with the device. The project would also allow the integration of features not available in conventional skeet, such as automatic score keeping, accuracy tracking, and head to head live-action competition.

The project will be implemented in a manner to meet the CREOL required technology as well as the CECS requirements. Additionally, we intend to gain experience in the implementation remote wireless sensor technology and microprocessors used in IOT and industrial applications. There is a wide range of laser tag type devices on the market. Our goal is to exceed expectations of these known devices and provide a higher quality product with exceptional features. A search of the internet revealed a price range of $25 to over $400 per device depending on the products features and quality. While these are similar in technology they are focused on implementing a different type game/sport. This leaves a large middle ground for product price and only limited competition on the high-end product. The fact that the electronic type will be reusable will help offset a cost of conventional clay targets, but still require a larger upfront cost. Marketing potential towards enthusiasts who can’t shoot in their own backyard, people who want to play it indoors, people who want a safer gun to teach their children how to handle firearms.

This device is to be designed with an understanding that the primary users would be enthusiasts of the skeet shooting sport and public safety. The final prototype will be that of a realistic rifle design, accurate skeet target dimensions and weight. Housing of both are to be durable for the nature of the sport and of sufficient materials to provide an indistinguishable realistic environment. All devices are to comply with regulations on imitation firearms, IR laser technology, and RF communications.

2.0 Project description

Laser Skeet shooting can be a new way to provide a safe method of practice or training for the skeet sports. Rather than always having to use conventional bullets and non-reusable clay targets, an individual can use this Laser Skeet device to trigger a re-usable target, which in the long run reduces the amount of lead waste, littering, whilst increasing safety and cost effectiveness.

2.1 Goals and Objectives

Primary goals of this project are to design and develop a new method to practice and implement the sport of skeet. Researching components that will provide the most accurate results, safety measures and meet regulation standards. Through our research endeavors, we aim to create a product that will close the gap in the market for a popular firearm sport by creating a difference in safety between firearms and home use.

Hardware – Two separate PCBs will be made to comprise of a single system. All components critical to power will be connected to the main board with external components mounted to the rifle and or target frame. The laser rifle will comply with regulations on the production of imitation guns.

Software – Software will be required for each of the PCBs. The target software's job will be to relay a laser detection hardware signal over the RF communication path back to the rifle controller. The Rifle controller software will provide the pulse wave modulation for the laser, timing of the pulse, reception of the hit signal form the target, and provide the user interface. Both will also contain the software stack necessary for implementing the RF communications.

User Interface – Design a simple structure for the user to operate the devices, this will be an intuitive process based on the realistic quality of the two devices. Providing an easy to understand display and controls will give this product the advantages over competitive products already in the market.

Power Supply – Power is to be supplied by two batteries in both devices to allow for the use of RF communication. Power will be stepped down and properly regulated for the laser driver system, communication systems and protect the MCU in any un-predictable dynamic occurrence.

Laser Driver – The IR technology utilized by the laser rifle system will abide by the FDA requirements on power limitations, wavelengths to be used and appropriate notice markings on the rifle. Safety measures are also taken to ensure that the laser will not discharge without proper intent.

Communication – RF processing for this will be completed using a 915MHz protocol located in the FCC freeband spectrum. Both the skeet target and laser rifle will be affixed to communicate through the twin MCUs on both products, these will retain communications in accordance to FCC regulations on power and range restrictions.

2.2 Requirement Specifications and Features

This section is divided into two parts, the first being a list of specifications that the team will be required to meet for a laser skeet shooting design, the second being a list of design parameters that the team would stretch to accomplish. Where having a design that can meet our own standards and requirements of a completed design, the ultimate purpose is to create a laser skeet shooting system that is able to shoot a target, detect the signal, transmit this detection via RF and capture this transmission on the rifle as seen below in (Table 1). Stretch goals would include factors that this team would implement if the given resources and times allotted is permittable.

Specifications – Design parameters that this team is entitled to meet and exceed.

Table 1 - System Specifications

Laser Rifle System	Skeet Target System
Approximate weight of 10lbs	Approximate weight of 110g
Achieve a laser range of 15 yards	Activate hit detection at 15yards
Dimensions – 50in long (standard feel)	Size of 110mm diameter x 26mm height
Modularized Shot Design, simulate various ammunitions	Capable of detecting Modular shot designs
Less than 1.5in of effective spread	Capable of detecting sensitive IR specs
RF Communication within Standards	RF Communication within Standards
System operates under 750mW	System operates under 750mW
Prototyping Budget of $325 (of $750)	Prototyping budget of $121 (of $750)

Features – Design feature characteristics that are not directly linked to the optimal design's performance. These are features in a design that would either enhance user experience or to give the system extra challenges to meet. They are listed in Table 2 below.

Table 2 - Additional Project Feature Characteristics

Feature	**Desired Characteristics**

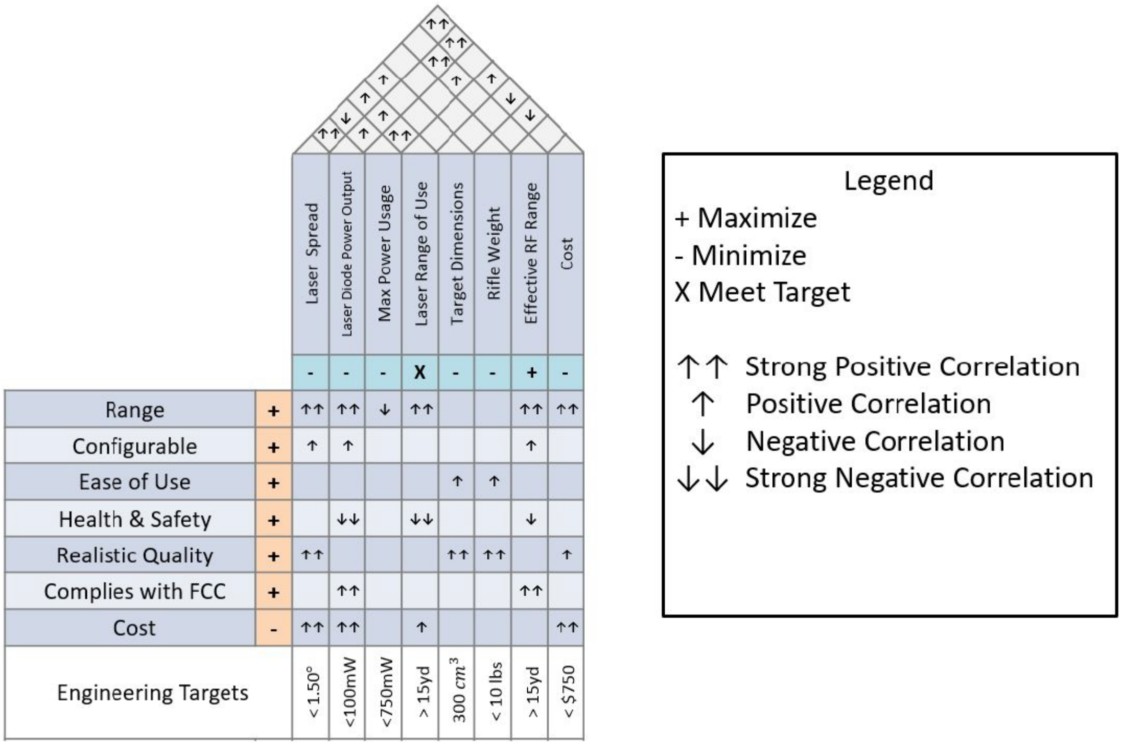
Laser Rifle	• Realistic resemblance of a rifle's weight and dimensions
	• Structurally capable of housing electronic components and safety protect the laser driver focus mechanism.
	• Hold all markings required for a laser and imitation rifle product
	  ◦ Visual laser warnings
	  ◦ Active laser indicator
	  ◦ Orange barrel tip
	• Speaker to alert the user of a hit detection
	• Vibration motor triggered by a laser shot signal and hit detection

Skeet Target	• Have more than one target created to allow for a full game to be played. 60 targets or so would be needed however, therefore multiple targets would be very limiting to our goals and objectives • Activate a de-flight sub system upon a proper hit detection • Activate LEDs upon a proper hit detection • High pitch tone speaker upon hit detection
Laser	• Retain safety measures to prevent accidental discharging • Abide by output power regulations for commercial use.
Range	• Final product expected to operate between 15 yards minimum with a stretch goal of 75 yards.
Microcontroller	• Control the Laser Driver activation, providing safety countermeasures • Communication through LCD and user input controls • Feature a pre-loaded MCU requiring no debug system on the final PCB
Power	• Develop a system that utilizes minimum amounts of power for operation.
Cost	• Retain a cost ceiling of $750 for initial prototyping and materials of housing the electronic components • Obtain high performance IR and RF components • Implement a prototype design that can be scaled down on specific components if mass production were to be considered.

2.3 House of Quality

A house of quality is designed to further investigate and confirm the qualitative aspects that will yield a maximized design (Figure 1). Overall, it is known to this team that in order to create a device that operated at incredible ranges, the ultimate cost of this unit will increase. Therefore, we have decided to choose a targetable range of 5 yards for preliminary testing to establish a baseline and increase testable ranges for preliminary components. The hopes of this process being that a larger range of operation can come from selecting quality parts from the get-go and observing the maximum range.

Figure 1 - House of Quality



		Laser Spread	Laser Diode Power Output	Max Power Usage	Laser Range of Use	Target Dimensions	Rifle Weight	Effective RF Range	Cost
		-	-	-	X	-	-	+	-
Range	+	↑↑	↑↑	↓	↑↑			↑↑	↑↑
Configurable	+	↑	↑					↑	
Ease of Use	+					↑	↑		
Health & Safety	+		↓↓		↓↓			↓	
Realistic Quality	+	↑↑				↑↑	↑↑		↑
Complies with FCC	+		↑↑					↑↑	
Cost	-	↑↑	↑↑		↑				↑↑
Engineering Targets		< 1.50°	<100mW	<750mW	> 15yd	300 cm^3	< 10 lbs	> 15yd	< $750

Legend

+ Maximize

- Minimize

X Meet Target

↑↑ Strong Positive Correlation

↑ Positive Correlation

↓ Negative Correlation

↓↓ Strong Negative Correlation

From the consumer’s standpoint, a laser skeet system should operate at common ranges between 15 and 75 yards depending on an establishments range configuration and the level of expertise the user wants to shoot from. This contributes to a higher requirement for laser spread accuracy, range of use and costs associated with these two parameters. Various types of shots and guns can be used and simulated by adjusting the laser output to operate under semi, full and burst fire conditions as well as manipulate the laser spread to further accommodate these variations. The device should meet and exceed a user's desire to operate this laser skeet system under the assumption of intuitive controls and realistic design. Health and safety is always a prime concern when it comes to using weapons in today's world. Therefore, the design will accommodate safety features in the laser driver system as well as the rifle housing itself.

In the skeet shooting world, this laser skeet system would provide a lower cost from conventional systems whilst being able to have a game of skeet shooting anywhere. Therefore, the differences in costs associated with the laser rifle and re-usable targets would make this design a cost saving practical way of training for a skeet competition, practicing at home, and overall fun. Without having to purchase an actual gun to use at every skeet event, not to mention constantly resupplying ammunition and targets, this design is an incredible way to save the consumer end market of the building costs.

2.4 Stretch Goals

This team would ideally have as many components as possible to give a realistic feel to the final design. Such items include but are not limited to, vibrational responses, varied tunable sounds, selection of target range practices, manipulation of the laser output to simulation various firing styles, two-gun mode-head to head competition. These would be magnificent to the final design and would prove otherwise that a more realistic counterpart to a prototype would be within reasonable range.

The idea of adding in all these multitude of vastly un-needed components, would traverse the team into fulfilling non-required objective. Solely speaking, this team aims to create a laser target and rifle that are able to work in conjunction with one another at the pre-speculated restrictions. Filing our primary goal as getting a single system working, tested and approved will be the first and foremost goal of this team. As time is a key resource, we will divulge the time and energy required to fulfilling these stretch goals on when sufficient amount of progress has been made on the primary system, such that these stretch goals can be simultaneously worked upon.

Goals to be stretched on would be the applications of non-essential system design components that would provide a benefit to the final user end experience. These consist of having speakers, motors, LEDs in a shooting and hit detection systems. These components are further outlined in the research section as well as the design sections of this document.

2.5 Project Instructions and Operation Manual

This section is to further outline the directions and simple operations to establish the first game of skeet shooting. Objectives here are to provide a user with the needed information to setup initial operation of the devices outlined within this project and to operate the system. These fundamental steps are to express to the user end community on how a typical start to an exciting and thrilling game of laser skeet shooting.

2.5.1 Setting Up a Rifle

The laser rifle itself holds a primary power switch, activating this switch will initiate the entire rifle, applying power to the system. This further enables the laser driver to enter a pre-threshold power level such that before firing, the power signal that delivers the laser blasts to the target can be achieved at a much quicker and safer rate. Once the laser rifle is powered on, the user operates the menu to select the shot type, range, and other variables pertaining to the user's skeet scenario.

The system provides three input buttons in addition to a reset.

Button_1 is the trigger and allows firing and also acts as the select for menu operations.

Button_2 is the menu control and provides a means to switch to the next menu.

Button_3 is reload control and acts to reset the remaining shots back to full.

Before the system is available to use the target skeets to be used must be joined with the rifle. When they system starts it should begin at the joining menu. If not on that menu Button_2 can be used to change to that menu. While on that menu ensure that joining is allowed. Button_1 will toggle joining on and off. While allowed the target skeets can be powered on or reset. They should then join the network. Once all desired targets have been joined to the network joining may be turned off.

Button_2 provides switching between the other options. When switched to the reset screen Button_1 will reset the scores. When switched to the mode select screen the shot mode can be changed between double, pump, and auto by using Button_1. Once ready to play switching to the game play screen will display the shot counts and allow Button_1 to operate the laser.

The laser rifle is then further primed by removing the lens cap, opening the safety iris, and switching the safety to off. The laser rifle is now primed and ready for safe use. The user can then press the trigger to activate the laser rifle. Note, holding down the trigger will not keep the laser on, this safety measure is protected within the MCU's programming such that the laser cannot be kept on unless explicitly desired.

Deactivating the target is performed by switched the safety switch back to on, placing the safety iris into a closed position, and replacing the lens cap to the front of the rifle. The rifle will now be appropriately deactivated such that the laser will not fire and or emit from the rifle's muzzle. The rifle can be operated safely now in the on position, or switched off to conserve power and store away.

2.5.2 Setting Up a Target

When powered on or reset the skeet target will be pre-programmed to with the information necessary to begin looking for the laser rifle communication network. The process outlined in the rifle setup should be followed to allow the target to join the network. Once the target devices are on and joined to the network communications will be enabled. This will stretch across a distance of approximately 75m, of which a game of skeet can be held. Once the target is activated, it may be confirmed to work by placing a single shot directly at the optical sensors located on the skeet target. The target can then be placed either stationary or launched as a projectile at a velocity no higher than 50 mph.

3.0 Project Research

The following subsections outline and envelope the research conducted on essential components that are vital to the specifications for system operation. Consisting of the laser system and optics, wavelength selection specifications, laser diode selections and much more, each section outlines the rationale behind the specification requirements and selection of components. The purpose of these sub-sections is further to compare and contrast multiple components for a particular aspect of design and conduct examinations on where specific criteria of a component fall under scrutiny and ultimately decide whether or not a part will make it into the final prototype. This section further covers the components that would not be completely necessary to the final design but would be an exemplary part to include in the completed product. These complimentary parts are used to enhance and enrich the user experience.

3.1 Laser System and Optics

To recreate a skeet shooting system without using disposable parts of the bullets and skeet, a laser detection system will be implemented in place of said parts. The laser will replace the bullets and a reusable skeet covered in photodetectors. The laser system will be housed in the ‘barrels’ of the gun and will triggered after a delay when the trigger is pulled. The laser light will then illuminate the photodetectors lining the skeet to register a hit. Optics will be used to both collimate and spread the laser light to a set value as well as offer a variable spread. Additional optics will be used for creating a more circular beam profile at the designated target distance.

The following information is standard information regarding shotguns that will be used in the following sections regarding the laser and detection systems. The shotgun size used for this system will be modeled after a typical 12-gauge shotgun. A shotgun spreads an average of a half inch per yard of travel, therefore; the minimum goal of this section is to create a spot size of 7.5 inches at a distance of 15 yards. The bore diameter of a shotgun barrel can vary between 18.5 mm and 20.3 mm for a typical 12-gauge shotgun, so the values of 18 mm to 20 mm will be used when designing the optics for the laser system that will be discussed later in this section. The barrel length can vary from 28 inches to 32 inches for normal shotguns with larger variations [17]. The values for the laser system will be set at a minimum bore diameter of 16mm and a maximum barrel length of 30 inches.

3.1.1 Wavelength Selection

An important parameter of the laser system is the wavelength of light used for the hit detection. The prevalent parameter for the wavelength include: eye safety, solar interference, power needed for operation, manufacturability, and price. The following section will discuss the previous mentioned parameters in length, as well as the implications they have on the selection of the wavelength.

The first and most important parameter is eye safety. Since the power level needed to harm a person other than the eye will not be used for this laser, the only hazardous effects to the eye will be discoursed in this section. The important information regarding eye safety is the power of the light, the exposure time of the light, the diameter of the beam, the pulse of the light, the visibility of the light and at what angle the beam of light hits the eye [18]. More power means a larger hazard to the eye. The laser light is hazardous because it causes the eye to heat up quickly, causing damage to different parts of the eye depending on where the light is focuses. The safe power ranges for lasers is typically 0-500 mW, but other parameters also play a part in what power level is harmful. The length of exposure time is directly related to the safety of the eye. The longer the eye is exposed to the laser light, the more likely there is to be damage to the eye. Even laser of relatively low power can cause damage if the eye is exposed for a long time. The exposure time of the system will be discoursed in the modulations section. The diameter of the beam is also directly related to the safety of the eye. The diameter of the beam relates to the energy density of the laser light. A smaller diameter leads to a higher energy density and vice versa. The higher energy density can cause the eye to heat up much faster than a lower one. The energy density is semi-independent of the laser power, the energy of the spot cannot exceed the energy of the laser, but a laser with an output power in the safe region can still cause problems if the beam is focused small enough can still cause damage to the eye. Since the focus of this laser system is to spread the beam and not narrow it, the danger of a narrow beam diameter is not a concern for the wavelength selection. The only place the beam will be small is in the actual laser system in the gun. This will be further discoursed in the optics section.

The pulse of the laser can also cause significant damage to the eye. Pulsing a laser can cause very high intensities in a very short period of time to occur. These pulses can cause the eye to heat up extremely quick. The laser system used for this project will not pulse the laser fast enough or cause energy spikes that can affect the safety of the eye, further discussion of this topic is located in the modulation section. The wavelength of the laser light relates to what part of the eye the light is focused on. The human eye has an adjustable lens which it uses to focus light onto the retina of the eye, and like a normal glass lens, the lens in the human eye focuses different wavelengths at different spots onto the eye. Wavelengths below 320 nm and above 1400 nm will not be focused onto the retina of the average human eye. These wavelengths can still cause damage at high enough powers to other parts of the eye, but they are far less likely to cause blindness. The other important safety pertaining to the wavelength of the laser light is the visibility of the light. The human eye can only see light in the visible region of the spectrum hence the word ‘visible’, and the light outside that region in not seen by the human eye. The danger from this is the eye reaction to close itself when the intensity of light is too high. When a person looks at the sun, they naturally start closing their eyelids because the light intensity is too high. This reaction only applies to the light the eye can actually see, so light outside the visible region do not cause the close reaction to intensity. Most lasers outside the visible region have additional safety measures in place to show people that the laser is on, this will be further discoursed in the laser section. The angle of incidence to the eye determines where the beam is focused determines where the light will hit inside the eye. As previously stated in this section, the spot of focus is related to eye damage. Since there is no preventive measure to cause the light to hit a certain angle, it will be assumed that the viewer is always looking directly at the laser light when discoursing the laser system in the following sections. Direct angle causes the most damage to the eye with larger deviation angles causing less damage.

Solar interference is related to the detection of the photodiodes. Most detectors cover a large spectral range and are focused around a central peak wavelength. Solar emission resembles a black body heat source with a peak wavelength of about 440 nm. The solar emission than slowly drops off as it goes farther into the infrared region. The solar spectrum exists above the atmosphere and at sea level. The emission above the atmosphere shows a fairly smooth line with a lot of variation around the peak. The sea level emission shows a similar trend at a lower intensity value, but it shows dips in the near infrared region. The dip centered around 940 nm is especially important since it coincides with the range where silicon lasers and detectors are most prevalent. Based on the trend of the solar emission line, the farther into the infrared region the spectrum goes the less light intensity reaches sea levels therefore the less noise the detectors will pick up [19]. Since the photodetector has a wide spectral width, the laser will be the deciding factor for this parameter since they have linewidth emission spectrums. Silicon based lasers are both plentiful and less costly than other semiconductors. Silicon is typically good for red and near-infrared wavelengths (600-1000 nm). As stated above the, 940 nm would be ideal for this range. Other areas of interest include 1400 nm since it is both an eye safe wavelength and the solar emission intensity at sea level is also near zero. 1400 nm is both costly and less prevalent.

Power needed for operation is also a concern for this laser system. The system itself will have to be compact since it needs to fit inside the area of a gun barrel. A laser diode would be more desirable than a larger gas media laser. Laser diodes also need less power for operation since they have higher efficiency than other laser types. Laser diodes have one central wavelength with some tunability. A laser diode can be easily powered with a more conventional power supply, say a AA battery.

Cost and Manufacturability are also important parameters in deciding the wavelength. As was discoursed earlier in when talking about solar emission, not every wavelength is available for purchase and some can be costly. This product is designed to be user-friendly and low cost, so a cheaper laser is desirable at the cost of more noise interference. A laser diode provides a wide selection of wavelength ranges. Silicon tends to be the least expensive of semiconductor devices, and they correspond to the wavelength range of 600 – 1000 nm. 1400 nm is less likely to be as available since it is a specific wavelength and typically not silicon based, and they would need their own detectors to operate.

Based on the previous information, the wavelength of 940 nm would be selected for the laser system. Depending on the availability of the laser diode and power rating. If 940 nm is not available, then larger wavelengths such as 980 nm will be selected. 1400 nm will only be used if both a suitable detector and laser can be found.

3.1.2 Laser

The laser by definition is the most important part of the laser system. As was stated in the previous section a semiconductor laser at a wavelength of 940 nm would be the most ideal for this system. A laser diode is both compact and needs low power for operation as compared to larger gas and chemical lasers. Laser diodes come with the previous advantages but come at the disadvantages of being temperature dependent, having large divergence angles, and running hot during operation. This section will discuss how those disadvantages can be mitigated or removed.

The first disadvantage of a laser diode is that they are temperature dependent. A change in temperature will have a change in the bandgap energy of the semiconductor. The bandgap energy is directly tied to both the wavelength and the power needed for operation. The wavelength of a laser increases by about 0.3 nm per 1 k change in temperature [20]. The temperature dependence can be an advantage if the temperature can be controlled. This laser system will be in a compact device as well as be outside, so there is less ability to keep the temperature controlled. Usually a heat sink will be placed around the diode to remove unwanted heat. Since the heat sink can only remove heat, it is a passive system that can only stabilize the temperature of the laser diode to a set point. A Thermo-electric control plate can also be used to control the temperature of a laser diode. The TEC is an active system that can actively tune the temperature and therefore the wavelength of the laser diode, turning a disadvantage to an advantage. The TEC comes with the disadvantage of consuming a lot of power as well as putting out a lot of heat. The TEC removes heat from one side of the plate and discharges it on the other side with the additional heat needed to run the device. The TEC plate will be harder to implement than a heat sink. A fan can also be implemented into the system, but has similar power problems to the TEC.

The second disadvantage of a laser diode is the large divergence angle of a laser diode. This large divergence angle comes from the light emitted from the edge of the diode diffracting of itself. The light emitting region of the diode is typically on the order of 50x100 um. The principle of light diffraction states that light has a tendency to curve around small edges. At 50x100 um, the deviation angle can be quite large, on the order of 30 degrees for the fast axis and 15 degrees for the slow axis. The fast axis refers to the larger angle since it divergence faster at corresponds to the 50 um side of the emitting region and the slow axis refers to the 100 um side. The output beam profile of a laser diode with no other elements in front of the diode shows a line profile. This line profile is undesirable for this application, so it needs to be corrected using optics. A collimating lens system can be placed in front of the diode to make a straight beam [20]. This beam will have a parallel beam with the lines being the top and bottom edge of the beam as viewed from the side, but the beams will still diverge. The divergence angle will be greatly reduced, on the order of milli-degrees. For this application, the divergence beam is not a negative since one of the features is an adjustable spot size at the target distance.

For this application a laser diode would be the most ideal. A heat sink can be placed on the laser mount to reduce the amount of heat on the laser, but the heat from being outside would be a larger concern. One solution is to adapt the optics and detectors to work at the new wavelength. The additional power consumption will not be a concern since it will not be a large increase based on the supply for the system. The divergence of the beam can be adjusted with a collimating lens. The collimating lens will be explained in the optics section. Comparisons of laser diodes are expressed in Table 3.

Table 3 - Component Comparison of Laser Diodes

Laser Diode	Wavelength (nm)	Output Power (mW)	Divergence (F/S) (Degrees)	Threshold Current (mA)	Price (USD)
M9-940-0100	940	100	28/8	140	304
M9-940-0200	940	200	28/8	20	579
L980P010	980	10	13/30	15	27
L980P030	980	30	10/30	50	66
L9805E2P	980	50	6/30	60	75

3.1.3 Laser Beam Shaping Optics

The optics in the laser system are for beam shaping of the laser to create the desired results, with the desired results being a circular spot size of 15 inches in diameter at a target distance of 15 yards. There are different solutions to this problem with each coming with different advantages and disadvantages. The following paragraphs will discuss each solution and how it affects the whole system at other solutions. Optics materials and safety will be discussed at the very end of this section.

The first optic element of the laser system is the collimating lens which was previously discussed in the laser section. The collimating lens can either be a single lens or a lens system or a multi lens system. The single lens system will consist of one aspherical lens that will collimate a beam when placed at the focal length. Aspherse are typically made from molded plastic and acrylic with more expansive ones being made of glass. The aspheric lens does nothing for the ellipticity of the beam, therefore there will still be a difference between the divergence between the slow and fast axis of the laser. The output beam diameter is directly related to the focal length of the lens and divergence angle of the beam. Larger focal lengths and divergence angles lead to a larger beam radius. The multi lens system con contain upwards of 6 lenses to collimate the laser beam. Typically, multi lens systems try to correct for other aberrations in the beam profile that a single Aspheres lens would not be able to do. Due to the complexity, price, and mounting problems associated with a multi lens collimating system, a single aspheric lens will be used to collimate the laser beam.

Additional optical components such as a radial iris and linear polarizer may also be used. The radial iris will be a mechanical user operated safely mechanism. The iris will be placed on the optical axis and closed to prevent the beam from exiting the gun. The linear polarizer is a device that can control the output power of the laser beam. The linear polarizer can be rotated from the maximum power transmission to a lesser transmission. The linear polarizer will most likely be in a fixed rotation in the optical system to allow for more freedom of design while not being unsafe.

The second optical component needed is a device that will correct the ellipticity of the beam to create a more circular beam profile at the target distance. Since the only way to correct the deviation angle of the fast and slow beams to match each other, simpler methods are needed with an emphasis of only correcting the spot size at the target distance and not for the entire length of the beam. Two optical solutions are a curved lens pair and an anamorphic prism pair [21]. The cylindrical lens pair is a pair of lensed that can correct for ellipticity and collimate the laser beam, but it does not do either very well. The lenses work by collimating one axis of the laser beam independently of each other [24]. The first cylindrical lens will be placed a focal length away and will correct the fast axis. The second lens will be placed another focal length away and correct for the slow axis. The lenses should be chosen based on focal length distance to match the ratio of the fast and slow axis to create a circular collimated beam. An anamorphic prism pair has the ability to magnify the one of the axis of the beam. The magnification can be controlled be the rotation angle of the prisms and the distance they are from each other. This device can magnify the slow axis of the beam so that when it deviates slower coming out of the system it will overcome larger deviation angle of the fast axis at the target distance. The disadvantages of the anamorphic prism pair are that they are costly and hard to mount. The prisms have less room for error when mounting them since the angle of incidence is a factor for how well they magnify the desired axis of the beam. Additionally, the anamorphic prism pair causes the optical axis to deviate, but for this application the deviation of the optical axis is not a concern. Because of the greater versatility of the anamorphic prism pair was chosen to be the corrective element for this optical system. The table below shows a comparison of the different ways explained to both collimate and correct the ellipticity of the laser beam (Table 4). This chart will be used later on to determine the most cost-effective way to create the laser system.

Table 4 - General Parameters for Beam Shaping

Collimation	**Size**	**Cost**	**Ellipticity**	**Beam Focus Ability**	**Diameter Control**	**Divergence Control**
Single Aspheric Lens	Small	Average	High	Good	Poor	Fair
Two Cylindrical Lenses	Average	High	Average	Good	Average	Good
Aspheric Lens + Anamorphic Prism Pair	Large	High	Low	Excellent	Average	Good

The next component for this system is an optical device to both expand the laser beam and control the divergence. This can be achieved with a beam expander. The simplest method would to use a single convex lens to diverge the beam. This system does not allow for divergence control or expansion of the laser beam. The two traditional beam expanders are the Keplerian and Galilean beam expanders [23]. The Keplerian beam expander consist of a single positive bifocal lens and a single Plano convex lens to expand the beam. The magnification of the beam is dependent on the focal lengths of the two lenses. The magnification is the focal length of the back lens divided be the focal length of the front lens. This setup provides an easy way to alter the magnification of the laser beam by varying the focal lengths. Since the beam does converge inside the beam expander, measures need to be taken so that the energy density of the laser at that point is not dangerous, but the laser used for this application will not be powerful enough to cause damage. Additionally, that focal point is a good spot to put a pinhole to clean the laser beam of stray light as long as the material used for the pinhole is able to withstand the heat of the laser at that set point. The second beam expander is the Galilean which uses a single negative focal length lens and a single positive focal length lens. Since the two lenses have different sign focal lengths, the beam will never converge inside the system causing problems like in the Keplerian system. The magnification of this system is also a ratio between the two focal lengths creating an easy way to adjust the magnification of the system.

Another parameter needed to be considered for optics is the material they are made of. The material plays an important part in component functionality and cost. Since this application only uses one wavelength, the material selection is simplified. Also, there is no need to correct for aberrations in the system since the system's only determining factor is if laser light was detected or not. Because of the previous two reasons, the material selection can be simplified. Another component of the material selection, is anti-reflection coatings to increase transmission. As the laser beam passes through each component of the system, it will lose power from the material absorption. An anti-reflection coating will cause more light to pass through the lens and not be reflected back. Back reflections only cause a problem when the lens system is open and when the light goes back into the laser causing it to become unstable. The laser system for this application will be closed, so only the light exiting the barrel will leave the system. Since the laser will only be on for a fraction of a second, the stability of the laser will not be a concern. The materials used for the components will most likely be uncoated NBK-7 and acrylic for the lenses.

There will be no parts comparison in this section of the report since the exact specifications for the required optical components are unknown. Also, since it has already been stated that the components will be purchased unmounted and uncoated if possible, the lens from one company will be the same from another company for the same specifications. When designing the optical components, the design components will have to be close to or exactly the same as off the shelf components since custom optics will not be used.

3.1.4 Modulation

In order for the photodetectors to register a hit, a modulated laser light will be used. Modulation can also be used for multi-gun detection. In order for the laser diode to be turned on, it needs a certain minimum current, the threshold current. Suppling current below the threshold will cause the laser diode to act like a LED while suppling current above the threshold will cause it to work as a laser producing coherent light. While in LED mode, the light will not be intense enough or directional enough to affect the photodiodes. The modulation itself will be provided by the MCU using pulse width modulation. PSM will allow rectangle pulses of varying duty cycle and voltage to be created. In order to reduce noise in the system, the laser diode will be held just below threshold current while the PWM will provide the necessary current to turn the diode off and on in the LD mode. The

PWM modulation voltage will be fed through a non-inverting summing amplifier along with the DC bias to create this signal. The operational amplifier circuit will have to be low noise as well to not introduce any variations in the input signal. This method will allow the diode to have a faster response time. Another component of noise will be the relaxation oscillation of the output power of the diode as a function of supplied current. The laser diode acts like a RC circuit in that it has storage elements that will need to be stabilized before they produce a steady output power. For this application there is no way to reduce the relaxation oscillation noise from the laser beam output, but if the laser is pulsed slow enough the relaxation oscillation will not cause a problem Additionally, a LED will be wired into the laser diode circuit so that whenever the laser diode is on the LED is also on to indicate the laser is in use as well as both a shunt diode and a fuse to protect both the operator and the laser diode.

3.1.5 Mounting and Placement

The mounting and placement of the optics is very important for the final product because they directly relate to how well the system will work. Mounting the nonmoving lenses can be done by using threaded pipe similar to how mounted lens holders used for testing are designed. By placing on threaded ring down the pipe at the desired distance will act as one side of the retaining wall. The lens will then be placed down the pipe, making sure that they do not scratch the sides, and fitted on top of the first retaining ring. The next retaining ring will then be threaded behind the lens until it is snug. Epoxy can be placed on the retaining rings to lock them in place after every element is properly aligned. Alternatively, a clamping ring can be placed around the outside of the lens and secured with a rubber tipped screw or a tension ring such as a O rings. This method allows for better off axis mounting of lenses with less chance of damaging the lenses during mounting, but this method does not work for small diameter lenses. The laser diode can be fitted with an adapter ring and placed inside piping and secured similarly, to the lenses. The collimator lens should be secured to the same pipe as the laser to allow for better collimation.

The movable lenses can also be placed into piping like the nonmoving lenses, but they must be secured in a way that allows them to move a designated distance. A micrometer and spring system used in translation stages can be adopted for this situation. The pipe contains the movable lens will be secured to the system with springs and a micrometer will be used to push against pipe to allow translation. The pipe needs to be secured in a way that will allow it to translate in only the direction it needs to. This problem can be solved by securing all the piping in a larger diameter pipe. Spots for the micrometer will need to be cut away, but it will allow only one direction of translation. Rotation will also be possible without additional measures to secure the lenses, but since the lenses are symmetric this will not cause an issue with the beam profile. The last element that needs to be placed are the anamorphic prisms. The prisms can be secured at the tips with clamps and epoxy. The whole system can be put together using piping fixtures. Since the optical axis is not straight due to the anamorphic prism pairs causing the beam to move the whole system will have to take two barrels worth of space.

3.2 Detection System

The detection system will be entirely enclosed inside the skeet, therefore; a compact and low power design is needed. The detection system itself consist of three components: the coupling optics, the photodetector, and the demodulation circuit. Each of those three components will be discussed in length in the following sections.

3.2.1 Coupling Optics

The coupling optics used in the skeet are used to both increase the amount of light that will be incident onto the photodetector and reduce noise from undesirable wavelengths. The first component needs to be able to increase the amount of light on the photodetector. This can be easily done by using a lens, but lenses are fragile, expansive, and large. A normal lens could increase light, but it would be more detrimental than advantages to implement into the skeet. The lens would have to be placed in a way that will directly focus the light, but that would be almost impossible since the skeet will tilt along the central axis as it flies through the air making a lens unlikely to always couple light onto the photodiode. Also, a lens is a fragile device and would be unlikely to repeatedly survive the impact of the skeet hitting the ground. A Fresnel lens can be used instead, since they are low cost, made of plastic, and can cover a wide area and acceptance area. A Fresnel lens is a lens comprised of many smaller lenses concentric around each other. Each individual lens has a small acceptance angle, but the multitude of them can cover a wide area. Since a Fresnel lens can be made of molded plastic, the lens can be shaped and bended to fit the space inside the skeet. The second optical component used will be an optical bandpass filter. The bandpass filter typically has a narrow bandwidth on the order of 20 nm with lager bandwidth of 50 nm for the full width at half maximum.

The filter will provide good protection for unwanted wavelengths to reduce the noise, but like the optics previously discoursed in the laser section, they reduce the optical power of the light. Most filters are coated with an antireflection coating to increase transmission, so typical values for transmission are around 90%. The filter also has a narrower acceptance angle, so careful selection of placement will be needed to ensure that maximum light makes it through both of the coupling optics. An additional optical element that can be added to the photodetector is mirrored film placed around the photodetector similar to a bulb to increase the light that is incident onto the detector. Since the light that is reflected by the mirror will have a different path length than the light that is not, it can increase the noise level but since the speed of light is much faster than anything that needs to be measured for detection, this parameter will not be considered. The placement of all components will be discoursed in the component section

3.2.2 Photodetector

The photodetector is the most important component of the detection circuits. This photodetector is placed in between the coupling optics and the demodulation circuits. The important parameters for this section include the acceptance spectrum, required power, sensitivity, size, and cost.

Spectrum - The acceptance spectrum of the detector is important because it states what wavelengths of light the detector accepts and what wavelength is more sensitive to the diode. The typical spectrum covers a large wavelength range with a central wavelength. Since the wavelength was picked to be in the infrared region centered at 940 nm ideally, the photodetector will also need to coincide with the same wavelength. Most infrared detectors used in normal infrared communication used in remotes and short proximity circuits are centered at 940 nm, but the detectors tend to have less sensitivity.

Power - The power needed to supply the photodetector is an important parameter if photodetectors that also integrate a gain circuit into them is used. A typical photodetector will not need much voltage to operate, no more than 5 volts should be needed since the photodetector in this circuit is not used to amplify the signal. Just pass the signal to the amplifying and demodulating circuit.

Sensitivity - The sensitivity is the parameter governing how well the circuit will be able to receive the signal. High sensitivity has both advantages and disadvantages since it is more likely to receive the signal but is also more likely to increase noise. If the coupling optics are able to remove enough noise, a more sensitive photodetector will be used. Avalanche photodiodes tend to be the most sensitive since they add in amplification into the actual semiconductor itself. The sensitivity is also inversely related to the bandwidth of the photo diode. Bandwidth is not as important for this application since the modulation frequency will be relatively low and there is no real data transfer between the gun and skeet with the laser light.

Cost and Size - Both the cost and size of the photo detector are less of a concern since typical photodetector are both small and cheap. These parameters are only important for the size of the activation area of the detector as well as needing a number of them to cover the skeet. The activation of the detector is the region on the detector that accepts light to feed the current in the device so a larger activation area would generally be more desirable than a small one. Since the skeet needs to be covered in the photodetector, a less costly detector would be more desirable. A total of eight detector should be needed to cover the skeet with each detector covering a 90-degree cone on the skeet. With an increase in photodetector, an increase in coupling is also needed for each photodetector.

Types - There are three different photodetectors available for use: the photoresistor, photodiode, and phototransistor. Photoresistors tend to be the worst in sensitivity and response time, but are the cheapest making them good for sensing relative light intensity hitting the activation area. Phototransistors offer the most sensitivity of the three groups while offering average response time. Photodiodes have very high response times with only average sensitivity.

Based on the three types of phototransistors, the Phototransistor is the best suited for our application. The sensitivity of the detector is more important than the response time in our application. Since the spot size is very large, the power distribution throughout the spot size is very low making sensitivity more important. The response time of phototransistors is typically measured in micro-seconds and the modulation frequency of the laser is in kilo-hertz, so the response time will not be an issue for this application. Avalanche photodiodes will not be considered because of the high cost. (Table 5) below shows a comparison of three different phototransistors. Only phototransistors with a center wavelength of 980 nm will be chosen even though other phototransistors could still detect the signal if their spectrum was broad enough since this project needs good sensitivity. The phototransistors for this wavelength are limited to the SFA and SFH series which has small changes to each component, mostly in packaging type and whether or not they come with a filter. One other phototransistor was found, the PT1302B, but it does not have a complete data sheet, specifically the view angle. The view angle of the SFA and SFH series is quite high for all the different components and should be adequate for the project.

Table 5 -Phototransistor Comparison

Phototransistor	***Center Wavelength***	***Rise/Fall Time***	***View angle***	***Sensitivity***
SFA 325 FA	980 nm	7/7 us	60 degrees	High
SFH3204	980 nm	7/7 us	60 degrees	High
PT1302B	980 nm	15/15 us	Unknown	High

3.2.3 Demodulation

The demodulation circuit for this application is relatively simple to other demodulation circuits since the only important information is to determine if there is laser light from the gun on the skeet or not. As previously stated in the earlier section cover photodiodes, a total of eight photodetectors will be used to cover the skeet. If a single photodetector does not work for each of the eight locations, a cluster of four detectors can be used at each of locations that will feed into the demodulator. Ideally each of these will have their outputs fed to the same demodulating circuit since only one photodiode will have laser light incident on it at any one time. If feeding all of them to the same circuit causes unwanted feedback, the detectors can be split up so that half go to one demodulator while the other half goes to a second demodulator. The halves will be split up so that the detector that are 180 degrees from each other are paired up and the photo detectors on the top and bottom are 90 degrees from each other. This setup will make it so that no photodiode on the same demodulator is receiving light with a diode on the same circuit. One possible demodulator circuit will contain a bandpass amplifier using and op amp that feeds its output to a peak detector. The peak will be converted to a digital signal that the skeet MCU will read. This demodulator needs the skeet MCU to constantly be checking for the signal, causing larger power consumption. The second demodulator will contain an op amp that compares the input signal and pulls high or low depending on if the signal is percent or not. This method will interrupt the skeet MCU, causing the skeet to use less power than continually checking for a signal.

3.2.4 Component Placement

Since the volume in the skeet is limited, placement of all the components inside is critical. The main circuit board, MCU, and power source will be centered in the middle of the device with the optics being placed around them. As stated in the previous sections, there are eight photo diodes placed to cover a 90-degree cone, so four will be on the top and four will be on the bottom of the device. Each diode will be placed in a mirrored housing with the bandpass filter being placed on top so that the diodes are completely enclosed. The Fresnel lens will be placed in front of the bandpass filter at the maximum distance that will still fit inside the skeet to allow more light to reach the photo diode. When The photo diode is placed inside the skeet, it will be laid in such a way that light directly above the skeet will not reach the photo diode, blocking sun light from creating noise inside the detection circuit. A solar filter film can also be applied to the outside of the skeet to reduce unwanted wavelengths from reaching the photo diode if the bandpass filter is not enough.

3.3 Power

Utilizing power sources is quintessential to any electronic circuit design. Using appropriate methods and standardized practices, power can be handles, delivered and manipulated in a safe manner to internal and external components. This section outlines the methods and means to which a power source is selected, manipulated, and regulated to the internal components of both the laser skeet rifle and skeet target. Both systems will require different power sources to maintain their independent requirements, but the methods of power to the MCU and various internal devices remains the same.

3.3.1 Sources and Regulation

Selecting an appropriate power source for both the laser rifle and skeet target are extremely important. An appropriate size and potential is researched to determine what power supply would make the most amount of sense for the types of loads and support that each will endure. The selected power source on both systems will need to support no less than the 3.3V needed to operate the integrated microcontrollers that the devices will each house. Therefore, the following power sources have been compared to determine the most logical, non-overkilling fit.

Skeet Target Power – Power requirements for this system must be able to handle the needs of a 3.3V microcontroller, a laser detection device to drive operational amplifiers triggering a hit, radio frequency communications and a flight-destabilizing mechanism. Whereas it would be extremely simply to strap in 4 AA batteries and call it a day, there are parameters in size and weight to this engineering designs. The entire device must fit into a small 100mm diameter by 26mm height target whilst retaining a target weight less than 100g. Ideally something more or less over 5V will perform adequately, while also being interchangeable and keeping mountable components to a minimum for housing the battery to the PCB.

Laser Rifle Power – Power requirements for this system will need to be as capable as the one to be selected for the skeet target except for the design parameters to retain a low weight. A few batteries can be selected and multiple ones will work, however, the main focus of this power supply is to activate the laser and retain an ability to have modulated power whilst retaining a charge for a long time. Ideally a rechargeable battery pack would be inexplicably well suited for this rifle, but at the higher costs compared to consumer end mass produced disposable batteries.

Regulation Requirements – Power regulation will come in very handy for protecting integrated circuit components while still supplying the necessary potential voltages. Voltage regulation will play a very important role as to not overload the MCU, which requires slightly less than 3.3V. Therefore, acquiring a DC battery power source that can be stepped down and arranged into complying with the necessary component requirements and support at least 150 mA of power will be a regulation goal.

3.3.1.1 AA/AAA Cells

A common enough power source, this design calls for an increasing amount of voltage if the intended user wished to use the device for prolonged periods of time. Having a low power rifle as it is, the modulation, frequency of firing and overall capability of using standard battery cells would be an ideal case. With AAs having a 1.5V capability, three to four of these would be needed to operate the skeet target effectively and for a prolonged period of time. However, the cause and hesitation with using such a power source is that the dimensions and weight do not fit into the target engineering specifications. Each AA measures approximately 50mm in length and 14mm in height while weighing 23g [35]. This means that using four of these batteries would actually result in our entire weight restriction being used, leaving nothing left for the PCB, components and the target case itself. AAA lithium batteries are not much better in regards to the skeet target and or meeting the output requirements of, while having roughly half the weight and a smaller height, fitting four 1.5V batteries into an appropriate case to house them, will essentially make up 25% of the total specified volume while also using up 25% of the final weight. Placing multiple amounts of these batteries in series would allow for a viable laser rifle power supply, at the cost of not being able to recharge the batteries but also allowing for prolonged laser rifle use, if a supply of batteries is readily available.

3.3.1.2 LP-503562

Small, compact, often rechargeable, these devices hold a commonly low cost between the four-dollar and twelve-dollar marks. These come in variety of compact sizes and offer a low height profile. While retaining a low cost at low amount of power, a 3.7-4.2V battery pack from Adafruit for would not be an ideal candidate for either the skeet target or laser rifle [33]. Common sizes found were still in the weight classes of 26g to 38g. Plus these would require a higher amount of volume within a small target. With a low voltage and operational range of 1200mA hours, this would be a decent candidate for the skeet target, had weight and size not been an issue.

Further entertaining the theory of using this for the laser rifle, an approximated 3000mA hours would be needed to flawlessly operate the laser rifle for a decent session of skeet shooting but would need to be of a higher voltage to allow for a better current supply to the multiple RF, IR, and amplification systems in this design.

3.3.1.3 Solar Powered

Looking for a small enough high potential solar cell, the Sunnytech 5V 100mA source came in a sleek 80mm x 80mm design [34]. Solar cells would complement the design's outdoors aspect, which will keep the device charged and operational so long as the devices are used outdoors. A low-cost solar cell would be able to actively perform at required parameters for a seven to eight-dollar monocrystalline solar cell. A solar power source would be a better candidate if a larger stationary target was to be used, but since this is not the case, a ceaselessly self-replenishing solar cell would not provide enough power and operating skeet target or rifle would not appropriately comply with this particular design. In addition to the power supply not being ideal for indoor scenarios, the target will be falling out of flight after every use and must be able to endure ground collisions. The housing required to safely protect this fragile solar cell would not be feasible to this design. The components also to add this to the PCB would add a considerable amount of weight and would require more regulated components to allow continuous supplied use.

3.3.1.4 CR2032

While retaining the smallest size in this power source category, these lithium anode batteries also hold a nominal voltage of 3V and are capable of being stacked easily. Their dimensions hold the best voltage/volume as far as the previous batteries look. At a 5.8mm diameter and 2mm height, these will be highly considered for the skeet targets. Housing for these 'coin cells' are also small in size and will take up next to no more than the coin batteries themselves [37]. These cells do come at a rather equally great price tag of thirty-three cents of a dollar, these pack quite a punch for their volume, weight, and cost per volt. The housing mechanisms for themselves also come in a through-hole mounted style, capable of holding two-coin batteries in series. This component will most definitely be a greater client for the skeet target rather than the laser rifle.

3.3.1.5 Rechargeable 9.6 V Nickel Metal Hybrid

Rechargeable Nickel Hybrids are commonly used batteries that offer a high-power rating, voltage and offers rechargeable capabilities. One specifically in question is the VB-Power 9.6V 1600 mAh NiMH Nunchuck Type Battery with charger. A component like this does come at a $34.95 price tag, but offers both a reliable power source and charger [38]. This component does allow multiple devices to be ran at the same time for a very durable and reliable session of skeet shooting. Charger in question can charge the battery completely in less than 30 minutes, which gives the user an open option to save down the line on reusable batteries. Another product comparable to this one would be the standard 9V battery, which for its size would adequately perform meeting minimum requirements for the microcontroller, but lacks in capabilities to supply an entire system by itself, placing two in parallel would be a cheaper alternative to a $35-dollar rechargeable battery but cost close to six dollars every instance that the batteries need to be swapped out, which could be anywhere from one to three sessions of constant play.

3.3.1.6 TC1262

Both the laser skeet rifle and skeet target will have power and voltage regulators on their respective PCBs to ultimately protect the MCU whilst providing safe amounts of regulated power and current to their respective sub-systems. Both systems will have voltages higher than what their individual components are recommended to be supported by [49]. Regulators will be a necessary component to bring these input voltages down to appropriate levels as well as manage the output currents. TC1262 operates at a maximum input voltage of 6V whilst providing a regulated 3.3V while also maintaining a low-profile surface mount. Ideally this can be used to safely run the MCU as well as the RF capabilities the MCU provides and allow the excess power to be utilized for the flight –destabilize mechanism. Costs for this package fall between twenty-five cents and seventy cents on the dollar.

3.3.1.7 LM7805

The voltage regulator LM7805 can accept an input voltage of 5 to 18v whilst retaining a 5V regulated output. The built-in safety features to the LM7805 allow for a safe restricting current while still proving the regulated output voltage [47]. This is an ideal safety mechanism to provide an intermediary power stepdown further from the 5V and below, as well as using it to power the laser rifle's primary laser driver. Costs for this package fall between forty cents and seventy cents on the dollar.

3.3.1.8 TPS76333

This voltage regulator is a variable low power and low dropout linear regulator. Input abilities are limited to a maximum of 10V while providing a linearly regulated output voltage from 5.0V to 1.6V while having a quiescent current of 2uA [52]. This five-pin package is also further capable in the realms of electricity meter monitoring, servo drive and motion control as well as driving sensor transmitters. The sharp regulation can be supported with pre-package operations to further limit two separate inputs. Each would come at a higher price than previous regulators mentioned at about one dollar, but this extra cost allows the regulation voltages to be variable controlled and therefore more applicable to many powered components.

3.3.1.9 TL084CN

Operational Amplifiers are a multi-purpose component that can retrieve an input signal or difference between two signals and amplify based on the circuit schematic. This particular op amp allows for four separate outputs to be utilized within one package. This amplifier is also rated to operate under 36V on supply power and is a through-hole component. The particular package does not save too much in size with its relative 120mm^2 area on the PCB [51]. This component also operates as a rail-to-rail power supply, which will clamp the output to a specific rail in the instance of improper biasing. A voltage regulator can be added to this input supply to further revoke the amount of output power being supplied to another part of the circuit. This particular general-purpose amplifier can then be used as a logic gate, in conjunction with a non-inverting amplification format to deliver a pre-determined amount of power to the laser driver at a slew rating of 13V/us, which is a faster slew rate than what is necessary for this design. This will also enact as a safety mechanism, further restricting possible damages the laser LED can be subjected to. A four-channel op-amp such as this one costs less than 80 cents.

3.3.1.10 TS972IPT

Usage of this operational amplifier is limited to a 12V ceiling and a 2.7V minimum input supply. The particular packaging is a low profile SMD styled mount with 100mA maximum output current. The package supports a two-channel output capability with a 4V/us slew rate [48]. This also offers a low noise ratio capability of 4nV/Hz, which would make for an ideal speaker amplifier or signal carrier op amp. Most operational amplifiers require or recommend that a capacitor is added to the output source to further limit the exposed higher frequencies of the DC transistors inside the package, but this device held no inclination towards adding additional components outside the necessary biasing practices.

3.3.1.11 TLV2711IDBVR

This Op-Amp is a single output rail to rail micropowered under split supply conditions. Operations occur between a supply voltage of 2.7 to 10V and is capable of supplying up to 50mA of current [50]. This particular operational amplifier is also useful within low power modes and yields a 0.025V/us slew rate. This is not too advantageous for PWM applications and driving a speaker, but for logical amplification for DC power this would be a cheaper opportunity while the 1 channel package is in stock for a cheaper price at a very small area of the PCB.

3.3.1.12 Power Conclusion

Formidably, we are looking to create a realistic and cost sensitive approach for not only us to manufacture this laser skeet shooting system, but also for any consumer end users. Taking into the account the power source and the capability to run longer lasting matches whilst also retaining high-power ratings and ultimately meeting the engineering requirements, it will be advantageous to use the CR2032 model coin batteries for the lightweight performance as well as low component costs. These will allow the skeet target to operate for a longer time with the extra power sources. Their ability to meet the target dimensions profile without needing to take up excess weight and volume are an excellent measure of why they are to be selected, (Table 6) below represents the comparisons among power sources researched.

There is still some debate as to what power source will be best suited to operate the laser rifle, but the one that suits best with our engineering directives would be the rechargeable Nickel Metal Hybrid. The amount of time that we can operate the laser rifle for and quick turnaround for recharging would ultimately benefit the user in the long run and reduce costs per round of skeet used. The additional weight that the 9.6V rechargeable battery will bring is also of benefit to bring up the overall weight of the laser rifle. This will provide additionally stability to the stock end of the rifle.

Table 6 - Power Source Comparisons

	#	Voltage (one)	mAh (one)	Volume (total)	Weight (total)	Additional Housing	Extra Support Components
Requirements	-	Above 3.3V	-	<300cm^3	< 100g	No	No
AA Alkaline	3	1.5	2500	8.5	70g	Yes	No
AA NiMH	3	1.5	2000	8.5	93g	Yes	No
AA Li-Ion	3	1.7	3000	8.5	70	Yes	No
LP-503562	1	3.7	1200	10	30	No	Yes
9V	1	9	1000	24	45	Yes	No
CR2032	2	6	300	1.8	6	Yes	No
Solar Cells	1	5	N/A	100mm Area	23	Yes	Yes
Rechargeable NiMH	1	9.6	1600	55	180	Yes	Yes

It is the opinion of this engineering team that using the TPS76333 voltage regulator for all regulation needs would provide the needed benefit of being a low profile multipurpose voltage regulator. Utilizing a voltage regulator for the MCU and laser driver, this package can support both while being further capable to have multiple ones in series to create a variety of regulated outputs for multi-purpose components. This package will be used to further expand any and all components added to the skeet target and laser driver rifle for all purposes. Comparisons can be observed in Table 7.

Table 7 - Voltage Regulation Comparison

	Max Vin (V)	Nominal Vout (V)	Vdrop (V)	Iout (mA)	Iquiescent (uA)	Additional Components Required
TC1262	2.7 - 6.0	2.5 - 5.0 Variable	0.35	500	80	1uF Vout Cap
LM7805	7.0 - 25.0	4.8 - 5.2 Variable	2.00	1000	-	.33uF Vin Cap, 0.1uF Vout Cap
TPS76333	2.7 - 10.0	1.6 - 5.0 Variable	0.18	800	2	Voltage Reference Biasing

Of the three operational amplifiers identified and researched for this laser skeet system design, all three will be implemented. Each has its own great benefits of providing consistent output per input as well as regulating a railed output for any arising errors, appropriate biasing and implementation of each will greatly support their corresponding sub-systems. Using the TL084 four channel will provide much needed voltage regulation and amplification to future sub-components used in the devices peripheral design and the higher slew rate will give the PWM signal a sharper waveform. Using the TS9712PT will provide the lowest area per the three devices and would be most compatible in the skeet target to drive the flight destabilization system. Based on information represented in the table below (Table 8), the TLV27 with the weaker slew rate and single channel, takes up extremely little area and can be used to substitute another op amp in the event of a size discrepancy for a DC powered output not depended on frequency.

Table 8 - Operational Amplifiers Comparison

	Supply Range (V)	Channels	Slew Rate V/uS	Area (mm^2)	Cost ($)
TL084CN	+-18	4	13	100	0.60
TS972IPT	2.7 - 10.0	2	4	20	0.94
TLV2711IDBVR	+-10	1	0.025	6	1.33

These conclusions are beneficial to the engineering team as well as the consumer end by providing a design that reduces the average cost for a round of skeet shooting exponentially. Having both the skeet target system and laser rifle system be of realistic quality and design is paramount to this team's interests. Not only will both systems receive the appropriate amounts of power, but have a little extra potential voltage to run multiple components of the system on top of the ability to add additional features in the future.

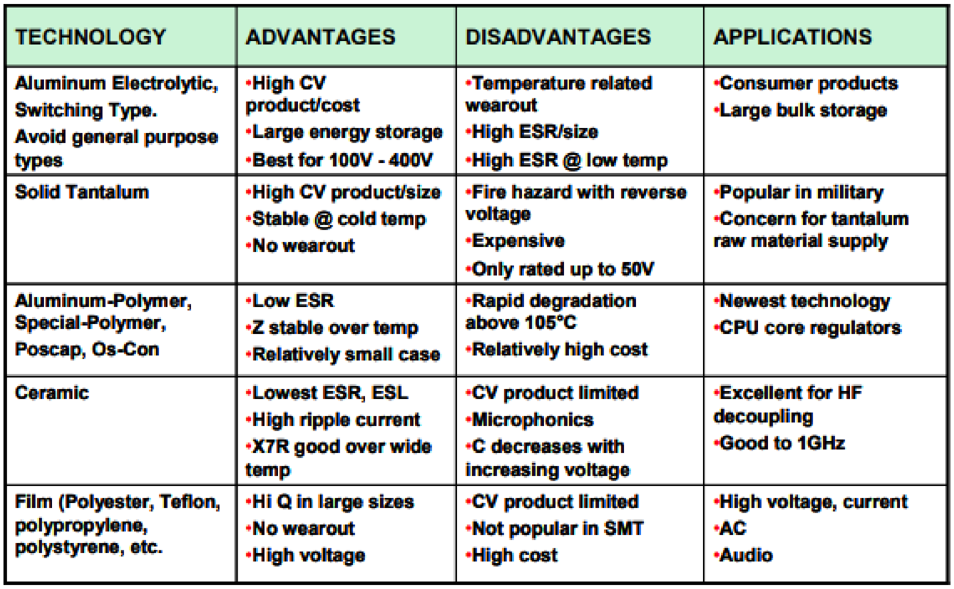
3.3.2 Power Decoupling Capacitors

Many integrated circuit incur performance issues caused by instability of DC power sources and noise on the circuit itself. Capacitors used on the voltage sources such that cleaner supply are provided to the high speed operational amplifiers and signal processing components such as the RF between laser rifle. Power supplies are to be rectified using recommended capacitances per datasheets, if otherwise unmentioned, capacitance will be determined to see what gives the cleanest power. Low frequency power supplies typically demand larger capacitors which act as a storage cell for charges in current. High frequency power supply noise is reduced with low inductance components to restrict system noise. [10]

Within this system the two primary frequency processes will be on the laser driver system and RF systems between the skeet target and rifle. Pulse width modulation on the laser driver will be regulated using ceramic capacitors for their low cost and abundancy in the market. The quality of which come standard and will be used to rectify the circuit's duty cycles and PWM, resulting in a better-quality laser signal being produced.

For the RF system, a high-speed capacitance will be needed to properly handle a high frequency transmitting and receiving process. Utilizing smaller capacitances of 0.01uF to 0.1uF on the power pins will localize noise in the system and prevent distortions on the signal amplification. Handling high speed signals a few tolerances must be met. Large enough frequency of operation, ability to handle distortion and keep external high frequencies from the circuit. Few variations of capacitors exist as surface mount components that meet out requirements. Between Solid Titanium having a high popularity on military circuits and uses in commercial aeronautics, their costs are rather high and in limited supply. Film capacitors are contingent on obtaining a high-quality factor and hold no wear out over time disadvantages and are used in audio circuits. This makes the component higher in cost as a surface mount component, as well as other comparisons observable in Table 9.

Table 9 - Surface Mountable Capacitor Comparisons



TECHNOLOGY	ADVANTAGES	DISADVANTAGES	APPLICATIONS
Aluminum Electrolytic, Switching Type. Avoid general purpose types	•High CV product/cost •Large energy storage •Best for 100V - 400V	•Temperature related wearout •High ESR/size •High ESR @ low temp	•Consumer products •Large bulk storage
Solid Tantalum	•High CV product/size •Stable @ cold temp •No wearout	•Fire hazard with reverse voltage •Expensive •Only rated up to 50V	•Popular in military •Concern for tantalum raw material supply
Aluminum-Polymer, Special-Polymer, Poscap, Os-Con	•Low ESR •Z stable over temp •Relatively small case	•Rapid degradation above 105°C •Relatively high cost	•Newest technology •CPU core regulators
Ceramic	•Lowest ESR, ESL •High ripple current •X7R good over wide temp	•CV product limited •Microphonics •C decreases with increasing voltage	•Excellent for HF decoupling •Good to 1GHz
Film (Polyester, Teflon, polypropylene, polystyrene, etc.	•Hi Q in large sizes •No wearout •High voltage	•CV product limited •Not popular in SMT •High cost	•High voltage, current •AC •Audio

[10] Analog Devices (Permission Requested)

A combination of ceramic and film capacitors will be utilized. Ceramic capacitances to assist in noise reduction on lower frequency and broad biasing operational amplifier filtration circuits for the laser driver. Film surface mountable capacitors will be used exclusively for RF transmitting and receiving processes. These selections are based not on cost alone, but rather high performances and specifications to their respectively related systems. The more accurate these passive capacitors are, the better performance can be driven from their sub-system circuits. These will be used in power decoupling, ac coupling, signal filtering and RF impedance matching.

3.3.3 Power Decoupling Protection

Optimal protection of the laser led is paramount to performance of the driver and provides a security in case of overpowering the laser by regulating a maximum amount of current. This fuse will be placed in series to the laser such that a safe and controlled amount of current will be directed to the laser, preventing overcharging, overheating, and damage to sensitive embedded components. This fuse is estimated to protect the LED if a current of over 50mA is supplied accidentally, preventing any damage to the circuit.

In conjunction with voltage regulators to supply adequate amounts of power to the laser rifle's driving mechanism, fuses and shunt diodes are to be added in series for a triple layer of current and decoupling protection. Utilizing shunt diodes of low amperage as well as a fuse system provides a vital and necessary protection to the laser diode circuit as well as the sensitively tuned electronics compiled with this system.

3.4 Processor Research

The Laser Skeet system is comprised of two parts. The gun with controller and skeet sensor part. The gun controller part will be the primary control device and the skeet will be wireless sensors. The primary control device will require a PWM output for laser control, SPI output for a display, less than seven digital inputs/outputs, and the capacity to handle the wireless communication protocol that is selected for use. The sensor device will not require SPI or PWM output but will need an additional input from the IR laser sensor detector circuit. The demands on both devices should be close enough that the same device can be used for both.

The demands of the system, the inputs and outputs needed, the requirement for low battery power, and compact size make this job fit for the lower power SOC(system on a chip) microprocessors. Additionally the need for wireless communication makes having integrated wireless RF also desirable although it could also be done with independent chips. Additional memory requirements will be needed to handle the RF stack within the Microprocessor.

Microprocessor vendors have a variety of products with different CPU core architectures. MIPS, ARM, and proprietary are the common choices. The MIPS is an open community supported architecture that could provide some cost saving from avoiding licensing fees. The proprietary selections would of course lock a product into a single vendor and require learning that vendors system. The ARM® architecture is used in many different vendors’ products and is commercially supported. Since ARM is the most widely adopted in the market, experience in this architecture is desirable when looking for employment [6]. This project is being done as part of an educational requirement that aims to promote opportunities and experience for employment. As such only the ARM product varieties will examined for use in the project even though it would be possible to complete the project using one of the other choices.

3.4.1.1 NXP KW01

The NXP microprocessor, KW01, formally sold under Freescale name, provides an ARM® Cortex® 48MHz M0+ microprocessor with 128KB flash, 16KB RAM, six timers/PWM, one SPI channel, two I2C channels, 12bit DAC, 16bit ADC, real-time clock, UART, and an analog comparator. It has an integrated Sub-1GHz transmitter and receiver supporting 315, 433, 470, 868, 915, 928, and 955MHz ISM bands. The built-in transmitter is capable of an output of 35dBm making it the most powerful transmitter in the devices examined. The device can be power by a 1.8 to 3.6 volt supply. It has a current load of 95 mA in transmit and 17 mA in receive.

It provides wireless connectivity using IEEE® 802.14.4 standard, zigbee, as well as supporting the wireless M-bus protocol. The product was in limited supply and priced at $4.23. The manufacture does have a development test board priced at $195. [5]

3.4.1.1 NXP KW21Z

The NXP microprocessor, KW21, also contains an ARM® Cortex® 50MHz M4 microprocessor with 256KB flash, 32KB RAM, and provides one SPI channel, two I2C channels, 6bit DA, 16bit ADC, two UARTs, real time clock, 24 GPIOs and USB in some versions. Variations or the device are available with 512KB flash and 64K RAM as well if additional memory space is needed.

This version provides support for the 2.4GHz band instead of the sub-1GHz. Output transmit power of 8dBm maximum is possible. It provides wireless connectivity using IEEE® 802.14.4 standard, zigbee, and the wireless M-bus protocol. The device can be power by a 1.8 to 3.6 volt supply. It has a max current load of 17 mA in transmit and 15 mA in receive.

The manufacture does have a development test board priced at $195. The product was European stocked with long lead times and priced at $4.53. [5]

3.4.1.3 Texas Instruments CC1310

Texas Instruments has branded their line of microprocessor products targeting the IoT and sensor connectivity as SimpleLink platform. There are a few products in this line that will be examined. The first is the CC1310 MCU.

The CC1310 provides an ARM® Cortex® 48MHz M3 microprocessor with 128KB flash, 20KB RAM, four 32bit(or eight 16bit) timers/PWM, two SPI channels, an I2C channels, 12bit ADC, real-time clock, and an analog comparator. It has an integrated Sub-1GHz transmitter and receiver supporting the 915MHz ISM band. There is a secondary ARM® Cortex® M0+ processor embedded to support the RF communication and a separate senor controller. The presence of a separate processor for the communication tasks help prevent the application from potentially causing trouble with the communication tasks. This way a tested and supported communication stack can be run with confidence that it will operate as expected.

Variations of the device are available with less flash memory, 32KB and 64KB. The device is also available in three different packages depending on the needed number of IOs(10, 15, or 30). The device operates on 1.8 to 3.8 volt supply and advertises current usage of 0.7 µA standby, 570 µA idle, 2.5 mA active, and up to 23.5 mA when transmitting. IO current draw is an additional load.

The parts are readily available from multiple suppliers as well a direct from Texas instruments. The 128K with 30 IO variant costs $6.57. The others are available for slightly less. When purchased in volume the parts are available for $3.00 and less. Texas Instruments offers a development board for this product, the LAUNCHXL-CC1310. The development board is available for about $30.00. Two development boards would be required to setup both ends of the RF link.

Texas Instruments provides an Integrated Development Environment free of charge for their products called Code Composer. They also have Sensor Controller Studio to support sensor interface. The device is compatible with FreeRTOS operating system for the ARM processor. Texas instruments also provides their own version call TI-RTOS. The drivers available provide wireless connectivity based on IEEE® 802.15.4. [7]

3.4.1.4 TI CC1350

Texas Instruments also has a variation of the CC1310 that contains both 915MHz band communications as well as supporting the blue tooth band. This version is available in the same variations of memory and package IO size as the CC1310.

Initially this looked to be preferential to the CC1310, as it would allow for more options for communication and possibly support growth in the future by implementing phone or tablet connectivity. This came at only a small cost increase. However, a closer look the device reveled that both the bands shared the same pin connections on the device. This lead to the restriction limiting use to only one at a time. While switching between would allow for connectivity it would not be available during game play as it would require putting the game play on hold. This could still have useful applications such as a method for providing user software updates or the saving of final scores to external locations. Neither of these options are planned at this time in our implementation. As the support for multiple bands requires additional hardware support for the RF switching between impedance matching and antennas, this device will not be used in preference to saving space on the PCB and reducing additional parts costs. [8]

3.4.1.5 Texas Instruments CC2650

Another offering in the SimpleLink line from TI, the CC2650 provides an ARM® Cortex® 48MHz M3 microprocessor with 128KB flash, 20KB RAM, four 32bit(or eight 16bit) timers/PWM, two SPI channels, an I2C channels, 12bit ADC, real-time clock, UART, and an analog comparator. It has an integrated RF transmitter and receiver supporting the 2.4 GHz ISM band. There is a secondary ARM® Cortex® M0+ processor embedded to support the RF communication and a separate senor controller. In this band it provides support for BLE, ZigBee, RF4CE, 6LoWPAN, and IEEE® 802.15.4. The built in transmitter is capable of a maximum output power of 5dbm.

The device power requirements are 1.8 to 3.8 volts. It has a current load of 1.0 µA in standby, 200 µA in idle with sensor controller active, 5.9 mA in active with RX, and 6.1 to 9.1 mA in active with transmit. Different packages depending on if 10, 15, or 30 IOs are needed.

The largest capacity chips are readily available at $4.90 in single lot and $2.65 or less in volume quantities. Their development board is available for $29.00. Two boards would be needed to handle both ends of the communication link. [8]

3.4.1.6 Atmel SAM R21E/G

The R21 provides an ARM® Cortex M0+ core with a max clock rate of 48Mhz. There are versions available with 8,16, 32KB RAM and 64, 128, 256KB flash. There is integrated support for three 16bit timers, three timers with extra features, real time clock, five serial interfaces that support SPI and I2C, one 12bit analog to digital converter, two comparators, and 16 or 28 IOs.

The chip provides RF connectivity in the 2.4GHz ISM band with support for 802.15.4 and Zigbee. The max transmit power possible is 4dBm. The chip is capable of running on 1.8 to 3.6 volts. The advertised current demands are 850µA for standby, 1.76mA for idle, and 7.3mA running at maximum demand. IO port current draw would add to the load and be dependent on the outside circuitry.

The Atmel provides an integrated development environment called the Atmel Studio. It is available free of charge. The device and IDE are compatible with FreeRTOS OS for the ARM processor. Atmel has a development board for this product at a cost of $58.00. Multiple boards would be needed to support developing both ends of the RF link. These chips are readily available from multiple sources for $4.24 in lots of one and are available in volume quantities at $3.63. This product is a good prospect to handle our needs. [3]

3.4.1.7 Atmel SAM®E microcontroller + AT86RF212B

The SAM® E would provide a 300MHz ARM® M7 microcontroller with a separate chip to support the Sub 1GHz band. 512KB flash, 256KB RAM, USB 2.0, SD Card interface, one ADC, one 12bit DAC, two UARTs/SPI, four timers/PWM, two four channel PWM, analog comparator, and real-time clock.

The AT86RF212B provides a separate chip to support the communication in the 915MHz ISM band. The chip provides IEEE 802.15.4 communication. The chip is capable of up to 11 dBm transmit power. The power voltage requirements are in the same range as the microcontroller so the same power source could be used.

This combination would be capable of completing the tasks that are needed. However, it come at additional cost due to multiple chips and multiple development boards needed. It is also an issue on the target sensor device since it is limited on available PCB space. This option also provides more processing power than is needed. [2][4]

3.4.1.8 Broadcom

As a large supplier of processors and wireless solutions in the cell phone and tablet market, Broadcom was examined as a possible provider for our product. When examining the offerings from Broadcom it was found that their products were targeted at that market.

They did have some Bluetooth SOC devices. These were being advertised to have support for providing HID (Human Interface Devices) like keyboards, mice, and headphones. They did not have information for supporting sensor type applications. Additionally, the Bluetooth provided was also intended for Personal Area Networks. This would be a concern as we want to cover a larger area.

Broadcom also had solutions utilizing WiFi, 802.11a/c/n, these came with larger processors, typically, quad core. These had larger power requirements than we desired and provided excessive processing power. The WiFi solution was also less than desirable since it would require the added necessity of setting up and providing a router device for interconnectivity.

The Broadcom products did not seem to be a good fit for our application. As such no device was selected for close comparison.

3.4.2 Comparison

The three processors selected for closer comparison are listed in Table 10 below.

Table 10 - Processor Comparison Overview and supply

Provider	TI CC13/26	Atmel SAMR21E/G	MXP KW01
Microprocessor	Dual M3 plus M0+	M0+	M0+
Bands	915MHz, 2.4GHz, BLE	2.4GHZ, 915MHz(only available in multiple chip solution)	315, 433, 470, 868, 915, 955MHz
Availability	Good supply	good supply	limited supply

When making the decision between the options we first eliminated the two options from MXP. While these products could work for our product, the availability was a concern as was the extra shipping time and costs that could be present with over sea shipping. Additionally, their development boards come at a higher cost. The additional $300 plus compared to other options would be a significant increase to our expected cost.

The options from Broadcom were also eliminated since it was not a good fit for our application. In the case of the Texas Instruments solutions, the CC1350 was eliminated due to our lack of need for the Bluetooth. This would have simply added extra complexity unnecessarily to RF design, by requiring RF switching. There was also a minimal increase in price for no reason.

In the Atmel solutions the option of going with a microprocessor and separate wireless chip was eliminated. A spate chip solution would allow a more powerful processor but this is not needed and a single chip is more desirable for better integration and space savings. With the elimination of those solutions rejected for reasons specific to the individual device, the three primary candidates TI CC1310, TI CC2650, and Atmel R21 will be compared more closely.

Current Comparison
Current and the resulting power demands are of interest in battery powered devices. Having a more efficient system will reduce the need for battery replacement. The current requirements for different states of the three top choices are listed below in Table 11 when using a clock rate of 48MHz.

Table 11 - MCU power use comparison

	TI CC13xx	Atmel R21	TI CC2650
Standby	0.7 uA	0.85 mA	1.0uA
Idle w/ active sensor cont.	0.4 mA	1.76 mA	0.2mA
Running Benchmark SW	2.5 mA	7.3 mA	2.9 mA
Running w/ RX	5.5 mA	Not given	5.9 mA
Running with TX	6-24 mA	Not given	6.1-9.1mA

Of the choices the Texas Instruments lines provide more efficiency in both the low power down states and the full speed bench mark. The difference in the full benchmark software load between the Texas Instruments and the Atmel is quite significant as the Atmel requires more than double that of the competition. While significant the differences in the benchmark load is not as important to us as our design is not expected to have high CPU usage and power saving modes could be used to reduce power usage. Also in the gun controller there will be other drains on the battery that will be adding make the MCU less of a contributor to the total power needs.

The differences in the idle state are more important, especially in the target sensor device. The sensor device will spend most of its time waiting making this the state the one expected to get the most use. In the sensor device the limited battery space makes power use more critical than on the gun controller device. In this regard the Texas Instruments is again a clear winner with only ¼ the demand of the Atmel.

The difference between the two Texas Instruments chips is negligible with regard to MCU usage. There is a more significant difference when it comes to running the transmitter. The CC1310 has a much higher maximum load when compared to the CC2650. This is due to the different band that is being supported. The 915MHz device supports transmit output power of 14dBm while the 2.4GHz device only supports 5dBm. The power level is controllable in the CC1310 device so the extra load would only be present if it was needed.

As such either one of the two Texas Instruments devices would be a preferred choice. The Atmel could still be used if there was some other motivation factor, as the only down side would be more battery replacements by the user.

Memory Capacity

There are two values to be considered. The available flash that is used for storing program code and settings. The other is the RAM used for variables and data buffer during code execution. They are compared in Table 12 below.

Table 12 - MUC memory comparison

	TI CC1310	Atmel R21	TI CC2650
Flash	128K, 64K, 32K Bytes	256K, 128K, 64K Bytes	128K Bytes
RAM	20K Bytes	32K, 16K, 8K Bytes	20K Bytes

Since we intend on using an OS there could be up to 10KB RAM and 30KB Flash needed to support just the OS. This is expected to be less, but the worst case needs to be accounted for. In addition, our code will need space. This eliminates the lower capacity versions of the R21 and CC1310, but since they offer larger version they would still have usable versions. This means there is no memory capacity issue preventing us from using any of the three options.

Cost

Cost is always a factor that needs to be considered for any project. It is even more impactful if the project is intending on making a product for mass production. The cost of our three primary MUC candidates are listed in Table 13 below.

Table 13- MUC cost comparison

	TI CC1310	Atmel R21	TI CC2650
Small lot	$6.57	$4.24	$4.90
Volume	< $3.00	<$3.63	< $2.65
Development Board	$29.00	$58.00	$29.00
Minimum cost for our project. 2 processors + 2 dev boards	$71.50	$124.48	$67.80

When initially looking at the small lot chip pricing the Atmel appears to be the best priced. However even at a $2.00 savings this is not significant for our prototype construction. More importantly if the product would ever go into mass production the volume pricing favors Texas Instruments. There is would provide a $0.37 to $0.98 savings per unit. In the case of the target sensor this could add up since multiple targets would be needed for every controller.

The bigger difference in cost for our project comes in with the development board. Atmel's price is almost double in this regard. This makes Texas Instruments a clear winner in regard to our project cost. The difference in the costs between the two Texas Instruments devices is small enough that either would be acceptable, and selection can be made depending on other desired attributes.

RF

The RF connectivity is an important feature to our project. The band and power output comparison of our three candidate parts are in Table 14 below.

Table 14 - MCU RF Power Comparison

	TI CC1310	Atmel R21	TI CC2650
Band	915Mhz	2.4GHz	2.4GHz
Max RF power	14dBm	4dBm	5dBm

In our implementation we expect to be using the link at ranges of potentially 70 meters or more. To get this range power and lack of competing interference are desired. The Texas Instruments parts both beet Atmel in the maximum power category. In addition, the Texas Instruments solutions give us two choices for the band of operation. When comparing the bands we feel there is less chance of interference in the 915MHz band. In the 2.4GHz band there is competition with WiFi that exists almost everywhere now, including everyone's pocket where their cell phone is kept. The 915MHz band is also expected to have more reach based on the frequency. As such the CC1310 would be the preferred choice.

3.4.3 Selected microprocessor

A Texas Instruments (TI) solution is selected based on the lower power usage and the lower cost. Of the two TI options the CC1310 is selected for the operating band and RF output power capacity.

The TI CC1310F128RGZR will be used for our build. This is the version with 128KB flash and 30 IOs. This is the same processor used in the development board from TI. This will allow transition from development board to new PCB design without the need additional software changes. The initial use of the 128KB flash version is also desirable since the final code size is unknown. It is expected that the 64KB version would be sufficient, but it is better to have the room for error with the minimal extra cost.

The same microprocessor will be used for both the controller and the sensor devices. This will ensure compatibility in the RF commination link and protocol. It also simplifies design as there is only one device to learn. In the event the product was mass produced this would also be advantages as only one part type would need to be stocked and would allow for more volume discount possibilities.

If this was to go into mass production it could be economically beneficial to change to a reduced capacity chip that would provide a 30 to 50 cent savings per unit, but for our limited build it would not provide a significant difference in cost.

3.5 Display

A display is needed to allow the user to get quick accurate feedback from operation of the device. The display needs to be easily readable in direct sunlight and be large enough to display information to the user clearly. The display also needs to be simple enough as not to over complicate things and change the required microprocessor specifications. The screen type chosen needs to be affordable and provide enough screen area to provide the useful information to the user. The interface used to send data to the LCD screen display must also be considered as this will have a large impact on connections and coding outputs to it. Power consumption will not be a huge factor in choosing the display but it still she be looked at in case a model uses an exceptionally large amount

3.5.1 Device Interconnection Choices

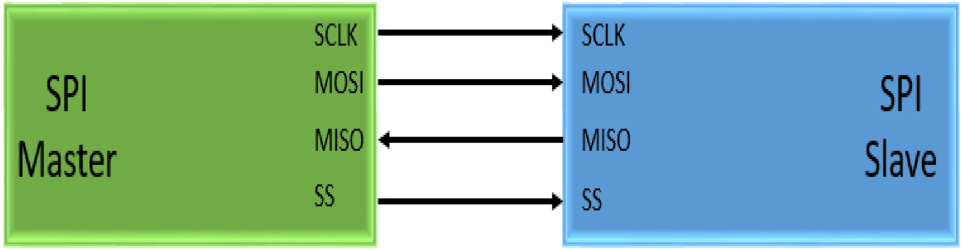
Choosing the communication type between the microprocessor and the LCD display determines the difficulty of programming, speed of data transfer, error correction, and PCB traces. Choosing the right form of communication will be heavily based on the microprocessors ability to implement without putting too much strain on programming.

3.5.1.1 Serial Peripheral Interface Bus (SPI)

Serial Peripheral Interface Bus (SPI) is needed for the microcontroller to handle what is actually put out onto the display screen properly. This is the most efficient way to control the LCD display. Without SPI multiple connections would be needed for the screen to be usable and connected to the microprocessor which does not even have enough pins to support this. SPI also allows for much easier programming for the display outputs. This form of wired communication can be comprised of one master and multiple slaves if needed.

SPI is comprised of 4 parts SCLK, MOSI, MISO, and SS. SCLK is the serial clock created by the master and is its output. It is important to look at the slave max clock speed because some might not be able to communicate properly. MOSI stands for Master Out Slave In. The MOSI connection is how information from the master is sent to the slave. MISO stands for Master In Slave Out. The MISO connection is how information from the slave back to the Master. SS is short for Slave Select. SS is for the selecting different slaves which allows for information to be sent and received from a specified slave and not all the slaves. SS also allows for each master slave connection to get its own turn so information from two slaves will not interfere with each other. Figure 2 shows how an SPI bus is interconnected. [29]

Figure 2 - Basic SPI Bus



One clock cycle for SPI will transmit a complete duplex of data. For use of the display for the design the master would be the microprocessor and the slave would be the display system. Note that SCLK will make both parts of the system on the same clock. The design and coding will mostly focus on SCLK and MOSI portions of the device interconnections since the master needs to send information to the display and be on the same clock rate. MISO does not really matter to much for the scope of the project design because the display screen does not need to send information back to the microprocessor because the display is not collecting any data from its surroundings. Even though MISO is not transmitting anything worth collecting still needs to be connected so that the data pushed in from MOSI will be sent back like a bent tube. Again, even though the slave is not contributing any new information MOSI needs to be connected for one directional data transfers because SPI requires one bit to be sent by MOSI and one bit to be retrieved by MISO in a sequence. SS also does not really need to be utilized since there will only be one screen and not multiple slaves.

SPI has some disadvantages that should be noted. SPI require more pins for integrated circuits than I2C does. Can only really be implemented for short distances as its easy for the clock to get out of synchronization with longer wires. SPI does not have an error checking incorporated in its protocols. Some variants only use a half-duplex so it is important to watch this.

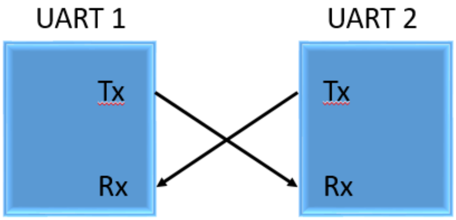
SPI will be the chosen way to communicate between the microprocessor to the display screen. The hardware interface for SPI is extremely simple compared to other models. SPI has one of the highest throughputs. Only four pins are actually required to fully implement SPI. SPI allows for a fast speed and good signal quality. This form of wired communication was chosen because it is not over complicated and is the bare minimum that is needed to obtain the design feature of having a close to real time screen to show player statistics.

3.5.1.2 UART

UART is short for universal asynchronous receiver/transmitter. This is a form of asynchronous serial communication. UART can be used on a variety of microcontrollers out there. Every member in the group is familiar with UART as it was used heavily in the lab for required course. Two UART hardware pieces are needed for use. One piece on the microcontroller that will take the data and put it in a sequence. The second piece will be on the receiving side and will take in the bit sequence and turn it into bytes.

UART is comprised of two parts the receiver and the transmitter each is made up of four essential parts which are a clock generator, input and output shift registers, transmit and receive control, and read and write control logic. In Figure 3 it can be seen that each UART has two pieces the transmitter and the receiver and that two UART components are needed to establish a wired communication. The clock generator creates the clock speed for data transmission and is usually a multiple of the bit rate used so sampling can be taken in the middle of a bit period. Input and output shift registers in input and output allow for converting between serial and parallel. Transmit and receive control controls how the transmit and receive operate so everything works well in synchronization. Read and write control logic takes in the clock value signal and uses this to set the internal time for the device, from this read and write control logic will take control over the read and write operations for the data bus. [30]

Figure 3 - UART Connections



The receiver operation side is different than the transmitter operation side. Every operation within UART is initiated by the clock signal. For each clock pulse the clock signals value or state is checked by the receiver to look for the start bit. If the start bit observed lasts longer than 50% of the data bit then it is accepted and the start of a new character is formed. If the start bit observed does not last longer than 50% of the data bit then it is ignored. Once one bit period is passed the state of the clock signal is sampled and moved into the shift register. After a certain number of bit periods have passed for the number of character length the data in the register becomes available to the receiver system. UART will then send an indicator that new data is available. On the receiving side it is very important that data comes in at a steady rate and that no data is missed. Since this is the case typically UART will resynchronize its internal clock whenever the data line is changed.

The transmitter side of UART acts as the sender and works differently than the receiver side. Timing for the transmitter is not derived from the state of the line. Transmission operation is also not set or controlled by a pre-set timing interval. As soon as information is sent to the UART transmitter to be sent to UART receiver the transmitter will create a start bit then transmit the data from the register followed by a parity and a stop bit. The reason UART needs a shift register in the transmitter side is because it needs to send a full duplex so two shift registers are needed since characters need to be sent and received at the same time. UART will keep a flag up as it is transmitting data so the CPU know it is transmitting data since the CPU will usually run faster than UART can.

UART can easily meet the needs for the project for speed. It only needs one wire which makes implementing very easy for the display to the microprocessor. UART might need multiple wires if higher speeds are needed since both ends need to be on the same clock sync. UART will most likely be harder to code and harder to implement properly than SPI. UART is a good second choice for this design.

3.5.1.3 I2C

I2C is short for Inter-Intergrated Circuits. It is a serial communication protocol uses a serial bus that lets multiple masters to communicate with multiple slaves. I2C is usually used to connect microprocessors to lower speed integrated circuits. When using I2C it is very important that all the traces on the PCB are at the same length or else it will be possible for issues with bit orders to occur. I2C is a well-known and understood format for wired communication from. This dorm of wired communication is able to talk to two slaves at the same time so complex designs can be implemented easily but do add extra strain on programming.

I2C is composed of a system that is very similar to SPI. I2C is composed of a master or multiple masters and a slave or multiple slaves. The master controls the clock signal and the message being transferred. The slave receives the clock signal and transferred signal from the master. Deeper into the design for this form of wired communication there are four forms of operation for a bus, master transmit, master receive, slave transmit, and slave receive. Master transmit is for transmitting data to a slave so it acts as a write mode. Master receive is so the master can receive data from the slave so it acts as a read mode. Slave transmit is so the slave can transmit to the master receive so the master can receive data transmission so this acts as a read mode. Slave receive is for receiving data from the master transmit so this acts as a write mode. [67]

I2C works starting the master which will begin a transmission by going into a transmit mode and sending a start bit followed by the address of the slave it wishes to communicate with and then finally a 1 or a 0 is sent to indicate if the master wants to read or write. The slave will then respond with an active low which acknowledges the message sent by the master has been received. The master will either transmit or receive data depending on if it wanted to read or write and the slave will do the complement and transmit or receive data to or from the master. Any string of messages either the data bytes or the address are always sent least most significant bit first. When a master writes to a slave it sends a byte with the slave sending an acknowledge bit after each one. When a master reads from a slave it will receive a byte from the slave then send an acknowledge bit back to the slave. After an operation of read or write the master will then send a stop bit or a new start bit for multiple messages.

I2C is easy to implement since it only needs two transmission lines. I2C uses addresses to communicate to multiple slaves so chip select connections are not needed which make implementing easier since less connections will be needed for the PCB. I2C can support multiple slaves that require different operating voltages. This is an important thing to note if the group decides to have two different screens later on since not all screens operate at the same operating voltage. This wired communication also allows for multiple slaves and multiple masters without needing to change the wiring. This is also important to note if the group decides to implement two separate screens for ease of use. I2C on microcontrollers usually needs some tedious base software which might be hard to modify which will prove troublesome. I2C needs very short wires to work properly which is a drawback because the display screen needs to be a reasonable distance away. I2C is also slower than SPI, how much this difference is, is currently unknown but speed of results on the display are important for this project so this may be a draw back for the scope of this project. I2C is really only capable of running a half-duplex while SPI can run a full duplex. Overall I2C is too complicated and slow for this project and will not be chosen.

3.5.2 Display selection

SPI is the chosen form of communication between the microprocessor and the display so displays with this form will be considered along with one very basic display as a back-up if implementation proves too troublesome. Ideally a few lines of text should be able to be read clearly, but cycling through a few one-line messages will also be sufficient for the scope of the design. When a hit is met a good indication should be put out and when a miss occurs a good indication of this should also be displayed. There are a lot of displays available and to keep things simple only screens under $35 will be looked at that are available at the same parts store the majority of parts are ordered from. It is important to note that this design does not need the largest and fanciest display screen just something that displays the message conveniently to the user with ease.

3.5.2.1 Sharp Microelectronics TFT LCD Display LS013B7DH03

This LCD display screen is made by Sharp which T.I. uses for their booster packs which means that there are multiple resources and it is known that this display will work fine with a T.I. board. This display has a resolution of 126 x 126 pixels and measures 1.28 inches diagonally. This display operates at 3 V which is not outstandingly high. This display is not recommended to be kept in direct sunlight for long periods of time so this will be considered in the build. The viewing angle is readable at almost any angle so this will allow more options for placement when actually building the design. This will likely be the chosen display component [36].

3.5.2.2 Lumex LCD-S401M16KR

This display is a very simple display. This display is quite small and only allows room for four numbers to be shown at any time. This simplifies the programming but harshly limits what can be displayed at once and would be inconvenient to the user. This LCD screen still offers the ability meet the functionality of the project. This screen operates at 3 V. This screen does not use SPI but is simple enough to not worry about. This display does not have any restrictions for direct sunlight but performance will drop and it may become difficult to read. As long as the display is at a reasonable angle it should be able to be read indoors fine. Implementing this display will be a hassle at first but is a sure-fire way of getting an operating screen for the user to get some general message out of [39].

3.5.2.3 Electronic Assembly EA LED78x64-G

This screen is designed to be a graphic display. It is able to be controlled with SPI and I2C so it meets the criteria needed. EA LED78x64-G has a resolution of 160 x 104 pixels. This display allows for special graphics to be displayed enhancing user experience. This component comes with source code when purchased to allow for easy programming and pre-designed graphic clip art to be used. This display operates at 1.9 V for red and yellow/green. White needs 8.8 V, green needs 9.0 V, blue needs 9.1 V, and Full color needs 4 V. This display is only recommended to be looked at directly straight on which might make implementing it into the final design more difficult. This display also offers the ability to switch the display 180 degrees which could make implementing it into the final design easier by giving another option to where the ribbon connection will be hidden. This screen does not have any specifications about direct sunlight [40].

3.5.2.4 Embedded Artists EA-LCD-009

This display is large compared to the previous displays looked at. The resolution of this display is 254 x 176 pixels. This screen is 2.7 inches diagonally. This display is at a higher cost but offers a big screen for easy viewing by the intended user. This display operates at 3.3 V. This components specs are readily available but the EA-LCD-009 data sheet is not readily available. Viewing angle and effects from sunlight are also unknown due to the lack of a data sheet.

3.5.2.5 Display Selection Conclusion

The most important features in choosing the display screen are outlined and observable in Table 15 below. The Lumex LCD-S401M16KR was not chosen because of the strain it would put on the user. The screen would need to cycle what is displayed because of its resolution. The Electronic Assembly EA LED78x64-G was not selected because the complexity of the coding for it. The Embedded Artists EA-LCD-009 was not chosen due to the high price and lack of a readily available datasheet.

The Sharp Microelectronics TFT LCD Display LS013B7DH03 will be chosen for this project. This display has lots of resources where it is implemented on T.I. boards which makes the job easier. The price for this LCD display is high but not too high. The screen size and resolution make it capable of displaying a few lines of text that are easily able to be read by the user. A viewing hole can be built into the rifle allowing the display to be hidden from sunlight but also make the display more visible to the user. This display is the easiest and cheapest screen to implement onto the chosen microprocessor that will meet the requirements and display all of the statistics on the screen at once.

Table 15 - Display Comparison

Screen	**Sharp Microelectronics TFT LCD Display LS013B7DH03**	**Lumex LCD-S401M16KR**	**Electronic Assembly EA LED78x64-G**	**Embedded Artists EA-LCD-009**
Resolution	128 x 128 pixels	4 digits	160 x 104 pixels	254 x 176
Component Size (mm)	26.6 x 30.3 x .741	20.32 x 10.16 x 2.8	78 x 64 x 3.6	60 x 74
Viewing Size (mm)	23.04 x 23.04	17.92 x 5.28	72 x 45	57.3 x 38.2
Required Voltage	3 V	3 V	1.9-9.1 V	3.3 V
Price	$21.61	$1.60	$11.92	$30.79
Implementing Ease	Easy	Medium	Hard	Hard
Ease for User	Medium	Hard	Easy	Easy

3.5.3 Uniformed Connections Between Screen and PCB

The LCD screen will need to be seen on the rifle while the PCB is hidden inside. This calls for the LCD screen to not be directly on the PCB, but instead be connected by a small length of ribbon wire connecting the two. A port will be needed on the PCB to connect the ribbon wire to the specific pins on the microcontroller. The LCD screen will already have this port built into it simplifying things on one end. The microprocessor chosen has all the required pins to implement SPI for the display. The ribbon wire connector on the PCB will connect the proper wires to the proper pins on the microprocessor. A trace will go to power and another will go to ground. SPI CLK will be connected to the SPI CLK on the microprocessor. SPI CS will be connected to the SPI CS pin on the microprocessor. For the actual message to be sent out to the display the SI will be connected to the MOSI connection on the microprocessor. The length of each trace will be the same length to ensure there is no lag and all signals are moving uniformly together.

3.5.4 Power Requirements

The design calls for the LCD screen to be on and stay on while the rife is on. This allows the main power supply on the rifle to power the screen easily. As to not drain power, the rifle is put into a sleep mode after a determined amount of inactivity such that the batteries are not being drained and the MCU can switch into a safe low-power mode until a user interaction is made. A power connection is needed for digital and analog for the display. Ground connections are needed for digital and analog for the display also. Since the power needed to run this is not very large no major changes will be needed for batteries or the power circuits, as the display will be run under control of the MCU and given regulated power.

3.6 RF

Wireless communication is a major requirement for this project. Without an accurate means of communication, the end project will not be enjoyable and most importantly not functional. RF is a well-documented and understood way to communicate wirelessly. Another option considered was IR but that is already being used for the actual shooting system and interference between the two could have been a huge potential problem. The skeet disc and the rifle will be communicating using RF. An antenna will be on the rifle and the disc and will be capable of sending and receiving data to each other. The data being transferred between the two objects are very simple messages so the design can allow for some noise to keep costs down. The frequency chosen is 915 MHz because it is roughly in the middle of the bandwidth that this projects communication system was chosen for to use and the frequency works nicely on the chosen microprocessor. The most important part is that the two antennas stay in contact with each other in while in use so data is not lost or missed. The disc and rifle will be moving a lot and will not always be pointing directly at each other so it is important that reception between the two devices is always there no matter what orientation the devices are pointed. At the frequency used there are FCC standards that need to be met for radio frequency. These standards are a part of using RF communication and will be gone over in further detail in the standards section of the document (4.1.4 FCC Regulation - CFR 47 Part 15).

3.6.1 Antennas

There are multiple types of antennas on the market. Choosing the right one is important for functionality, cost, and the final look of the project. The antenna chosen needs to be small and light weight as to not mess with the disc performance in the air. Two antennas need to be chosen one for the target disc and one for the rifle system. To simplify things the same type and model antenna will be used for both, this will make it so impedance matching is easier and only needs to be done once also, this will make both devices have very similar range for transmitting and receiving. The gain of the antenna is an important factor to make sure signal strength is strong enough to reach the distance the project requires. It is also important that the RF radiation is spread evenly and not just focused in one direction. There are four main types of antennas to choose from PCB, chip, wire, and whip.

PCB antennas are antennas built inside the PCB itself rather than being an external component. Some launchpads include a PCB antenna and a silhouette can be seen when held up to light. PCB antennas are produced at a fairly low cost and can be mass produced easily. Lots of various PCB antennas are readily available that meet the frequency chosen. These antennas are very accurate at the frequency they were designed for. In general PCB antennas very rarely have manufacturing errors making them great for production. One major drawback with PCB antennas is every component has to be built around the antenna so valuable space on the PCB is lost. Another issue with PCB antennas being built inside the PCB is that if something goes wrong on the PCB a new PCB with antenna will have to be built or if the antenna is bad a large amount of PCB becomes unusable and will be wasted [41].

Chip antennas are antennas that are on a chip that can be put directly on a PCB. They are essentially PCB antennas that are not built inside the main PCB and can be put on like a chip component saving space. These antennas are small in size and can hang off of the PCB saving room for other components. These antennas are available in a wide variety of frequencies and can be found and bought easily. This antenna has all the advantage of a PCB antenna and gets rid of a lot of the disadvantages associated with one. One disadvantage is that since the antenna is a large for a component and is not in the PCB where its structurally stable if the rifle is dropped in use the antenna could break connection with the board.

Whip antennas are usually long tubes that offer great performance. These antennas can be seen on Wi-Fi routers and cars. These antennas usually have to be away from the board because they are rather large and bulky in size. Whip antennas are available in variety of frequencies but cannot be modified once chosen. These antennas offer a large gain and a full radius of signal.

Wire antennas are pieces of wire that act as an antenna. These antennas can usually be seen on remote controlled toys like an RC car. A wire antenna is usually cut to a fourth of the wavelength of the desired frequency to be used. These antennas are very cheap and can actually be made by hand rather than purchased from a vendor which makes them very cheap to use. Wire antennas can be modified or replaced on the fly and trimmed down to get the best results. Pros and Cons can be viewed among the antenna selections in Table 16 below. A few problems with wire antennas is that they can receive undesired frequency and can be very temperamental.

From the Table 16, it is clear that the two best choice of antenna would be a PCB antenna or chip antenna. This decision was made because of pricing, performance, size, and the number of different models of these antennas to choose from to meet the specifications. To make things easier a chip antenna will be chosen rather than try and implement a PCB antenna into the PCB layout. The chip antenna chosen needs to be designed for 915 MHz and stay in a range of 902-928 MHz for FCC regulations

Table 16 - Antenna type comparison

Antenna Type	Pros	Cons
PCB antenna	Fairly cheap for mass production Lots of models readily available Can be in the actual main PCB Great performance at target frequency	Can't manipulate too much Could get interference from rest of board Entire PCB has to be moved to send and receive a better signal Can become pricey for prototyping
Whip antenna	Great performance Readily available	Large and bulky High cost
Wire antenna	Very cheap Can be modified on the fly for testing	Can be troublesome Can easily break or bend Large and bulky
Chip antenna	Small in size Readily available Medium performance	Medium cost Needs to be on the PCB or relatively close

3.6.1.1 Johanson PCB Antenna 0915AT

This chip antenna is available at a very low price but at a cost of low gain. This antenna is specifically designed to be used at 915 MHz and has a range between 902-928 MHz. This chip offers a low gain of –4 dB which might not be enough to keep a solid signal for the desired range. The radiation pattern for this antenna is good but does have some blind spots and only in a very small area so this can be worked around in the final design. The pricing for this component is very cheap so it can be tested to see if it can get the strength and range needed without a huge loss to the group's budget. This small sized antenna can easily be hidden [42].

3.6.1.2 Yageo PCB Antenna ANT1204F005R0915A

This chip antenna offers a nice gain and still a low price. This antenna is set for 915 MHz. The bandwidth for this antenna is 30 MHz so it can go from 900-930 MHz which means it is capable of breaking FCC regulations that enforce staying within 902-928 MHz ranges. Breaking FCC regulations can be avoided through the use of protocols but this antenna will still accept a small amount of bandwidth that isn't addressed by the FCC. This strength of this antenna for its price is appealing for the design constraints. The radiation pattern is very close to an ideal isotropic meaning that this antenna will spread out pretty evenly in every direction. The direction that are not too strong for this antenna will still be strong enough to meet the communication requirements [43].

3.6.1.3 Abracon PCB Antenna APAES915R6460C16-T

This antenna is a very thin and might be a good option for keeping the build compact. The gain for the model antenna is high at 3.5 dB. However, the price for this antenna is not too appealing at $27.29. This antenna is set for 915 MHz and has a range from 902-928 MHz meaning it is safe for FCC regulations. This antennas radiation pattern is not evenly spread out it offers a great gain in a few directions but does not really offer a great strength of connection in every direction so this antenna may be hard to implement into the design at the end [44].

3.6.1.4 Taoglas PCB Antenna 915 MHz

This Taoglas antenna is built for 915 MHz and has a bandwidth of 26 MHz which fits the needs for the design. The gain for this antenna is good at .9 dB and the cost is not terrible at $12.96. This design offers a reasonable gain at a small size. This chip comes with a coaxial cable on which will need to be scraped which will in turn make it more difficult to be put on PCB. The radiation pattern is spread pretty evenly and looks really close to an isotropic antenna. The gain in the lowest parts will still meet the needs of the design easily [45].

3.6.1.5 Taoglas TI.16.5F11

This antenna is not a chip antenna but a whip antenna and is only being considered as a backup plan if the chosen chip antenna is not strong enough. This antenna is set at 915 MHz and fits in the FCC regulation for bandwidth. The gain on this antenna is large at 5 dB. This antenna will only be used if all else fails because it will hinder the flight dynamics of the disc. The other issue with this antenna is even though it creates a very strong signal at a lot of angles the signal will be very small and will probably be lost, which bad for design specification requirements [46].

3.6.1.6 Antenna Choice Conclusion

In Table 17 below the key features of the antennas are looked at. The Taoglas TI.16.5.F.11 will not be considered unless the chosen antenna fails for signal quality and range. The Johanson PCB Antenna 0915AT will be bought and tested because of its cheap price, but will not be considered an optimal match for the design requirements of the project. The Abracon PCB Antenna APAES915R6460C16-T is small and offers a very large gain but is ultimately too expensive for the design. The Taoglas PCB Antenna 915 MHz is great on size but does not offer the gain per dollar that is reasonable for this design.

Table 17 - Antenna Comparison

Antenna	Size (Height/Length)	Gain	Impedance	Price	Max Input Power
Johanson PCB Antenna 0915AT	2mm / 7mm	-4 dB	50 Ohms	$0.92	2 W
Yageo PCB Antenna ANT1204F005R0915A	38mm / 25mm	1.59 dB	50 Ohms	$1.68	1 W
Abracon PCB Antenna APAES915R6460C16-T	62.5mm / 62.5mm	3.5 dB	50 Ohms	$27.12	N/A
Taoglas PCB Antenna 915 MHz	3.2mm / 10mm	.9 dB	50 Ohms	$12.96	5 W
Taoglas TI.16.5F11	620mm / 25mm	5 dB	50 Ohms	$19.25	50 W

The Yageo PCB Antenna ANT1204F005R0915A will be the official chosen antenna for the project design. The size of 38mm by 25mm is big for a chip antenna but is still small enough to be on the PCB and concealed inside the rifle body. The gain for this antenna is 1.59 dB and it only comes at the cost of $1.68 which is desired highly.

3.6.2 RF antenna impedance matching and PCB considerations

To transmit the strongest signal possible out of the antenna the transmitter output impedance must match the antenna impedance. When impedance matching is in place the maximum power is able to be sent out of the antenna which will be half of the power originally sent. Two capacitors and a resistor will be needed to be put in between the microcontroller and the antenna. These components need to be chosen properly by calculations and need to be very precise to achieve the maximum power possible and not waste any. The matching process causes a voltage division between the receiver and emitters, allowing half of the power to be captured and processed.

3.6.3 RF Power Output Required

The more power used for the RF transmission the cleaner the communication will be as the signal will get stronger and noise will have less of an impact. The max amount of power possible to safely use without damaging other components will be used to ensure a strong signal. There is an upper limit for power on the antenna but the microcontroller limits are well below this. Power will be determined during testing to determine the amount of power needed to get a clear signal from a reasonable distance. Another important thing to consider when powering the antenna is the RF energy reflected back to the MCU device. Due to impedance matching some of the power sent to the antenna is sent back into the chip, it is important to understand how much power the chip can accept flowing into it such that it will not burnout the device, which would wind up costing the team a new microprocessor and time spent.

3.7 Wireless Communication Protocols

Our network topology will require a central unit, the controller, and multiple sensor devices located within direct communications range. This make a simple star topology network preferred over other more complex possibilities such as mesh network. Both the target disc and the rifle system will be able to receive and transmit information to each other. The key aspects in choosing the wireless communication protocol for the project are range, ease of implementation, data rate, power consumption, and frequencies available.

3.7.1 802.15.4

IEEE 802.15.4 is the largest standard for wireless personnel area networks (WPAN). 802.15.4 was specifically designed for low data rate applications and extended low power consumption uses. 802.15.4 also has carrier sense multiple access with collision avoidance (CSMA-CA) which would allow for a few more systems to be connected like extra discs or multiple shooters. 802.15.4 protocols allow for a high tolerance towards noise. Most devices on average use about 1 mW which fits well for the design. Most systems cover a range of 10 to 75 meters under 802.15.4. In North America 802.15.4 is set at a range of 902-928 MHz and can hold 10 channels within this bandwidth using a 64-bit identifier for each device involved in communications [32], [58].

The 802.15.4 standard has two different set node types, full function device (FFD) and reduced function device (RFD). Full function devices can communicate with any other device as well as pass along messages acting like a coordinator. Reduced function devices are only able to communicate directly and cannot act like coordinators and pass messages. 802.15.4 communication topologies can be set in two different ways, as a peer to peer or as a star network. A peer to peer topology requires all components of the system to be fully functioning devices. This is because a peer to peer topology will pass messages to one another to reach all devices. Peer to peer topology would be useful because two devices that are out of range would be able to communicate to each other through the others. The star topology uses a central coordinator along with a full function or reduced function devices directly connected to it. For our design a star topology will be used but a peer to peer topology could be used if we want multiple shooters and multiple discs.

3.7.2 ZigBee

ZigBee is an extension to the 802.15.4 standard and is its own standard. ZigBee only defines the networking, application, and security layers of the protocol added on to the standard PHY and MAC layer defined by 802.15.4. ZigBee adds security encryption, data routing, and the ability to forward data which allows for a mesh network. If multiple systems are in use better data connections can be established. If the design wanted to be modified in the future to allow a lot of target discs and a lot of rifle systems to all be used at once ZigBee would be the best solution. ZigBee's advantages can really be seen for low power devices because when not receiving or transmitting the device using ZigBee can automatically be set to low power mode [55], [58], [59].

ZigBee operates at a frequency of 868-921 MHz or 2.4 GHz. Power consumption is low which works well for the design. Range is accurate to 75 meters which will provide adequate range for this project. ZigBee was designed to be much simpler than other wireless personal area networks. ZigBee is designed to transmit data at a rate of 250 kbps.

3.7.3 6LoWPAN

6LoWPAN is a combination of Internet Protocol (IPv6) and Low-power Wireless Personal Area Networks (LoWPAN). This type of communications system was created to be able to work with 802.15.4 and devices on Internet Protocol. An extra device is needed to make these different communication protocols work together. This type of protocol is great for bringing different types of protocols together, but does not offer great constant range. 6LoWPAN operates between 868-921 MHz or at 2.4 GHz. Power consumption for 6LoWPAN is designed to be low [56].

6LoWPAN was designed with the idea that low powered systems with weak processing ability be able to be a part Internet of Things. 6LoWPAN is able to form large mesh networks which could be beneficial if later down the road multiple devices are implemented at once.

3.7.4 Wi-Fi

Wi-Fi is a wireless communication protocol that is great at moving data quickly. This wireless protocol is based off IEEE 802.11. Wi-Fi is short for Wireless Fidelity. Wi-Fi is based on the 802.11 standard. The average range for Wi-Fi is around 30-100 meters. Wi-Fi gets its best data rates at close range but its data rates suffer at longer ranges. This protocol is not power efficient but does not draw enough to worry about for the scope of this project. Another drawback is that this protocol needs a strong signal to work properly [55] [57].

Wi-Fi is a star topology network where there is one central device that can communicate with multiple end devices. Wi-Fi is also available to form multiple ad-hoc nodes which allows for devices to connect and communicate with each other instead of passing through the base station. Wi-Fi protocols from IEEE 802.11 define a media access control layer and a physical layer for the wireless local area network it create.

3.7.5 Bluetooth

Bluetooth is a wireless communication protocol that is usually used for communication between two devices. This protocol is usually seen for transferring music from a phone to a speaker at a close range. Range is not great for Bluetooth and accurate range maxes out at around 10 meters. A connection between two Bluetooth devices can be set to connect automatically. Power consumption is neither good nor bad for Bluetooth. Bluetooth operates at a high frequency of 2.4 GHz only. [55] [57]

Bluetooth was originally designed as a short-link radio frequency. Bluetooth works by taking data for transmission and dividing it into packets and sending it over through a channel. Bluetooth has 79 channels each 1 MHz wide so a lot of data can be moved through this protocol. Bluetooth communication topology can hold a communication line between a max of 7 different devices which is known as a piconet a form of ad-hoc. With Bluetooth there is usually one master and multiple slave. At any point master and slave roles can be switched so if two shooters were playing at once one could be active and send its stats to the other so both player can know how they and their opponent is doing. An important part of Bluetooth protocols is the initial pairing of the two device which might need to be done if multiple times if connection is lost.

3.7.5 Wireless Communication Protocol Conclusion

In Table 18 below the key aspects in choosing the wireless communication protocol for this design are looked at. Bluetooth was not chosen because of its inability to be used at long ranged. 6LoWPAN will not be used because extra constraints and standards are needed to implement it. Consistent information on 6LoWPAN could also not be found further making it less appealing to be used. ZigBee will not be used as a mesh network topology is not needed and would add additional complexity to the final design. Wi-Fi was considered but accepted due to the higher power consumption from Wi-Fi had the potential to impact use time on the disc severely.

802.15.4 will be the used protocol for this project. This protocol operates at a preferred frequency, has the needed range for the design, is friendly to work with, meets the network topology desired, and even with a low data rate will be able to move information from the rifle system to the disc system fast and efficiently. 802.15.4 is a simple wireless communication protocol but it goes beyond any communication requirements that this project needs. 802.15.4 is also conveniently ready to be used on the Launchpad that will be used for testing before the PCB design is finalized.

Table 18 - Communication Protocol Comparison

Type	802.15.4	ZigBee	6LoWPAN	Wi-Fi	Bluetooth
Operating Frequency	868-921Mhz, 2.4 GHz	868-921Mhz, 2.4 GHz	868-921Mhz, 2.4 GHz	2.4 GHz, 5 GHz	2.4 GHz
Accurate Range	1-75 meters	1-75 meters	N/A	1-100 meters	1-10 meters
Price	Low	Low	Medium	High	Medium
Network Topology	Star / Point to Point	Mesh	Star / Mesh	Star	Piconet
Power Consumption	Low	Low	Low	High	Medium
Data Rate	20-40 kbps	250 kbps	N/A	150-200 Mbps	1 Mbps

3.8 Microprocessor Operating Systems

Operating systems are commonly understood to be required to run a personal computer, server, tablet, or phone. Microcontrollers on the other hand do not require an operating system. Originally, they were typically programed directly in assembly or C language. This was appropriate for the simple single tasks they were originally being used for. They are now being used for more complicated missions and in connected Inernet of Things (IoT) devices that required the handling of connectivity protocols on top of the task that they are performing. This make it more desirable to have an operating system to handle tasking and provide standardized communication protocol support. Our project will require communication protocol handling, so we will look at embedded operating systems that will provide that support.

3.8.1 FreeRTOS

FreeRTOS is one of the larges if not the largest utilized embedded operating system in use. It owned and maintained by Real Time Engineers Ltd. The origin goes back to 2003. They provide the OS free of charge under a modified BSD style license that permits the user to keep their code private while avoiding intellectual property infringement. FreeRTOS has been ported over to support 35 or more architectures. This make code developed on the platform more portable that coding directly on a single architecture [14].

The OS utilizes proven efficient means for handling timed events. This provides the means for producing code that is less processor intensive. This in turn can be translated to power savings by reducing clocking or entering idle power saving state. The OS is designed for imbedded devices and as such has a small code foot print of only 6K to 12K bytes. They have packages available that include features for IoT, Fail Safe File System, TCP stack, UDP stack, Safety Certified kernel, SSL, FAT file system support and IO. There are also additional community supported add on projects to add functions to the OS.

FreeRTOS would be a candidate for running on any of the microprocessor devices that we are considering, while also gaining knowledge in POSIX

3.8.2 Contiki OS

Contiki OS is an open source project that focuses on meeting the needs of microcontrollers that are used with internet connectivity and complex wireless systems. Contiki is free and distributed under a BSD style license. The OS provides full IP networking, routing, and support for 6lowpan, RPL, and CoAP IETF protocols. The code footprint needed to support the OS is 10K RAM and 30K ROM. This may be excessive considering our limited RAM [13].

The OS is available for a number of devices from Texas Instruments, Atmel and Microchip. The devices supported are similar to the ones we are looking at using, but direct support is not certain. Additional work may be needed to make a custom build or configure the OS to work on the microprocessors being considered. This along with an excessive amount of features we do not need makes this selection undesirable. On top of the complex design that this Contiki component would bring, these challenges are not particular to accomplishing the team’s goals for a working prototype design.

3.8.3 TI-RTOS

TI-RTOS was formally known as SYS/BIOS when it was part of Spectron Microsystems. After being acquired by Texas Instruments they have been providing it free of charge to support their products. The OS has a number of separate packages for feature support allowing the inclusion of only what is needed to support the application. There are also add on packages available from third parties. As this OS is from TI it is well tested and supported on their products. TI has a good supply of training and examples for use on their devices. Support for this OS is integrated into TI development tools. If a Texas Instruments microprocessor is used TI-RTOS would be a viable choice [1].

3.9 User Enhancement Components

To enhance the user experience a small speaker will be used in the device to add sound effects. The speaker will play sound clips that will let the user know when their rifle shoots and also help the user decipher a hit or a miss audibly. Vibration motors will be used in the rifle to give a physical response to the user that can be felt and add to the overall realism and fun to the design.

3.9.1 Speaker Selection

The speaker chosen does not need the best sound quality, it needs to be able to play short sound clips or variable tones. The speaker should not take up a lot of space but should not be so small that it is barely audible whilst in use. The bare minimum for the speaker's capabilities is to play two tones one for a hit and one for a miss. The ideal speaker for this project will be able to play a shooting sound when the trigger is pressed a short jingle for a hit and an unpleasant sound sequence for a miss. Power usage is an important feature to look at when choosing the speaker. Specifications and criterion for selection would also be that of low-power consumption, ability to reach high pitch tones, while also being compact.

3.9.1.1 PUI Audio AS03104MR-N50-R

The PUI Audio AS03104MR-N50-R speaker is a medium sized speaker that will be able to fit on the rifle body without having too large of an impact. This speaker measures 31.4mm in diameter offers a decent sound quality and volume and is priced at $8.48. A great range of frequency responses is allowed within the 200Hz to 20kHz ranges, which would suffice for having a variable sound cycle. This speaker is rated for three to five watts and has an impedance of 4 Ohms. The type of magnet used is a neodymium magnetic motor to create a high variable output and smallest form. There is also no framing on this speaker so it is smaller but does not allow for solid way to hold it in place inside the rifle. The design of which would evolve into some design complications later on in the laser rifle housing [60].

3.9.1.2 CUI CMS-160916A-SP

The CUI CMS-160916A-SP is a square speaker that is medium in size and should offer a decent sound. The square body of this component will make installation easy to implement into the design compared to a circular speaker. This speaker measures in at 16mm x 9mm x 3 mm which will not take much room and can easily be concealed. This speaker is fairly cheap at $3.32 making ordering multiple of them a feasible option if the sound can't be distinguished. This speaker has a power rating of up to 1.0 W and an impedance of 6 Ohms and uses a neodymium iron boron magnet to induce the electromechanical motion that creates a pulse for the speaker [61]. Ontop of the sleek design and low profile, this component has the potential of saving capital if mass production were to be taken into consideration.

3.9.1.3 PUI Audio AS06608PS-WR-R

The PUI Audio AS06608PS-WR-R is a round speaker that is medium sized and offers a high range of frequency all the way up to 12kHz. This speaker is rated up to 4 W and has an impedance of 8 Ohms. The price is decent at $7.95 so this is a viable option. This speaker uses ferrite magnet to induce the electromechanical motion to create the sound waves. This round speaker is constructed and contained inside a square holder that measures 66.3 mm x 66.4 mm x 29mm so implementing will not prove to be too difficult in the design of the rifle body. The use of this speaker would provide a higher quality sound factor while also raising costs, this product will be purchased and tested to determine whether or not the difference in audio quality can be conceived in the final design. The cost of this speaker will be taken into consideration for mass production factors, as the final cost can be cut by over 50% after 1000 orders [62].

3.9.1.4 Mallory Sonalert PT-3110P-05Q

This is a very simple buzzer designed to work at one frequency which is 1.1 kHz. The designed frequency can range plus or minus 500 Hz from the intended frequency. This audio device is a transducer. This speaker is small in size and has a diameter of 34.5 mm. This buzzer is rate up to 5 V and 2 mA. The price is cheap at $2.57 so it is very appealing. This speaker is small enough and more importantly designed to fit onto a PCB which will make implementation much easier for the final design. This speaker specifications state it will put out 90 dB of sound pressure at 8cm so it will be clearly audible to the user [63]. Featuring a two pin connection, the testing as well as design can be easily developed.

3.9.1.5 Mallory Sonalert PT-1520PQ

This is speaker is very similar to the PT-3110P-05Q except it puts out a higher frequency tone. The frequency put out is set at 2 kHz and has a tolerance of plus or minus 500 Hz. It is rated for 3 V and 1.5 mA but has a max operating voltage of 25 V. This audio device has a diameter of 17 mm. Like the PT-3110P-05Q this component is also a transducer. This device can be implemented onto the PCB directly easily. This component is priced at $2.74 which is a nice price. The specifications state that this device can output 72 dB at 10 cm so it will be clearly audible to the user [64].

3.9.1.6 Speaker Selection Conclusion

The PUI Audio AS06608PS-WR-R will be the chosen speaker for this design. The PUI Audio AS03104MR-N50-R will not be chosen as it will be much harder to secure it in the frame than the other choices. The PUI Audio AS03104MR-N50-R does not have a fully complete data sheet which is another reason why it won't be chosen. The CUI CMS-160916A-SP was a close second for the decision. The CUI CMS-160916A-SP faults are that it does not have a large range of frequencies and multiple of these speakers might be needed which will make it more difficult to implement into the final rifle design later. The Mallory Sonalert PT-3110P-05Q and PT-1520PQ would be and easy to implement but both would be required for the user to differentiate a hit from a miss and there is only one output available on the MCU for a speaker so this option is not viable.

The PUI Audio AS06608PS-WR-R offers a nice range which will allow for a variety of different sounds which will enhance the user experience of the device. This speaker will be easy to implement and also be able to convey an accurate and easily recognizable message to the user audibly. Volume of the speaker will not be easily adjustable only pitch. A high frequency tone will be used for a hit as it will sound pleasant. A low frequency tone will be put out to let the user know they missed.

3.9.2 Speaker Power Requirements

The speakers will be connected to pins coming off the microcontroller to allow for each speaker to be turned off and on independently. The volume will be controlled by the battery the speaker is connected to and not the MCU. The power supplied will be correlated to a logic gate system design, connected to a regulated power source to not exceed the power rating. The speaker will only be active when a shot is made and a hit is detected, this works out nicely since the speakers will only be operational when the MCU is communicating to the user the status of the skeet target. The electronic switch will be a transistor capable of high switching speeds for the speaker and will be connected to the microcontroller so that the microcontroller can control the switching going to the speaker so rapid shots can be made and the user can detect this. Various amplifiers may be needed to achieve the best results.

3.9.3 Vibration Motor Selection

The vibration motor will add to the overall realism to the project. It is not a key aspect for the system to function but offers a nice touch to it. Ideally the vibration motors should run for a split second when the trigger is pressed. When the rifle is powered on an ideal feature would be for the motors to run for a short burst to give another indicator that the system is running.

3.9.3.1 Parallax Vibration Motor 28821

This vibration motor is a light weight slim design that offers a large enough impact to be felt. This type of motor is known as a coin vibration motor due to its thin profile. This motor is designed to be flat so it will be easily concealed in the rifle body. This design does not use too much power to function properly. Ideally this motor is designed to operate at 9,000 revolutions per minute. This motor is capable of creating an acceleration of 22 m/s^2. This vibration motor is very durable as it is designed to be able to take a 1.5-meter fall without breaking which means when it is implemented into the rifle body the location will be more focused on results than protection which is good. This motor is priced at $3.99 so it is possible to use multiple if it is discovered that the vibration is not strong enough for the user to get an enjoyable feel from. [65]

3.9.3.2 Parallax Vibration Motor 28822

This vibration motor is concealed in a cylinder and has a large mass attached to the end of the motor. This motor is large in size but offers a strong force that can easily be felt. This component needs a fairly large current compared to the rest of the system to operate at max strength. This vibration motor ideally operates at a speed between 9,500 to 14,500 revolutions per minute. This motor is able to run clock wise and counter clockwise depending on which way the power flows through it. This motor is capable of creating an acceleration of 22 m/s^2 providing more than enough force to excite the users grip and give a realistic sensation of firing the laser rifle. This motor has a large off centered mass and can create a large force for the user to feel, appropriate positioning within the laser rifle will be tested to determine the maximum user felt impact [66]. The datasheet also refers to this Parallax vibration motor as the ‘Pancake Motor”, after its large off centered mass.

3.9.3.3 Vibration Motor Power Requirements

The vibration motor only has a positive and negative connection so it will be connected to the trigger power system so that when the trigger is pressed the motors run. Since the motor is connected to the trigger system it will be ran on a chain coming off the mains power source. All of the above motors can be put in two directions clockwise and counter clockwise so if two are used one might be hooked up backwards to create a stronger vibration. Each motor needs roughly half its required current to overcome its internal inertia and counteract the static forces within. Changing the connection polarity on either of the motors would provide an indistinguishable difference, except when multiple motors are used to achieve a counterbalancing effect, further magnifying the vibrational output at only double the power and volume of components.

3.9.3.4 Vibration Motor Conclusion

The choice for Vibration Motors is limited to two options because the website most of the components are being ordered from on offers those two. A decision on which motor will be used will be decided closer to the build date because this is a very mechanical decision. A combination of the two may be used depending on the final design. The 2821 will be able to fit in thin narrow areas and could create a strong force. The 2822 can take up a large room in the hollow part of the rifle systems body. The 2822 will create a large force.

4.0 Design Constraints and Standards

Standards are important for the interoperability between components across different disciplines. These standards provide the foundation of which we stand, operate, communicate, and develop new ideas. Constraints further enhance the safety and environmental awareness for the design under scrutiny. Both of these engineering practices allow for the safe development of practical and useful ideas while also maintaining a cooperative and understandable environment.

4.1 Constraints

Constrains on a project are better defines as limited goals to which a project can reach, these are known as the boundaries in which the fundamental design must follow, approach and not exceed. These constrains consist of more than just time and money, but also the legal and safety ramifications of the intended product. Due to the very nature of having a 'Laser'-'Rifle', it has become very clear that guidelines and scrutiny will be fundamentally key in formatting a design that not only conforms within our specs, but does not exceed our constraints. Such as having a high performance, high range of use and low cost, these cannot co-exist and are limited further by power standards, ethical standards, legal standards and laser safety standards, it may only be feasible to have a high performance and low cost design.

4.1.1 Laser Safety

The safety of this laser is very important to be qualified as a successful product. The minimum safety standards will be met by the regulations set by the CDRH in 21CFR subchapters 1040.10 and 1040.11 which are discussed in section 4.2.7, Laser Regulations and Standards [28]. It will be assumed the laser in question will operate in the infra-red region and will be modulated as well as stating that the laser will not be a class four laser since this classification possess to much danger to a person and will not work as a commercial product. For a more accurate and focus look at required safety measure needed to meet FDC regulations, the laser will be assumed to be a class three laser. The following is a list of safety measures based on the assumed laser system, these are subject to change depending on the result of the final prototype. The first safety measure is a general warning notice with instructions for safe handling of the laser product in question as well as designate the laser is solely used as a component of the product. The second safety measure is to ensure that the laser itself is not removable from the product. The third safety measure is to provide at least one safety interlock for each part of the laser system that can be removed as well as a written warning on all interlock for the laser classification for the laser in use. For a class three laser the warnings “CAUTION—Laser radiation when open. DO NOT STARE INTO BEAM OR VIEW DIRECTLY WITH OPTICAL INSTRUMENTS” and “DANGER—Laser radiation when open. AVOIDE DIRECT EXPOSURE TO BEAM” depending on which particular subclass the laser falls under. If the interlock is defeat able, an additional warning must be in place. The fourth safety measure is a key control needed for class three B and class four lasers [22]. The fifth safety measure is a laser radiation emission indicator that provides a visible or audible signal to signify that the laser is in operation without being obstructed by protective eye wear or need the operator to look into the output beam to see the indicator. The sixth safety measure is a beam attenuator that will provide a means of blocking the output emission without using previously mentioned safely measures. The seventh safety measure is to ensure all controls needed to operate the laser are not located in the laser output path. The eighth safety measure is proper labeling of the laser system to be plainly seen on the product. The label should be plainly visible upon the laser as well as being placed in a way in which it is still viewed without having to look through the laser output. Labels should be clearly legible and contain pertinent information about the laser such as wavelength, output power, and whether the beam is continuous or pulsed. Additional labels include warnings not to view with optical instruments. Figure 4 below shows the label needed with a class three laser. The label in position 1 should read “LASER RADIATION—AVOID DIRECT EYE EXPOSURE” and position 2 should read “CLASS III(a/b) LASER PRODUCT”.

Figure 4 - Laser Warning Label

4.1.2 Social, Ethical, and Environmental Concerns

Social
Due to the fact that there is a segment of the population, celebrity, and politicians that are strongly opposed to firearms, there could be complaints or hostility toward a product that simulates a shooting sport especially since the project may be used to help children transition into the actual shooting sport. At the same time, since the firearm has technically been removed and replaced by a lookalike laser source, there will be those that look at it positively. In the end it would be a wash and not be a concern.

Ethical
No ethical concern has been identified since if the product were to be marketed it would be done so with the inclusion of documentation and rules that would promote safe use. Engineering designs however the ethical concerns that the team would have do sometimes fall under the speculation of misuse, therefore is those savvy enough with electronics to override the safety measures that are put in place.

Environmental
This product has the potential to positively impact the environment. In normal skeet the shotgun may use lead shot that is then spread over a large area and may contaminate nearby water sources. The shotgun also expels plastic pieces of shot housing that liter the environment if not picked up. In addition to the physical waste it produces a loud bang which contributes to noise pollution. Normal skeet discs shatter into many pieces and are never fully able to be picked up. Our product would eliminate these pollutants.

As a negative contributor the only thing that would need to be considered is the production. The production process of both the housing and electronics can have harmful waste. Disposal at the end of life can also contribute to extra demands for the landfills. Additionally, the electronics could use lead solder which is an environmental concern. If the product were to go to mass production this can be minimized by selecting manufactures that employ green technology standards.

4.1.3 Resource Constraints

Manpower
Our team is comprised of 4 individuals. As such all work will need to be done with available time the four of us can contribute. Team members have work and other classes that will limit availability and restrict when the team can meet. The school has also placed a time constraint on us by virtue of the class schedule. With this limitation we will not be able to push deadlines out to get more time. Furthermore, the team has different skill sets. Care will need to be taken in the project not to overload any particular area while making sure to contain sufficient content everyone's course requirement. The team will come together for weekly meeting

as well as coordinate specific times for multiple system-part testing, such that no two components will be non-compatible when the final design is made.

Financial

As students rather than a large corporation our finances are more limited. The intent is to complete the project within costs that we can personally absorb. This in turn has impacts on what tools can be used. We are restricted to using the basic lab equipment and design software available at UCF unless other free resources are found for use. The test equipment in the engineering and photonics labs is expected to be adequate with exception of some additional tools needed for optics. Our photonics team member is investigating getting the additional needed equipment purchased for the lab so that we will not have to take on that cost.

4.1.4 FCC Regulation - CFR 47 Part 15

The Code of Federal Regulations (CFR) has section 47 which concerns the topic of telecommunication, in this section there is subsection 15 which goes into the regulations of radio frequency devices. This subsection contains the regulations needed to be met for this project to be safe and legal for the wireless communication aspects. Since the purpose of this project is to create a functioning prototype and not mass produce the design the system will be compliant with FCC CFR47 Part 15 subsection 23. No more than five of these system designs will be prototyped and developed. Part b of subsection 23 states "It is recognized that the individual builder of home-built equipment may not possess the means to perform the measurements for determining compliance with the regulations. In this case, the builder is expected to employ good engineering practices to meet the specified technical standards to the greatest extent practicable." This requirement will be met and kept in mind throughout the process of experimenting and testing of the final design. Part b of subsection 23 also states that all requirements in subsection 5 must be met. The key parts of subsection 5 that must be met are that this device must not produce harmful interference intentionally, unintentionally, or incidentally. The device must be able to be turned off if requested by a commission representative. [31]

If the design wants to go to market and be sold additional requirements to the ones mentioned above must be met. Emissions should be as suppressed as much as what is practical but shall not pass levels specified by the regulations. Nothing can be available that can easily be adjusted by the user to break violations of the regulations. The design should use the lowest field strength to work properly so as to not pollute the air space with unnecessary noise. The design should note that even if all compliances are met it is not possible to stop harmful interference under all circumstances. The device cannot be used to eavesdrop on conversations. Harmful interference created by the device must be engineered to be as minimal as possible. All device must contain this statement in an easily visible place on the device "This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation." The label must be permanent and not easily removed. The manual for the device must state that if the user modifies the device in any way that is not expressly approved by the party in charge of compliance to the regulations the user can lose authority to operate the device. All data and certifications for the design must be available for inspection by a Commission representative upon request. The device may not break regulations if supplied voltage is between 85-115% of the designed voltage amount. Maximum conductive power can be 1000 mW. [31]

4.1.5 Export Control Regulations

There are two primary entities that regulate the international shipment of technology the International Traffic in Arms Regulations (ITAR), 22 C.F.R. §§ 120-130 and the Department of Commerce Bureau of Industry and Security. As these regulations apply to technologies that include communication, encryption used for communications, and any product that could be adapted for use in weapon systems they tend to frequently apply to any technical design. Our product uses a microprocessor that would fall within the regulated type of equipment. Since we will not export our prototype it will not affect us. It is however important to keep these regulations in mind when developing products if they are intended to be marketed internationally. Furthermore, the destination of the product should also comply and follow the regulations and standards from the original source.

4.1.6 Software Licensing

In products that are developed that incorporate software it is important to be aware of any costs or restrictions that come with the use of the software. Software licenses come in many forms. General Public License (GPL), Massachusetts Institute of Technolgy (MIT), and Berkley Software Distribution (BSD) are examples of some free available software. Even though they are free, restriction can still exist, such as requirements to make your code public or inclusion of origination of the software and the original license. Many proprietary licenses also exist since the originator of each software has the option of making their own licensing term.

In our case, the use of Texas Instruments' code, drivers, and RF stack will require us to adhere to their license. Luckily since their desire is to sell chips the requirements are minimal. The software is free. The only restrictions are that it is used for their devices only and that the software source code retain the licensing terms.

4.1.7 Manufacturing Constraints

The microprocessor selected only comes in a surface mount package. While pretty much all circuit board manufactures today are capable of mounting surface mount components, our prototype build could give us some difficulty. Special soldering tools are needed for doing surface mount soldering. Even if we have access to the tools it is tedious and delicate work. Instead of risking damaging the MCU and other delicate components we are checking on the possibility of having them mounted by a local circuit board assembler or the circuit board manufacturer that we order our PCB from. Limitations further examined on the market base would be those that constrain the manufacturer to withhold a product, taking up their inventory space, time and resources. Therefore, it is very likely that the opportunities to correctly assemble the PCB in a one-time go are limited and costly, meaning that more testing and design manufacturing will have to be taken into consideration prior to arriving at the final placement.

PCBs are constantly advancing manufacturing technologies that allow for more precise traces and milling for components. The issues however faced with PCB designs would be the excessive cost accumulated from wasted space, aesthetics designs and more milling than what would be necessary. Avoiding larger PCBs which would save space in the design for common practice errors to exist, tends to be the easiest manner of designing the final PCB. Drafting a schematic with the least amount of traces crossing over not only creates a sleeker looking PCB but also prevents common practice errors such as transmission crossings and low-trace widths for delivering power. Furthermore, drafting the PCB also must follow the manufacturer’s abilities to perform, therefore the company building the actual component will consume time to examine the idea and determine whether or not the component can be made. This further intensifies the level of care that must go into the initial drafting offer. As time is of the essence, the PCB will need to have a longer period of design time before the final product assembly is determined.

4.1.8 Sustainability Constraints

Our product is intended for the consumer entertainment market. There is no plan to have required maintenance on the product. In the case of a failure it is expected that the owner would dispose of the unit and by a new one or receive a replacement if under warranty. The only normal service would be battery replacement which would be done by the consumer. Intentions of this product are also not to design faulty equipment which would cause an unsustainable condition on the user ends. The complete design will be constructed within the mindset of using this product under standard conditions such as but not limited to avoiding weather, freezing or excessive heating conditions, extreme humidity and rain, underwater use, and other electronic damaging conditions.

4.2 Standards

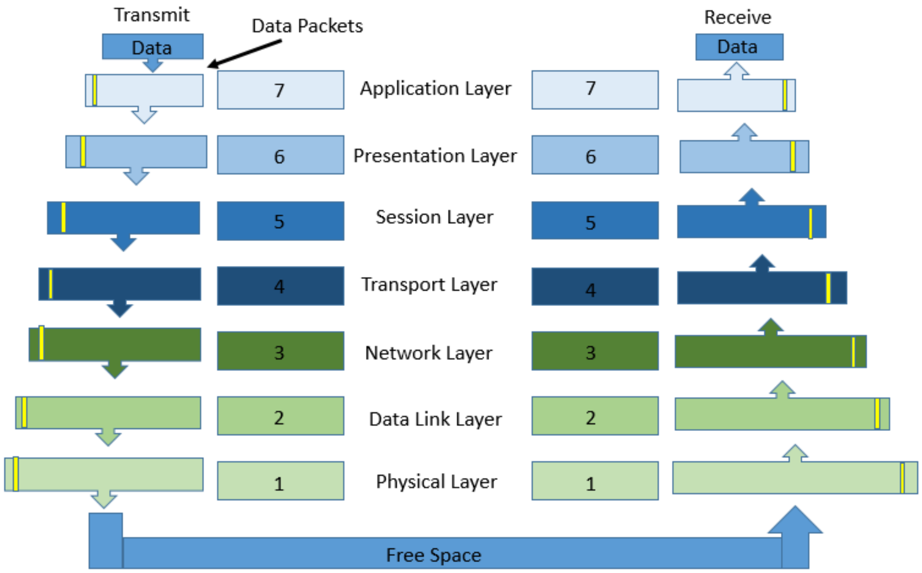
Standards are an important aspect for engineering. Standards are needed to keep system devices safe for people and other devices. Standards make sure formatting for various aspects stay the same across the board making things connect seamlessly and operate as intended. Various standards also protect the general public from malpractice attempts, uncertain principles in electronics as well as ethical performance. Determining which standards the project categorically falls under is an essential part of assuring ourselves and the project, that the final outcome is something that can be classified, registered, and approved for use.

4.2.1 IEEE 802.15.4

For use in North America the use of 802.15.4 must stay within 902-928 MHz. 802.15.4 protocol follows a basic Open Systems Interconnection (OSI) model seen in Figure 5 and starts with the physical layer which creates a signal from data bits sent in. The second layer is the data link layer which corrects errors that may have formed over transmission. The third layer is the network layer which gives out addresses to each device to allow data to be routed to it. The fourth layer is the transport layer which gives specific times for devices to communicate. The fifth layer is the session layer which manages when a session is open, closed, or managed. The sixth layer is the presentation layer and is in charge of translating the data taken in into something the device can use. The seventh and final layer is the application layer which makes sure the devices are using the same protocols used by the host. 802.15.4 sets the standards for the physical layer (PHY) and the media access control layer (MAC). The PHY sets the frequency, modulation, power, and other wireless conditions for the connection. The PHY also activates and deactivates the transmitter. The MAC sets the format and data handling. The MAC layer also is in charge of guaranteed time slots, frame validation, and node associations. Higher layers exist in 802.15.4 but are not really set as standards and it is in these higher nodes that more complex wireless communication protocols are seen such as 6LoWPAN and ZigBee.

IEEE 802.15.4 allows for data rates of 250 kbps, 40 kbps, and 20 kbps. Addressing modes can be 16 bit short and 64 bit IEEE addressing. Connection between the devices is automatic. 802.15.4 is designed to be low on power consumption. At the frequency chosen it is possible to have up to 10 channels so the design is able to be scaled up with more discs and rifles. The standards set up by 802.15.4 allow for an equal tradeoff between data rates and range. Standards allow for guaranteed time slots so devices will not try and transmit data at the same time. Transfer reliability is improved since the protocols are designed to be the same on both devices. The use of a set standard conserves power so low power consumption devices can communicate. Energy detection and link quality indication are possible through the protocols set by 802.15.4 standard [32].

Figure 5 - Open Systems Interconnection (OSI) model of network operation



The 802.15.4 standard sets the 902-928 MHz frequency to use binary phase shift keying (BPSK) for modulation which allows for a lower bit error rate. The data rate at 902-928 MHz is defined to be 40 kb/s.

4.2.2 JTAG

The commonly known JTAG is the abbreviation for Joint Test Action Group. It is the test access port (TAP) implementing boundary scan architecture for digital integrated circuits to provide testing, debugging, and programming of the chips. The standard was initially community supported and being led by JTAG Technologies. The work they did led to the adoption on Institute of Electrical and Electronics Engineers (IEEE) 1149.1 standard in 1990. This was later extended to support faster data rates, easier connections to multiple devices using a star topology, and fewer pins in the cJTAG IEEE 1149.7 standard. The connection required for using each are listed in Table 19.

Table 19 -JTAC / cJTAG Connections

JTAG		cJTAG
TDI (test data in)		TMSC (test serial data)
TDO (test data out)		TCKC (test clock)
TCK (test clock)		
TMS (test mode)		
TRST (test reset)		

These pins are laid out in different formats and connector types depending on the vendor providing the microprocessor. In our case we are looking at ARM® microprocessors. ARM® uses two different connector forms. In our case we are interested in the compact variety. It is a ten-pin male pin connector with 0.05" pin spacing laid out in Table 20.

Table 20 - JTAG Connector Pinout

VCC	1	2	TMS
GND	3	4	TCLK
GND	5	6	TDO
RTCK	7	9	TDI
GND	9	10	Reset

Communication and control over the interface is done using the Boundary-scan Descriptive Language (BSDL). It defines the syntax, commands, and messages that can be exchanged [9], [8].

The JTAG is an important tool in the design of projects with microprocessors and other programmable devices. It allows for the reprograming of the device after it has been mounted as well as supporting debugging during development. Having a standard for this allows for the use of standardized equipment debugging. This way a different piece of equipment is not required for each different product. Even with the use of different connector types, the same test equipment can used by simple using an adaptor cable.

4.2.4 Coding Standard

Coding standards are important to provide quality and consistency in software. Coding standards provide the guidance beyond the rules imposed by the programing language and compiler. Things specified in the standard are naming conventions for variables, functions, and constants. They also give a standardized way for formatting code with regards to placement of punctuation like '{ }, ( )'. It provides guidelines for placement of white space and location for comments. Having a consistent form helps avoid confusion and by this helps reduce errors in the code.

Coding standards are available from many different sources. They can come from the language controlling body, the IDE tool provider, standards bodies, or many times a company may even define their own. The Barr Group has a published standard, the "*Barr Group's Embedded C Coding Standard".* They provide a good example of how a coding standard is defined. In our case we will be using Texas Instruments drivers and starter projects. Since they already are in the project following the same style as TI uses will provide more consistency and less confusion.

4.2.4 Power/Battery Standard

Power standards associated with this particular design would be those pertaining to the DC batteries operating both the skeet target and laser skeet rifle systems. The use of batteries in today's market do hold adverse effects if thrown away without properly dispensing of them, these adverse effects consist of harmful chemicals such as nickel and cadmium [16] that release toxic waste into the environment that can easily spill into water supplies and are unfit for human consumption. Therefore appropriate disposal of these battery sources must be noted for the user to see, in the hopes that this will have a positive impact for our environment.

The 9.6V NiMH battery features a common connector type called the mini-Tamiya female, this connector features a hard-plastic casing for sturdy connections as well as a clasp to fasten the battery end into the receiving load end [53]. The connector type does also feature a one way of connection design, such that placing the battery in reverse polarity will not be possible, this design protects the internal circuits and ensures proper use every time the battery is re-connected. The connector caps can also be purchased from common electronic vendors for relatively cheap, which allows a spare connector to be purchased in order to trim one end for a PCB connection. The particular connector is not available as a surface mount component however and is not expected to be purchased online. Therefore, having the external system that is easily within reach of the user will also provide a sense of security to the primary PCB hardware and allows a weatherproofing of the electronics system by creating a user isolated environment.

Power standards within a PCB are commonly limited by the PCB size and various trace widths and channels that deliver power to the circuit. The power specifically being held on a copper trace, would require some calculations such that the current is capable of being handled by the traces, a small trace would lead to over-heating and complications over the longevity of a final circuit.

Furthermore, the power within the PCB will also be regulated across the MCU, laser driver and other critical components that rely on a constant input for appropriately regulated operations. This particular action of restricting power would cause excessive heat to dissipate into the board, which means that a large portion of the PCB should be dedicated to wicking heat away from the vital components. This can be done by adding thermal components to the known heat-expending components. This would allot a temporary fix for the heating issue but would not provide a long-lasting solution. Ideally having an entire plane of the PCB allotted for heat sinking purposes would be ideal [53]. Experiments would need to be conducted to determine if a separate component is necessary to control the heating power, such as a coolant system, or fan operated cooling.

4.2.5 Charging Standards

Some versions of low power charging for smaller AA batteries have a tendency to be of a safe operation, but however for a fast charger such as the one for a 9.6V NiMH battery pack, which replenishes to 95% charge in a matter of 30 minutes, does come with a few warnings that other higher power charger does as well. Most are designed exclusively for indoor use, otherwise external environments and uncontrollable situations can lead to overheating and damage the charger. The charger as well should never be covered, which increases internal temperature and causes overheating, which also leads to damaging the charger [38]. The charger should also not be left on flammable surfaces either in the instance of overheating and possible electronic faults within the charger.

The charger features self-built in ac to dc conversion, using a standardized wall outlet, the user is able to plug in directly to their home's mains electricity outlet. This provides the charger with 120V input supply while having the ability to charge the 9.6V NiMH rechargeable battery using a driving output voltage of 7VDC to 12VDC and a charging current of 2A to 3A. This standard with the online-purchasable charger is capable of retrieving the 1600mah within 35 minutes as opposed to a standard USB 3.0 wall charger which would roughly take 5 hours to retrieve the same power.

In addition to the charging and standards of power handling, heat of such a step down does become a prevalent issue whilst charging a large battery. Therefore, the cable connections between the wall to charger and charger to battery are affixed with thermocouples that monitor the heat energy output from the charger. This system comes with a built-in safety mechanism that stops the charger from overheating by restricting power flow entirely. This severance prevents the battery pack from exploding, prevents the charger from catching fire, and prevents the wall outlet from shorting through the components and causing extensive damage to the charging environment [38].

4.2.6 PCB Standards

Printed circuit boards (PCB) enable the user to remove a breadboard aspect as well as creating a planar dimension and tight fitting electronic components using minimal amounts of area. This creates a clean and low-built in error, whilst retaining the ability of being easily replicable and mass produced, the PCB design replaces common wires with traces to provide low resistance and tight grouping connections over multiple layers. These traces are not able to cross, therefore multiple layers and connections can be made such that multiple traces can cross over but not through each other [53]. These traces that collide, would be considered a new net and or bus. Such a connection is primarily used to tie power supplies together before extending out to the external power systems. Dependent on the size of the power supply being used, larger traces will be required, such that the board does not get burnt out by the power supplies. Industry standard is to determine the weight of the copper traces being used and what purity is needed for the internal heatsink, such that the weights used can absorb the power dissipated by the battery dissipation. Because the system in question will be using low power systems and small current, a standard 1.0oz copper trace and 10mil to 20mil trace widths. This provides a universal trace for the PCB, making manufacturing quicker and simpler. This particular design and aspect can be enhanced and maximized after the prototype is conducted.

Within the PCB connections lay the components. These components can either by surface mounted (SMC) or through hole components. The major differences are the capabilities that the components have to interact with another, using surface mount components for example will provide the smallest surface area connections needed, whereas through hole components will connect all the layers that the pins of the component penetrate. Component size and trace sized are a concern in the industry and for that matter the electronic components can all be scaled up or down to acquire a compact and clean designed PCB. Small powered devices typically utilize the industry standard of the times, such that today's current standard in America is the imperially coded 0805 models of compact devices. This is a standard of saying the component is 08mils by 05mils, as technologies develop, many components can become smaller in size which increases overall production. An example of this PCB standard changing is the evolution of resistors using standardized metals such as copper, gold, aluminum to create resistances, higher quality thermal films have been manufactured and trimmed to be especially smaller than their standard 2512mils sized components [53].

Additionally, the PCB is made from a resin cast board with the standard copper traces, the resin in question is usually designed from plastics, fiberglass composites, and low conductance substrates. These allow the boards to be manipulated and traces etched into these malleable fragile boards. When the final design is created and implemented using a Gerber image, which exercises the inputs of the fabricated materials, verifies the range of distortion between components, and assigns the traces dimensions between components. This Gerber simulation can be used among many free software's such as EagleCad, DesignSpark, TinyCad, and many more [53]. These designs are the schematics used to express to the producer the exact specifications for the PCB to be built.
It is up to the manufacturer to determine the abilities that their machinery can handle and if the traces, pads, connections, surface mounts sizes, and any errors in a super high-quality design is feasible. Many contractors will remain up-to-date on latest machinery to avoid losing customers, but it is not necessary however for particular businesses to avoid these irrational requirements as soon as they come out, as the industry standard is typically what motives businesses to advance their own operations. Within manufacturers operations, the additional option to insulate the PCB by using a silk-screened layer of Liquid Photo Imaging (LPI) to create graphic designs on the face as well as insulating the board. The designs are

common in practice to be kept to the component names per the user's specifications. Commonly send on most boards is the manufacturers name and model of the PCB designers.

Minimizing costs on a PCB can be primarily done by using smaller traces, surface mounted components with small packages, and overall maximizing the distances between traces to obtain the smallest PCB area manageable. Overall, the density of components should be very high whilst keeping the PCB area manageably low and lightweight from the manufacturer.

Furthermore, pre-design steps need to be taken in accordance with the aforementioned efficiency of PCB design steps. For instance, the density of components being extremely close together not only saves money, but promotes component efficiency. Such as having a single larger railed trace for the power supply and regulator inputs, this allows the beginning of a density to product design and retains lower voltage/current drops over the longer traces of the board. In addition to this, the space conscious parts need to be placed first, such as the microcontroller, power supply ports, larger operational amplifiers. This allows the design to actually branch off from the central operation performance characteristics and allows the process of creating and assembling the PCB to be much faster and far more effective. In the instance of most designs, corners and sides of the PCB are left blank such that pilot holes for drills and screws can be used to fasten the PCB to essential components [53]. Where some PCBs retain an edge as the contacts for connecting the PCB to a system, most designs now rely on an external pin connection system such that damages to the PCB can be limited.

Advancing into the subject of component placements, the other conscious objective is to make sure that two signal carrying traces are not running in parallel to each other on their respective plane. This is done to reduce the amount of transmission causing signal dilapidation and distortion of the signals being carried. Therefore, if two carrier traces would be crossing in an unavoidable nature, they should only impact each other for the shortest duration of space, which would be a perpendicular crossing. High frequency signal processing should also be kept to an independent area of the PCB to restrict the amount of transmission lining effects that would otherwise ruin the signal integrity. Now that the components are nice and dense to one another, their heat generated and dissipated into the PCB will overall lower the qualities integrity of the PCB [53]. The heat generating components can be placed onto heat sinking planes of the PCB, larger heat producing components would need equally scaled heat sinking components.

4.2.7 Laser Regulations and Standards

Since this project makes use of a laser, regulations, standards, and safety mush be understood to create a successful and functional product. The important organizations that govern laser regulations are the Center for Devices and

Radiological Health (CDRH) within the Federal Food and Drug Administration (FDA) and the Occupational Safety and Health Administration (OSHA). The important organizations that govern laser standards are the American National Standards Institute (ANSI) and the International Electrotechnical Commission (IEC). All previously mentioned organizations promote and specify proper laser handling and safety. The FDC regulations are most important since this product will fall under a ‘Demonstration laser product’ which falls under FDC regulations.

Regulations

As previously stated the CDRH, FDA, and OSHA are the governing bodies regarding laser regulations with the CDRH and FDA being the entities writing the regulations and OSHA being the entity reporting on regulation in fractures. As of August 2, 1976, laser products must comply with the Federal Laser Product Performance Standard (FLIPPS) created by the CDRH as well as the title 21 code parts 1000 through 1005 [26]. The FLIPPS comprises the 21CFR subchapters 1040.10 and 1040.11 and classify lasers into broad categories based on how harmful they are to human health [27], [28]. The pertinent factors related to harmfulness include the wavelength of light, the output intensity of the laser, and the exposure time. The classifications include four levels with sublevels within class three lasers. Class one in the lowest class and pertains to lasers that pose little two no harmful effects. Class two lasers are also still within the ‘safe’ range as far as harmful effects go. These lasers are harmful when viewed with optical instruments where class one is not. Class three lasers are at a cross point between the ‘safe’ and ‘harmful’ regions, and the reason for harmfulness can vary. Class three is divided between visible and non-visible subsections. All non-visible lasers start in this region because the human eye does not reflexively close to wavelengths it cannot see, making all those wavelengths dangerous even at ‘safe’ laser outputs since the exposure time can be very high. Class four lasers are well into the ‘harmful’ region for both direct and scattered light. Each increase in classification increases the danger of the laser as well as increase the required safety measures that need to be placed on the laser as well as documented in the area of laser use. Required safety measures for this application will be in the laser part of this section.

Title code 1000 through 1005 are the first part of FLIPPS and are general regulations regarding the use, production, and sale of laser products. These regulations will not apply to production of the prototype product this project aims for. If the project is successfully moved into production, then these regulations will be revisited. The other regulatory body, OSHA does not make regulations or standards. This organization is tasked with maintaining safety in the work place, so they fall back on the FLIPPS regulations as well as the ANSI Z136.1 standards for maintain safety. The FLIPPS, specifically 1040.0 and 1040.11, regulations contain many regulations regarding the construction and sales of laser products that will not be mentioned in this document since this document only covers the prototype project and not full development of the project. If the project reaches full production, these regulations will be reviewed.

Standards

The standards for lasers are set by ANSI and the IEC as well as the previously mentioned regulations and standards set by the CDRH.IEC covers a more international market while the CDRH only cover the United States. ASNI, like the CDRH classifies lasers into four categories based on harmfulness to human health set by the ANSI Z136.1 standard [26]. ‘Harmfulness’ is determined by exposure time, laser wavelength, and output power. The three previously mentioned parameters are used to calculate the Accessible Emission Limit (AEL). Some additional parameters that go into defining the harmfulness of a laser is the entrance pupil of the human eye assumed to be 7 mm at full dilation, beam hotspots assumed to be 1 mm, and the penetration of certain wavelengths of light. The near-infrared region shows the greatest penetration depth, therefore; making it relevant to this project since the laser being used will be in the near-infrared. The ANSI categories start with class one being the least harmful lasers, needing no beam hazard control measures. Class two a slightly more dangerous and emit more power, but do not sustain the output power long enough to be harmful. Class three is similarly split into two subcategories as the CDRH categories. This classification contains lasers entering the harmful range and are in need of control measures. Control and safety measures will be discussed in the last part of this section. The two divisions are split with into wavelength and exposure time called three-A and three-B respectively. Class four lasers are in the harmful region and require the most control measures. The IEC set its standards in the document 60825.1. The IEC standards are very similar to the ANSI standards but also include viewing conditions, i.e. wearing glasses or using binoculars. The IEC system of categorizing lasers also uses a four-class system, but with more sub classifications than other systems with the introduction of the ‘M’ subclass which governs viewing conditions. Class M classification is based on using different parameters to calculate the AEL of a laser. Instead of basing the calculation of an unaided eye, the calculation substitutes other viewing devices such as binoculars, telescopes, eye loupes, and magnifiers. This class system follows the ANSI categories almost exactly for non ‘M’ classifications. For both classification systems. The laser for this project will most likely be a class three A/R or B laser requiring control measures be in place.

5.0 Design

This design section is to be used as a guideline of the nature in which the final laser skeet system product is to me constructed and implemented by. This methodology will be used to better identify the targeted component and conclusions ascertained within the research section of this project document. The objective of the design process is to be used as a clear and comprehensive recording of the projects key functions, expected outputs/inputs and important components selected. Not only will the hardware design of the laser diode and power systems be outlined, but also the most essential coding aspects and software designs for the MCU and peripheral devices.

5.1 Hardware

Hardware will make up a large quantity of components on the PCB and interior parts composites, compared to the MCU required components. Further explanation and design will be discussed in this section to the more tangible aspects of this laser skeet system's design and methodology. Components selected were outlined in the research section and are to be implemented in the final design.

5.1.1 Laser and optics

This section will cover the design of the laser as well as the optical components. For this application, the laser will be a laser diode since they are portable, have high emission power, and are cheap. The optical design will consist of three components: the collimator, slow axis magnifier, and beam expander. Additional components non-optic components needed for the design will be mentioned at the end of this section. The vender used for the laser and optical components is Thorlabs since they average to be the least expensive for the selected parts. Additionally, it should be noted that all calculations in the following sections will be used as a starting point. The final system will be an optimized system from the starting point. Tweaks in the starting system will be made based of testing results to best optimize the overall performance.

5.1.1.1 Laser Diode

For this application, a laser diode will be used since they are small, portable, high emission power, and are cheap. Things to consider when designing with the diode is the temperature, both ambient and inside the device, and the divergence angle. Laser diodes tend to run hot with increased heat for higher output power emission diodes, so steps need to be taken in order to mitigate heat. The laser diode will need to be put inside a heat sink to remove any heat buildup from the diode to ensure stable operation. The ambient heat cannot be removed with a heatsink, so lens design and placement will have to consider the change in wavelength from the laser diode. Additionally, the drive current will need to be tweaked to correspond to the new drive current. The divergence angle of the laser diode is not a parameter that can be changed within the laser diode itself, so optical design and placement will have to consider this when picking the collimator lens. Since the fast and slow axis of the laser diverge at different angles, the largest angle should always be used in calculations for the optics. The laser power should be picked after the transmittance of all the optics is known. Table 3 shows a selection of different laser diodes suitable for this application. The 940 nm diodes are far more expansive and have higher power than what is needed and safe, so the 980 nm diodes will be used. The three diodes shown are from Thorlabs and are from the same family of diodes making them vary similar except for their output power and drive current. The 10 mW laser diode will be used for the calculations in the following sections since it has the highest divergence angles of the diodes, therefore; all other diodes should work in the optical system.

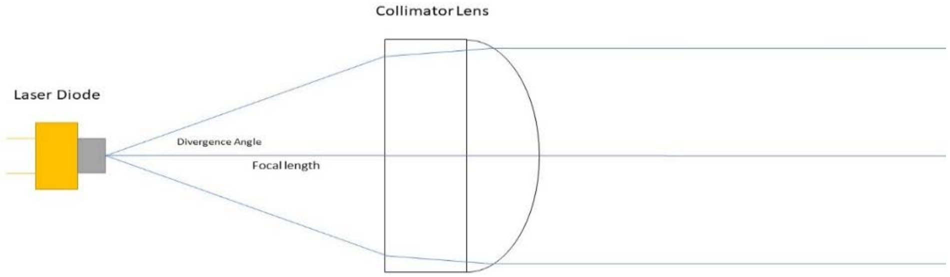
5.1.1.2 Collimator Lens

The first optical component is the collimator lens. This lens is a single lens made of molded plastic, acrylic, or glass. These lenses are both small, economical and easy to use over older collimating lenses and lens systems. The collimator lens will face the laser with the positive radius and the plane side will face away. The radius of the output beam is related to the divergence angle and the focal length of the lens. When the laser is placed a focal length away from the lens, the radius of the output beam will be the focal length multiplied by the tangent of the fast axis divergence angle. This radius will be relevant in the beam expander section. Since there are two different divergence angles, the radius of the output beam will not be constant around it is creating an elliptical beam. This elliptical beam will them move to the anamorphic prism pair for correction.

The first parameter of the collimator is the material used for the lens itself. The collimators can come in plastic, acrylic or glass (only N-BK7 will be considered because of cost). The material itself will need to be able to withstand the power of the laser. The plastic lenses offer the least power resistance, but are also the cheapest. Acrylic offers moderate resistance and is only marginally more expansive than plastic. Glass offers the most resistant and is on average twice as expensive than acrylic. Since the lens will be outside, the change in refractive index needs to be accounted for when picking the material. Plastic and acrylic show the least amount of variation, but are more susceptible to deformation in higher heat. Glass shows the most variation, but is resistant to heat. For this system, acrylic would be the best option since it is a balance of all parameters and is relatively inexpensive as long as percussions are made when mounting the lens to reduce heat on the lens. Lens mounting will be explained in a later section.

The second parameter of the collimator is the size of the lens. The size of the lens is important because it determines the total amount of light that passes through the lens. If the laser light coming towards the lens is larger than the actual lens than light is lost in the system. The output beam diameter will be determined by the relationship: D=f*tan (divergence angle) [25]. A standard rule of thumb is to have the lens be one and a half to two times the output beam diameter while also remembering that usable lens diameter is eighty percent of the actual diameter of the lens. The lens is shown in Figure 6 below.

Figure 6 - Setup for the collimator lens



Looking at the Thorlabs catalog for acrylic collimating lens shows that the standard diameter for this lens is 3 and 6 mm. Since a greater diameter will offer more freedom and ease of design, the 6 mm diameter lenses will be chosen. Based on the relationship shown previously a small focal length will be more beneficial than a longer one. The smallest focal length available is 6.05 mm, creating an output beam diameter for the fast and slow axis of 1.62 and 0.69 mm respectively. The fast axis output beam diameter clips slightly based on the standards for lenses previously mentioned, but more than ninety percent of the light will make it through. Based on the data sheet for this lens, the normal transmittance of the material is about ninety-two percent bringing the total transmittance to eighty-two percent. This transmittance can be increased by adding an anti-reflective coating to the lens. Thorlabs offers a coating for this applications wavelength for only an additional 6.85 USD with the original price at 18.40 USD for a total of 25.25 USD.

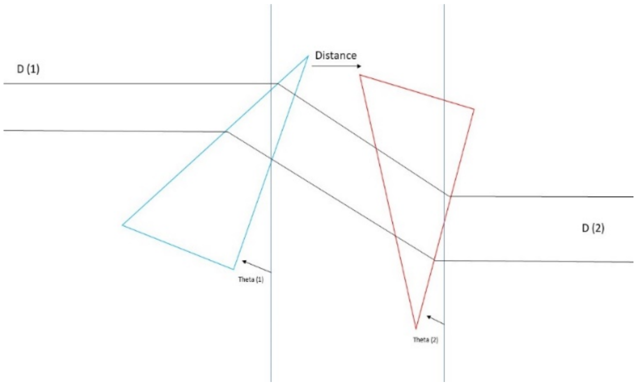
5.1.1.2 Anamorphic Prism Pair

The second optical component is an anamorphic prism pair. This component consists of two prisms that can magnify one axis of the beam. This component will be used to magnify the slow axis of the beam. The slow axis can be magnified to have the same radius as the fast axis, but the prism pair does not correct for divergence angle, so the beam will still be elliptical in the far field. This difference in divergence angle will be magnified by the next component, so it is better to magnify the slow axis more to create a circular spot size at the intended range and an elliptical beam everywhere else. The magnification of the prisms is determined from the spacing between them and the angle of rotation perpendicular of the optical axis.

The input beam into the first prism can be said to be said to be the same parameters as the beam that left the collimator assuming the they are not separated by a great distance, no more than 100 mm. The input from the slow axis is 0.69 mm and the fast axis is 1.62 mm. To create a circular spot size, the two axes must be equal, so the slow axis must be magnified by 2.35 times. It should be noted that the prisms only magnify the diameter and not the divergence angle, meaning the beam will be circular when it comes out of the second prism but will eventually become elliptical as it is travels further away. This can be compensated by magnifying the slow axis even more to compensate for a specific plane away from the laser. Increasing the magnification to 2.5 should keep the beam circular from 10 yards to 20 yards with 15 yards being the most circular. They are made of N-BK7 glass and cost 25.00 USD. They are not coated, so the transmittance is less that what could be achieved. The lenses will remain uncoated since coating for two specific items is much higher than in full production.

The placement of the prisms determines the magnification. The two important parameters to consider are the angle of rotation from the optical axis and the distance the two prisms are away from each other with the rotation being the more important of the two. Figure 7 below shows a setup for the prism pairs. The two angles theta (1) and theta (2) are measured the middle of the side that crosses over the two-vertical axis that lay perpendicular to the optical axis. The distance is the measure from the two closest vertices of the prisms. For this application the distance will not affect the magnification much since the prisms will be a close as possible for a compact design, so it can be assumed that the beam between the two prisms is uniform in diameter.

Figure 7 - Setup for the anamorphic prism pair



5.1.1.3 Beam Expander

The third component of the system is the beam expander as well as divergence system. The first purpose of the beam expander it to turn the beam coming from the prism pairs into a larger collimated beam. The second purpose is to allow the second lens in the system to move, causing the output beam to diverge in a controlled manner. The beam expander will be a Keplerian beam expander with one bifocal lens and one planoconvex lens. The beam will enter the biconvex lens and will exit the system through the planoconvex lens. The expansion of the beam is a ration of the planoconvex focal length to the biconvex focal length, making calculations easy for beam expansion [23]. The planoconvex lens will be allowed to defocus itself to allow the output beam to spread based on the users desired spread angle. Additionally, since the beam focuses inside the system, a pinhole will be placed at the focal length to clean the beam.

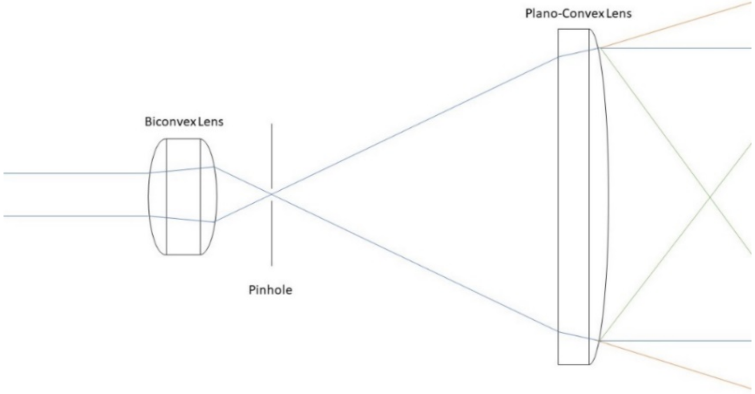
The first parameter of the expander is the material of the lens. N-BK7 is the standard for lenses and offers a solution while being the cheapest material. Similarly, to the other components, the refractive index will be used for the temperature and wavelength of operation. Temperature will also expand the lenses, so care should be taken when mounting the lenses to allow for thermal expansion.

The second parameter of the expander is the diameter of the two lenses. The first lens, the biconvex lens, needs to be large enough than the input beam from the prism pairs. The second lens, the plano-convex lens needs to be large enough to pass the expanded beam. The eighty percent rule needs to be accounted for when choosing the diameter of the lenses.

The third parameter of the expander is the focal lengths of the lenses. The ratio of the plano-convex focal length to the biconvex focal length determines the ratio of beam expansion. A smaller focal length for the biconvex lens will allow for easier selection of the plano-convex lens.

When light travels from the prism pairs to the biconvex lens, the diameter of the beam for either axis will not exceed 4 mm for the whole beam so the biconvex lens should be at least 5 mm in diameter based on the eighty percent rule. The standard lens size of ½ inch (12.7 mm) will be chosen since it offers a decent sized buffer for the lens diameter, and the larger size will make it easier to mount than a smaller lens. As stated before, a smaller focal length will be more beneficial when calculating the expansion ratio. The smallest focal length offered by Thorlabs in this size is 15 mm. A smaller focal length can make mounting harder since smaller focal lengths correspond to higher radii of curvature, but this focal length is not small enough to pose any real problem with mounting. The diameter of the plano-convex lens will be determined by the diameter of the output beam. Ideally the output beam should be at least 18 mm since that was previously stated to be the smallest bore diameter for a shotgun. If the output beam is 18 mm the lens needs to be at least 22 mm. The next standard lens size up from that is 1 inch (25.4 mm) offering a decent buffer for the diameter. If the output beam is 18 mm and the input beam is 4 mm than the expansion ratio is 4.5. This ratio needs to be multiplied by ½ since the original divergence angle was given at the FWHM of the spread, so the expansion ratio is 2.25 to let all the light pass through the last lens. If the biconvex lens has a focal length of 15 mm, then the plano-convex lens needs a focal length of 33.75 mm. Thorlabs offers a plano-convex lens in this size with a focal length of 35 mm. Similarly, to the collimating lens, anti-reflection coatings are offered for both of these sizes for marginal increases in price. The biconvex lens totals at 32.75 USD and the plano-convex lens totals at 32.00 USD. Figure 8 below shows the general setup for the Keplerian beam expander.

Figure 8 - Beam Expander



The beam expander is also needed to diverge the beam of the output laser beam. In order to diverge the beam, the plano-convex lens needs to be defocused. When the lens is at focus, the output beam will be an expanded collimated laser beam. In order to get the beam to diverge the lens will either need to be moved forward or backwards to cause the beam to diverge. If the lens is moved forwards the laser beam will be focused to a point than start to diverge. The problem with this is the same problem with the beam focusing at the pinhole, the laser power density is unsafe at this point. This is shown by the green lines in Figure 8 above. The lens can be moved backwards to cause the beam to start diverging as soon as it leaves the lens. This is shown by the orange lines shown in Figure 8. For this application moving the lens backwards will be more ideal. The lens will need about 10 mm of movement for required divergence of 0.5 - 1.5 degree.

5.1.1.4 Additional Optical Components

Additional optical components include a rotational iris, pinhole, and linear polarizer to control the laser beam. The rotational iris will be a pure user operated safety mechanism to stop the laser beam. The linear polarizer will be used to control the power of the beam. Since the transmittance of the laser through the optics is unknown, a larger power laser may be needed. The linear polarizer will allow for power adjustment and will not be user operated.

Rotational Iris - The rotational iris will be a safety switch built into the system that will prevent any laser light output from the system when closed. This device can be put anywhere in the system except between the two prisms and at the focus of the beam expander. Ideally it will be placed after the last optical element, the plano-convex lens, since the least amount of power in the system is at the end. Less power ensures the iris material does not deform after continued use. Placing the iris at the end also causes it to act as a barrier to prevent dust from getting into the system and keeping the optical elements clean.

Pinhole - The pinhole for beam cleaning will need to be tested to ensure it will withstand the power of the laser focused down onto o small point. Ideally the biconvex lens will focus the point to an infinitely small point, but that will not happen since the lens does not do perfect point to point imaging and has spherical aberration added in when the laser passes through the lens. Thermal resistant plastic or coated metal will be sufficient materials to serve as the material for the pinhole. Plastic will be more suitable over metal since the metal will need to be coated with something to remove the reflectivity of the metal. Vespel plastic offers a high working temperature shown in Table 21 below, but it is also the most expensive and the sheet sizes sold are too large for a prototype. Because of cost PVC will be used since it has a working temperature almost 50% more needed for outside use and the amount of heat absorbed from the laser light is small. The only concern with PVC is the deformation caused by continued use. A 12-inch square 0.188 inch thick sheet of PVC is around 5 USD. Vespel or Torlon would be useful in large scale production since the actual pinhole is quite small, so a 12-inch square for around 300 USD can make around 930 pinholes if the hole size is 5mm square. The size of the pinhole needs to be large enough to pass the beam, but small enough to block stray light from passing. If the input beam is stated to be 6 mm, then the focused point can be approximated to be 1 mm. The pinhole size would need to be 1.5 mm to account for the thickness of the pinhole and the geometry of the input beam coming into and leaving the pinhole. The pinhole itself should be coated a mate black to not cause back reflections in the system.

Table 21 - Thermal properties of different plastics

Plastic	**Vespel**	**Torlon**	**Ryton**	**Noryl**	**PVC**
Working Temp. (C)	300	260	218	105	60
Softening Point (C)	none	none	none	154	84

Linear Polarizer - The polarizer if needed will work as a power regulator for the laser system. The need for a polarizer will be determined based on the transmittance of all the optical components has been determined. The polarizer will be added if the transmittance causes the need of a higher laser diode to produce the minimum output power needed but exceeds the safe laser output. The polarizer itself can be put anywhere in the system except in-between the two prisms or at the focal point in the beam expander. The most ideal placement would be before the collimating lens since it is the weakest lens in the system because of the material. A high laser output could cause the lens to deform with continued use, causing the collimator to not collimate. Similarly, to the pinhole the polarizer would also need to be made of a material that can withstand the power going through it. The power would be the ratio it is blocking to what is letting out. The ratio will be determined by how much the polarizer rotates away from the polarization of the laser. Lasers produced linear polarized light, so the polarizer would also be a linear polarizer. When the polarization of both the laser and orientation of the polarizer match, all of the light will be passed. When the two are not matched, the output light will decrease as a function of rotation. Most polarizers come in films, so in order to protect it, the film can be sandwiched between two pieces of glass. This will also aid in mounting.

5.1.1.5 Laser System Mounting

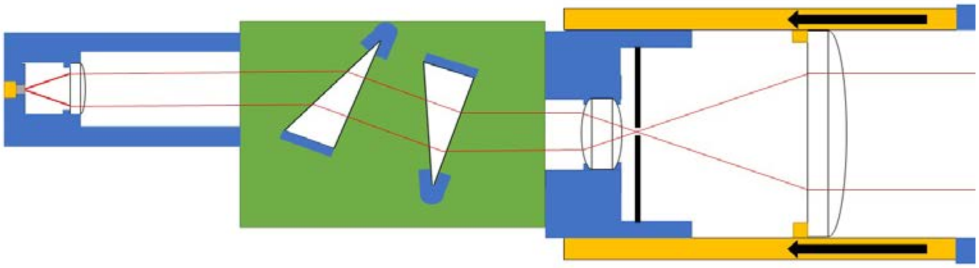
The mounting of the laser and optics is crucial for a good detection system since misalignments will affect the output power, spot size, divergence angle, and spot location. Figure 9 shows a representation of the mounting setup that will be expanded upon in this section. It should be noted that the picture is only a graphical representation of how the system will fit together and is not to scale per figure. The linear polarizer is not shown since it is not known if it is needed at this point in time. Additionally, the epoxy used for mounting the optical elements will be a fast-drying clear epoxy. The epoxy chosen is JB Weld Clear Weld which cost 6.00 USD for 25 mL. All optical elements will be inspected and cleaned before mounting.

Laser Diode and Collimator – Both the laser diode and the collimator will be mounted in the same tube as seen in Figure 9. The laser diode will be mounted so the emitting section (grey) will fit into a hole smaller than the base of the diode (gold). This will allow the diode to be fit so the emitting section is perfectly perpendicular to the optical axis. The collimator lens will be epoxied to a retention ring on the flat side of the lens, the side that faces the diode. Both the diode and the collimator will be fitted into a pipe that leads to the next optical element. The clamp for the diode and the retention ring for the collimator will be made from plastic because it is easier to form.

Anamorphic Prism Pair - The anamorphic prism pairs will be mounted in their own module shown in green in Figure 9. The module will be made of plastic as well as the two holders for each prism shown in blue. The two holders will allow the prism to be locked in place without it obstructing the light coming in. This module will also contain fixtures on the ends to allow for the two connecting pipes to be attached.

Beam Expander – The beam expander contains four elements. The biconvex lens, pinhole, planoconvex lens, and rotational iris. The biconvex lens and the pinhole will be mounted in the same tube. The biconvex lens will contain two retention rings to hold it in place. These retention rings will be beveled in the locations where they come in contact with the lens to prevent fractures and scratching. The placement of the lens into the tube does not matter since the incoming beam is collimated, but should be as close to the last prism as possible. The pinhole can be threaded into the tube to the desired position. The plano-convex lens and the rotational iris are in the second tube shown in gold in Figure 9. The plano-convex lens like the collimator lens only needs one retention ring on the flat side to be mounted. The rotational iris shown as the blue squares at the far right of the gold tube can be mounted to the end of the tube directly. The gold tube needs to be able to be moved backwards enough for the output beam to diverge as well as not being able to move forward to cause it to converge inside the system. Stops can be used to both prevent the forward movement and limit the backwards movements of the tube. The movement itself can be done by threading the outside of the biconvex lens tube and threading the inside of the plano-convex tube so the operator can twist the tube for movement. This will not disrupt the output beam any since the lens is symmetrical and is mounted perpendicular to the optical axis. Only once all the elements have been placed and the system has been tested should any of the optics in the beam expander be epoxied into place.

Figure 9 - Lens Mounting Setup



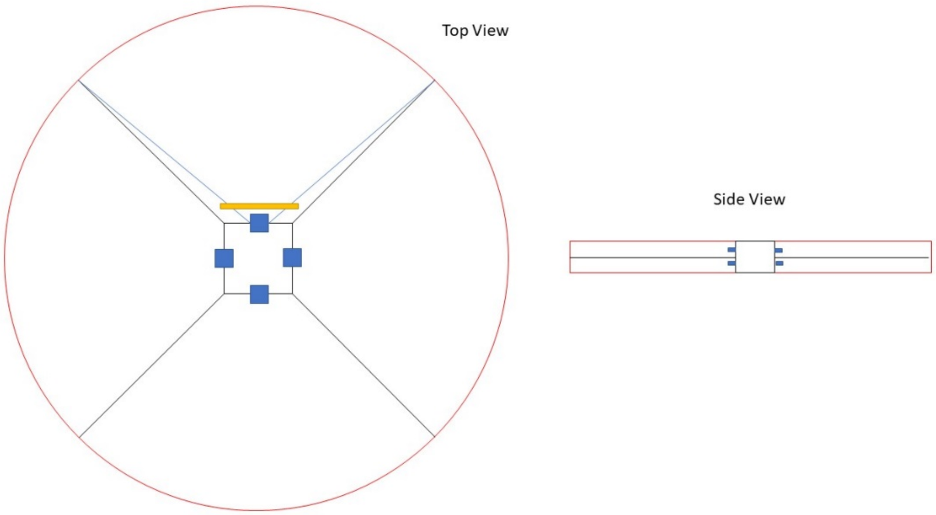
5.1.2 Detector and Optics

The following section will cover the detector selection and placement as well as the optical components used for coupling light into the skeet for the detector. The optical elements include a Fresnel lens and a bandpass filter. Mirrored film and a solar filter may also be used depending on the results found in testing.

Detector and Placement – The phototransistor chosen was the SFH 352 FA. This phototransistor was chosen because it corresponds to our wavelength, has a large acceptance angle, and is fairly sensitive. This phototransistor also comes with a filter which will be removed since a better filter will be used. The placement of the phototransistors is important to capture all of the light as possible from the laser. To capture all the light eight phototransistors will be used. Four will be on the top and four will be on the bottom, each placed 90 degrees from each other to cover the whole 360 degrees of the skeet. This is shown in Figure 10 below with the blue squares being the phototransistors. the phototransistors can also be clustered to help improve the signal acquisition based on the phototransistor acceptance angle. No more than 4 phototransistors for each cluster would be needed. The middle square shows the location of the control circuits and power supply. The size of that area is not currently known.

Optics - The optics used in the skeet are a Fresnel lens and a bandpass filter. The bandpass filter is shown in the top cell of the skeet in the top view in Figure 10. The purpose of this device is to block unwanted light from reaching the phototransistor and causing unwanted noise. Ideally the filter should be placed right on top of the phototransistor to maximize the area of the phototransistor clusters. Because the acceptance angle of the phototransistor is large, the incoming laser light divergence due to index changing through the bandpass filter will not cause a problem. The bandpass chosen is a 980 nm center wavelength with 10 nm pass band for 10.00 USD. Depending on the activation area of the phototransistor and cluster size less filters may be used by cutting the filter, this also depends on the filter size. The Fresnel lens will consist of a thin sheet of molded plastic that will be used to cover the outside of the skeet. The Fresnel lens is shown in Figure 10 as the red circle in the top view and the red rectangle in the side view. The purpose of the Fresnel lens is to focus the incoming laser light onto the phototransistors to boost the signal, but the Fresnel lens focuses all incoming light so it will also boost noise. Ideally the Fresnel lens will boost the signal and noise while the bandpass filter removes the noise without reducing the signal. Fresnel lens come in the standard sizes of 3X and 5X magnification. The magnification of the lens will be determined once the center rectangle is known.

Figure 10 - Phototransistor and Optics Placement



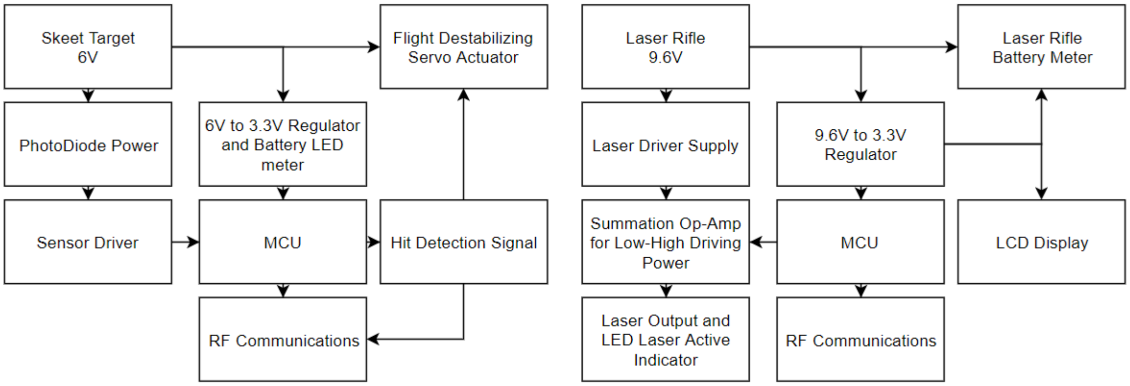
5.1.3 Power

The following section entails the process by which the selected power systems were chosen and why the particular designs were implemented. This section also further extrapolates information on measuring the active power systems and monitoring methods to assure appropriate operations. The devices in question receiving power are the skeet target and laser skeet rifle. Both of which will be powered by internal batteries which will provide current to the microcontrollers and peripheral devices. These sources will need to be regulated and augmented to better fit onto the PCBs. In the case of the laser skeet target, two-coin cell CR2032 batteries will be used in series to provide a 6V potential and then be regulated for appropriate uses. The amount of power being consumed per shot is rather minimal compared to the constant functioning laser rifle device. The laser rifle will consist of a 9.6V rechargeable battery pack that will also need to be regulated down. 9.6V is selected not only for the high potential and peripheral power delivery but also the rechargeable capability and cost longevity savings.

Primarily, a long lasting device system would be beneficial for the engineering team to construct by overshooting some power capabilities whilst providing a longer lasting round of skeet. Typically, some rounds of skeet can extend into 250 hit target races; therefore, a longer lasting charge on both devices would be ideal for a single target and rifle system.

Three sections will be covered below, one is the implementation of DC batteries into their respective skeet systems, another for the individual regulation components and power control designs, and lastly the pulse width modulation control for the laser driving circuit are also represented in Figure 11.

Figure 11 - Power System Design Skeet Target and Laser Rifle



5.1.3.1 Voltage Regulators

A voltage regulator will be used in order to limit the current and voltage inputs the microcontroller device will obtain as well as regulating peripheral devices to achieve optimum power efficiency. Our aims are to reduce the necessary amount of current supplied to the devices to achieve a longer lasting power source, reducing the amount of energy that an average game of skeet will entail. Using linear voltage regulators will make the system design much easier in the sense of a more compliant output with easy initial design biasing.

A voltage regulator on the both the skeet target and laser rifle will be used to give the MCU appropriate biasing levels, and then secondary regulators are implemented to align with operational amplifier designs later discussed. These regulators are placed near crucial components and are also power decoupled.

5.1.3.2 DC Power Implementation

Both DC power components will require their individual connections to the PCBs of their respective systems. Each will be connected via a surface mounted component or connector type soldered to the PCB.

Skeet Target – The power for this is housed by two 3V coin cell batteries stacked in series and later regulated with a 3.3V output to the MCU. The primary 6V will be housed in this double stacked coin cell surface mount component BAT-HLD-001-THM. This device is approximately 15mm tall and will fit in a 21mm portion of the PCB. Connecting this in series with a visible MHS122 Slide switch, wired to an external face of the skeet target for user input. This switch is capable of supplying 300mA at 30Vdc and is to be connected with soldered wires onto the PCB.

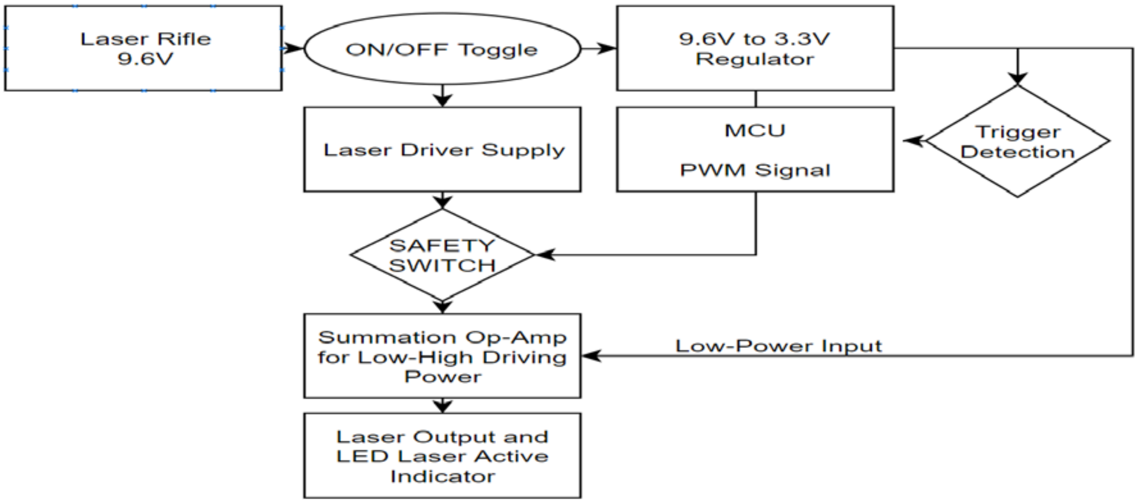
Laser Rifle – In order to attach this battery component, a secondary piece of hardware is to be installed onto the PCB itself and securely fasted into the laser rifle housing. The connection type for the 9.6V NiMH is a Mini-Tamiya Female connector, therefor a male connector will be connected to the PCB such that the battery pack can be taken out, charged up, and then placed back onto the Mini-Tamiya male connector for operational use.

5.1.3.3 Pulse Width Modulation and Operational Amplifiers

Flawless performance operation of the laser driver mechanism will be given quite a bit of time and energy. The design aspects of this particular circuit are to enable the laser diode to achieve a low-power mode whilst the rifle is put into active mode and then modulate the laser power only when the safety switch is disabled and a confirmed trigger fire action has been initiated. Utilizing an operational amplifier to supply the 9V necessary to drive the circuit and a voltage regulator controlling the affixed outcome, the laser will then be controlled by the CC13130 MCU onboard PWM pulse width modulation signal. Per Figure 12, power will be delivered to drive the laser LED completely to a pre-determined and regulated power of no more than 50mA per FDA regulations outlined in previous sections [47].

The laser rifle will have a primary on/off SPST 16A rated Rocker Switch, this will control the battery connection to the rest of the laser rifle, saving power whilst not in use. The entire laser driver supply can be further regulated to provide power from the PWM signal but is not entirely necessary as we will be restricting the amount of current to be supplied into a buffering summation operational amplifier. The PWM signal will be connected to the base index of a standard 610-2N2222A npn- bjt transistor rated for 50Vdc. This bjt is selected for its practical applications and high switching speeds of 35ns to 300ns for on and off, this more than covered the desired 30kHz modulation rate.

Figure 12 - PWM Power Transfer Design



The summation operational amplifier will collect two separate signals. One is collected from the primary rifle being turned on and safety switch being deactivated. This provides the laser driver circuit with a low current for shorthand DC biasing. This allows the laser to rest at a low emission mode whilst remaining under the laser emission threshold. By keeping the laser in this state, the pulse width modulation circuit with the modulation signal being applied to a NPN transistor will provide the power control. With the PWM signal being applied, the summation amplifier provided by the high speed non-inverting operational amplifier TL084CN [51]. By providing a railed output, this summing amp is also capable of yielding a clean DC output signal for the laser diode.

5.1.4 MCU Design

While most of the MCU's operational components are integrated within the device there is still the need to interface it with external devices and provide it with some needed resources. The device is provided in a surface mount 7X7 mm package type VQFN48 (RGZ). The device support requirements and interconnection are provided in the remainder of this section.

5.1.4.1 Development board

The Texas Instruments LAUNCHXL-CC1310 will be used for prototype testing before transitioning to BPC built system. Two of the boards have been purchased and have arrived already. One board will be used to developing the gun controller and the other used for the target sensor controller.

The development board provides breakout connection points for 28 general purpose inputs or outputs (GPIOs). This is more than adequate for our testing needs.

The development board also includes a debug interface that can be isolated and used separately from the on board MCU. The intent is to use it after the transition to the PCB build for code loading and debugging the controller and sensor PCB mounted MUCs.

In addition to the MCU development board an expansion 430BOOST-SHARP96 board was purchased to help develop the display portion of the gun controller. The LCD display it uses is not identical to the one selected for the build as availability for a same type unit was not there. The board should still be close enough for needs as it is the predecessor to the one we intend to use and only differs in the pixel resolution provided.

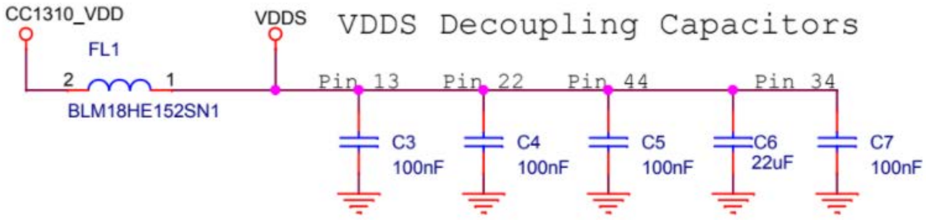
5.1.4.2 MCU Clocking

The CC1310 MCU has one required and one optional crystal connection. A 24Mhz crystal is required for providing clocking for the RF oscillator in the MCU. This crystal mandatory since it is necessary to maintain a stable and accurate frequency for the transceiver. It connects to the X24M_N and X24M_P CPU pin connections. There is a second optional crystal for the real-time clock. It uses a standard 32.768K crystal. It will be utilized and connected to the X32K_Q1 and X32K_Q2.

5.1.4.3 MCU Power Connections

The MCU requires power from the PCB on four different input, VDDS, VDDS2, VDDS3, and VDDS_DCDC. These require DC decoupling as shown below in Figure 13 depicting Texas Instruments (TI) recommendation.

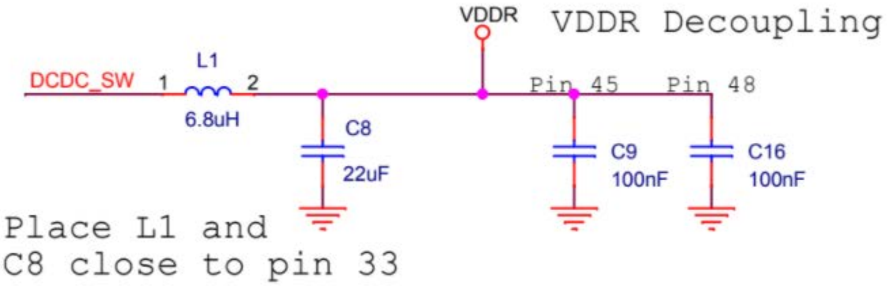
Figure 13 - MCU Power Decoupling



TI design use under TI licensing terms.

Two other input power connections are required, VDDR, VDDR_RF. The input for these is provided by an internal DC-DC converter on the DCDC_SW output pin. The voltage for these inputs require a tighter tolerance than the other power inputs since they are used for reverence and determine RF power output. They also require decoupling based on TI recommendation as seen in Figure 14 below.

Figure 14 - MCU more Power Decoupling



TI design use under TI licensing terms.

In addition to the pin power connections the MCU has a ground plane on the bottom of the chip that must be connected as well.

5.1.4.4 MCI Input and Output connection assignments

The MCU provides a number of pins for interconnecting to the reset of the system. These pins are flexible to an extent in there assignment. While some functions are restricted to a subset of the pins the exact assignments can change. As part of our project the assignment and uses need to be defined. Since we are using the development board from Texas Instruments some of the input-output pins have assigned uses already to work with their expansion boards. Also not all pins are accessible on the test board. Our assignments will try to match with pin assignments that work well with the CC1310 LaunchPad Development board. It is possible that these pins assigned may not work out well during the PCB board layout phase of development. If this is the case it may be possible to reassign them in the PCB version of code. This will try to be avoided as it would require modification of configuration and initialization software. It also adds complexity of needing 2 versions of code. One for the development board and another for deployment board.

The gun controller MCU will need inter connections to support four user control buttons, a speaker, a LED output, seven connections for LCD display output, a pulse wave modulated output to modulate the laser signal, and connections for programing and debugging. The intended connection IO assignments are listed in Table 22 below.

Table 22 - Rifle Controller MCU IO connections for Gun Controller

Use	**Direction**	**I/O**	**Chip / dev-board Connection**
Button 1, Trigger/Select/OK	IN	DIO13	19 / LP13
Button 2, Next Menu/Screen	IN	DIO14	20 / LP12
Button 3, Reload	IN	DIO15	21 / LP11
Reset Button	IN	Reset	35 / Reset
UART (boot loader)		DIO2	7 / LP debugger
UART		DIO3	8 / LP debugger
UART Bootstrap execute	IN	DIO18	28 / LP debugger
JTAG p2		JTAG_TMSC	24
JTAG p4		JTAG_TCKC	25
JTAG p8		DIO16 / TDO	26
JTAG p6		DIO17 / TDI	27
LED (Red)		DIO6	11 /LP 39
Laser PWM (green led)	OUT	DIO7	12 / LP40
Feedback on/off	OUT	DIO21	31 / LP8
Speaker	OUT	DIO5	10 / LP10
Display	OUT	SPI_MISO /DIO8	14 / LP14
Display	OUT	SPI SIMO /DIO9	15 / LP15
Display	OUT	SPI Clk /DIO10	16 / LP7
Display	OUT	SPI CS / DIO24	37 / LP6
Display	OUT	Com INV/ DIO12	18 / LP19
Display	OUT	Enable / DIO22	32 / LP5
Display	OUT	Power / DIO23	36 / LP2

The skeet sensor MCU will need inter connections to a user reset button, status and feedback LED, laser detector input, action initiation control output, and connections for programing and debugging. The intended connection IO assignments are listed in Table 23 below.

Table 23 - Skeet Controller MCU IO connections for Gun Controller

Use	**Direction**	**I/O**	**Chip / dev-board Connection**
Push Button 1, (test only)	IN	DIO13	19 / LP13
Push Button 2, (test only)	IN	DIO14	20 / LP12
Laser Detection signal	IN	DIO25	38 / LP23
Reset Button	IN	Reset	35 / Reset
UART (boot loader)		DIO2	7 / LP debugger
UART		DIO3	8 / LP debugger
UART Bootstrap execute	IN	DIO18	28 / LP debugger
JTAG p2		JTAG_TMSC	24
JTAG p4		JTAG_TCKC	25
JTAG p8		DIO16 / TDO	26
JTAG p6		DIO17 / TDI	27
LED (Red)	OUT	DIO6	11 /LP 39
LED (green led)	OUT	DIO7	12 / LP40
Action Initiator	OUT	DIO21	31 / LP8

5.1.5 Controls and User Feedback

This section will cover all the hardware needed for the user to interact with the device. Hardware is needed for physical inputs and physical output to be sent in and out of the device. Four buttons will be used to make user inputs to the device. One speaker will be used to output an audio response for the user to hear. One display will be used to display messages to the user and provide a menu to go through. Vibration motors will be used to let the user know when the trigger button is pulled.

5.1.5.1 Button Inputs

The first button will be a used to fire the laser, select items from the menu, and confirm. This button when pressed will allow current to flow into the MCU as seen in Table 22. This button will not be pressed by direct contact with the user but pressed in once the trigger pulls in which will then compress the button. This button will be connected to power and will only allow a signal to be sent when pressed. This button will also complete a second circuit independently which will turn the vibration motor on when pressed in

The second button will activate the next menu option on the display. This button will be placed in an easy to reach place when the user is holding the rifle. This button will be connected to power and when pressed will allow current to flow into the MCU as seen in Table 22.

The third button will be used to reload the rifle to act as an extra step in the shooting process to enhance the experience for the user. This button will be placed in a position towards the front of the rifle so the supporting hand used will press it. This button will be connected to power and when pressed will allow current to flow into the MCU as seen in Table 22.

The fourth button will be used to reset the device. If an error occurs in the code or the rifle starts to misbehave it will need to be reset. This button will be accessible but not able to be easily pressed accidently. This button when pressed will complete a circuit connected to the reset pin on the MCU as seen in Table 22 and will reset the device.

5.1.5.2 Speaker Hardware

A speaker needs voltage oscillation to produce a sound it cannot just make a tone by having current flowing through it. The chosen speaker PUI Audio AS06608PS-WR-R will be connected to a very simple switching circuit allowing current to flow through the speaker only when the MCU is sending a signal to do so. The MCU is capable of sending a fast switching signal that will allow the speaker to oscillate creating modulated sound for the user to hear. The voltage source supplying the energy for the speaker will be a regulated voltage from the main power source.

5.1.5.3 Display Hardware

The display pins have already been assigned as seen in Table 22. The Sharp Ls013B7DH03 was the chosen display which has a 10-wire ribbon cable coming off it. Leads on the PCB will connect the designated pins on the MCU to a 10-wire housing component on the PCB so the display can be connected to the PCB without tedious soldering.

5.1.5.4 Vibration Motors Hardware

The vibration motor circuit will be an independent system from the rest of the design. It will be connected to the second connection from Button 1. This will not be a complex circuit and does not need to be on the PCB if space is needed to be saved. When the button is pressed current will flow through from the main power source through the second line on the button through the vibration motors and back to ground.

5.1.6 Schematics

The schematics are too large for one sheet and are spread across multiple sheets for both the controller and skeet. Passive components have not been designated yet, as these designs will need finer tuning once in production. Each schematic highlights the primary components that will be utilized in this project's design. Connections between sub-systems are also noted. Certain user enhancement ideas are not represented, as these schematics are to represent the essential and critical components needed for appropriate functionality and performance. Designs and initial connections are noted in Figures 15 to 19 below.

Figure 15 - Schematic, Controller Power and Laser Driver

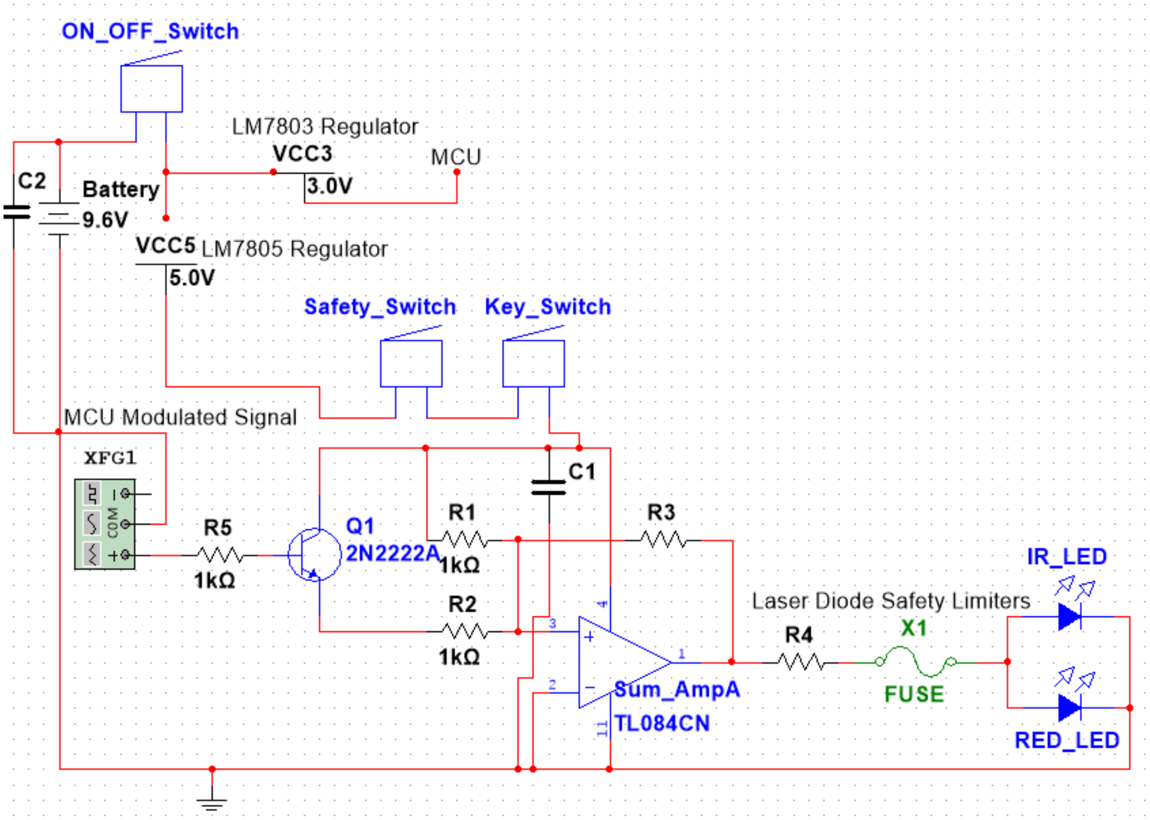


Figure 16 - Schematic, Controller & Skeet RF Antenna Coupling

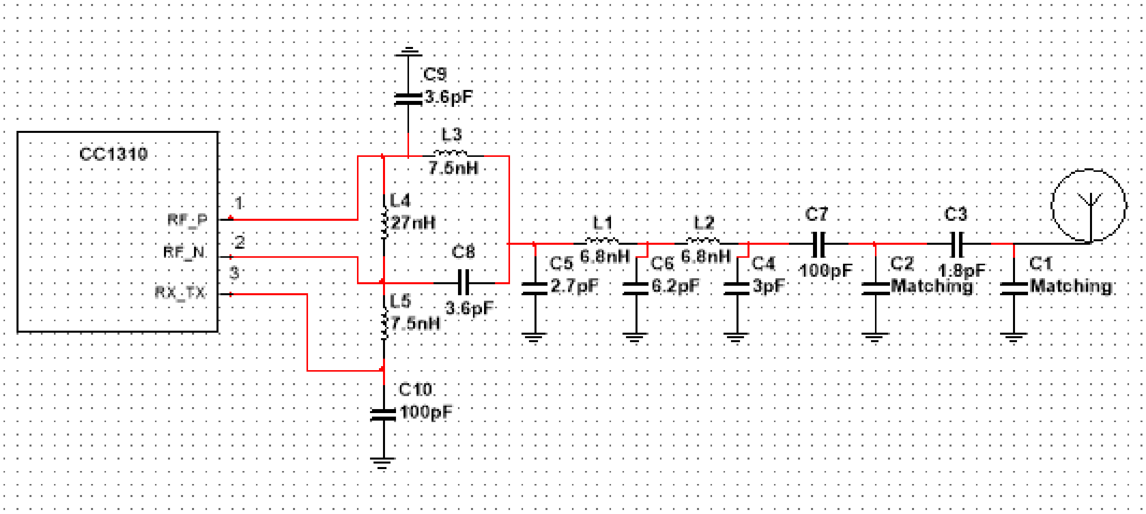


Figure 17 - Schematic, Controller MCU and Switch IO

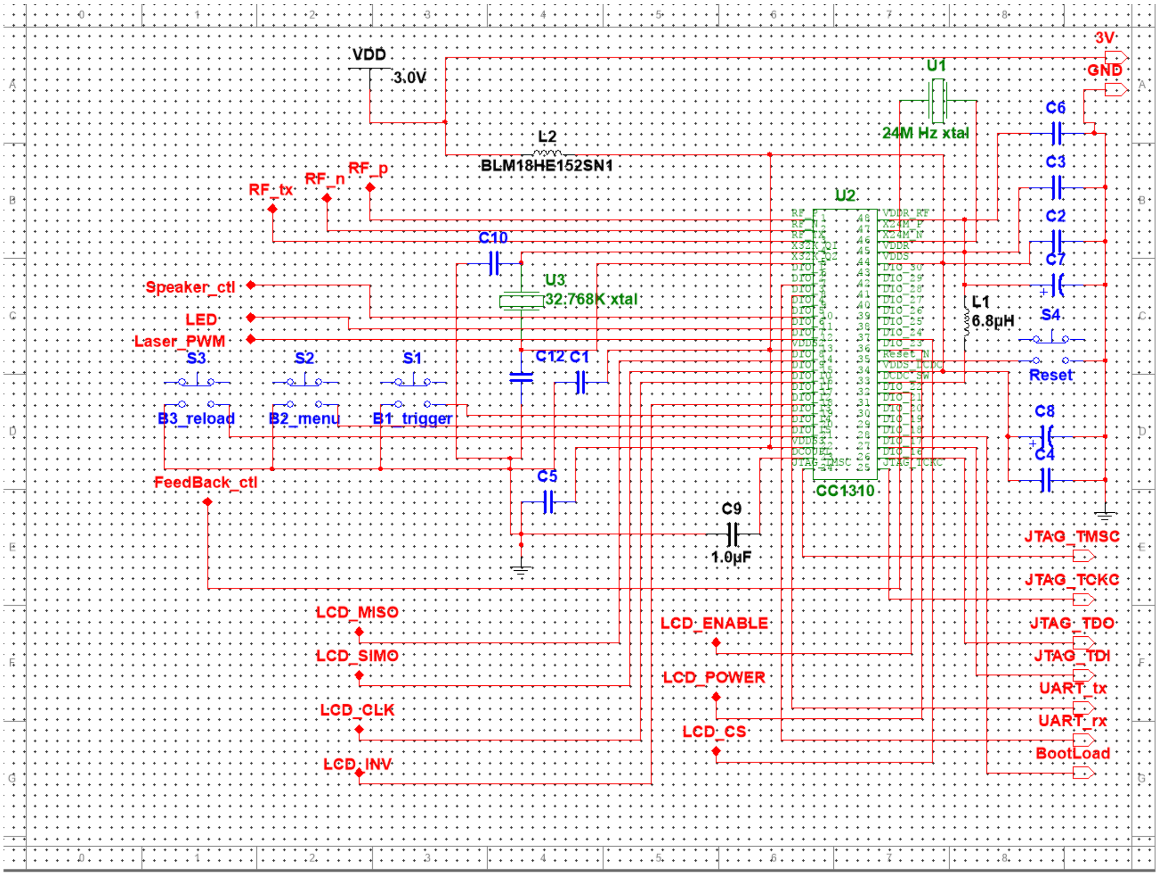


Figure 18 - Schematic, Skeet Power and Laser Detector

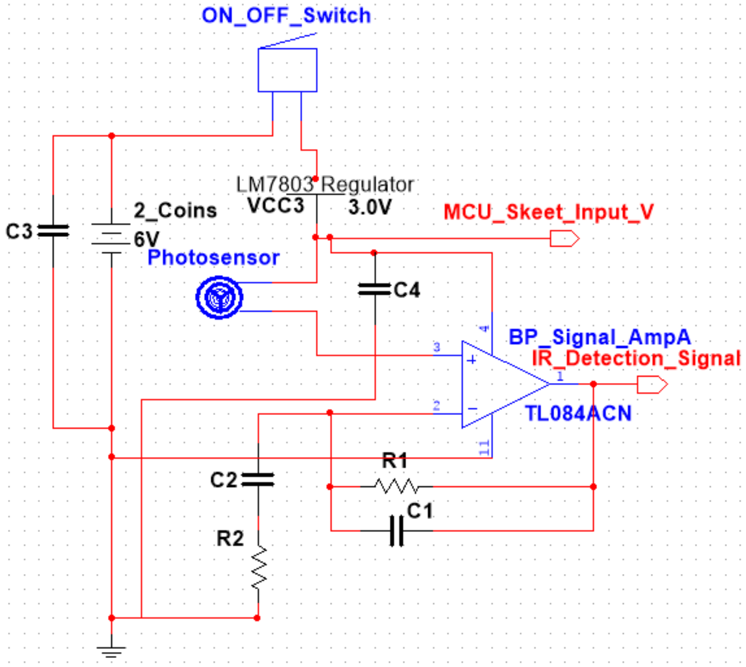
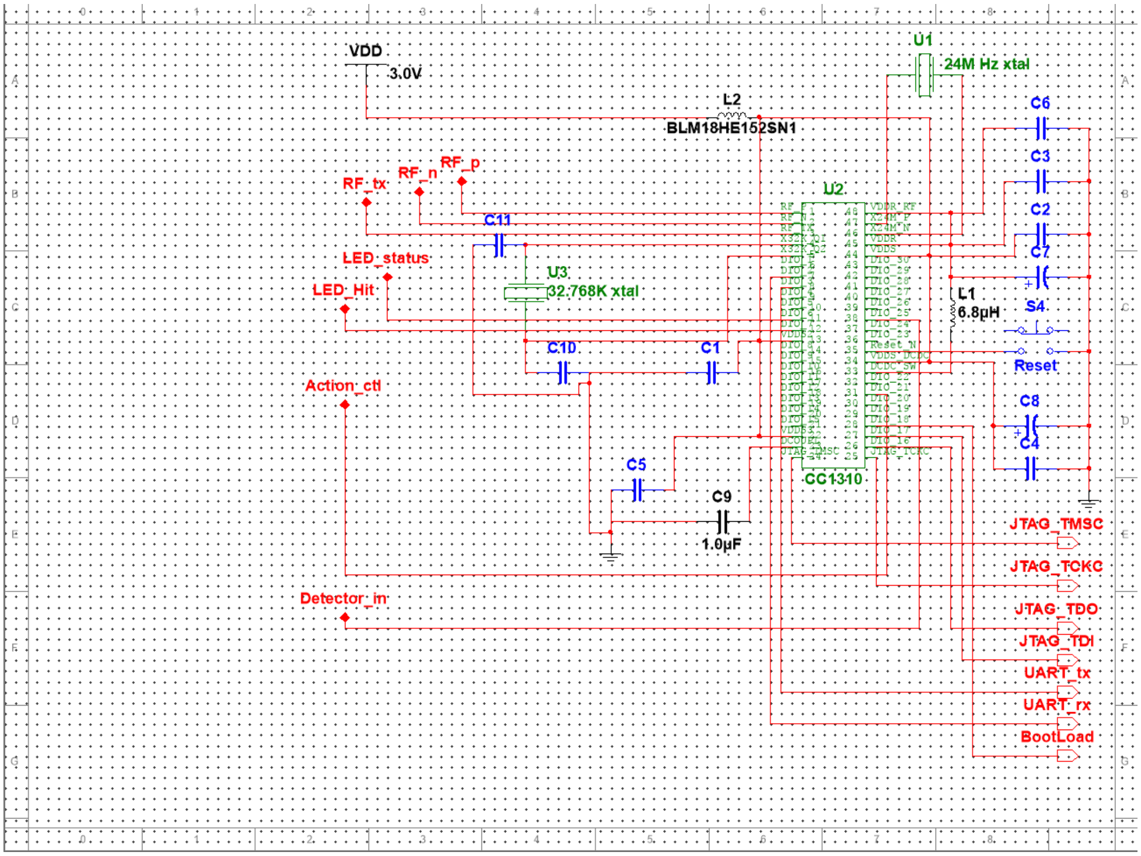


Figure 19 - Schematic, Skeet MCU and Switch IO



5.2 Software Design

Our selected MCU the CC1310 is actually a collection of three different programmable sections responsible for the different aspects of the system on a chip (SOC). There is a main processor, a low power sensor controller, and a processor responsible for the RF radio communications. All of these must be set up to get the system to work.

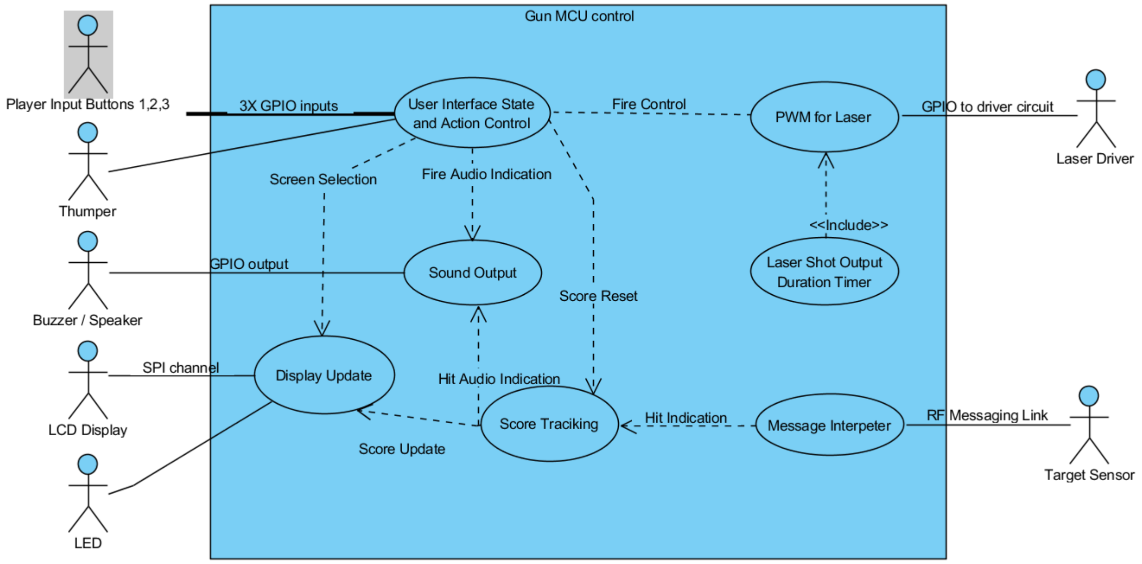
In our system we will also have two different software setups. We will need one for the gun controller that takes care of gun controls and provides the HUB function for the radio network. Another is needed for the skeet sensor device that will monitor the sensor and report back strikes by way of the RF link.

During development there are multiple methodologies available for use. I this projects case the small number of personnel involved makes coordination less of an issue. None the less, the functions of planning, designing, coding, and test confirmation are still required. Of the common design methodologies the one that most closely follows what we will do is the phased methodology. While this is not exactly a classical phased development since we are only providing a single released product, it still has characteristics of this style. First we are actually starting with a product, development kit and example project that implements some base functionality. This will be built upon to add our functionality. Also since there is no one in the group familiar with the software development kit or programing in the TI-RTOS operating environment required for supporting the RF protocol stack, every function implemented will require learning. Since this is the case, functionality will be implemented in phase approach. This will allowing the focusing on one problem at a time and testing its operation.

5.2.1 SW Overview

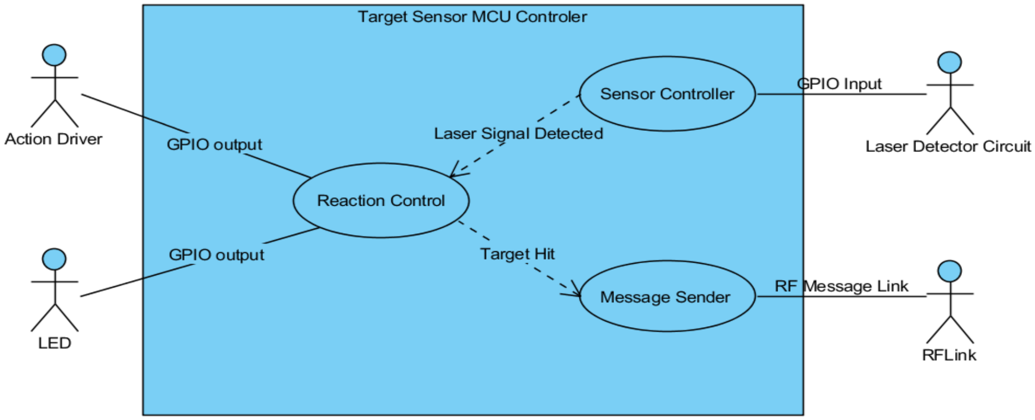
Before the specifics of the software programing can be done it is necessary to understand the high-level objective that we want to accomplish. In order to understand the control inputs, required outputs, and their relationship in the software system diagrams are useful. The use case diagrams provide this high-level picture for us. Below in Figure 20 and Figure 21 are the diagrams for the controller and sensor units.

Figure 20 - Use Case Diagram for Gun Controller



As seen in the diagram the controller functions needed are pulse wave modulation (PWM) and timing for the laser, user input control processing, display output, sound buzzer output, score tracking, and RF messaging processing.

Figure 21 - Use Case Diagram for Skeet Sensor



The sensor functional needs are control output for LED and action feedback, input sensor signal detection, RF messaging.

5.2.2 SW design Tools

In order to complete the software development task certain tools are needed. The main tools needed are an editor for writing the code, a complier for the language being used, a debugger for locating faults, and any software libraries needed.

IDE
For our software development Texas Instruments' Code Composer Studio IDE will be utilized. The integrated development environment (IDE) provides the editor, C/C++ compiler, and debugger for the MCU. The selection of this IDE was partial determined by the microprocessor selection. While other environments could be used this one has the configurations built in to support TI products. The IDE is actually built upon the Eclipse development environment, giving it roots in a widely used platform. It also has a debugger that is able to communicate with the development board from TI. An additional feature unique to this IDE is the incorporation of linking to the TI example code and projects.

The IDE built in compiler provides support for compiling both C and C++ code. While the object oriented C++ would be preferred for use, C code is required for integrating with the Texas Instruments software development kit and drivers.

Another important task that the IDE is handling for us is boot loading the software to the devices. The IDE has the ability to connect to the TI XDS110 debugger and programing device that is located on the CC1310 Launchpad development board. The debugger also has the ability to be used independently allowing it to be used with the custom PCB solution a long as the interconnections are provided over a cable connection.

Version Control and Code Backup

During the development of software, the code undergoes many changes and growth. While it is hoped that every new change is good, this is not always the case. It is therefore useful to keep track of old versions of the software for future reference if needed. This is the job of a revision control manager. Git is one such solution that is widely used. It is available for free and runs on the user's computer. It handles tracing of changes as well as having the ability to integrate changes done by other coders into the local file store. This provides the ability to have multiple people in a team working on the same code project.

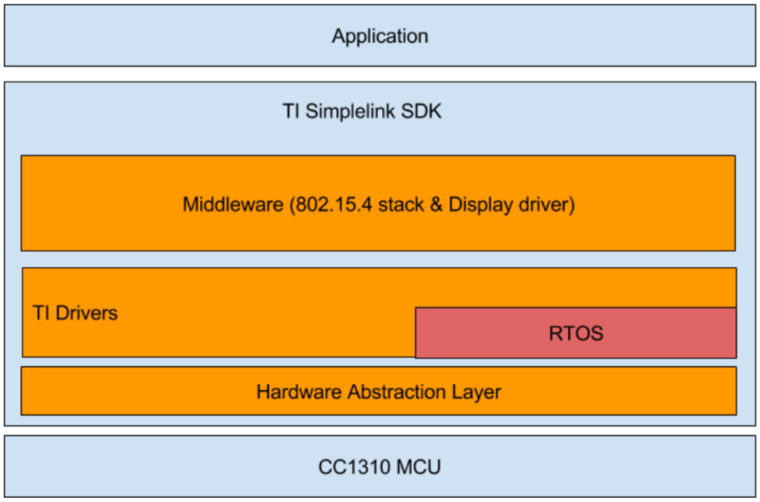
The other part of handling code is the storage of the data. GitHub is the storage repository portion of the solution. Having an on-line storage component provides a backup in the event that the local data is lost. A central repository is also essential for the ability to collaborate with other people. We intend to use Git and GitHub to aid in our revision control and backup for the project.

SimpleLink MCU SDK

Texas Instruments provides the CC1310 MCU as part of their SimpleLink product line. This solution comes with a set of development tools. Texas Instruments intended that the tools be constant over multiple products that they offer. To accomplish this they provide intermediary software that provides abstraction between the hardware MCU that you are using and the software code implemented in the application. The components are shown in Figure 22 below. The kit provides device specific drivers that are in turn converted to standardized TI drivers. The drivers work in concert with a real-time operating system (RTOS). TI supports their own as well as FreeRTOS.

We will use TI-RTOS. The RTOS is a cut down operating system that can best be described as an interrupt handler. It is also referred to as SYS/BIOS. It allows the efficient allocation of processor resources necessary to perform the communication functions along with application tasks at the same time. The RTOS also provides the integration of the separate software tasks necessary to coordinate power savings functions. TI-RTOS also provides a standardized method for interfacing with the device's hardware I/O and pin connections, making portability of the design's code possible between two different devices. The RTOS is then able to control going into idle when processing power is not needed. The previously described RTOS and drivers are necessary to support the 802.15.4 protocol communication stack provided by TI as part of the SDK [54].

Figure 22 - TI SimpleLink SDK Stack



TI-15.4 Stack

The TI-15.4 stack runs at the highest priority in order to maintain proper RF communication operation. Interactions between the application and the communication stack is implemented using an Indirect Call Framework (ICALL). The stack runs in its own thread. This allows abstraction of the protocol stack interaction and allows separation of the functions required to keep the application from causing blocking of stack operations. The application thread interacts with the communication link thread by calling the ICALL function and then the ICALL module handles the details of dispatching the command to the communications stack. During the communications process the ICALL and user application will stop and wait for the stack to finish executing the command. There are additional functions provided called the MAC API, this API provides the commonly required services to the user task. The API then sends the required commands to the ICALL functions and ICALL relays them to the separate stack task thread. Our needs should be met by the API, but if different or additional functionality is needed it can be expanded by adding functions that utilize ICall. Due to the shared resources the application is required to use ICALL services for Messaging, Thread Synchronization, and Heap Management when interacting with the stack task thread. One of the primary concerns is addressed with the ICall_malloc() and ICall_free functions. They are used for allocating memory for message data that is allocated in one place and then freed separately in a callback function [1].

Drivers

Of the drivers provided from TI we expect that we may use the ADC.h, GPIO.h, PIN.h, PWM.h, SPI.h, UART.h, buzzer.h, Display.h, and DisplaySharp.h Drivers.

Demo Starter Project

Texas Instruments also provides a starter template application that can be used to build the desired custom application. We will be starting with the Collector and Sensor Demo Applications. This will provide the basic star network topology we need for our project. The demo includes all the files necessary to get the 802.15.4 network up and running. Included in the package are the logical link control function. This handles the tasks of network detection, node joining, and rejoining. It also takes care of more complicated tasks like frequency hopping and encryption if they are enabled.

Without the tools provided by TI it would not be possibly to complete the project in a reasonable time. The tasks of creating a protocol stack and controls is quite large and would exceed time and manpower restrictions. This is a good example of the principal of software reuse for reducing development time.

5.2.3 802.15.4 Stack Configuration

While the stack takes care of most of the communications operations we must still let it know what we need. The configuration settings for the 802.15.4 stack to be used in the project are stored in the Services/subg/config.h file of the application. Many of the defaults will work, but some need to be checked and set.

CONFIG_PHY_ID - This defines the ISM band, number of channels, and data rate. There are two valid value settings for use in the United States:

1	with defined name APIMAC_STD_US_915_PHY_1
129	with defined name APIMAC_GENERIC_US_LRM_915_PHY_129

Value 1 provides a 50Kbps data rate with 129 possible channels. Value 129 provides a 5Kbps data rate with 129 possible channels. The 5K rate allows for longer range transmissions. We are using value 1. If range becomes an issue this could be changed to 129, since we do not require a high data rate.

CONFIG_CHANNEL_MASK - Provides the settings to enable or disable channels for use. This is a bit mask for channels 1-129. Of enabled channels the PAN controller will try to find the quietest channel of those allowed for use if frequency hopping is not being used.

CONFIG_PAN_ID - Sets the desired PAN ID. We have picked 4FF4 randomly for use initially. Having an ID rather than FFFF (unassigned) reduces the chance of having other types of equipment attempting to join our network.

CONFIG_FH_ENABLE - Enables or disables frequency hopping. The default of disable is used. Frequency hopping can be enabled to reduce the effect of interference. The simpler fixed channel will be used for testing the operation of the system. This can be enabled and tested separately once the system works.

CONFIG_MAX_DEVICES - The default of 50 is used. This determines the number of remote sensor nodes.

CONFIG_SECURE - The default of True is used. This could be changed later to reduce code space since the network is no carrying any critical information.

CONFIG_MAC_BEACON_ORDER - Default of 15 (disabled) is used. This can be changed to 8 to allow for the PAN controller to operate in beacon mode rather than non beacon. In the default setting the stack operates in an asynchronous mode using CSMA/CA. Carrier Sense Multiple Access (CSMA) provides the listen before talk required for free band operation.

CONFIG_TRANSMIT_POWER - The package comes with a current default setting of 12 (dBm). This can be lowered depending on need.

Additional setting are available for setting beacon order, frequency hopping channels, polling, tracking, and reporting times. [1]

5.2.4 Controller SW

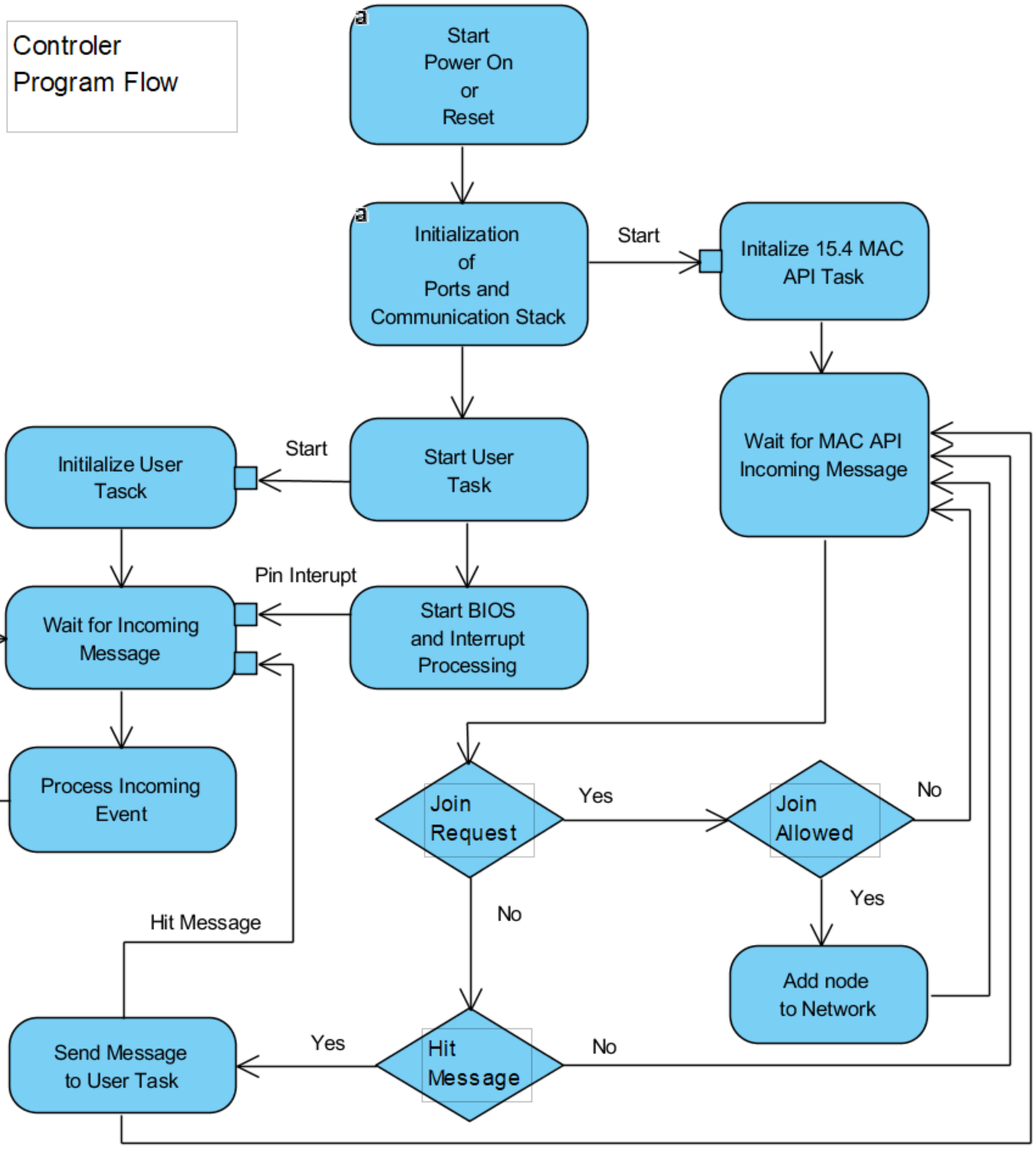
The gun controller has the bulk of the responsibilities in the software system. It is responsible for handling user input controls, providing modulation and shot timing for the laser, tracking scores, establishing the wireless personal area network (PAN), joining and tracking the sensor nodes on the network, sending audible, visual, and mechanical feedback control signals out, and displaying information on the LCD for the user. The high-level program flow and be seen in Figure 23 and is described below.

Operation is started from a power on or a manual reset button. At this point the main function initializes the MCU ports. It also starts the TI 802.15.4 API task and user task. The BIOS is then started to allow the tasks to run and interrupts to be processed.

The 802.15.4 stacked task that was started begins operation as a coordinator device. The stack checks its permitted channels to find one with minimal interference that is not busy and selects it for use. The stack then starts listening in non-beacon mode on that channel for nodes requesting to join the network and for incoming messages. At this point the skeet sensors if powered on can join the network.

The user process started will operate as the Game State Event Handler. Due to the need of the network 802.15.4 high level MAC API requiring high priority processing to allow the network to run properly, the user programs must be implemented in at fashion that does not interfere with it. To do this and to minimize processor use the user process cannot use a continuous running loop that ties up the CPU resources unnecessarily. The user process must go into a waiting condition when it has nothing to do.

Figure 23 - Controller Program Flow



This is implemented through the TI-RTOS by using a separate thread from the communication processes. Then initiating events by using semaphores, Message Queues, interrupts, and registered call back functions. When the new call-back functions are implemented for handling the added functionality to the program it is important to keep the actions performed minimal. The callback function will tie up the calling process until it returns. Making them lengthy can interfere with the communication stack or possibly perform actions that are not thread safe. The callback functions can be looked at like a software interrupt handler. The suggested method for minimizing the call-back function activity is that the function should post an event to the appropriate thread task. It then can allow that thread to handle the processing by posting a semaphore that allows the releases a prior wait condition. Once the event is posted to the destination task thread and any data copied to the target, the callback function can release memory used in messaging and return. This allows the calling function to resume and processing will be handled based on appropriate thread priority of each task. The receiving tasks have the ability to stop and wait for a semaphore post when done with any posted incoming events. By using a design that allows the user task to stop and wait provides a structure that is conducive to allowing the OS to manage power savings features.

Below in Figure 24 the user control states and action events for the user process are shown. Depending on the user control state button action and display outputs are different. Each of the state and event pairs are listed in Table 24 below along with the required action for the event.

Figure 24 - Controller State / Menu Flow

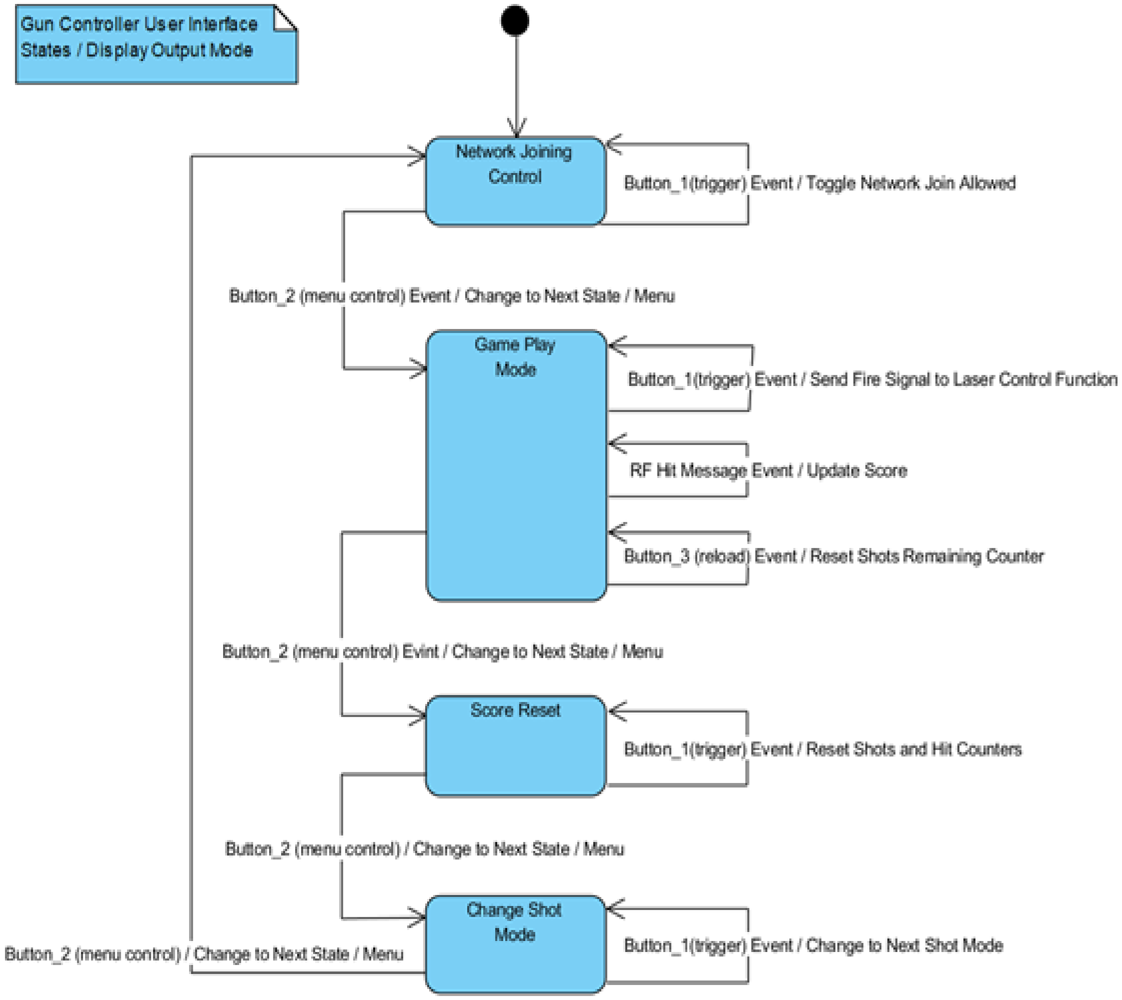


Table 24 - State Event Actions

State and Event	Button_1 Event & Joining State
Actions to be taken	1. Toggle network join allow.

State and Event	Button_2 Event & Joining State
Actions to be taken	1. Change state to Playing. 2. Update display with Playing View.

State and Event	Button_1 Event & Playing State
Actions to be taken	1. Activate PWM laser output signal. 2. Set Laser Shot Timer. 3. Activate audible feedback tone output. 4. Set Tone Timer. 5. Activate mechanical feedback output. 6. Set Feedback Timer. 7. Increment score shot counter. 8. Update display with new counters.

State and Event	Button_2 Event & Playing State
Actions to be taken	1. Change state to Score Reset. 2. Update display with Score Reset View.

State and Event	Button_3 Event & Playing State
Actions to be taken	1. Reset shots left Shot Mode value (2, 1, 127).

State and Event	RF Hit Message Event & Playing State
Actions to be taken	1. Increment score hit counter. 2. Activate audible feedback tone. 3. Set Tone Timer. 4. Toggle LED. 5. Set Blink Timer. 6. Update display with new score values.

State and Event	Button_1 Event & Score Reset State
Actions to be taken	1. Score shots and hits counters are reset. 2. State is changed to Playing. 3. Display is updated with new 0 score.

State and Event	Button_2 Event & Score Reset State
Actions to be taken	1. State is changed to Shot Mode Select. 2. Update display with Shot Mode View.

State and Event	Button_1 Event & Shot Mode Select State

Actions to be taken	1. Cyclically switch to next shot mode. (Double 2 shot, Pump 3 shot with manual reload, Auto unlimited) 2. Update display to show selected mode.

State and Event	Button_2 Event & Shot Mode Select State
Actions to be taken	1. State is changed to Network Joining 2. Update display with Network Joining View.

State and Event	Laser Pulse Timer Event & Any State
Actions to be taken	1. Switch laser PWM signal OFF

State and Event	Tone Timer Event & Any State
Actions to be taken	1. Switch tone output OFF.

State and Event	Feedback Timer Event & Any State
Actions to be taken	1. Switch feedback signal to OFF.

State and Event	Blink Timer Event & Any State
Actions to be taken	1. Toggle LED output state ON-to-OFF or OFF-to-ON.

The collector starter application already has a structure in place for handling messages on the 802.15.4 link and for handling application tasks. Our application specific needs will be added into this existing framework. The message formats are defined in smsgs.h. An additional message will need to be defined to accept the incoming laser hit message type from the sensor. The new message will be defined by making the following additions to smsgs.h: Adding define for SMSGS_HIT_MSG_LENGTH 3, adding to Smsgs_cmdIds_t typedef our new command ID Smsgs_cmdIds_hitMsg = 11, and adding a new typedef struct _Smsgs_hitmsg_t {} Smsgs_hitMsg_t containing our message format.

The collector.c dataIndCB() function handles processing of incoming messages. A new case will be added for our new message type Smsgs_cmdIds_hitMsg. It will call a new function processHitMsg() to handle recording the scoring when the hit message is received and to provide user feedback.

Application operations are handled by functions in csf.c. The csf_processEvents() function handles user key inputs. An additional input key will need to be added in the initialization function for the third needed input key. The function then will be changed to provide the game and menu control. Application variables will be added to support game data, gameState, scoreHits, scoreTries, shotMode, and remainingShots. The following game states will be defined, STATE_JOIN = 1, STATE_PLAY = 2, STATE_RESET = 3, STATE_MODE = 4.

New functions will be added for timing actions. Table 25 below lists the time functions to be added. When an event is processed by the game task the appropriate time out clock will be set. The callback functions will be programed to turn off the corresponding output. Since turning off an output should only require minimal time we expect to be able to handle the change without resorting to setting and posting events to handle the task.

Table 25 - New Timing Functions

New Function for Timing	Task handled
csf_initShotClock()	Initialize the parameters for shot duration.
csf_setShotClock()	Set and start the Shot duration clock.
csf_processShotTimeoutCB()	Turn off laser PWM output.
csf_initFeedbackClock()	Initialize the parameters for clock to time duration of the feedback activation signal.
csf_setFeedbackClock()	Set and start feedback duration clock.
csf_processFeedbackTimeoutCB()	Turn of feedback signal output.
csf_initToneClock()	Initialize parameters for tone duration.
csf_setToneClock()	Set and start tone duration clock.
csf_processToneTimeoutCB()	Turn off output tone.

The display update will be handled by adding csf_displayUpdate() function that will provide the output needed for the current menu/game state. The following TI LCD output functions are included in the starter project and available for providing output to the LCD display, Board_Lcd_writeString() and Board_Lcd_writeStringValue(). They utilize the sharp display drivers in the SDK. They will be used by our function in updating the display. In addition to adding the new outputs to the LCD the exiting demo temperature display will need to be removed.

An initialization function, initLaserPWM(), will be added for the laser PWM output. The TI PWM driver provides the following functions and parameters for controlling the output. The driver will be used for setting the output frequency to 30,000 and turning on and off when needed. Below are the driver functions and configuration parameters required to set up the driver for use.

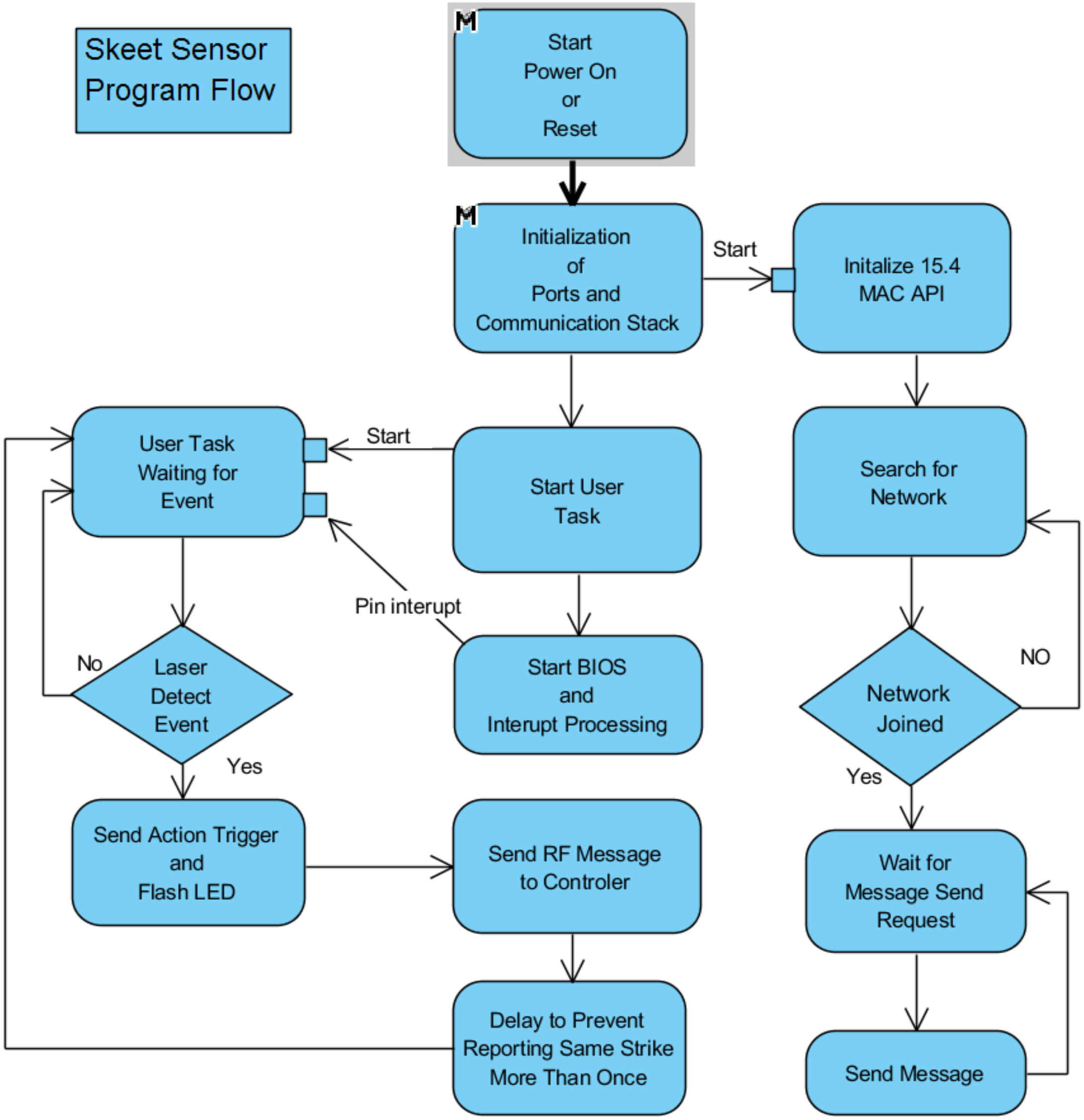
```
        PWM_init();
        PWM_Params_init(&pwmParams);
        pwmParams.idleLevel = PWM_IDLE_LOW;
        pwmParams.period.unit = PWM_PERIOD_HZ;
        pwmParams.period.value = 3e4;
        pwmParams.duty.unit = PWM_DUTY_FRACTION;
        pwmParams.duty.value = 50;
        pwm = PWM_open(Board_PWM0, &pwmParams);
```

The PWM output will be activated when the trigger button is pressed while in the play mode. The output will be timed and shut off after 0.1 seconds to simulate a single shot. This can be done easily after setup by calling the driver PWM_start(pwm) and PWM_stop(pwm) functions.

5.2.5 Sensor SW

The skeet sensor node software is responsible for activating effects on the skeet when a laser hit is detected and for communicating the hit event back to the gun controller for scoring. The programs functional sequence flow can be seen below in Figure 25.

Figure 25 - Skeet Program Flow



The operation of the skeet sensor is initiated with either a power on or a manual reset button press. After starting the main function starts the 802.15.4 stack API task and user task. The BIOS is then started allowing interrupts and tasks to run. Before being able to function, a connection must be established to the gun controller. To establish the connection the controller must have first been turned on and have a network up with joining enabled.

At this point the sensor software should automatically start trying to find a network to join. This is done by having the AUTO_START option enabled in the TI 15.4 stack. As this is set up as a non-beacon configuration the sensor node must attempt to find the gun PAN controller on each of the enabled allowed channels for the network. The sensor does this by transmitting out a request and waiting to see if there is a reply for each channel. To avoid the joining with random controllers a predetermined agreed upon network ID is used. This the ID make the chances of finding the wrong network unlikely.

Once joined to the network the skeets primary job is monitoring for a laser hit event. The detection is done with external circuity and notification is relayed to the MCU on an IO pin. Once notification of the detection is received the software has three tasks to perform. It sends out a signal on the IO pin assigned to activate optional response action device, visually provide indication of hit by blinking LED controlled by another IO pin, and send 802.15.4 format message with indication of a hit to the gun controller.

In order to prevent multiple reports from the same laser shot a delay may be added to prevent reporting new event for a period greater than the laser shot duration. Once the cycle completes the skeet returns to waiting for a laser detection signal.

The sensor starter application already has a structure in place for handling messages on the 802.15.4 link and for handling application tasks. Our application specific needs will be added into this existing framework. The message formats are defined in smsgs.h. An additional message will need to be defined to communicate our laser hit to the controller. The new message will be defined by making the following additions to smsgs.h: Adding define for SMSGS_HIT_MSG_LENGTH 3, adding to Smsgs_cmdIds_t typedef our new command ID Smsgs_cmdIds_hitMsg = 11, and adding a new typedef struct _Smsgs_hitmsg_t {} Smsgs_hitMsg_t containing our message format.

A new message event will be needed to trigger sending the hit message. The event ID will be defined in sensor.h as SEND_HIT_MSG_EVT 8. In the sensor.c file a new case will be required in Sensor_process() function to handle our SEND_HIT_MSG_EVT. A new function will be need for constructing our message and calling the send function. For this we will create a new function call sendHitMessage().

Application operations are handled by functions in ssf.c. The Ssf_processEvents() function that processes application events will be expanded to process the laser input detection and LED flashing duration timeout events. The input pin from laser detection circuit will be added to pin initialization so that it's interrupt is included with those processed by Ssf_processEvents(). On laser detection our SEND_HIT_MSG_EVT will be sent to Sensor_process(), the action output pin will be cycled and LED flashing started. New functions ssf_initFlashClock() and ssf_setFlashClock will be added to handle timing of visual LED feedback. A new callback function ssf_processFlashTimeoutCB() will be added to stop LED hit indication after time expires.

6.0 Test

This section is to better define and outline the test procedure used to identify possible errors in our design. With multiple components and sub-systems, each system is tested individually for performance and then as a whole with the MCU.

This section covers:

- Laser Driver Accuracy Test Conditions and FCC Standard Compliances
- Photodetector Circuit Activation and Outputs
- Performance Specifications on Laser Driver per Engineering Design
- Laser diode and optics performance
- Laser system performance
- RF Communications Compliances and Performance
- Software Design Performance and Control

6.1 Parts Acquisition

As part of preliminary testing parts were acquired to ensure availability and suitability for our needs. The below Figures 26, 27 and 28 depict the purchased parts and variously acquired components to be used for components.

Figure 26 - Parts, Laser Components

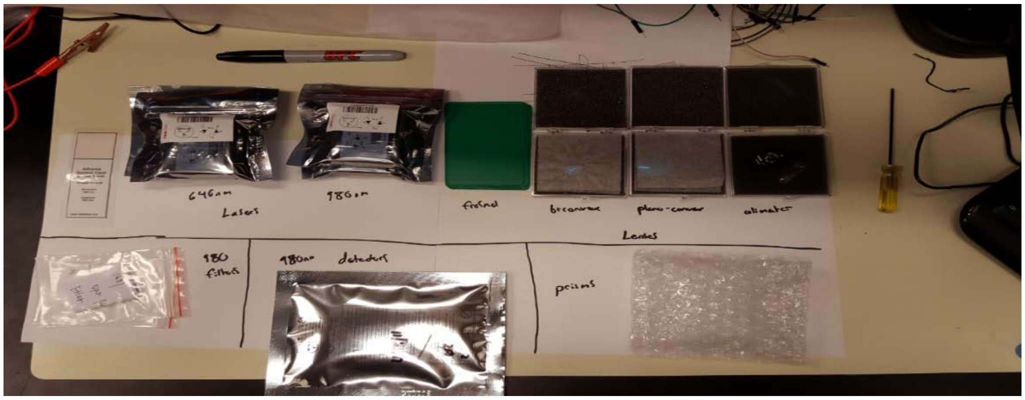
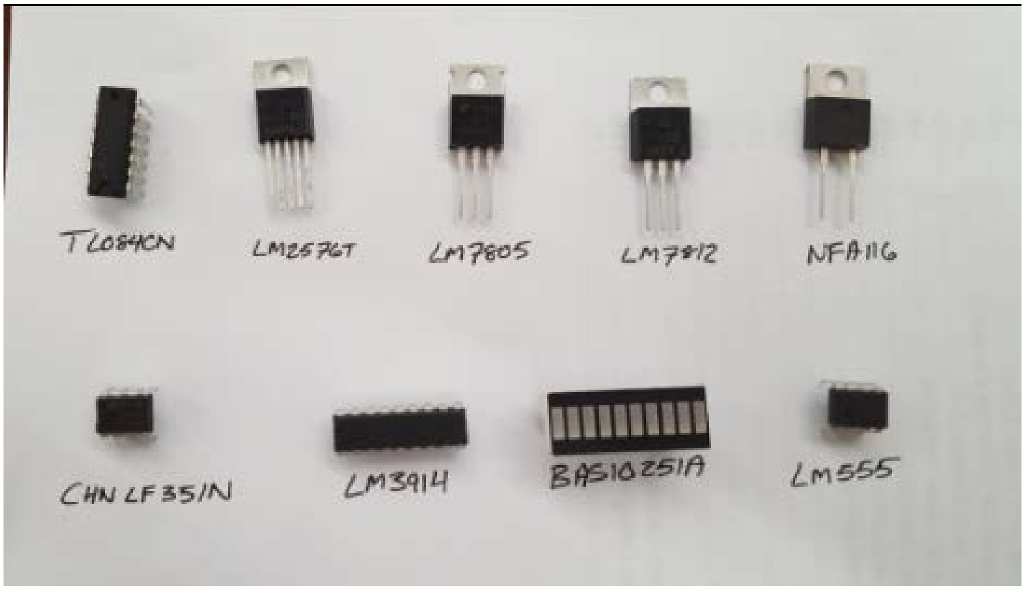


Figure 27 - Parts, MCU Components

Figure 28 - Parts, Electronic and Power Components



6.2 Component Testing

A great deal of electronic and optical components is to be tested on the entirety of this project. The microcontroller and Radio communications fall under the ideals of software testing, whereas the signal communications within PCB and power supply to sub-systems are a primary focus.

In this hardware section of testing a primary emphasis will be given to the targeted components that must comply with specific purpose laser products Code of Federal Regulation Title 21 – Part 1040 of the US FDA[citation].

6.2.1 Hardware Testing Overview

This section is to outline the simplicity of measuring and testing the common components found within this design. Each component serves a specific purpose, which is important to measure to ensure the components operate as expected prior to committing them to a PCB board.

Voltage Regulators – Every voltage regulator component is tested to ensure no abnormalities will occur in the instance of a failure or exceeding input limit sources. Varying the input and ensuring that the output value does not deviate too much from the expected value. Each regulator will be fed by a single power source that will make up the single input DC voltage, therefore each regulator will be tested simultaneously to check for conformity and appropriate regulated voltage outputs. LM7804 Linear voltage regulator was obtained, tested for conformity and passed.

Operational Amplifiers – Each operational amplifier is tested to ensure no abnormalities will occur in the instance of a failure or exceeding input limit sources. Such that the outputs of each amplifier are known, the input signal is traces and tested such that the input signals will not cause a chain of destruction on the amplifiers output. Each operational amplifier will be tested and vetted by manipulating the input voltages and determining their responses on an oscilloscope. These findings aid greatly in providing a sense of security for the devices being powered. TL084CN Operational Amplifier was obtained, tested for conformity and passed.

Passive Components – These components consist of capacitors, inductors, resistors and diodes. The discretion on the parts accuracy compared to their advertised listing values would pose a minor problem in compliances with government standards in RF and IR communications. Therefore, all major and primary components to these sub-systems are measured with a multi-meter and or experimented with and calculated to ensure utmost accuracy is achieved and that the sensitive systems they belong to are not drastically affected. The sub-systems of the components are to be vetted as well for sensitivity issues caused my inaccurate components.

Battery Measurement LED – This component is tested by connecting a DC power supply and determining the qualitative levels in which each voltage delivers. It is expected however that the top operational voltage of this device is 3.7V, of which two can be placed in series to provide a 7.4V battery level indicator, which will be a crucial measurement of informing when the device will not have nominal supply to continue normal operations. A 3.7V Battery Measurer will be installed to the target as well, notifying the user of an impending battery change requirement. This is conducted by setting the reference voltage to that based off of the regulators. When the voltage being measured is equal to or close to that of the 3.3V regulator value, the LED bar will move closer to a depleted visual. Component was obtained, tested and approved under these aforementioned conditions.

MCU & RF Connectivity – The development boards we received have been loaded with TI’s collector and sensor demo software and connectivity has been confirmed at 100 yards. This range is adequate for our need so we know that the solution will provide the needed performance.

6.2.2 Laser Driver Testing

Power Testing Qualifications – Power supplied by the MCU to support trigger action features and sub-system controls is to be closely monitored. Specifically required by the FDA a secondary LED must be activated to represent when the Laser Diode is activated. In accordance's with this secondary confirmation LED, the laser will also feature a safety latch signal, such that when a safety switch is engaged, the laser will not operate at full potential even if the trigger is pulled. This prevents any sort of unwanted misfires during handling. Once these two requirements are met, it becomes safe to check the remainder of the system consisting of the driving op-amp and measurements of the duty cycle to drive the LED. These measurements can be taken and recorded using an oscilloscope to confirm that the driver remains under the activation threshold whilst safety is on and is only put to full power once safety is off, and the trigger sensor provides the PWM. Laser driver system was confirmed using the previous TL084CN op-amp in conjunction with a standard red LED, the driver system operated and delivered the expected amounts of power and performance.

6.2.3 Photodiode Testing

Photodiode – The circuit is tested without the photodiode included to confirm that an input current will allow a proper hit signal to be registered and confirmed for the MCU later. The photodiode is then configured separately to appropriately confirm that the photodiode will initiate current under the Laser's tuned parameters. This mating process will then determine the amount of time that the laser needs to be in contact with the sensor to achieve a confirmed hit. This amount of time is recorded and tuned to be the MCU's signal input time for a minimum release of power. This system of checks and balances enables a safe mechanism for the firing and also allows time between shots to not keep the laser on longer than needed. Furthermore, the system is tested under conditions that may accidentally trigger the system such as interior and exterior lighting and prolonged sun exposure.

6.2.4 Laser Testing

Laser Diode - Since this project contains a laser to be used for detection, the properties of the laser diode must be understood to best optimize and utilize the laser for this specific application. The specific properties of the laser that must be texted is the emission wavelength, The IV characteristics, and temperature dependency. The first property, emission wavelength, can be tested by setting the input current to the normal operating current specified on the diode's datasheet and coupling the output light into a spectrometer. By measuring the emission wavelength in a dark room, the center wavelength and the linewidth of the laser. The second property, IV characteristic, can be determined by varying the current through the laser diode from 0 mA to the maximum amperage stated on the diode's data sheet. By stepping the current in 2 mA steps, the curve can be determined. The curve itself should show two linear lines for the LED mode and LD mode. Back tracking the linear LD mode curve, the threshold current for the laser can be determined. The third property, temperature dependence, effects the first two properties. By repeating the previous two experiments, the temperature depended can be determined. Special note will be for temperature of expected operation which in this application corresponds to roughly 35-45 degrees Centigrade. Plotting the wavelength and threshold current as a function of temperature will show the dependence for the laser. LED obtained, activated, and verified turn-on threshold levels to be appropriate.

6.2.5 Optics Testing

Optics - This project contains seven optical components as well as two non-optical components that will be in the optical system. They consist of the collimator lens, anamorphic prism pair, biconvex lens, plano-convex lens, Fresnel magnifier, optical bandpass filter, pinhole, and linear polarizer. First, the three lenses will need to be tested to make sure the focal length is the same as shown on the data sheets. The collimating lens will produce a collimated beam if the laser is at the focal length of the lens, so by placing the laser at the focus and testing the change in the output beam will determine collimation. If the beam is consistent at steps of 10 cm for a 100 cm, the beam can be said to be collimated. For the biconvex lens with two focal points, one in the front and one in the back, a laser pointer can be used to determine the focal planes. By shining the laser pointer at the center of the lens and moving it forward until the laser forms a point on the other side of the lens will show the two focal points of the lens.

The plano-convex lens focal point can be determined the same way as the biconvex lens except that the laser will never image another point but instead create plane waves that are parallel from the top of the beam to the bottom of the beam. Second, the anamorphic prism pairs need to be tested to determine the magnification as a function of angle variation. By shining the laser pointer through the prisms and varying the angles will determine how magnification functions with angle. The angles should be moved in steps of 5 degrees with only one prism moving at one step while the other moves through the whole range for each step the other prism moves. Recording the width of the magnified axis will determine the characteristics.

Third, the Fresnel lens magnification can be found by moving the Fresnel lens away from an object, preferably text, and determine the point of best clarity will show the magnification the lens. Fourth, the pass band of the bandpass filters can be determined by shinning a white light source through them, and measuring the emission wavelengths. Fifth, all of the optics will need to be tested for transmittance. Transmittance can be tested by shining the laser used for the gun through the element and determining the power out of the element versus the total power coming out of the laser diode. The pinhole will need to be tested to determine if it can withstand the energy of the focused beam. The data sheet for the material used should show the specific heat as well as working temperature ranges. Additionally, the laser being used can be focused onto the material to determine when or if the material degrades from the laser beam power. Sixth, the linear polarizer will be tested to determine the output power as a function of rotation. Passing the collimated laser beam through the linear polarizer and recording the output power at each 2 degrees turn of the polarizer will show the rotation to output power relationship. All lenses were obtained and confirmed to be the appropriate shape, focal lengths were found to be accurate to the corresponding data sheets, and were made of the correct materials ordered.

6.2.6 Laser System Testing

Once the laser system is constructed, it needs to be tested to determine its output power and beam shape. These two parameters are important to both understand and optimize for safely and performance of the system. The output power can simply be measured by using an optical power meter to record the power coming out of the device. The beam shape of the laser system corresponds to the divergence angle of the output beam for both axis, the spot shape, and the location of the center of the spot as it changes with distance. The divergence angle can be determined by using the knife edge technique. An edge will be placed on the side of the detector and will be translated from the max power until the FWHM power of the power. That will be repeated five times axially along the optical axis for both axis to determine the divergence angles. The knife edge technique will only be viable for a collimated output beam since the detection area of the detector is not large enough for the larger spot sizes this project hopes to achieve. Those larger divergence angles can be determined by translating a large grid along the optical axis. Similarly, to the knife edge method, the angle will be determined by measuring the power at the center and FWHM for each axis.

This method is not as accurate as the knife edge since it relies more on eye measurement to determine the angle. The spot shape and location can be measured in a similar way that the divergence angle was determined. By translating a grid along the optical axis and measuring each axis length and the center location. The spot size should be the most circular at the target distance since that is the size that was used in calculated in system. The center of the spot should not move as it travels away from the laser, if it does than at least one of the optical elements is not aligned right and needs to be corrected.

Confirmation of the Laser System design is to be further conducted once all components are configured to work appropriately in a controlled environment. The system test will then be repeated under stressful and non-ideal conditions to prove and affirm expectations of operations.

6.3 System and Software Testing

Particular components within the primary design need to be tested before a final presentation and implementations. The components in question are separated to the MCU signal handling as well as the compiled hardware components that will ensure safe handling of the laser devices. These components are split into two separate sections, System Hardware and System Software. The hardware section outlines the testing done as a whole system among each part to determine the failures early on in any electronic design. Wireless and Software cases are conducted to determine fallacies within programming and to ensure that the appropriate pins are activated or triggered within the specified control action parameters. Separation of testing and then integration of parts is most essential to extract which components or processes are failing to meet specifications, the act of vetting components before, during and after

6.3.1 Assembled System Hardware Testing

Due to the very nature of some sub-systems being controlled based on the MCU inputs, the devices will be tested without the MCU and by using the appropriate MCU responses for each particular device. Once the components are pieced together in their respective sub-systems, the components will be tested to perform the full function that they were selected for.

Power System Assembly – The power system plane will be tested first to confirm that the nodes at which power is delivered to different sub-assemblies will retain their full power potential given an appropriate main power source. This will be done by placing the voltage regulators and accompanying components onto a breadboard and issuing varying input ranges from 3V to 10V. The stress test will ensure that none of the components fail when worked in unison. The NiMH battery pack will undergo substantial amounts of charging and discharging to accurately represent the continuous use of its potential [38]. The battery will also be connected to the final sub-assembly system to correctly measure the output power delivered to the system and compare this value to that of the team's specifications.

Laser Diode Modulator Assembly – The power system plane will be connected to the laser driver modulation, and the modulation supplied by a function generator. This will allow the circuit to be tested at the pre-designed input values as well as perform stress onto the components to test for discrepancies as a system. These tested components will further ensure correct operations by measuring the maximum output currents and voltage supply nodes that will later be connected to the actual laser device. Measurements are made to also ensure that the safety devices in place won't be purposefully triggered or close to triggered. This will be completed by placing two separate resistor components in parallel

Laser Photodiode Trigger Mechanism – Confirming the photodiode at various ranges will be a crucial aspect to ensuring the maximum range and operation of the device. The circuit will first be tested using a digital multimeter to confirm that the triggering photodiode will supply an adequate amount of current through the circuit. The photodiode itself will be tested to confirm conformity with a testing laser modulation. Once the circuit and components are accurately working, the components will be tested at the entire range that is required for operational success. Confirmation of the final power output as well as regulating the input supply powers will be crucial for this most essential component. Final confirmations are made once the photodiode can be correctly triggered by the laser being used and can return a SR latched gate output to trigger the MCU. Then that the SR latch gate works appropriately once the skeet target confirms the activation.

The previous system tests are confirming that the hardware electronics in both the skeet target and sensor work appropriately. In a previous testing section, each component undergoes an independent test to ensure that the component itself does not fail as well as performing at optimum desires. Some sub-assemblies consisting of speakers, LEDs, battery measurement tools and vibrational motors are also tested in an individual fashion as well as ensured to work on their own with an MCU controlled driving system.

6.3.2 Wireless Communication Testing

Establishing Wireless Communication - Verify that both systems can communicate with each other. A simple code will be sent wirelessly to turn on an LED connected to the other device to prove connection. From there max range will be determined and the transmitter power will be raised to meet the necessary range or lowered if the range has already been met to lower power usage.

Communication System Under Stress - Testing needs to be done to see under what factors the communication system will fail. Distance while the target disc system is moving will be measured and a fail point will be determined. Quality of the data will be assessed during a variety of different situations to determine any limiting factors. Such stressful environments include, but are not limited to, dry heat, rain, sunshine, active RF signal backgrounds, EMF submission and emissions, conjoined with altitude and pressure.

6.3.3 Software Testing

Software testing is actually done in multiple stages. The first part of testing is the module level testing. The code as it is written will be checked to confirm it works as desired. The fact that the parts work as expected alone does not mean it will work once all together. The additional testing function testing in the sections below will also be done to verify everything works when hooked up to the rest of the system.

6.3.3.1 Software Test Cases

To confirm the proper operation of the gun controller software each of the provided functions will be exercised and the required output confirmed. Since the user interface on the gun controller determines the action that take place, testing will closely follow the user menus and possible inputs. Table 26 below will indicate the functions that will be tested, evaluated and confirmed later in more integrated testing.

Table 26 - SW Test Cases

SW TC1	Controller Startup and Joining Test: 1. Initiate a power on or reset action. The controller should begin in the joining control state. It should automatically begin startup and channel selections. Once a channel is selected the display should indicate the channel that the controller has selected for use. 2. Once the channel is selected the joining enable disable function can be tested. Joining should toggle on and off when button_1, the trigger, is pressed. 3. The ability to join a skeet sensor should be confirmed at this point.

SW TC2	Controller Button_2, Menu Control Test: 1. As Button_2 is pressed the display should cycle through the different states (Joining, Playing, Reset, and Mode Select) and display the corresponding information on the display.

SW TC3	Controller Play Mode Function Test: 1) While in play state confirm the current shots and hits count is displayed. 2) Activate button_1 and verify: a) That PWM of the correct frequency is output to the laser driver. b) That the pulse duration is correct. c) That the output remains low when the pulse completes.

	d) That audible feedback pin output is cycled. e) That the motion feedback pin is cycled. f) Also confirm that shot count display is incremented.

SW TC4	Controller Reset Score Test: 1. While in the reset state confirm display indicates reset prompt. 2. Activate button_1 and verify: a. That the controller switches back to play state. b. That the displayed counters are returned to zero.

SW TC5	Controller Play Mode Selection Test: 1. While in mode select state confirm current play mode is displayed. 2. Activate button_1 and verify play mode cycles between Double, Pump, and Auto. 3. For each of the modes enter the play state and confirm the shots permitted before using reload button matches the mode. (Double = 2, Pump = 3, Auto = 100)

SW TC6	Controller Button_3 Reload Test: 1. When all available shots have been used in each shot mode, activate button_3 reload and confirm available shot count has been reset to the correct number.

SW TC7	Skeet Sensor Startup: 1. Initiate a power on or reset. The sensor should automatically start trying to find a network. Complete with TC1. Controller should indicate the sensor has joined the network.

SW TC8	Skeet Laser Strike Detection Test: 1. Strike the skeet with a laser shot signal and confirm that the skeet action control pin and LED cycle.

SW TC7	Skeet to Controller Messaging: 1. Strike the skeet with a laser shot signal and confirm that the controller feedback tone pin cycles and hit counter is updated on the display.

7.0 Housing and Assembly

The nature of this project is also aimed at creating a realistic looking device and target to be near indistinguishable from the real deal. This however is restricted by the U.S. Code 5001 regarding penalties to manufacturing imitation firearms. The code outlines a specific set of contingencies that must be abided by to sell, manufacture or poses an imitation firearm [11]. This code applies to our device under the scrutiny that it will be developed after 1898, does not fire like a traditional B-B or Paintball gun. The exact nature of our projectile being a laser driven source, further investigation leads to the scrutiny of appropriate laser hazard markings be placed on the device. The markings in question are later defined in the laser housing and assembly section. The compiled design of the Laser Rifle assembly is to roughly resemble that of Figure 29 below whereas the same rough estimate for the Laser Skeet Target is depicted in Figure 30 below.

Figure 29 - Laser Rifle Compiled Parts Design

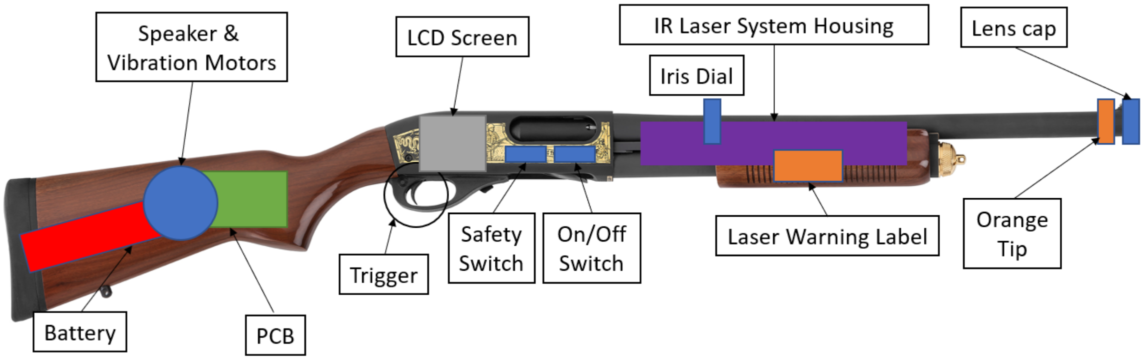
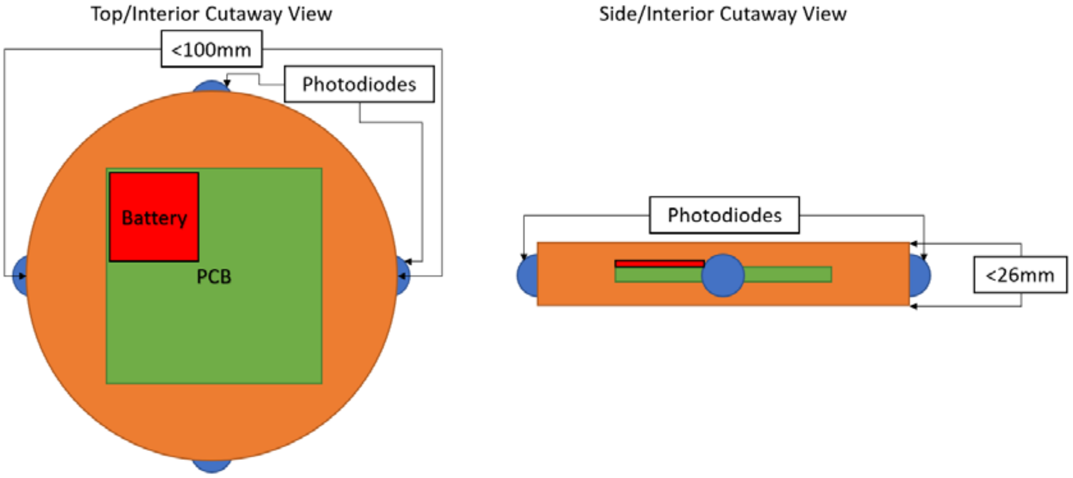


Figure 30 - Skeet Design



7.1 Target Housing and Assembly

The laser target will consist of the laser detection and RF relay systems. This design should be robust in nature as to not break upon impact with the ground. A cylindrical design for the target will be used to keep the standard skeet shape. The target in question is to be 100mm in diameter whilst retaining a ceiling height of 26mm. This overall is the general housing for the internal electrical components, PCB, photodetection system, RF communications system, and the flight destabilization wheelhouse.

Ultimately the housing for the products will be made of an easily replicable plastic design, maybe some sleeker plastic coating, finishes, and decals to have a more eye-appealing final product. The exterior will be able to house the photo sensing components as well as house the flight destabilization arms. The destabilizing system will consist of either a parachute to reduce fall damage or actuator powered arms that will erupt from the facades of the target.

The overall design will be sleek and contour to the original idea of keeping this product as closely related to skeet targets as possible. Weight is also a factor of following this system, such that the total target weight is close to 100g. This is done by determining the excess weight of materials that the electronics won't take up and evenly distributing that as materials towards the housing's design, structural integrity and other more dynamic stress protections. A small switch and LED will be used to toggle the target on and off, although a common component, this allows power savings and reduces further costs on the user application aspect.

7.2 Laser Housing and Assembly

Contents of the laser device will be hard mounted into a cylindrical tube to create a modular design that is easy to install into the final laser rifle assembly. This component may be useful to have adjusted along the length of the barrel of the laser rifle. Therefore, having a compact and modular design will allow a two-channel link for supplying power to the laser diode and delivering the modulated power signal. The primary exterior housing will be capable of handling thermal changes and of a quality such that no airborne materials can interfere with the internal laser optic assemblies. These assemblies hold glass, focusing components and the primary laser, these will need to be kept in place with sturdy and non-bending fasteners. The assembly should all be a contained unit with the only moving part the very end to control the scatter of the output beam. The material used should be a matte color to reduce the reflections of stray laser light from potentially leaving the system. All holes in the system should be sealed to not allow light out with the only section open being used for the electronic connections. The lenses will be mounted using rings around the outside of the lens using epoxy. When using epoxy, extra care should be made to make sure none ends up on any of the optic components.

7.3 Rifle Housing and Assembly

Final compilation of the Laser Rifle sub-parts will be composed of the interior electronics, exterior aesthetics and the modular laser device. All of these will be combined into one finalized product by using lengths of appropriately gauged wire to the sub systems that will extend beyond the primary PCB. Therefore, the core design will be a hollow system that wires and connections may run through the interior of, such that the exteriors aesthetics will provide better realistic qualities.

7.3.1 Rifle Materials and Design

A few materials may be used for the entirety of the design, but the main body and housing structure is initially thought to be made up of PVC piping and shop scraps. This body can be made out of almost any sort of composite from hollowed wood, to cast iron, concrete, 3D printed resin, to a pre-purchased plastic rifle. The best method for the team would be to ideally not have to craft from scratch an entirely new model of a firearm for this project. If such a design were to stumble upon the team such that an easily replicable, low-cost and sufficiently sized design was feasible, then that would be the best practical approach. Otherwise the laser rifle itself will need to be crafted in two mirroring pieces, to better create a 'backing' to the inside of the laser rifle that the "front" can be applied onto.

Metals – This would provide the sturdiest design whilst also being the most realistic. Modern firearms are usually made of plastics and metals for the main body that houses the primary firing system and structural design. Attachments would typically be made up of a fiberglass or poly-material composite. Metal will also provide the absolute best foundation and defense from the elements whilst allowing the team to keep a decent amount of realistic weight on the rifle design. Whilst being the easiest to work with of the following materials listed, metals would be a onetime cast with a higher expense compared to using plastics and molding techniques.

PVC – Cheap and durable, the costs associated with this would be feasibly next to nothing. PVC is commonly used in most plumbing applications, which benefits making a rugged and waterproof design whilst also being an insulator for the electronics. The primary issue with PVC is the ability to become dinged up when mishandled, and also the warping that can be caused by heat. PVC parts can be interchangeable and often fit with each other very well if one knows how to correctly assemble plumbing objects to look more like a laser skeet rifle. With the modular designs of the components, the final product may look more like the modern-day potato gun, rather than the intended product. A few materials in the final design may be housed in PVC for waterproofing, but truly nothing more than that would benefit the aesthetics of the design.

Shop Scraps – Undoubtedly the best way to retain a realistic looking firearm, utilizing any connections to the public that we can as students, reaching out to gunsmiths and appropriate shops of the like for their scrap parts would benefit the team greatly. Most fare-arms nowadays are custom made for individuals which allows the owner to have a sense of sentiment with their arms. Creating a joint effort with another shop would enable us to have an entire completed design that we can piece together or have someone help us out with, this would bring forward a sense of community in which both sides win! Ideally having the scrap parts match some of the team's specifications would allow the components to fit snuggly inside the rifle and protect the sensitive electronics. If there are no other feasible options in time, this may be a close second to a last-minute grab for a final product.

Premade Plastic Body – Having a premade plastic body of our choosing would be a costly endeavor if looking for a brand-new store-bought model. However, these often come in models for airsoft and paintball and could feasible be deconstructed to the point where new parts and components can be seamlessly added into or onto the existing design. This would offer one of the shortest amount of prototyping costs whilst also enabling the team to better use our engineering practices on more pertinent matters of the design. If time is lacking, this may be the last resort option to obtaining a final product.

3D Printing – Whereas this will yield an easily replicable design, the lack of experience among the team leads us to using open sourced products for creating this laser rifle. Also, the lack of a printer for such a large component puts a greater strain. This option would undoubtedly be one of the coolest methods that would be feasible given the aforementioned conditions were true. 3D printing would be a fascinating centerpiece to our team but at the cost of distracting the primary focus of the design away from advancement of integral components, this centerpiece would simply not vouch for a final design.

Concluding, the final design will be made up of a composite amount of materials, in the hopes of creating a final product that the more functional than aesthetically pleasing. However, an engineering goal is to design and draft an aesthetic product nevertheless. Therefore, utmost responsibility and delegation will be used whilst compiling materials to assemble the completed laser rifle design.

7.3.2 Rifle Interior Mounted Components and Fixtures

Interior Mounting will be subject to change based on PCB and component wiring. The device as a whole will be mounted using four PCB surface to hardware fasteners and appropriate shock absorbing washers to minimize vibrational handling of the sensitive electronics housed. Any and all external facing devices will be independently assigned an external housing contingency plan which will then later wired into the main PCB board. Such devices needing additional internal components would be the battery pack, which will require a rear facing battery cap held in place by a few screws or a latch lock. Another interior device will be the laser housing itself, this will be connected via lengths of wire extending from the PCB components through a hard-mounted fuse and then finally into the laser mechanical housing. Such a design will be the pinnacle of creating an interior connection, assuring that the laser rifle works flawlessly.

The interior of the laser rifle will consist of hard surfaces in which the electronic devices can be mounted to and fastened by securely. Such surfaces would need to be custom ordered in nature or for the prototyping purpose, fit into a casing and then fitted into the available laser rifle space. The ultimate design this teams hopes for is to showcase the PCB through a clear cover such that the final product and all connections associated will be viewable by a panel and the general public.

7.3.3 Rifle Exterior Mounted Components and Fixtures

By far the harder part of creating this design, housing the components sought after and putting them into a single sleek design may be troubling for us engineers. Therefore, the final product in question may not be the most beautiful device known to man, but a functional one.

Ideally the hopes of this team are to compile together the external components in such a manner that the use of the laser rifle is intuitive and exciting. This design with primarily have a right-handed shooter in mind with the knowledge that a mirrored version can be created for left handed users. The ease of use will come further into play by adding adjustable components such as sights, tactical grips, comfortable bump stock, attachment rails and further components to give the user an increased sense of customization.

Trigger and safety mechanisms will be facing the external shell of the laser rifle making an obvious statement as to the functionality of safety and shooting capabilities. A simple trigger will be used as the primary connection component to alert the MCU that a shot is desired. A secondary system of a safety switch is implemented to prevent the laser from going unintentionally active. These are both common designs on most rifles and will be utilized for our final design. A removable endcap will be used such that the battery is able to be replaced and housed safely in the butt end of the laser skeet rifle.

User interface through an LCD screen will be safely mounted and placed against a hard-backing surface to prevent bending and misuse. The LCD will be mounted on the left end of the stock such that a right-handed user can easily view the screen as well as operate the LCD menu options. Further non-essential components to enhance user experience may be added later based on aesthetic design and allotted time.

8.0 Administrative Content

8.1 Finance Costs Estimates and Tracking

Initial accumulated cost of this project prototype is estimated to fall under $750.00. This cost is manageable by self-funding from within the team. A party has expressed interest in acquiring the prototype after completion, but firm requirements and commitment for participation in project are not expected before completion. Estimated cost is primarily determined by the Optical and Signal Transmission Hardware requirements and further raised from the PCB and Aesthetics of Design for the Gun and Target as seen in Table 27 and Table 28.

Table 27 - Controller Costs

Gun Controller Costs	Estimated Cost	Actual Expense
Laser diode and optics	$150	$120
LCD display	$10	$14
Misc. low cost components	$25	$50
MCU	$10	$6
Custom PCB	$30	tbd
Non-technical mode parts (Physical)	$40	tbd
Development test board	$30	$30
Chip programmer PC adaptor	$30	tbd
Laser Gun Total	$325	$220

Table 28 - Skeet Costs

Skeet Sensor Costs	Estimated Cost	Actual Expense
Laser detectors, multiple for coverage	$25	$14
MCU	$6	$6
Misc. low cost components	$20	$50
Custom PCB	$30	tbd
Non-technical mode parts (Physical)	$10	tbd
Development test board	$30	$30
Skeet target Total	$121	$100

* If multiple devices are built are built then cost will be multiplied by that factor

8.2 Schedule and Milestones

Appropriate organization towards achieving a common goal is essential. The team felt it would be best to decide a more or less strict timeline to achieve the semester project's research and assignment goals. Decisions were made as to how and when we would accept the designs, order parts, and conclude research. Dates and statuses can be observed in Table 29, particular dates extend further into Senior Design II with the hopes that work can be conducted over winter break.

Table 29 - Schedule / Milestones

Item	**Task**	**Start** Date	**End** Date	**Status**
Senior	Design I			
1	Project selection	8/23/2017	8/30/2017	Complete
3	Project Documentation	8/30/2017	12/4/2017	Complete
4	Part / Design Research	8/30/2017	11/3/2017	Complete
5	Order parts for testing	11/6/2017	11/20/2017	Complete
6	Schematic Work	11/6/2017	12/4/2017	Complete
7	Breadboard testing of components	11/6/2017	12/4/2017	Complete
8	SW design/coding	12/4/2017	TBD	
9	PCB layout controller	12/4/2017	TBD	
10	PCB layout Skeet	12/4/2017	TBD	
11	Order additional Parts	12/4/2017		
Senior	Design II			
1	Order BCB	1/30/2017		
2	Assemble Circuit boards	2/10/2017		
3	Test Operation	TBD		
4	Physical Device construction	TBD		
5	Finalize Documentation	TBD		
6	Project presentation	TBD		

9.0 Summary and Conclusion

With the work and research that we have completed so far, we expect to be able to construct a prototype next semester that meets our desired goals. The team has cooperated quite well along the way providing valuable information, research and skills to aid in the development of the Laser Skeet Shooting system. During the process we have expanded our knowledge in the areas RF communications for the use in wireless networks, RF FCC regulations, antennas, and embedded operating systems, regulations for laser devices, laser detectors and use of modulation to differentiate a laser signal from noise. The project as of today has been built on an adequate foundation for furthering the developmental process.

Presently the project has a completed list of components and an abundant amount of ideas to further test, build and assign components into their respective sub-systems. The team broke-up this assignment into four parts of each respective field, consisting of photonics, power systems, RF systems and Embedded design. By splitting these endeavors, we each have a chance to contribute an exceptional amount of value to the team, the project, as well as gain experience in a very particular aspect of personal interest. Expending each member's knowledge in a particular field allows us to hold an expert accountable in the different realms of this design, ultimately though our majors correlate on certain subjects, having a dedicated member of the team enacts particular solutions to achieve maximum quality is the explicit aim for our group. The team aims to come together in harmony to fulfill this project within the next coming months.

Quite a few hours have gone towards achieving our current project's state, we look forward to continuing our work on the project next semester and developing what is hopefully a monument of success.

Appendices

A.1 References

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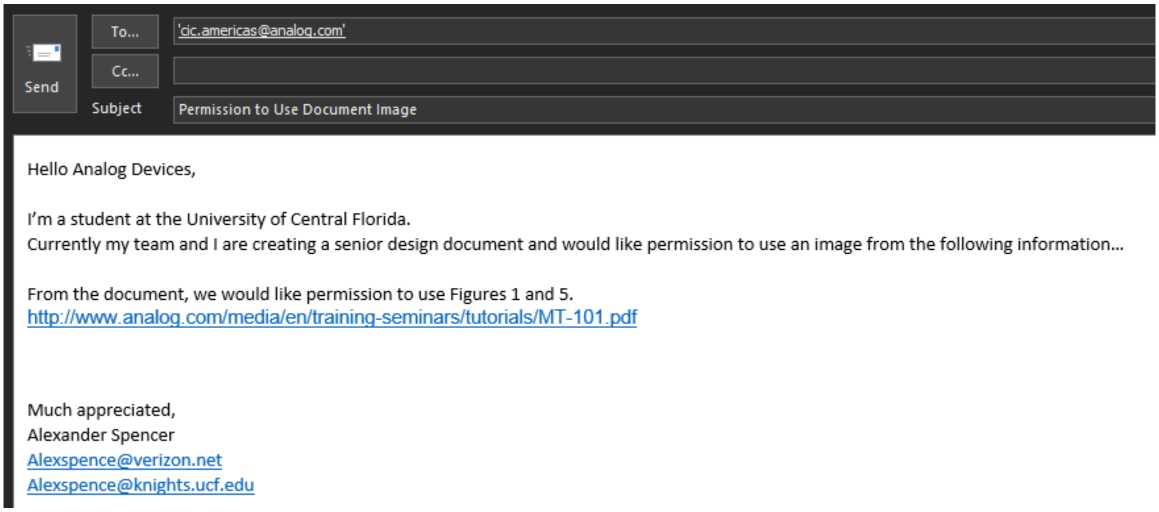

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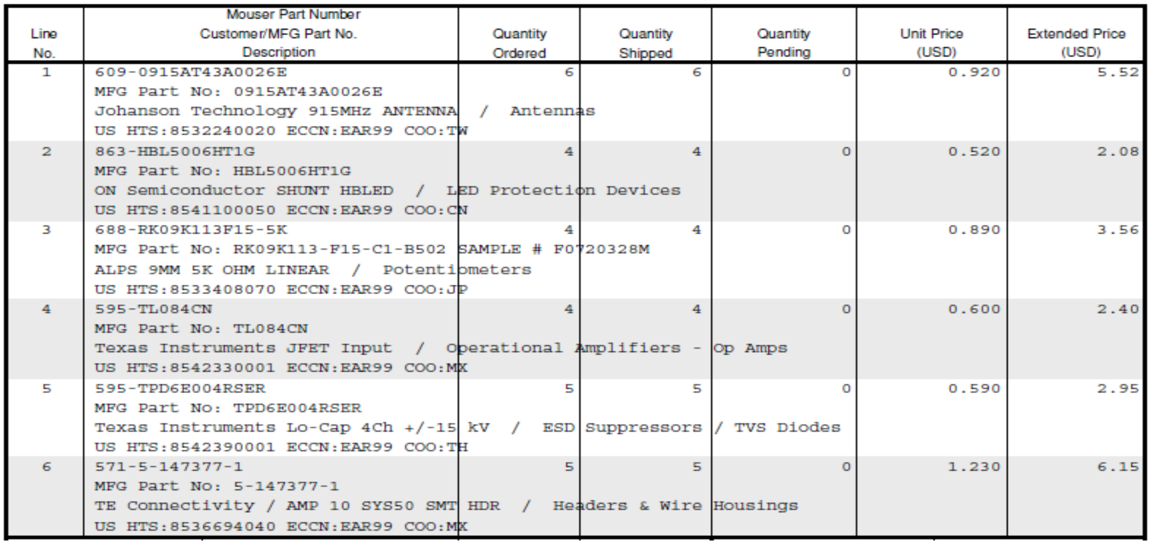
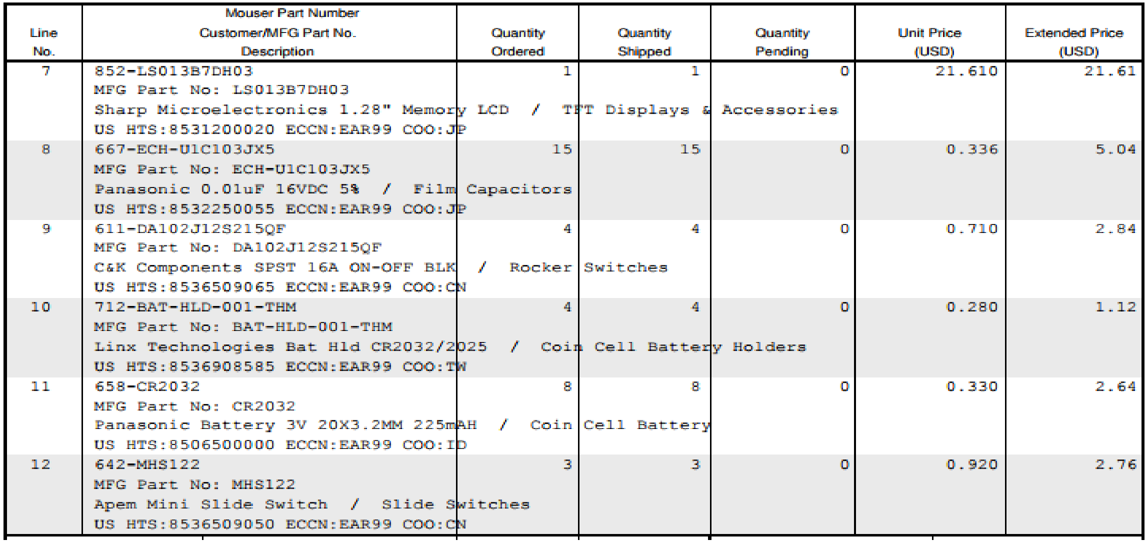
A.4 BOM

Quantity	ID	Description	Part No.
2		MCU with 915M RF	CC1310F128RGZR
15		980 nm Phototransistor	SFA 325 FA
2		980 nm Laser Diode	L680P010
1		Molded Plastic Asphere	APL0606
1		Bi-Convex Lens	LB1092-B
1		Plano Convex Lens	LA1986-B
2		Anamorphic Prism Pair	Custom
2		980 nm Bandpass Filter	Custom



Line No.	Mouser Part Number Customer/MFG Part No. Description	Quantity Ordered	Quantity Shipped	Quantity Pending	Unit Price (USD)	Extended Price (USD)
1	609-0915AT43A0026E MFG Part No: 0915AT43A0026E Johanson Technology 915MHz ANTENNA / Antennas US HTS:8532240020 ECCN:EAR99 COO:TW	6	6	0	0.920	5.52
2	863-HBL5006HT1G MFG Part No: HBL5006HT1G ON Semiconductor SHUNT HBLED / LED Protection Devices US HTS:8541100050 ECCN:EAR99 COO:CN	4	4	0	0.520	2.08
3	688-RK09K113F15-5K MFG Part No: RK09K113-F15-C1-B502 SAMPLE # F0720328M ALPS 9MM 5K OHM LINEAR / Potentiometers US HTS:8533408070 ECCN:EAR99 COO:JP	4	4	0	0.890	3.56
4	595-TL084CN MFG Part No: TL084CN Texas Instruments JFET Input / Operational Amplifiers - Op Amps US HTS:8542330001 ECCN:EAR99 COO:MX	4	4	0	0.600	2.40
5	595-TPD6E004RSER MFG Part No: TPD6E004RSER Texas Instruments Lo-Cap 4Ch +/-15 kV / ESD Suppressors / TVS Diodes US HTS:8542390001 ECCN:EAR99 COO:TH	5	5	0	0.590	2.95
6	571-5-147377-1 MFG Part No: 5-147377-1 TE Connectivity / AMP 10 SYS50 SMT HDR / Headers & Wire Housings US HTS:8536694040 ECCN:EAR99 COO:MX	5	5	0	1.230	6.15



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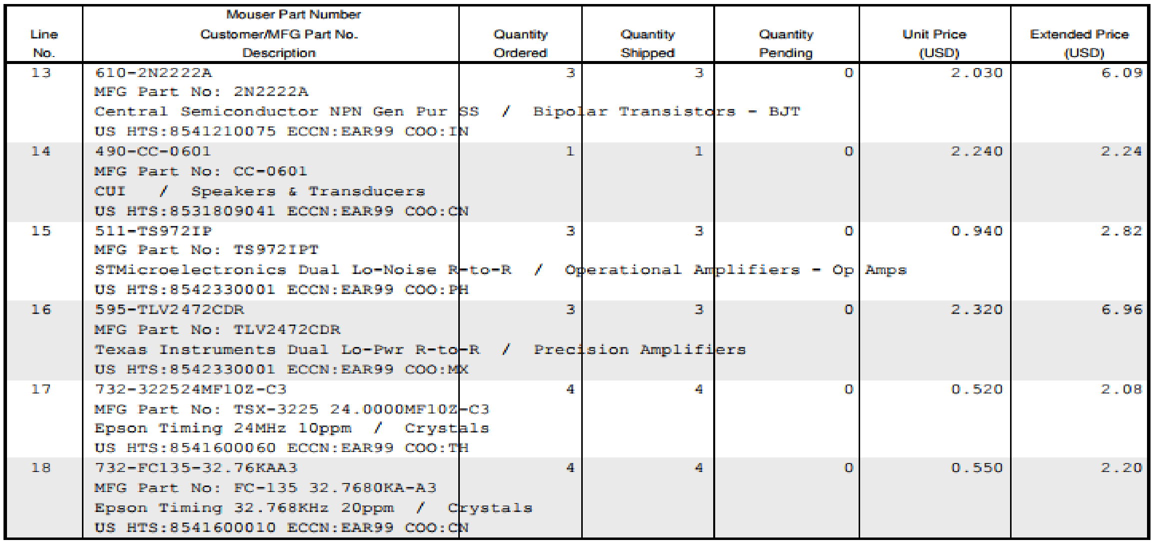
7	852-LS013B7DH03 MFG Part No: LS013B7DH03 Sharp Microelectronics 1.28" Memory LCD / TFT Displays & Accessories US HTS:8531200020 ECCN:EAR99 COO:JP	1	1	0	21.610	21.61
8	667-ECH-U1C103JX5 MFG Part No: ECH-U1C103JX5 Panasonic 0.01uF 16VDC 5% / Film Capacitors US HTS:8532250055 ECCN:EAR99 COO:JP	15	15	0	0.336	5.04
9	611-DA102J12S215QF MFG Part No: DA102J12S215QF C&K Components SPST 16A ON-OFF BLK / Rocker Switches US HTS:8536509065 ECCN:EAR99 COO:CN	4	4	0	0.710	2.84
10	712-BAT-HLD-001-THM MFG Part No: BAT-HLD-001-THM Linx Technologies Bat Hld CR2032/2025 / Coin Cell Battery Holders US HTS:8536908585 ECCN:EAR99 COO:TW	4	4	0	0.280	1.12
11	658-CR2032 MFG Part No: CR2032 Panasonic Battery 3V 20X3.2MM 225mAH / Coin Cell Battery US HTS:8506500000 ECCN:EAR99 COO:ID	8	8	0	0.330	2.64
12	642-MHS122 MFG Part No: MHS122 Apem Mini Slide Switch / Slide Switches US HTS:8536509050 ECCN:EAR99 COO:CN	3	3	0	0.920	2.76



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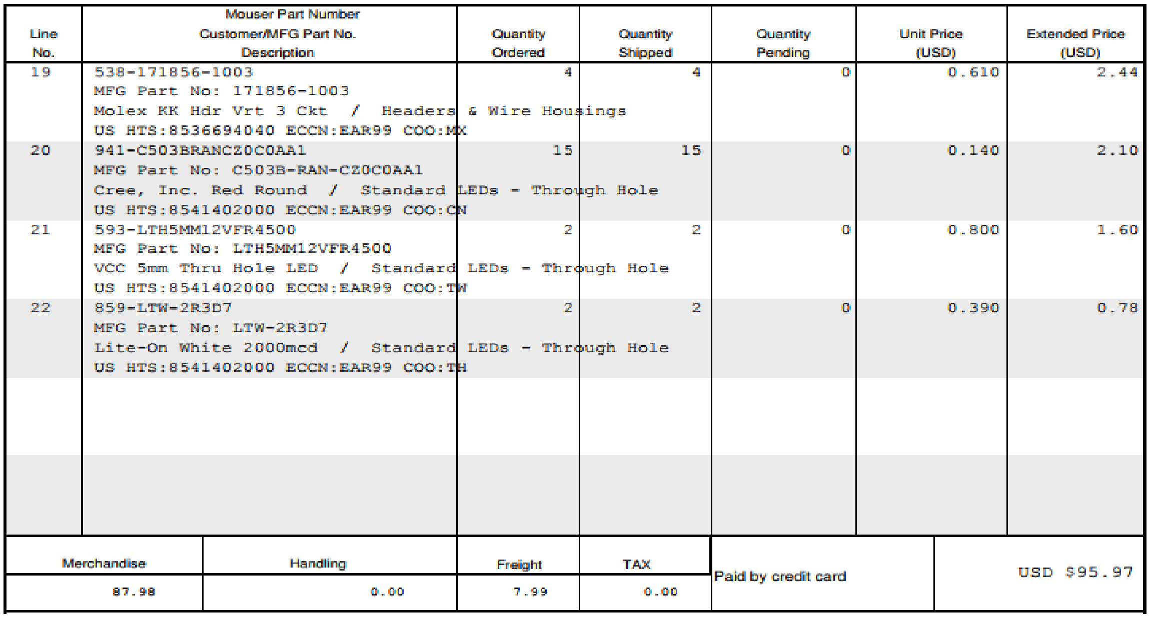
13	610-2N2222A MFG Part No: 2N2222A Central Semiconductor NPN Gen Pur SS / Bipolar Transistors - BJT US HTS:8541210075 ECCN:EAR99 COO:IN	3	3	0	2.030	6.09
14	490-CC-0601 MFG Part No: CC-0601 CUI / Speakers & Transducers US HTS:8531809041 ECCN:EAR99 COO:CN	1	1	0	2.240	2.24
15	511-TS972IP MFG Part No: TS972IPT STMicroelectronics Dual Lo-Noise R-to-R / Operational Amplifiers - Op Amps US HTS:8542330001 ECCN:EAR99 COO:PH	3	3	0	0.940	2.82
16	595-TLV2472CDR MFG Part No: TLV2472CDR Texas Instruments Dual Lo-Pwr R-to-R / Precision Amplifiers US HTS:8542330001 ECCN:EAR99 COO:MX	3	3	0	2.320	6.96
17	732-322524MF10Z-C3 MFG Part No: TSX-3225 24.0000MF10Z-C3 Epson Timing 24MHz 10ppm / Crystals US HTS:8541600060 ECCN:EAR99 COO:TH	4	4	0	0.520	2.08
18	732-FC135-32.76KAA3 MFG Part No: FC-135 32.7680KA-A3 Epson Timing 32.768KHz 20ppm / Crystals US HTS:8541600010 ECCN:EAR99 COO:CN	4	4	0	0.550	2.20



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19	538-171856-1003 MFG Part No: 171856-1003 Molex KK Hdr Vrt 3 Ckt / Headers & Wire Housings US HTS:8536694040 ECCN:EAR99 COO:MX	4	4	0	0.610	2.44
20	941-C503BRANCZ0C0AA1 MFG Part No: C503B-RAN-CZ0C0AA1 Cree, Inc. Red Round / Standard LEDs - Through Hole US HTS:8541402000 ECCN:EAR99 COO:CN	15	15	0	0.140	2.10
21	593-LTH5MM12VFR4500 MFG Part No: LTH5MM12VFR4500 VCC 5mm Thru Hole LED / Standard LEDs - Through Hole US HTS:8541402000 ECCN:EAR99 COO:TW	2	2	0	0.800	1.60
22	859-LTW-2R3D7 MFG Part No: LTW-2R3D7 Lite-On White 2000mcd / Standard LEDs - Through Hole US HTS:8541402000 ECCN:EAR99 COO:TH	2	2	0	0.390	0.78

Merchandise	Handling	Freight	TAX	Paid by credit card	USD $95.97
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