

LAZERKART

A Multi-spectrum Communications and Control System for Recreational Motorsports

Senior Design 2
Fall 2013

Group 15
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Sponsored By Fun Spot, Inc.

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1.0 Executive Summary

Since the 1990's, many millions of people who play video games have played a game from the Mario Kart series produced by Nintendo. The game pits up to 8 go-kart racers against each other to see who can finish the race first, with one caveat, each car can obtain randomly selected items placed around the racetrack that can help them win the race. The question that was asked amongst the group was "How fun would it be to do this with real go-karts?" So, the main objective of this project, called LazerKart, is to produce a similar experience to the Mario Kart video game that would immerse the driver in a battle race that would require skill and a little bit of luck. The Overall design is relatively inexpensive, applies to existing go-kart venues, and captures the imaginations of those who have played the game along with those who haven't.

The LazerKart concept involves multiple go karts, a go kart racetrack, and the system integration. The most basic implementation allows the driver of a Kart to obtain an "item" by driving over a colored marker which is located on the track. Once driven over, a microcontroller on board the kart randomly generates an item and illuminates a "ready" light. When pressed, a trigger button located on the steering wheel activates the acquired item. The items alternate between an Infrared "lazer cannon" that cuts a target karts' throttle down to idle for several seconds or a turbo booster that briefly accelerates the kart beyond its normal top speed.

In order to make LazerKart realizable, a low-power distribution system and microcontroller was feasibly employed to sustain an optical sensor sub-system, an IR emitter/receiver subsystem, a throttle control subsystem, and still have headroom for additional components heretofore unmentioned. Each of the main systems and subsystems have undergone extensive research, design and testing. It is able to operate outside in broad daylight, at night, in varying daily weather and all the while demonstrates a fun, balanced game play mechanism that makes the experience worthwhile. All testing was done outdoors on asphalt at a car lot using a temporarily donated go-kart from The Fun Spot in Orlando, FL.

Since the basic LazerKart implementation became fully functional and passed all tests, other subsystems and extensions of existing systems are being designed to enhance the overall experience. The plans for this next stage of development include adding sound effects to supplement the item usage, an LED display (segment or dot-matrix) to replace the ready light, ZigBee wireless networking to allow for more interesting items and to maintain leader boards, RGB LED accessory lighting that visually enhances the game, and a handheld lazer cannon for two-seat go karts, among others.

2.0 Project Description

2.1 Motivation and Goals

Many people have had the exciting privilege of playing the Mario Kart video games, and some of those people have also driven an actual go-kart at a recreational center on a go-kart track. In both instances, all the respective go-karts achieve approximately the same top speed, and if you pit two skilled drivers against one another, it becomes difficult for either one to pass the other and take the lead. The difference between the two is that, in Mario Kart, there are easily obtainable items, or “power-ups”, that are placed around the race track that can be used to slow opposing karts down or speed up one’s kart in order for one to take the lead against the other competitors. This was the inspiration for the idea to incorporate such a concept from the video game world into the real world.

The technologies involved in bringing LazerKart to life were interesting and diverse enough to allow the group to maintain a high level of dedication. From the long range, broad-daylight carrier frequency encoding IR transmission, to figuring out how to get sufficiently reliable DC power from a small engine AC lamp coil, to implementing an optoelectronic color sensing system, to electronically overriding the engine’s throttle and integrating the system with a low-cost microcontroller, there were a variety of topics to be researched and developed. Additionally, there is still room for additional components that will further make LazerKart more interesting, time permitting.

The fun part about a project like this was the testing phase. This involved a considerable amount of time driving the go karts and fine tuning the aspects of the system that made the execution seamless, balanced, and enjoyable.

The ultimate goal to be reached in the design process was to create a fully functional, multiplayer go kart experience that allows for any number of go karts (usually about 16) to be driven with the ability to shoot other go-karts with a time-limited IR lazer cannon and make them stop for just enough time to be passed by the shooter, but only after acquiring the IR weapon activation from the marker on the track.

The intermediate goals were as follows:

- Obtain a reliable donor go-kart and a testing facility.
- Develop each subsystem individually with any requirements from neighboring systems taken into consideration.
- Create Prototype (bread/perfboard) units to apply to the donor kart for testing.

- Have a working concept go-kart to demonstrate basic (un-tuned) functionality.
- Obtain a second (perhaps a third and a fourth, eventually) donor go-kart and set up the prototype system to begin gameplay mechanics testing
- Vigorously test the system using standard and worst-case scenarios and all those in between (on and off racetrack).
- Unify the components and sensors onto PCB(s) and standardize any connections.
- Create weatherproof and shock-absorbent enclosures for all components. Fabricate all mounting hardware.
- Install finalized system on a set of go-karts and demonstrate LazerKart.

As of the end of the fall semester, we achieved all of the single kart goals. Our prototype kart works perfectly and has passed all of our tests. Next, we will be taking the kart back to Fun Spot for multi-kart testing.

The plan was that once all of those goals have been met, the group has expressed interest in potentially marketing the LazerKart system to go-kart venues. Unmentioned in the above goal list is the development of the additional subsystems and expansions such as the ZigBee network and LED accessory lighting. These are not critical to the project requirements, but will be carefully considered and implemented given any extra available development time left over after completing the project requirements.

2.2 Objectives

The main objective of this project was to make sure that LazerKart is fun and a worthwhile enhancement to the typical go-kart experience. In order to do that, multiple play tests were held with as many scenarios as possible in order to bring a fun balance to the game. LazerKart should be attractive to drivers of all skill levels and ages. The gameplay will allow more control of the karts to competitors, but the venue will be able to override the entire system when necessary. What is equally as important, if not more so than the fun factor, is the safety of the karts. LazerKart must be deemed safe to operate on existing go kart racetracks. The system will be expandable to integrate as many go karts as necessary.

From an academic standpoint, the objectives were to utilize the skills that have been acquired throughout the UCF Electrical Engineering curriculum and showcase them in such a way that reflects on the talent of the group as well as the inspiration and top-tier education that the UCF faculty has provided. There should be no question that after seeing a demonstration of LazerKart in action, the group will have demonstrated excellence in designing a fully functional, well-engineered product that exhibits both teamwork and individual effort in multiple disciplines within the Electrical Engineering domain. The various subject areas to

be demonstrated include but are not limited to: semiconductor devices, analog and digital communication, operational amplifiers, low-voltage power systems, and embedded systems.

An additional objective was to design LazerKart in a modular fashion, with easily obtainable components, with low cost and simplicity such that the system could be marketable and easy to maintain. We have met these objectives and will proceed with marketing the system.

2.3 Specifications and Requirements

The first donor go kart that received the LazerKart treatment was one from Fun Spot (fig.) in Kissimmee, FL. It is powered by a 9hp Honda GX-270 4-stroke gasoline engine. The engine supplies a 3A max AC lamp coil that will be the source of all things electrical with LazerKart. The voltage supplied by the coil



Figure 2.3.1: Donor Go-Kart

varies with RPM of the engine. At idle, 9 Vrms was measured with respect to ground on the engine block. While at full throttle, 20 Vrms was measured. This AC voltage needed to be converted to DC to supply to the electronic subsystems. The MCU and the sensor op amps requires 3.3 V to operate, while the IR and servo system requires 5V. Other supply voltages can be obtained if necessary. The throttle has a servo mounted on a bracket to be able to increase throttle beyond the foot pedal limit and to cut the throttle to idle. This servo will be activated by the IR subsystem and speed boosts mentioned later.

The power up acquisition subsystem was designed to be responsive to the effect of the go kart going approximately 20mph over a marker that is 24in. x 12in. and needed to be unaffected by ambient daylight that might seep around to the underside of the go-kart. The IR lazer tag subsystem was designed to function in broad daylight and not draw more than 1A of current. Although the other subsystems draw very little current, it is important to keep enough headroom to possibly incorporate future subsystems. To operate effectively in daylight, the IR emitters and receivers will communicate via a 56KHz square wave carrier frequency that will encode 1's and 0's that the IR system will use to tell the MCU to activate the throttle idler. This is futhere discussed in the IR and Servo systems sections.

The LazerKart code integrates all of the subsystems onto a Texas Instruments MSP430 G2553 microcontroller. It will draw up to 100mA at full load and will have a 3.3V operating voltage. One microcontroller has enough pins to run the basic system integration. If any of the expansion subsystems are implemented, i2C will be utilized accordingly and more microcontrollers will be added.

To summarize the basic operational requirement for LazerKart: a kart will be driven over a colored marker, the optical power-up sensor under the kart will detect the color of the marker and set the corresponding input on the MCU. If the marker was an item marker, the MCU will randomly select from a list of weapons or boosters that the driver can engage with a button on the steering wheel. A weapon item will utilize the IR lazer cannon (transmitter) and will be used to aim at the IR receiver on the rear of the other karts. If a receiver is hit, the IR system will send a signal to the MCU to slow the kart to idle for several seconds. There was an idea to add the ability to differentiate between marker colors, but the voltage levels proved too dynamic. If the marker had been a turbo boost marker, or if the power-up generator resulted in a turbo boost, the MCU will receive a signal (either from the button or the optical sensor) to increase max throttle temporarily.

As mentioned earlier, the go-kart provides electrical power via the AC coil, however, the LazerKart system could very well be run off of rechargeable battery power if the designated go karts have no coil or are perhaps electric go karts. The following tables represent both the supplied power from the AC coil and a rough estimate of the power requirements for the basic implementation of the LazerKart system to function.

Throttle position	Idle	Pedal-to-the-medal	Boost! (redline)
Vrms	9.34 Vrms	19.26 Vrms	23.03 Vrms
VDC (across cap)	22.35 V	43.6 V	47.2 V
RPM	1490	3220	3600
Tp	40.2ms	18.6 ms	16.6ms
Frequency	24.83 Hz	53.67 Hz	60Hz

Figure 2.3.2: AC coil specs

Module Part	Supply Voltage	Operating Current	Power
IR Rx TSOP4856	5.0 V	1.5 mA	7.5 mW
IR Tx TSAL6100	3.3 V	1.5 A (surge @100us)	3.9 W(surge)
Pickup sensor UV LED (2)	5.0V	40mA	0.2W
User trigger	5.0 V	20 mA	0.1W
MCU MSP430G2553 (2)	3.3 V	230 uA	0.8mW
Servo motors HS-311 (2)	5.0 V	200 mA	1W

Figure 2.3.3: Power Supply Requirements

2.4 Sponsorship Description

2.4.1 Motivation

When the decision was made to start planning how the project was going to be executed, a major concern was the demonstration of the project and whether or not we would use full-scale go karts or just use small RC cars for proof of concept. The first task was to choose how to acquire go karts if a full-scale version of the game was indeed the direction the project would take, since there is not enough money in our senior design budget to purchase the go karts needed. The solution was to find an establishment that would allow access to multiple go karts. After considering several options the decision was made to contact Fun Spot Attractions in Orlando, FL (Figure 2.4.1.1). Shortly after making contact with the CEO/owner of Fun Spot, Mr. John Arie Sr., an onsite meeting was scheduled to further discuss the concept of the game and what would be

expected on both ends of the project in order to make access to the go karts a possibility.

During our first meeting the group presented Mr. Arie with the game play dynamics of Nintendo's Mario Kart 64 and how the concept could be implemented in a realistic setting. The presentation included a description of how successful Nintendo's Mario Kart 64 has been since its release in December 1996 and how the game is still being played today as well as the release of many newer versions for other Nintendo gaming consoles. The presentation included examples of other similar projects that had been attempted such as the one designed by Waterloo Labs encouraging others to expand on the idea which further validated the motivation and desirability of such a game. Mr. Arie was impressed by the presentation and was willing to give the group access to the go karts as needed.



Figure 2.4.1.1

2.4.2 Sponsorship Agreement

Another meeting was scheduled so that the group could become acquainted with some of the staff members that are in charge of the tracks and the go karts, as they would be a helpful resource if mechanical assistance was needed. Mr. Arie gave permission to take one of the go karts during the beginning stages of R&D so that we would have convenient access. Mr. Arie also gave permission to use the go karts tracks as a way to test the design and gameplay dynamics once working prototypes were completed. The group was given a tour of Fun Spot Attractions and the current large-scale expansion of the park such as the new roller-coasters and waterpark being built along with the renovation of one of the

four go kart tracks. We were given the opportunity to ride the go karts around each of the tracks multiple times in order to decide what track would suit the game when testing. Since Lazer Karts is a multiplayer game it was stated that at least two karts would be needed in the long run and Mr. Arie expressed that the use of as many Karts as needed to develop the game may be granted.

Another key topic of the sponsorship discussed, considering the design of Lazer Karts is successful, was the possibility of permanently converting and designating one of the four tracks to a Lazer Karts track, which would go hand-in-hand with the current expansions and additional rides being built. The conversion of the track would require the use of around 15 karts and give the group a large scale project to undertake once a working prototype was built, potentially leading to a post-graduation employment opportunity for the four of us working on the project.

One go-kart feature that was mentioned was the addition of LEDs. The group will attempt to integrate programmable LED strips into the game of lazer karts. These lights will display different patterns for the different functions of the microcontroller including flashes, cascading and dimming effects when the user is either hit, fires or picks up a weapon/boost from the track respectively. The lights will add excitement and grandeur to the game, attracting customers.

While communication between Fun Spot and the group is ongoing, both sides are very pleased with the outcome thus far and the potential opportunities for an ongoing business relationship. The group plans on giving multiple presentations to Mr. Arie and several staff members using the prototypes so that they are kept aware of the current progress of the project.

3.0 Research

3.1 Existing Similar Systems

3.1.1 Mario Kart

In 1992, video game maker Nintendo released "Super Mario Kart" for the Super Nintendo Entertainment System. Since then, Nintendo has released 8 more hugely popular Mario Kart games selling a total of over 90 million units. The Lazer Kart system was inspired by a desire to bring the game mechanics that make this video game franchise so popular to the real world. As such, a brief overview of the Mario Kart game is appropriate here.

Mario Kart is a Go-Kart racing game, but with the important difference of "Items" that are picked up as races travel around the track. These Items give the racer a brief advantage in the race and add a new dimension to traditional racing. The items take fanciful forms such as magical mushrooms, enchanted turtle shells, power stars, etc. The physical appearance of the item is not important to gameplay, so this report will focus only on their functions. While the exact items vary from game to game, they can generally be divided in to two categories. The first category of Items give the racer a temporary speed boost of approximately 25% lasting between 3 and 7 seconds. Some items give only one such speed boost while others give multiple speed boosts to be used as directed by the racer. The second category of Items is designed to slow down one or more opposing racers. Generally, this is accomplished by a racer positioning themselves behind an opponent and firing the item at the opponent. If the item hits the opponent, that racer is slowed or stopped for a brief period of approximately 5 seconds. This gives the first racer an opportunity to easily pass the opponent. These are the types of functions that this project aims to recreate.

3.1.2 Mario Kart in Real Life

Our Lazer Kart System will not be the first attempt to bring the mechanics of Mario Kart to the real world. Late in 2012, a group of engineers from National Instruments known as Waterloo Labs set out to recreate the Mario Kart experience at a local go-kart track. Being National Instruments engineers and possibly sponsored by the company, they developed their system using high level NI equipment based around a cRIO controller and several NI modules.

In their system, actual physical items are used. Foam rubber items embedded with RFID tags are hung around the track to be grabbed as racers drive by. These items are then either thrown or launched at other karts where the kart's RFID system detects them and takes appropriate action. When an item is used

that would slow down the racer, it causes the computer to lock the brakes with a pneumatic actuator and lock the steering wheel hard over. This causes a crash into the race track wall. Each kart is also equipped with a wireless router for communication and two servos to control the engine throttle. See the following diagram (Figure 3.1.1) for an overview:



Figure 3.1.1 Waterloo Labs Mario Kart System Block Diagram
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They developed a very powerful and robust system, but we noted some drawbacks to their approach. First of all, items must be manually reset after every lap. This is not a good approach for a commercial site desiring high throughput and limited labor costs. Second, the thrown/ launched items create a hazard on the track. While they may not damage the karts, they could get stuck in the wheel area or next to the very hot engine area. Also, the wear and tear on the items would necessitate frequent replacement. That is also undesirable. In addition, pneumatic systems would require frequent refilling, causing downtime as well as increased labor and hardware costs. Next, the parts they used, especially the cRIO and modules, are very expensive. The cRIO controller alone costs over a thousand dollars. They are also large, heavy, and delicate. Finally, a commercial entity can limit the possibility for kart damage and injuries by not forcing the wheel to lock hard over and the brakes to lock up. That is simply unsafe. When our karts are “hit”, they will not crash, but only cut the engine to a coast for a few seconds. The driver will retain complete control over steering.

There are some things our project can build upon from Waterloo Lab's. Our project will also use servos to control the engine, but we can do it with one, not two. We will also use wireless communication, but we will use small, light, efficient ZigBee modules instead of Linksys Wi-Fi routers. Instead of actual items being grabbed and launched, we will use virtual items, pickup pads, and IR

“lazers” to achieve the same type of game play, but at greatly reduced cost, complexity, and increased safety.

3.1.3 Commercially Available MILES

As stated the previous section, physical items increase cost, complexity, man power required, and downtime. Therefore, we will use infrared transmitter and receivers as the “lazer” system in our karts. Many people have played a recreational form of “Lazer Tag”, and commercial systems are available for off the shelf Lazer Tag play. However, we require something more powerful. Our karts will operate outdoors in all weather all year round. For inspiration, our system looks the United States Military. In the 1980's the US Army introduced a training system that would more accurately simulate force-on-force engagements. These systems use military grade IR transmitters and receivers to simulate small arms fire, “hits”, and “kills”.

The systems have been upgraded over the years and are now provided by Cubic Corporation. A smaller, civilian industry has sprung up in recent years to provide high quality recreational lazer tag gear to the general public by taking advantage of the decreasing price of electronics of the last two decades. One such company is Combat T.A.G. LLC. They offer very high quality lazer tag systems and equipment. They offer a full range of kits, modules, and components ranging from full up systems that are ready to go out of the box to subsystems that can be integrated together by the end user to individual parts. Their kits are built behind the Vishay Semiconductor TSOP4856 IR Transmitter and the 6100 IR Receiver. These appear to be high quality parts that are marketed as being immune to ambient light, designed for outdoor applications, and have a range of 45 meters. While we won't be needing any of the pre-built modules or kits that are commercially available, we will be using the 4856 IR Transmitter and the 6100 IR Receiver that are at the heart of high quality commercial systems.

3.2 Technologies

3.2.1 Photo-detection

One of the key technologies involved in creating LazerKart is the concept of Photo-detection. For the gameplay aspect of the entire system to work, A photodiode is placed underneath the kart that will detect different colored markers on the track. The inherent spectral sensitivity of the photodiode is what is utilized to distinguish color and an analog to digital converter captures the voltage obtained by way of a transimpedance amplifier converting the photocurrent to a voltage. The color and light source used to generate usable output of the system is a UV LED and neon colored indicators that glow brightly under the UV LED.

3.2.2 IR Communication

3.2.2.1 Technology Determination

For the initial brain storming about the project, three different technologies on how best to implement the game into the karts were discussed. The original suggestion was to incorporate a augmented reality unit in the karts to accurately represent the video game style that was to be mimicked. This would involve creating a head unit for the driver to wear, and the need to devise a way to accurately track each individual car as it maneuvers around the track. Using this system, it would be possible to immerse the drive in a semi-virtual world. While the end product, as envisioned, could be amazing, it was determined that as a practical and commercial matter, it would not be feasible at this time.

Another option considered was the use of a kart mounted heads up display (HUD), or a kart mounted display unit. By attaching a display to the kart, you could add the video game element to the race, without requiring headgear for the rider. Communication could be done wirelessly between karts, and the game could run on an off kart base unit. With the HUD, racers would have to ability to see the real karts and have digital displays such as those seen on aircraft, and use that to shoot at the opposing players. For the standard video display unit, an digital recreation of kart and track positioning could be displayed on the unit. Ultimately, it was decided that these would also not be practical for the purposes of the project.

Infrared LED communication was the most obvious choice for our project. The technology is widely researched and available, and the cost is reasonable. The project build would need only an IR LED transmitter unit and a receiver unit on each kart, along with a trigger. No augmentation would be required, and the chance of the driver being able to damage the parts would be minimized. It was determined that while other options might offer a more dramatic demonstration of technology, the IR Communication was the most practical solution. Paired with a wireless communication, all of the functionality desired is possible.

3.2.2.2 IR Transmitter

IR Communication is widely used in technology today, most commonly in remote controls for household items. The technology typically uses pulse width modulation riding on a carrier signal to transmit data by line of sight from and infrared led to an infrared receiver, paired to the same wavelength and carrier frequency. For the purposes of the project it is necessary to use a high power LED to maximize performance. For most do-it-yourself lazer-tag builds, the LED of choice is the TSAL6100 by Vishay. It is known for its high reliability, high radiant power, and has an angle of half intensity of $\pm 10^\circ$.

The LED is housed in a tube and tests determined that the game play necessitates a lens component. The lens is used to focus the IR light, increasing

the range at which the receiver can be triggered. Play testing was required to determine how focused the beam needs to be. In contrast to a normal laser-tag game, the laser kart project required a shorter range but wider beam angle, due to the riders not having fine control over the aiming. The height of the receiver in relation to the transmitter was also taken into account.

3.2.2.3 IR Receiver

The infrared receiver is designed to detect the signal produced by the IR transmitter. Interference from other light sources is an issue when selecting the receiver. In choosing a receiver it was necessary to pair it to the transmitter and function required for the design. For the purpose of the project, the Vishay TSOP4856 module was chosen. It contains a photo detector and preamplifier, along with an internal band pass filter so that we can use Pulse Width Modulation for our communication. The 56 kHz variant was chosen because it matches well with the TSAL6100. For PWM communication the receiver recommends a burst length ≥ 10 cycles/burst. The TSAL6100 produces a 940nm wavelength, which pairs well with the TSOP 4856. The 56 kHz frequency translates to a 17.9ns cycle, or approximately 34 cycles per 600ns burst, well above the threshold recommended. The block diagram for the TSOP4856 taken from the Vishay data sheet is shown in Figure 3.2.2.1.

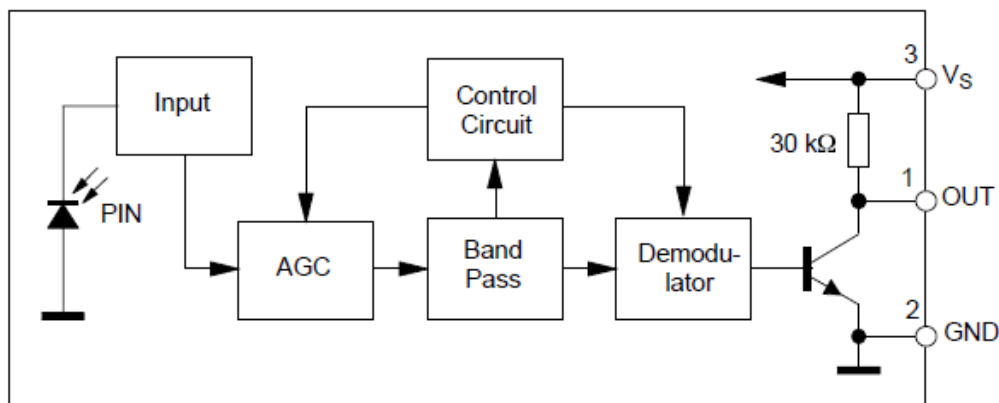


Figure 3.2.2.1

3.2.2.4 Pulse Width Modulation

Now that the components have been chosen, it is necessary to devise a method of delivering the data between them. Pulse Width Modulation (PWM) is typically how this is done. Pulse Width Modulation is an easy way to transmit binary data through IR communications. For instance, by creating a signal of pulses, for a "0" the carrier signal is on for 600 μ s and for a "1" the carrier signal is on for 1200 μ s. For basic functionality, the karts now have a binary way to transmit data. If the purpose was to just detect any 56 kHz signal, PWM would not be

necessary, however, in order to create a final score at the end of the race we do need to transmit some information. In order to indicate the start of a signal, a header pulse is needed, which should be at least twice the size of the longest pulse, or in the case of the above example. 2400 μ s. Real life testing will obviously be needed to fine-tune the sensors. The signal from the receiver is inverted from the input signal from the LED, due to the output being active low as shown in Figure 3.2.2.2. PWM has not yet been implemented, more testing is needed.

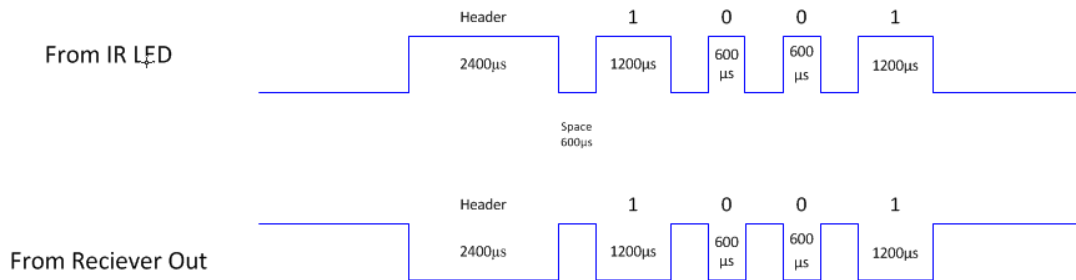


Figure 3.2.2.2

3.2.3 ZigBee Communication

One of the first expansion units that will be considered at the completion of base model testing is the addition of a wireless network designed to allow the karts to communicate with each other and a base unit. This added feature will allow for scorekeeping to determine a race winner, as well as give added controls over the karts for increased safety. With this addition, the ride operator will be able to control individual karts from the vase station, through the link that has been established to the throttle control of the kart.

3.2.3.1 Technology Selection

The requirements for the wireless communication portion of the project are low cost, ease of setup, short range (<200m), high reliability, and low power consumption. The technologies that were considered include the ZigBee, Wi-Fi, Bluetooth, and IR.

Using IR communication would seem to be ideal, as the system is already incorporated onto the lazer kart platform, however, the limitations of this technology to line of sight has serious drawbacks. In order to track and transmit scores to the base unit, a handheld tagger/receiver combo would have to be created that would collect the data from each kart at the end of the race. This would slow down the race process considerably. Also, this would require the use

addition of a memory system into the project, which needlessly increases the complexity.

Bluetooth technology does not allow us the range needed, and has a complex set up process and long device connection times.

The Wi-Fi standard was originally considered as the best option, it is a well developed, mature technology, and can handle the range needed for the project. Wi-Fi's major drawbacks are the power consumption and increased set up complexity.

The ZigBee standard allows for the creation of an ad-hoc mesh network, provides the range necessary, and, for the purposes of the project most importantly, has a very low power draw. The low transmission rate, ZigBee's primary deterrent, is not considered an issue for the purposes of the project. This component will be added after multi-kart testing.

3.2.3.2 The ZigBee Specification

The ZigBee standard, is defined by IEEE 802.15.4. This is used for low data rate wireless personal area networks. The specification was designed with the intent of creating a low power solution for wireless communication, primarily for battery operated control devices, due to the limitations provided by Wi-Fi and Bluetooth. A typical ZigBee network consists of a single Coordinator (C), which is responsible for the establishment of the network, and multiple Routers (R) and End Devices (ZED). The routers can act as end devices and also retransmit data, and end device can only communicate with its parent device, either a router or the coordinator, it cannot relay information from other devices. This is done to allow the end device to operate in a powered down mode, conserving battery power. With the laser kart system operating without battery, the network will be set up with the coordinator located in the base unit of the track, and each kart will have a router connected in a full mesh network for greatest reliability. Figure 3.2.3.2.1 show the communication used and gives a representation of how the range impacts the network.

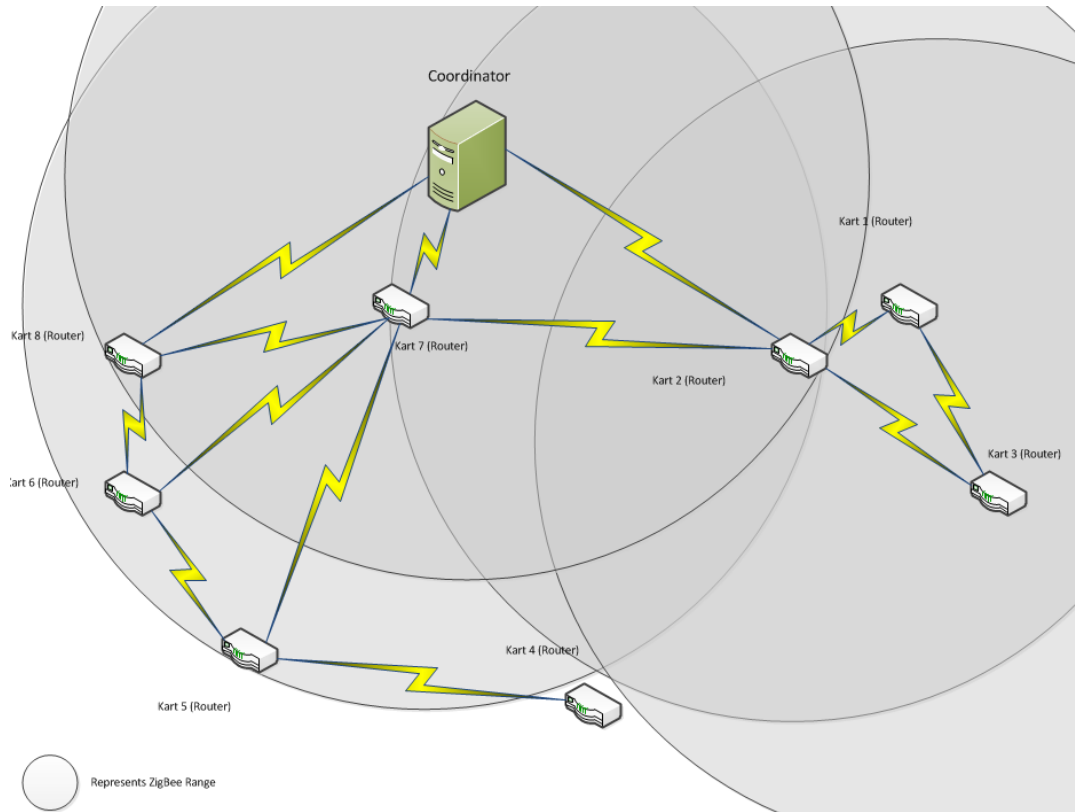


Figure 3.2.3.2.1

3.2.3.3 Adaptation to LazerKart

Using the ZigBee network for the purposes of the project allows for greater control over the karts, and gives an added feature to show to the drivers, end of race scoring. The mesh network will allow for increased ranges, as the karts are spread around the track, it is unlikely that there will be enough separation to create a dead spot in the entire track.

4.0 Hardware and Software Design Details

4.1 Flow Charts

4.1.1 Hardware Block Diagram

The Laser Kart system is based around an MSP430 microcontroller. It communicates with input devices and LEDs. The inputs and outputs are shown below with grey blocks. It also controls two servos via a pulse width modulated signal. We've left room to expand with the wireless communication system via UART protocol. The power regulator distributes 3.3V and 5V power to the microcontroller and all of the other systems. Power distribution is shown in red. Data paths are shown in green and blue. AC components are shown in yellow. Driver inputs are shown in orange. Figure 4.1.1.1 illustrates this system.

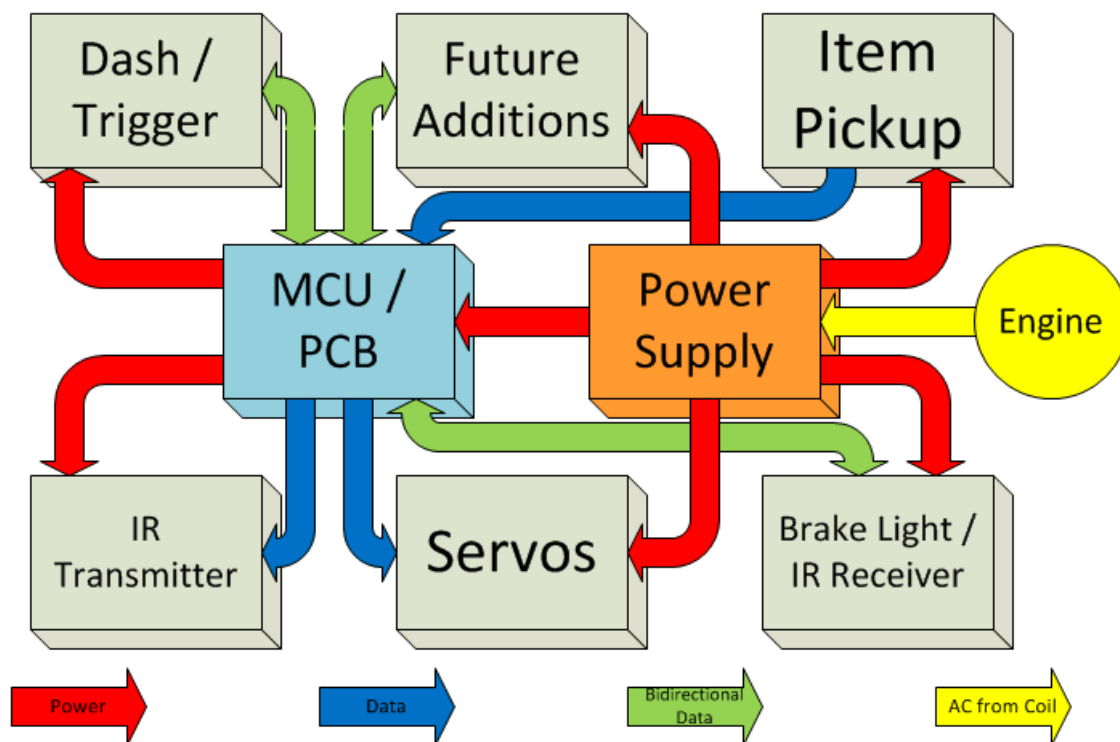


Figure 4.1.1.1

4.1.2 Software Flow Chart

The flowchart shown (Figure 4.1.2.1) is how we are going to implement the game logic for LazerKart. It contains an initialization procedure and a main loop that is interrupt driven and monitors the subsystems for action. Play testing may alter the design in the future.

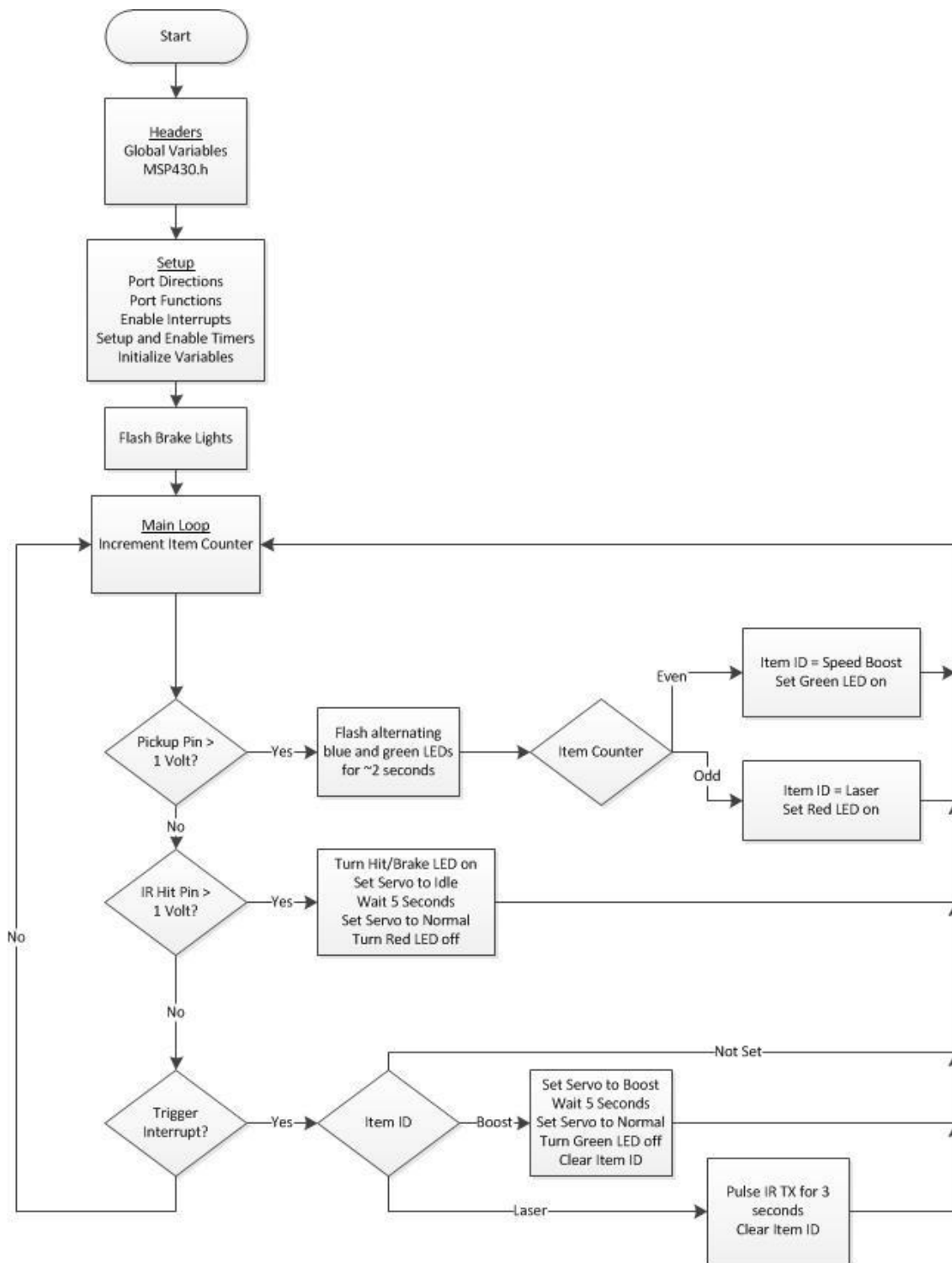


Figure 4.1.2.1

4.2 Power Systems

The main objective of the project's power systems is to provide the peripheral circuits, including the weapons pick up circuit and UV LED, MSP430 microcontroller, brake light, IR Tx/Rx, user dash/trigger LEDs, and the boost and cut servos, as well as the projected additional modules including the programmable LED lighting, no bumping sensor and warning, Xbee wireless module and sound effects (to be added) with the appropriate dependable regulated DC voltage and current that is required by each component. In order to provide the DC values necessary, the task is to convert the available AC voltage produced by the Honda GX270 engine to a stable DC value. Initially, this was done using several of the considered rectifier circuits and regulators discussed. Once the voltage was converted the system needed to accurately divide the source voltage into the different values needed to power each component (3.3V and 5V) using one of the voltage regulators researched, while maintaining the correct maximum and minimum currents in order to ensure that components are operating at the desired power level. Later iterations of the power supply were built tested and redesigned before a final acceptable system was used.

4.2.1 Power Supply Characteristics

In order to begin the research for power systems hardware, it was important to understand the characteristic of the waveform produced by the Honda GX270 AC coil because the signal produced by the coil is what needed to be conditioned. The amplitude and frequency of the voltage waveform changes with respect to the RPM/throttle-position of the Honda. There was a need to measure the range of frequencies and amplitudes of the signal, as seen in Figure 4.2.1.1 below.

Throttle position	Idle	Pedal-to-the-medal	Boost! (redline)
Vrms	9.34 Vrms	19.28 Vrms	23.03 Vrms
VDC (across cap)	22.35 V	43.6 V	47.2 V
RPM	1490	3220	3600
Tp	40.2ms	18.6 ms	16.6ms
Frequency	24.83 Hz	53.67 Hz	60Hz



Figure 4.2.1.1: AC Coil Specs and waveform

The output of the Honda engine's AC coil did not have a "clean" sinusoidal output as expected. The signal rises and falls rapidly and begins to rise and then fall for a short amount of time among other unexpected signal characteristics produced by the coil. These characteristics made it necessary to adjust the power supply hardware and circuit in order to accommodate various signals. For example, since the signal rises and falls quickly similar to that of an impulse signal, additional capacitors were experimented with to harness the rapid changes in voltage. There was also the option of adding inductors to the circuit in order to store a magnetic field while the signal quickly drops to zero so that the ripple voltage could still be obtained.

Initially, for the sake of research, obtaining usable values from the GX270 was necessary. A quick and easy way to measure the signal was by measuring the range of RMS values produced by the coil. When idle, the engine is running at about 1,200 RPM or about 20Hz. At this frequency the voltage of the coil was measured and produced an RMS value of about 6.4V. This RMS value was used to determine the minimum peak voltage. The RMS value of 6.4V can be multiplied by the square root of 2 or about 1.41 to get a value of about 9.0V peak, which is the peak value for the AC signal produced by the coil when idle. This procedure will be repeated to determine the maximum RMS value on the coil while the throttle on the Honda GX270 is all the way open. While the throttle is all the way open, the motor runs at about 3,200 RPM or at about 53.3Hz and has an RMS value of around 24V. Again the maximum RMS value of 24V is multiplied by 1.41 yielding a value of 33.8Vpeak or 67.7Vpp. The 6.4V-24V RMS, 9.0-33.8Vpeak and the 18-67.7Vpp are the values that will be considered when selecting the converters maximum and minimum input voltage requirements as well as the value used for the initial simulations run using LTspice.

4.2.2 Rectifiers

One option was to use an ideal rectifier. This design requires the use of an op-amp in order to eliminate the turn on voltage loss through the diodes but would require a DC voltage to power the op-amp which will not be available until after the AC voltage is converted to DC or through the use of a battery. The design could include the ideal op-amp through the use of a battery but this would be an additional cost for each go kart as well as additional maintenance to charge the batteries after each use making this approach an undesirable solution. This option would only be considered if the loss of the turn on voltage across the diodes does cause issues, in this case the use of a step-up transformer would have been used for the systems that require higher voltage since those systems would be the ones that will not receive the appropriate voltage when the engine is at idle. The use of batteries is further discussed in a later section.

Another option to obtaining a DC voltage from the coil was through the use of a half-wave rectifier. This design is very simple design and would have a very low cost since it only uses one capacitor, a resistor and a single diode. The down side to this design is that the output signal has a wide range of values with comparison to other more effective circuit designs. The wide range of output voltage would require the regulators to work with less efficiency and likely heat up which could potentially lead to premature failure.

The most efficient and relatively low cost option to be considered for the power systems AC-to-DC converter was to build a full-wave bridge rectifier using four 1N4148 diodes to convert the sinusoidal waveform produced by the coil using both the positive and negative values as part of the output, unlike the half-wave rectifier. A rectifier that uses four Schottky diodes will also be designed to compare with the results with those obtained using the 1N4148 diodes. The full-wave rectifier was then put in parallel with multiple 4,700 μ F 50V, radial coupling capacitor to flatten out the positive rectified wave to a rippled DC value to obtain as minimal ripple voltage as possible.

Once the ripple voltage was obtained, the “high” node would be the input to each of the regulators used for any of the peripheral systems and the “low” node would be the universal ground for the rest of the system. To allow easy access to the “low” ground node, a rail will be around the PCB designated specifically for all of the subsystems to use as ground.

4.2.3 Simulations

When in the design stage it was helpful to simulate the full-wave bridge rectifier to show the rippled DC output waveform seen in Figure 4.2.3.1. A load resistance of $R_L=1k\Omega$ and a 20Hz 9Vp input signal (blue) was used and referenced to ground not “low”. It should be noted that this input is what is expected to be produced while slightly above idle. As stated before the input signals frequency and magnitude will change along with the internal resistance of each regulator as well as the load on each of the regulators themselves; so this simulation is only one of the many conditions that the system will experience. To show consistency the simulated circuit’s stimuli is a signal that would mimic the conditions expected to be produced by the coil when the throttle is all the way open as seen in Figure 4.2.3.2. Keep in mind, that the input will increase and decrease to all the possible values between 9.0V and 33.8V many times throughout one game of LazerKarts.

For the idle simulation the peak-to-peak value of the ripple voltage was measured at about 60mV which is small enough to work as a sufficient input to the voltage regulators for each system. The maximum change in frequency is only about 30Hz so there is no need for additional coupling capacitors. The maximum change between idle and full-throttle peak voltage is approximately

24V which will be an important factor when choosing regulators since they are listed and categorized based on maximum and minimum input voltage. For the fully open throttle simulation in Figure 4.2.3.2 the peak-to-peak ripple voltage actually dropped to around 53mV which means that the output to the rectifier is even more stable at higher frequencies.

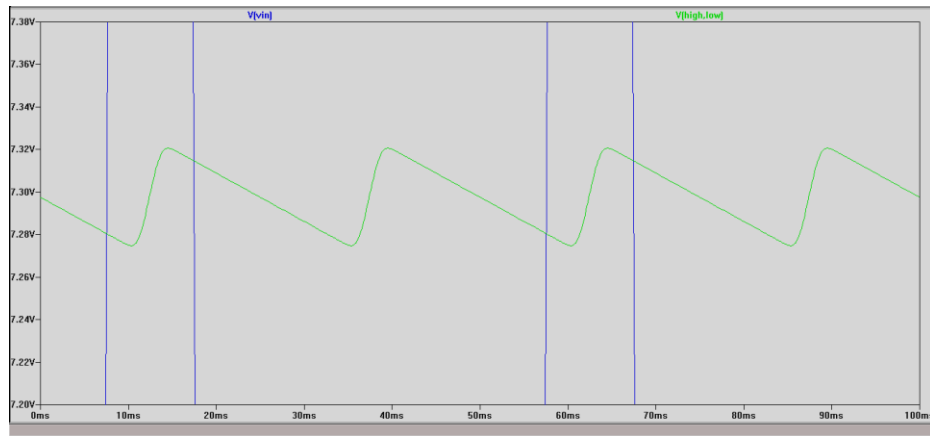


Figure 4.2.3.1: Idle Simulation for full-wave rectifier $V_{in} = 9V_p$ a $f = 20$ Hz, “high”

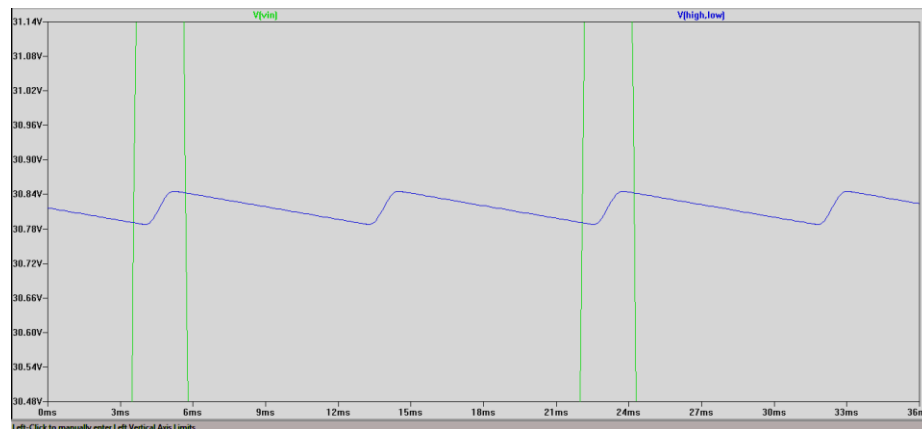


Figure 4.2.3.2: Fully open throttle simulation $V_{in} = 33V_p$ $f = 54$ Hz “high”

4.2.4 Regulators

Once the power supply had been converted to a stable DC signal, the next goal was to condition the ripple voltage with the use of regulators so that the peripheral systems are connected to a pure DC value. The power supply requirements needed for each of the modules are shown in Table 4.2.4.1. When designing a regulator circuit the goal was to try to do so based on these values or select a regulator that can output a fixed value that is midway between the max/min values seen in their data sheets. It is important to choose regulators that are low in cost but meet the requirements of the systems.

The first system to be considered is the MSP 430 G2553. A sufficient regulator for the MSP430 is the LT3008 Series - 3 μ A IQ, 20mA, 45V Low Dropout Linear Regulators. According to the datasheet found at the LT website (LT3008) this regulator has the following features

- Input Voltage Range: 2.0V to 45V
- Output Current: 20mA
- Dropout Voltage: 300mV
- Current Limit Protection
- Thermal Limit Protection
- Feedback Protection

The input range on this regulator does not cover the range of DC values at the output of the rectifier while at idle all the way through the values for the fully open throttle. However it provides more than enough power for the MSP430. Additionally, it has no need for feedback protection which is key when the frequency and amplitude of the coil are going from high to low or when the throttle gets cut to idle after being hit by an opponent.

The circuit in Figure 4.2.4.2 is the one used to simulate the LT3008. The input pin was connected to the output of the rectifier. The output pin has a load resistance 'RLMSP' that is approximately the operating resistance of the microcontroller. Next we ran a simulation of the circuit using the LT3008 and plot the output across the RLMSP resistor. The output waveform can be seen in Figure 4.2.4.3. The output of this regulator is very accurate with only a variation in voltage of about 196 μ V. This variation is well within the tolerance of the MSP430 and provides the 3.3 volts as well as the 250 μ A required to power it. The power supply for the MSP430 is only taking into consideration the amount of power necessary for the MSP430 to run as a standalone unit. It should be noted that while the MSP 430 is performing a function such as activating the break light or sending power to the servo motor to cut the throttle, it will be drawing much higher amounts of current than it will when in standby mode

Next consider the weapons pick up system which uses the 2-channel op-amp to amplify the voltage received by the photodiode. This part requires between 5 and 15 volts. Since this system requires a higher voltage than the others it is likely that we would have had to use a transformer in order to step up the voltage output of the rectifier so that even when the motor is cut to idle position and the output of the rectifier drops below 9V this system will still be connected to a sufficient power supply that is above the minimum required voltage of 9V. A solution to this issue was to use a different op-amp with a lower input voltage requirement. This is further discussed in the weapons pick up portion of the report. The possibility of a step up transformer would only be implemented after testing proved it necessary, which was not the case. The use of a regulator for the weapons pick up and simulations will omit these details.

A possible candidate for the weapons pick up regulator is the LT3014 - 20mA Low Dropout Micropower Linear Regulator. According to the datasheet this regulator has the following key features (LT3014).

- Wide Input Voltage Range: 3V to 80V
- Low Dropout Voltage: 350mV
- No Protection Diodes Needed
- Adjustable Output from 1.22V to 60V
- No Reverse Current Flow from Output

The LT3014 meets all the requirements of the weapons pick up system. Most of all it has the option to adjust the regulated output voltage which will be useful when testing different op-amps with different voltage value requirements to power them since we were able to change the output by simply choosing different ADJ pin resistors. This regulator circuit and simulation results can be seen in Figure 4.2.4.4 and Figure 4.2.4.5 respectively. In the simulation, the input to the rectifier was chosen to be the idle throttle position to simulate the worst case scenario (low supply voltage). The load resistance RLWP was chosen to be 3.3k so as to give a load current requirement 2.8mA.

The last regulator to consider is the one that will be used to power the IR TX/RX module as well as the other peripheral modules requiring a 5V DC value such as the servo motor. Since this regulator needs to deliver much higher currents than those used for the weapons/boost pickup and MSP430 regulators, it is important to choose one that has a higher max current output. One regulator that seems to meet the requirements of these modules is the LT1086 - 1.5A Low Dropout Positive Regulator. According to the data sheet found at the LT website this regulator has the following relevant features (LT1086).

- 3-Terminal
- Output Current of 1.5A
- Guaranteed Dropout Voltage at Multiple Current Levels
- Line Regulation: 0.015%
- Load Regulation: 0.1%
- 100% Thermal Limit Functional Test
- Ripple Rejection >75dB
- Available in 3-Pin TO-220 and 3-Pin DD Package

The circuit configuration and a simulation of the output, with the rectified ripple voltage as an input, using the LT1086-5 for the IR Tx/Rx and other modules needing 5V DC, can be seen in Figure 4.2.4.6 and 4.2.4.7 respectively. The output is a very steady 5V with only a 96 μ V peak-to-peak.

Although the above regulators would have worked, they were not part of the final power supply design. Instead we ended up using the LM2576HVT which is further discussed in section 4.2.6 power supply iterations.

Module Part	Supply Voltage	Operating Current	Power
IR Rx TSOP4856	5.0 V	1.5 mA	7.5 mW
IR Tx TSAL6100	3.3 V	1.5 A (surge @100us)	3.9 W(surge)
Pickup sensor UV LED (2)	5.0V	40mA	0.2W
User trigger	5.0 V	20 mA	0.1W
MCU MSP430G2553 (2)	3.3 V	230 uA	0.8mW
Servo motors HS-311 (2)	5.0 V	200 mA	1W

Table 4.2.4.1: Power Requirements for Each System

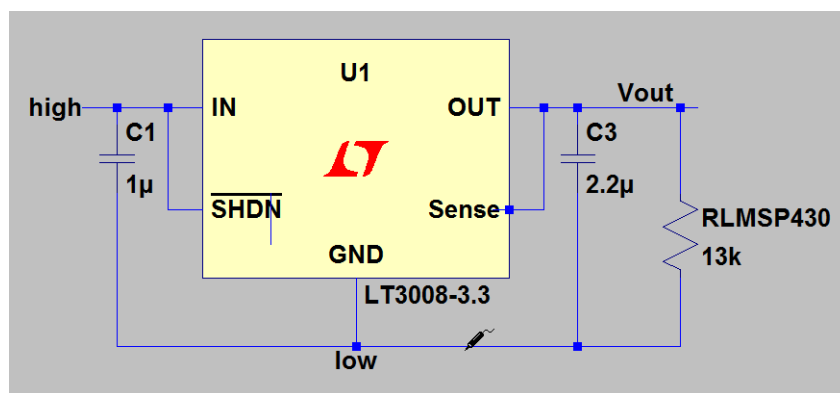


Figure 4.2.4.2: LDO regulator circuit for MSP430G2553

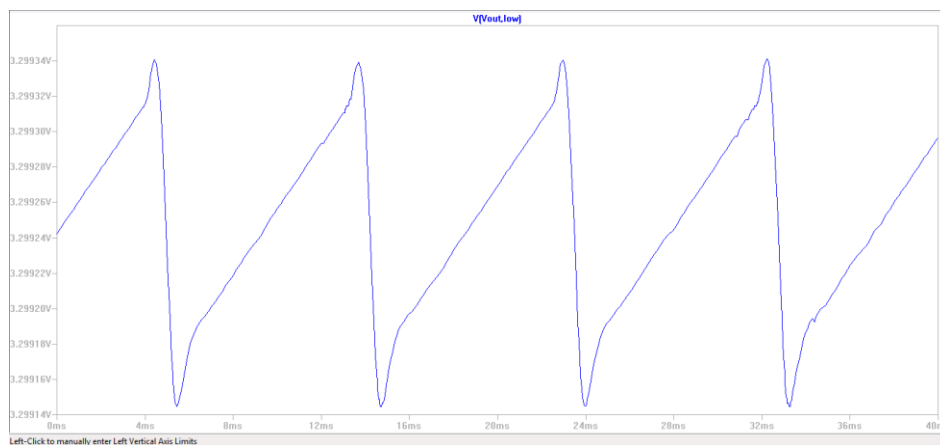


Figure 4.2.4.3: Vout of 3.3V fixed Regulator for MSP430G2553

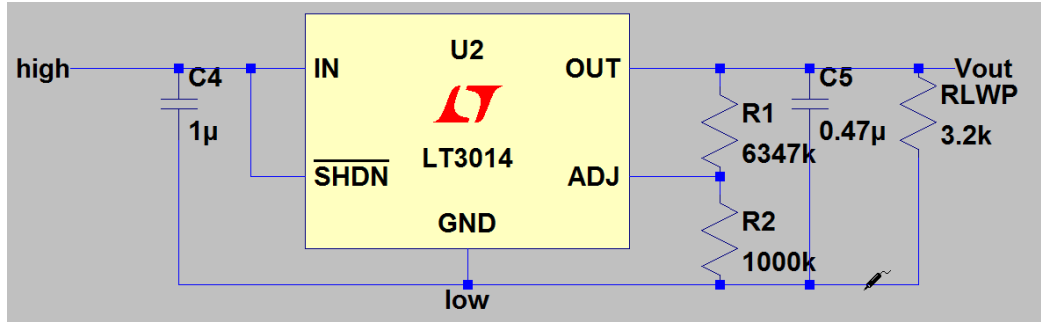


Figure 4.2.4.4: LT3014 Regulator for weapons pickup op-amp

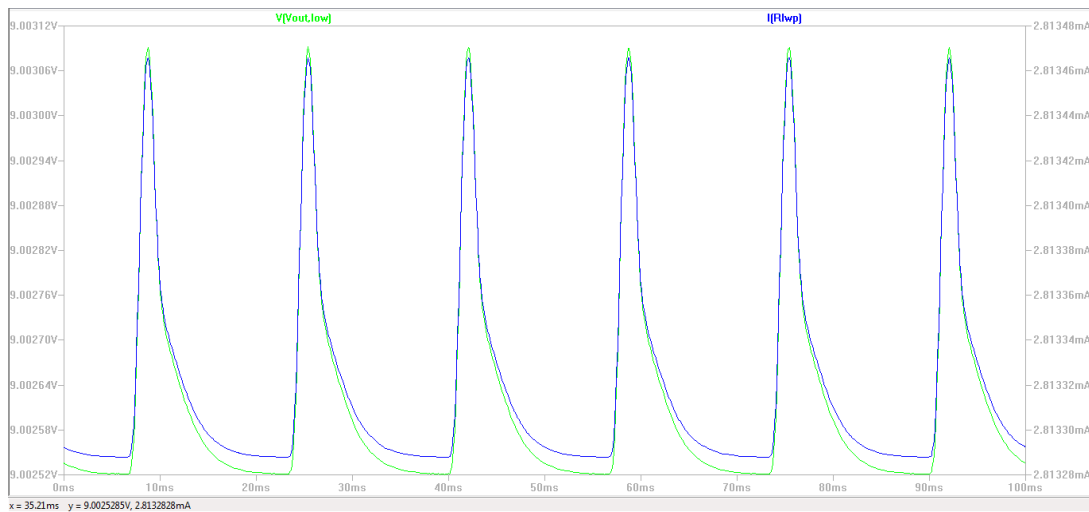


Figure 4.2.4.5: Vout and current RLWP for LT3014 Regulator

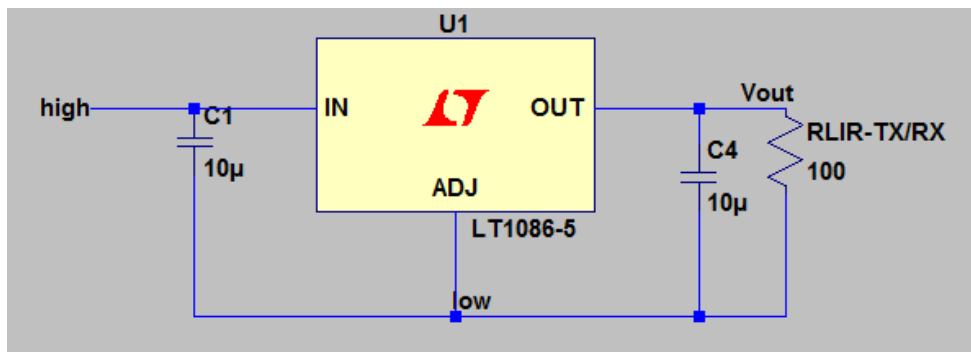


Figure 4.2.4.6: LT1086-5 Regulator for IR Tx/Rx and other components

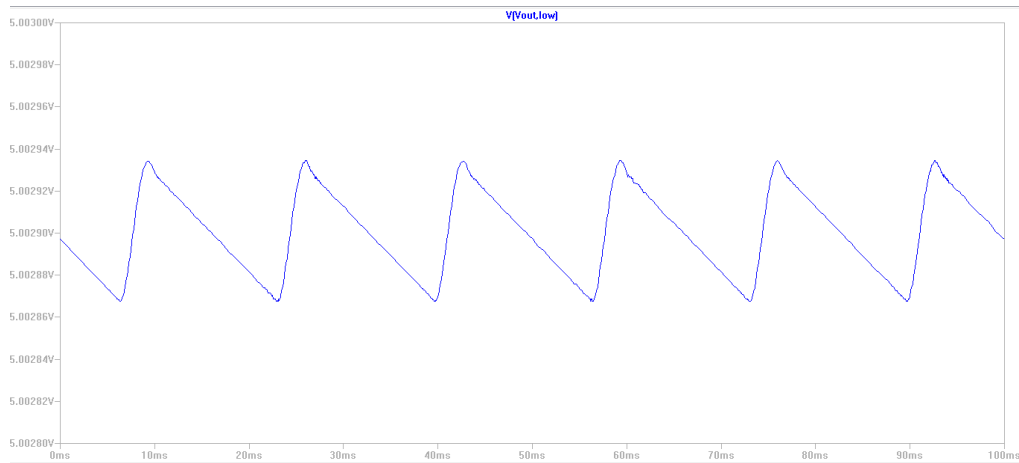


Figure 4.2.4.7: Vout of 5V LT1086-5 fixed Regulator for IR Tx/Rx

4.2.5 Batteries

Although the goal was to power the Karts using the already available AC coil for better long term system sustainability; in the case that the signal produced by the AC coil cannot be converted to DC due to unexpected signal characteristics such as sparkplug interference, or that there was simply not enough power being produced to run all the systems, it would have been necessary to purchase the appropriate batteries to power the system for the demonstration and testing. An advantage to the use of batteries is that the Karts will not require the use of a rectifier circuit or additional PCB design requirements. Since there are several systems requiring power for each Kart there are a number of batteries that were considered such as the common alkaline, lithium-ion, nickel-metal hydride and nickel-cadmium batteries.

The use of an alkaline battery would be appropriate for the IR Tx/Rx since his system requires higher power. Alkaline batteries are commonly used in electronic devices that require higher power, work well with additional alkaline batteries and have a long shelf life. A downside to alkaline batteries is that the rechargeable versions have a reputation of only being rechargeable a handful of times, making replacement a frequent and costly necessity.

According to one source, the use of rechargeable nickel-metal hydride or nickel-cadmium batteries would be compatible with power requirements of the MSP430 and weapons pickup systems considering they use low power allowing for a minimal amount of recharging. The drawback to these batteries is that they do tend to discharge themselves while not in use and are more costly than alkaline batteries (Nickel Metal Hydride).

Lithium-ion batteries seem to be the most promising alternative solution to the AC coil for means of powering the systems. As stated by one online article, the lithium batteries are slightly more expensive but have a much higher energy density than nickel-metal hydride or alkaline batteries which would allow nearly all the systems on the Kart to be powered by only one or two batteries. Li-ion batteries require much less maintenance which is ideal for the staff at Fun Spot. These batteries have much less self-discharge when not in use and are less impacted by memory (Is Lithium-ion the Ideal Battery).

There are several optional modules such as the 8 x 8 LED displays, programmable LED strips, audio components, additional microcontrollers and ZigBee network that may be added to this list of devices connected to the power system. There are also some components such as the break light and servo motor that will require a 5V line. Conveniently, these modules will use either a 3.3V or 5V operating voltage so it is possible to integrate them to the already existing power system. A circuit diagram can be seen in Figure 4.2.5.1 to illustrate the core modules that will be connected to the rectifier. Other components will either use the same voltage or are not part of the core system.

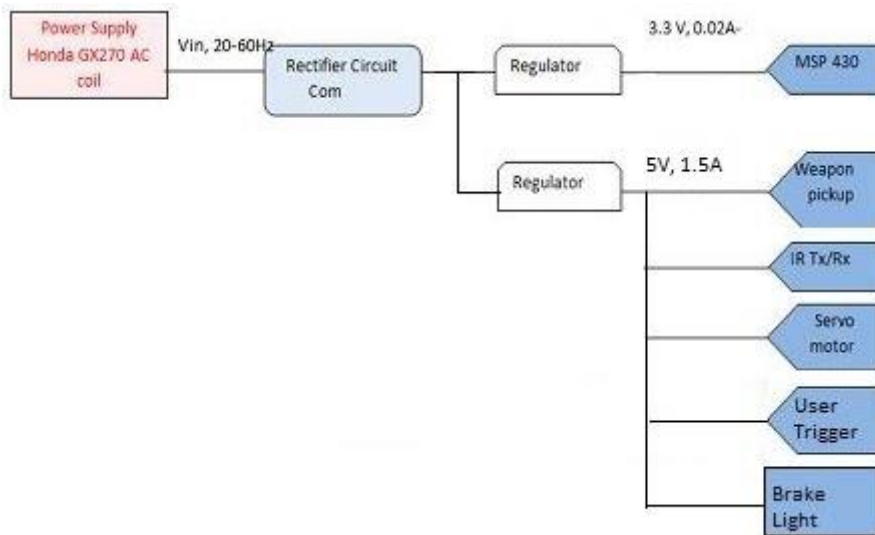


Figure 4.2.5.1: Circuit Diagram of Core Power System.

4.2.6 Power Supply Iteration

Although the above attempts worked relatively well there were some issues that made redesigning the power system necessary. The 1N4148 diodes were unable to handle the amplitude of the voltage produced by the AC coil. To address this issue the GBU601 high power rectifier was used and did in fact allow us to obtain the rectified signal we needed.

Other prototypes were designed using the LM317HVT LDO regulators to drop the high voltage coming off the coil down to a value that the 5 volt and 3 volt regulators could handle and be put in series with the LM317HVT. The issue with this prototype was that the high voltage drop across the LM317HVT was too large when the throttle was all the way open causing the regulators to dissipate too much power in the form of heat. There was also an issue with stability at the output of the LM317HVT regulator when a load was put on the system.

The final power supply system that was put on the kart was very similar to the one seen above but instead of using the LM317HVT linear regulator, we used the LM2576HVT switching buck regulator for its higher efficiency and ability to handle the large voltage produced by the coil under normal operating conditions. The LM2576HVT has the following key features according to the datasheet.

- 5-Terminal
- Output Current of up to 3A
- Wide input voltage range 4V to 60V
- High Efficiency
- Requires Only 4 External Components
- Thermal Shutdown and Current Limit Protection
- Internal Frequency Compensation

The output to the LM2576HVT-12 was used as the input to a LM1084-5 linear LDO regulator which was used to power all the systems except the MSP430 controller. Below are some of the key features of the LM1084-5 regulator.

- 3-Terminal
- Output Current of up to 5A
- Current Limiting and Thermal Protection
- Industrial Temperature Range -40°C to 125°C
- Line Regulation 0.015% (typical)
- Load Regulation 0.1% (typical)

Finally, the LM2576HVT-12 output was also connected to the input of the UA78M33C LDO linear regulator. This regulator was only used to power the MSP430G2553. Below is a list of some of the key features for the UA78M33C.

- 3-Terminal Regulators
- High Power-Dissipation Capability
- Output Current up to 500 mA
- Internal Short-Circuit Current Limiting
- No External Components
- Output Transistor Safe-Area Compensation
- Internal Thermal-Overload Protection

control a servo. Additionally, pins may be needed to control more lighting, sound, and communications equipment.

A core feature of the laser kart system is the ability to electronically and programmatically control the engine. There are three states that the system can select from. First is the normal state where the engine speed is completely dependent on the driver's input to the gas pedal. Second, when the kart is "hit" by a "laser", the engine is forced to idle for a short period of time. Finally, when a "boost" is activated, the engine is allowed to briefly run at higher power than is normally allowed. As discussed later in this paper (Section 4.7), the Honda motors on these karts are equipped with a governor that allows for engine power modification. When rotated clockwise, the engine throttle is set to the idle position. When rotated counterclockwise, the engine throttle is opened further than normal. This arrangement lent itself to being controlled by two servos attached to the governor with thin cables. Servos are controlled with PWM (Pulse Width Modulation) with a standard period of 20 milliseconds and pulses lasting from 600 microseconds to 2400 microseconds with 1500 microseconds commanding a neutral setting. Therefore, a core requirement of our microcontroller is the ability to output two reliable pulse width modulation signals.

As previously mentioned, there are several core and optional functions the Laser Kart system can perform. As such, expandability of the microcontroller is very desirable. The chosen microcontroller must be able to communicate with a second microcontroller as well as multiple other devices and subsystems. The I2C protocol is an excellent method of this type of communication so support for I2C was a required feature.

One of the most exciting optional features of the Laser Kart system is the ability for communication and control through a wireless channel with other karts as well as a base station. There are several available methods for this type of communication, but most of the more popular ones use modules that interface via UART communications. Therefore, our microcontroller needed to have UART support.

This project was developed from scratch and is heavily software based. We anticipated going through several versions of software for our microcontroller. In fact, we went through 15. We had to rewrite our code each time a feature was added, as well as during testing as the inevitable bugs were discovered and worked through. Each version of the software needed to be developed, tested, debugged, and flashed to the microcontroller. Because we anticipated going through this process several times, it was important that our chosen microcontroller was supported by a simple, reliable, robust, easy to use programmer, debugger, and development environment.

Because the final goal with this project is a full track of 8-10 Laser Karts, it is important to keep the total price of the build as low as possible. The price of the microcontroller had to be under \$5 per unit.

4.3.2 Selection Criteria

To summarize the previous section, our microcontroller must have:

- Minimum of 16 General Purpose I/O pins
- I2C Support
- UART Support
- Programmable Timers able to support PWM
- Analog to Digital Conversion ability
- Excellent Manufacturer Support
- Easy to use programmer/ debugger
- Low Cost, Readily Available

4.3.3 Selection Process

The microcontroller market is dominated by a few major companies. These include Texas Instruments, Microchip Technology, and Atmel. All three of these companies manufacture a wide variety of microcontrollers that vary widely in price, performance, pins, and features. When narrowing down the choices, the first decision that was made was what package style microcontroller should be used. The simplest choice is a DIP package. These are easiest to solder and work with, but are limited to 20 – 28 pins, with 20 being the most common. Next up are *thin-shrink small outline package* microcontrollers. Finally, we have quad flat mount packages either with or without leads. These are available with every feature in the book and can have up to 64 general purpose I/O pins. They can be very powerful and would allow us to do everything we want on one chip. However, for our project we will require the ability to swap microcontrollers in and out of the final circuit for testing and programming purposes, so options like the quad flat package with no leads were not really an option. Zero insertion force sockets are available for these, but they are priced at up to \$100 and are not affordable. Thin-shrink and small outline packages are not as costly, but they need to be soldered in place to work and do not lend themselves to the type of development work we will be doing. That leaves DIP's. Dual In-Line Packages are easier to work with and solder and sockets for them are available for as little as \$0.11. DIP's are very common and are supported by readily available tools. It was decided that although microcontrollers such as the Microchip Technology PIC24F08KL402, TI MSP430F235, or the Atmel AT32UC3B0128 would be great to have, their form factor was a major drawback. If we could find a suitable microcontroller in 20 pin DIP form, then we would use it.

After deciding on the form factor, the next most important criteria were the programming and debugging hardware. A really powerful chip with lots of

amazing features is worthless to us if we can't easily and efficiently development code for it. Atmel offers several customized development boards with built in programmers, but they are priced at up to \$200 and are fairly specialized. Microchip Technology has a product known as the Microstick for 3V PIC24F series microcontrollers. It is a development platform that combines programming and debugging, power regulation, solderable pads for each pin on the chip, and reset button. It is only compatible with Microchip's KL and KA line of microcontrollers, but that isn't an issue because the PIC24F16KL402 meets all of our requirements. The development board retails for \$35 and the PIC24F16KL402 retails for around \$2.58 (depending on quantity purchased). Finally, Texas Instruments offers a similar product called the Launchpad. It is also a development platform that combines programming and debugging, power regulation, and reset button, but it is fitted with male headers for easy connection instead of solderable pads. The Launchpad also has 2 on-board LEDs. The TI Launchpad supports their "Value Line" of microcontrollers. This is also acceptable because the TI MSP430G2553 meets all of our requirements. The MSP430G2553 also retails for around \$2.50, but the TI Launchpad is available for only \$5.00. For coding, Microchip Technology is supported by their MPLAB development environment. It offers C and C++ coding and full debugging and is compatible with nearly all of their chips. TI similarly has the Code Composer Studio. It is also a full featured development environment.

These factors narrowed the choice of microcontroller down to the TI MSP430G2553 and the Microchip Technology PIC24F16KL402. While the PIC controller offers more I/O pins than the 430, they both support I2C, and are therefore expandable. Using I2C, our project could be expanded to 2, 3, or more chips, each with 16 IO ports. It would be desirable to demonstrate our team's ability to use I2C, so this is actually a benefit.

TI MSP430G2553IN20

Frequency: 16 MHz
Flash Memory: 16 KB
SRAM: 512 bytes
IO Pins: 2 Ports, 8 Pins/port
Timers: 2x 16 bit Timers
USCI_A: 1 UART
USCI_B: 1 I2C/SPI
ADC: 8 Channels, 10 bit ADC
Package: 20 pin DIP
Price: \$2.79 from Digikey.com

PIC24F16KL402

Frequency: 16 MHz
Flash Memory: 16 KB
SRAM: 1024 bytes
IO Pins: 3 Ports, 8 Pins/port
Timers: 2x 16 bit Timers
USCI_A: 2 UART
USCI_B: 2 I2C/SPI
ADC: 12 Channels, 10 bit ADC
Package: 28 pin DIP
Price: \$2.58 from Digikey.com

4.3.4 MCU Selection

Ultimately the cost of the development tools and our teams existing familiarity with Texas Instruments products led to our decision to select the MSP430G2553 as our microprocessor. Additionally, the engineering and manufacturing industries have been recently pushing for the use of COTS, or Commercial, Off The Shelf, products. We actually had a MSP430G2553 sitting On The Shelf, and so feel that utilizing this part is in keeping with the current industry trends. It is also worth mentioning that Texas Instruments is again sponsoring a college level project design contest and will be supplying free parts and the chance to win large cash prizes to projects that use their products.

4.3.5 MCU Technologies

4.3.5.1 Digital I/O

The microcontroller is the brain of our project, but it will be interacting with several other types of components. Each component is connected to the microcontroller through one or more pins. The pins on the MSP430 are configurable as either input or output pins. This selection is made by setting the bits in the PxDIR register (where x is the Port number) to either 1 or 0. Zero designates the pin as an input pin and 1 designates the pin as an output pin.

Pins configured as Output pins can be written to by the software. Writing a 1 to an output pin tells the microcontroller to pull the pin high (to Vcc) and writing a 0 tells the microcontroller to pull the pin low (to Vgnd). Lazer Kart uses simple output pins to illuminate LEDs.

Other pins are configured as Input pins. These include the pickup sensor, the hit sensor, and the driver's trigger. The simplest is the driver's trigger. It is used to activate the item currently held by the driver. It is a simple switch that will pull the corresponding pin high, which for this project means to 3.3 Volts, the same is Vcc. The microcontroller reads this as a digital 1 and can react accordingly. The pickup sensor and the IR system will be discussed further in their own sections, but they also communicate with the microcontroller by pulling their pins high.

4.3.5.2 Interrupts

Once an input pin is pulled high, there must be an association in the software to that event for anything meaningful to happen. For example, if we wish for a subroutine to be called when the trigger is pulled, then the microcontroller must first know to check on the pin associated with the trigger, and then know to execute some code depending on its state (high or low). One way to do this is called polling. The software contains a line of code to explicitly check the status

of a pin. This is often followed by an if statement. The problem with polling is that it is inefficient to always have the microprocessor checking a pin. Plus, if an event pulls a pin high for a brief time, the microcontroller might miss it because it was doing something else between pin checks. A better way is to use interrupts. An interrupt literally “interrupts” the code being run and immediately executes different code. It then goes back to where it left off and continues as normal. To use interrupts on the MSP430, the software first enables them by writing a 1 to the corresponding bit in the Interrupt Enable register PxIE. Then, the software selects an interrupt type known as edge select. An interrupt can either be triggered by a rising edge from a 0 to 1 transition or a falling edge from a 1 to zero transition. This is selected by writing a 1 or 0 to the appropriate bit of the PxIES register. Once an interrupt has been triggered, the code will immediately go to an Interrupt Service Routine. The Interrupt Service Routine is like a function that is called by an Interrupt and returns to the code when it's completed. Laser Kart uses rising edge interrupts to call routines for trigger presses.

4.3.5.3 Pulse Width Modulation

Servo motors are controlled with a Pulse Width Modulation type of signal. The Lazer Kart systems use a servo to control the engine governor, so our microcontroller must be able to output a pulse width modulation signal. The MSP430 is able to output such a signal by using an integrated Timer. When this on board Timer is engaged, each clock cycle, the microcontroller will, in addition to any other code being processed, increment the Timer Register. The timer can also be configured in other modes, such as decrementing the Timer Register, but Lazer Kart uses Up Mode, so it will be the only one discussed here.

Once engaged, the time will increment the timer register each clock cycle until reaching a set value called TACCR0. Upon reaching TACCR0, the timer will reset to 0x0000h. This is visually explained in the MSP430G2553 User's Guide with the following figure 4.3.5.3.1:

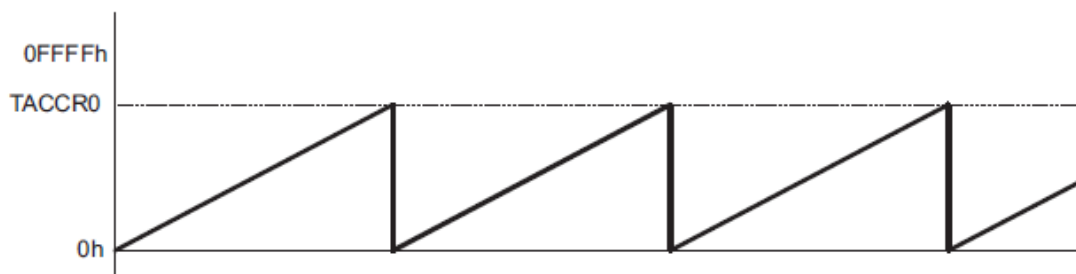


Figure 4.3.5.3.1: Diagram For MSP430 Timers
Reprinted from the User's Guide as allowed by TI

Our servo requires a Pulse Width of 1.5 (+- 0.9) milliseconds every 20 milliseconds. Given a clock rate of 1 MHz, setting TACCR0 to 20000, we can use the Timer as our 20 millisecond period. Now, we need a way to set the output pin to 1 for just the first 1500 clock cycles. This can be done by using Output Mode 7 (Reset/Set) and another value known as TACCR1. When the Timer Register reaches TACCR1, the Output Pin associated with the Timer will Reset, or go to zero. When the Timer Register reaches TACCR0, the Output Pin associated with the Timer will Set, or go to 1. This is again visually explained in the MSP430G2553 User's Guide as shown in Figure 4.3.5.3.2 below:

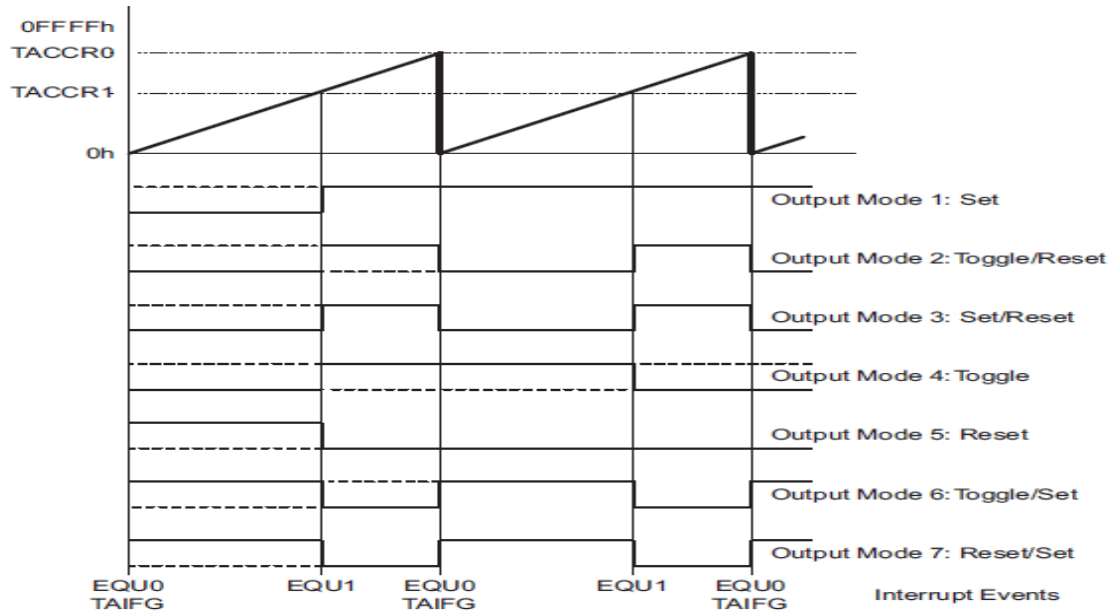


Figure 4.3.5.3.2: Output Modes for the MSP430 Timers
Reprinted from the User's Guide as allowed by TI

As you can see from the last waveform on the above graph, the MSP430 can in this way generate a pulsed signal equal to 1 for the first 1.5 milliseconds of period 20 milliseconds. The servo can then be controlled simply by changing the value of TACCR1. The servo operates based on a center position with rotations of +- 90 degrees possible. The center position is commanded with a pulse of 1.5 ms or 1500 cycles for TACCR1. The Servo maps +90 degrees to 2.4 ms and -90 degrees to .6 μ s. Therefore, we can use the formula $1.5 \pm (\text{angle desired off of center} * .00001 \text{ seconds}) = \text{Pulse Width in milliseconds}$. Then the pulse time is multiplied by 1000000 cycles/ second to get the number cycles for each pulse. The Lazer Kart will be using +- 45 degrees, which equals 1050 cycles and 1950 cycles.

4.3.5.4 I²C

While a single MSP430G2553 only has 16 general purpose input/output pins, this project needs to be expandable so that other optional modules can be added. Modules such as the sound board and extra lighting require more pins than a

single 2553 can provide. The solution is to use multiple MSP430's networked together using the I2C protocol. I2C stands for Inter-Integrated Circuit. It is a two bus protocol where there is one controller that functions as the "master" device and one or more "slave" devices. Each MSP430 on the network will utilize 2 pins for I2C communication, one for the clock signal and one for data. All of the clock pins will be connected to the same bus.

The Master MSP430 generates the clock signal and all of the other microcontrollers will use the Master clock to keep in time. Additionally, all of the data pins on the other MSP430's will be connected to the same data bus. This allows the master to communicate with any slave controller by first sending it's address, followed by a command. Optional modules can be added with their own microcontroller and set of commands. These slave microcontrollers could drive a LED matrix display, control accessory lighting, implement a basic audio system, or control bumping and safety sensors. Each of these subsystems and their associated microcontrollers will be discussed in their own section of this report. This section will continue discussing the functionality of the master MSP430.

4.3.5.5 UART

Each kart racing around the track will have its own Lazer Kart system installed. Each system has the ability to directly control that kart's engine. For safety reasons, it would be useful for a ride attendant to be able to wirelessly control a given kart. Details of the wireless communication system will be covered in its own section of this report, but one important detail is that the wireless communications system will interface with the microcontroller using the MSP430's UART port. The ZigBee board will accept a stream of UART data from the MSP430 and transmit it to the ZigBee on another kart. The receiving ZigBee will then output the same UART data into the main MSP430 controlling that receiving kart. Each kart can also be sent commands from a base station. Commands will include All Karts Stop, Kart X Stop, Kart X Slow Down, and Kart X Play Sound File N. In this way, the operator can control all the karts, stop an individual kart, or send an audio warning to a specific kart about bumping or reckless driving.

4.3.5.6 MSP430 Pin Diagram

The MSP430G2553IN20 is a 20 pin DIP package microcontroller. The following Pin Diagram (Figure 4.3.5.6.1) from the MSP430's Datasheet shows the location and function of each pin on the MSP430.

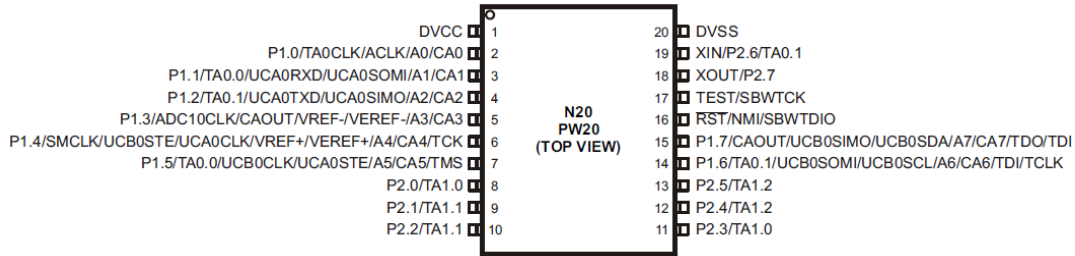


Fig 4.3.5.6.1: Pin Layout of MSP430G2553IN20
Reprinted from the Datasheet as allowed by TI

As you can see, there are 10 pins on each side. Our master MSP430 will be using these pins as a combination of digital inputs, digital outputs, PWM outputs, and special functions (Figure 4.3.5.6.2).

Input Pins

- 1.3 Item Pickup
- 1.4 IR Receiver
- 1.5 Trigger for Items

Output Pins

- 2.0 Boost Ready Light
- 2.1 Laser Ready Light
- 2.2 Hit and Brake Lights
- 2.2 PWM Servo Control
- 2.4 PWM Servo Control
- 1.6 IR Transmitter PWM

Special Pins

- 1.0 Xbee CTS
- 1.1 UART RX
- 1.2 UART TX
- 2.6 Sounds
- 1.7 Accelerometer

Function	PIN	PIN	Function
3.3 V	VCC	Vss	Ground
Xbee CTS	P1.0	P2.6	Sounds (PWM)
Xbee DOUT	P1.1 (UART RX)	P2.7	
Xbee DIN	P1.2 (UART TX)	TEST	NA
Item Pickup Detect	P1.3	RESET	Reset Button
Hit Detector	P1.4	P1.7	Accelerometer
Trigger	P1.5	P1.6	Fire IR
Boost Ready Light	P2.0	P2.5	Xbee RTS
Laser Ready Light	P2.1	P2.4	Cut Servo PWM
Boost Servo PWM	P2.2	P2.3	Hit/ Brake Light

Figure 4.3.5.6.2

4.4 The Printed Circuit Board

To simplify construction and installation of the Lazer Kart system, many of the core components will be grouped together on a printed circuit board. At the center of board will be the microcontroller, surrounded by all of the required electronic components for the Lazer Kart system. The only items that will not be mounted on the printed circuit board will be the IR transmitter, IR receiver, pickup sensor, and the driver's trigger and item indicator panel. These sub-systems will be discussed in detail in their own section of this report.

4.4.1 Components

Before the microcontroller can be powered, the power sub-system must supply a regulated 3.3 volt DC source. The power supply module supplies regulated 3.3 and 5 volt power as well as ground to the CPU module. One of the 3.3V regulator outputs will go to the Vcc pin on the MSP430.

The microcontroller is mounted on a 20 pin DIP socket that is soldered to the printed circuit board. The input pins are routed to wire terminals for easy connection of the Boost Pad detector, the item pickup detector, the hit detector, and the trigger. The Boost Ready LED, the Laser Ready LED, and the Servo control can all be driven directly from the microcontroller. These pins will also be traced to wire terminals.

Because there will be several LEDs used for the Hit and Brake lights, they need to draw more amps than the MSP430 can safely supply. Therefore, the 3.3 volt signal from the controller is used to turn on or off a MOSFET in dashboard and brake light to illuminate the LEDs. The IR transmitter also requires a high current and will so also be controlled indirectly using a MOSFET. The Reset pin is wired to Vcc.

4.4.2 Traces

Many of the traces on our printed circuit board will only be carrying information, not power. That is, they will be operating at 0/3.3V and carrying almost no current. These traces can be quite small. Our chosen PCB manufacture can lay down traces as small as 8 mil, but we will use 10 mil for information traces.

Power traces must be much larger. These will be carrying current for the IR transmitter, brake lights, and the servo. The servo may be drawing up to 1.5 amps during operation and the coil on the kart engine is capable of supplying up to 3 amps. That many amps on such a small trace will cause the temperature to increase drastically. Pushing too much current through too small of a trace will damage the board. As such, power traces must be sized accordingly. Many printed circuit board companies, such as Armistead Technologies, recommend a 30 mil trace for currents up to 3 amps. That size trace will limit the temperature increase to less than 28 C. Therefore, our traces will be 10 mil for information and 30 mil for power.

4.4.3 PCB Diagram

The PCB was designed in Eagle and manufactured by Osh Park. The Layout is shown below in Figure 4.4.3.1.

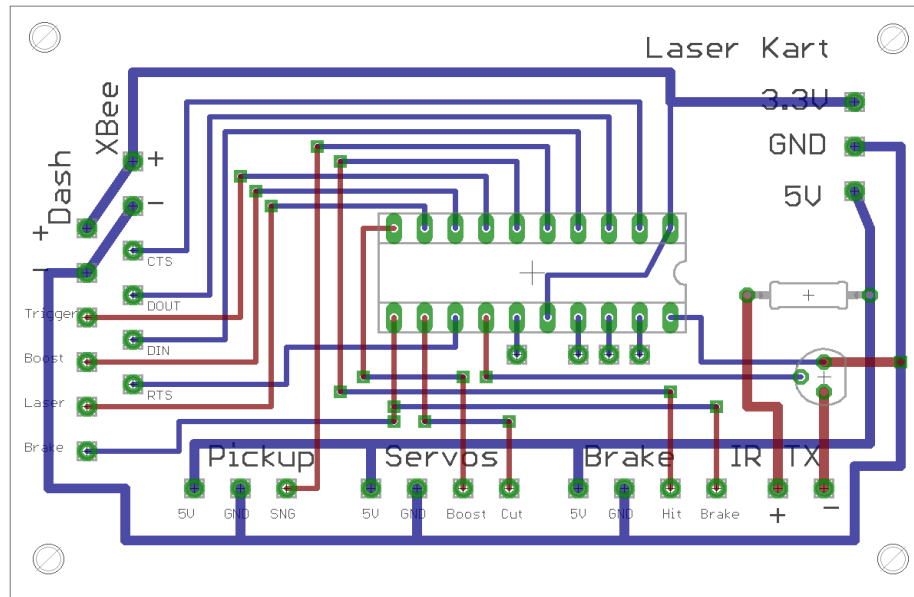


Figure 4.4.3.1: PCB Layout

4.4.4 Manufacturer

Our finished printed circuit board was manufactured by Osh Park. Their price was \$2.50 per square inch and we got 3 copies of our board. Our board measures 2.5 inches by 3.5 inches as shown above for a total of 8.75 square inches at a cost of \$21.88 + \$10 for a total of \$31.88 for the board. This project could have used a simple prototype board with jumper wires, but this PCB will look much more professional.

4.5 Item Acquisition

One of the key aspects of implementing the LazerKart enhancement system is being able to obtain an item or “power-up” that allows the driver of the kart to gain a better position on the racetrack. In order to do this, the kart must be driven over some sort of marker that the kart can unmistakably sense as a power-up marker. Several different methods were considered to effectively accomplish this task.

4.5.1 Implementation Options

The first method was to have a projector (i.e. Christmas decoration type) located under a bridge or an over pass of the track display an image onto a steady stream mister or fog from a fog machine. The driver would then drive through the mid-air image, while an RFID reader located near the fog machine would read an RFID tag on the kart and activate the power-up algorithm. The image would shut off for a second or two and then regenerate, similar to how the item boxes disappear and reappear in the Mario Kart video games. The inherent problem

with this system is the cost and feasibility of the RFID system in addition to the visibility of the projector during daytime operation.

The next method that was considered was embedding small RFID tags on the track and placing the RFID reader on the kart. The RFID tags would be marked by colored tape or paint to be visible. While this method isn't entirely unfeasible, the cost of an RFID reader that could acquire a tag from 4 inches off the ground at a speed of up to 25 mph seemed to be prohibitive for the scale of this senior design project.

The most cost-effective method for power-up acquisition as of yet is the optical sensing method. The concept is simple, an LED, located underneath the kart, shines light down at the ground. When the kart drives over a colored marker, the light from the LED needs to reflect that color back up to an optical sensor which can distinguish that color from the color of the ground and other colors. This implementation was chosen to be incorporated into LazerKart.

4.5.2 Optical Sensor Subsystem

An initial idea was proposed for the optical sensor subsystem to be comprised of photodiodes with colored filters that would react to the colored marker that corresponds with each filter. While doing research about this topic, a Google search for photodiodes gave results that mentioned the use of LEDs as photodiodes. There were many LEDs on hand and no photodiodes, so the choice was made to see how far an arrangement of different colored LEDs could go as far as accurately differentiating color and whether or not it could be done at all.

A particular source (<http://www.robotroom.com/ReversedLED.html>) showed a picture of a Digital Multi-Meter measurement across the pins of a disconnected LED in a well-lit room. The DMM showed a positive voltage just from the ambient light striking the LED. So at that point a measurement was taken using a 5mm red (680nm) LED and a Tektronix CDM-250 Multi-Meter. In a normally lit room, the LED produced a voltage difference of 90 mV. When the lights went off, the voltage went to 0 volts. The decision was made to put the diode across the input terminals of one channel of a TL084 op-amp and see if it would give an amplified output accordingly to the off and on switching of the ambient room light. The results of that basic test were successful, with the light off, output was the $-V_{cc}$ rail and with the light on, the output was the $+V_{cc}$ rail.

4.5.3 Continued Research and Initial Circuit Design

LEDs are designed to emit light with highest energy at a certain wavelength, however, they happen to also emit smaller and larger wavelength light, but with decreased energy. LEDs are sensitive to light in a similar way, but they respond with the most energy to light that is at a slightly smaller wavelength than the light they were designed to emit. For instance, a green LED might respond more so

to bluish green light than to pure green light. So, this must be taken into consideration when testing for color differentiation using LEDs.

Now that it is established that an LED can be effective at sensing ambient light, a circuit needed to be created that would detect and respond to individual color bandwidths and not just white light. To do this, 3 channels of a TL084 op-amp had their input terminals occupied by LEDs of differing color: one red, one green, and one yellow. Each of the outputs had another LED of the corresponding color to its inputs, but anode was connected to ground while cathode was to the output. That way, the output LEDs would turn on when the room light was turned off and vice versa. This was called the “Night-Light” test. With this circuit functioning properly and responding to ambient light, the next step was to add a constant-on white LED to the circuit and shield it from the other LEDs. The point of adding the white LED is that now the test is to scan an object over the white LED so that light reflects off of it and back down to the sensor mode LEDs.

At first, it was thought that a highly reflective material would be the solution to getting the light to the sensors effectively. So, a red bicycle reflector was used as a test as well as red, blue, and green reflective foil paper. When scanning any of these objects over the white light, all of the sensors were tripped. The realization was made that highly reflective material had a glossy coating that exhibits specular reflection in that all of the incident white light will be reflected down on the sensors, thus the sensors are sensing their portion of the spectrum included in the white light. The solution was to use something that was more diffuse like a brightly colored t-shirt. A red t-shirt was scanned over the white light and only the red output light turned off. This means that the shirt absorbed all frequencies of the white LED except for a region of red frequencies, which were reflected down onto the sensor LEDs, with the red LED having the most responsiveness to that wavelength of light while the other LEDs had no responsiveness. However, if the energy of that red spectrum of light were higher, it could have tripped the other sensors (as we will see later). Another shirt, this time a blue one, was scanned over the white LED, and only the green sensor LED responded. So, this test was a success that gave confidence in the use of LEDs as color sensing elements, however it must be noted that the response times to the light reflected off of the diffuse t-shirt material was slow, in that the shirt would have to be held over the white light for about half of a second before the night-light turned off.

4.5.4 Optimizing LED Sensor Circuit

The initial test circuit was designed to determine if LED color sensing was possible. Now that it has been confirmed to be the case, a more useful circuit needs to be designed that will more closely fulfill the requirements of the LazerKart system. To avoid complicating the power distribution system to offer a +Vcc and a -Vcc power supply, it is required that a single supply op-amp is utilized in the sensing circuit. The TL084 can be used in single supply operation, but at a cost. The low output voltage will be some value above zero volts, while the high output voltage will be some value below the +Vcc rail. The TL084

requires +Vcc to be at least ____ so the decision was made to give it a +Vcc of 9V. At this point, The low output voltage was measured to be ~1.5V and the high output voltage was measured to be ~8.5V. Another single supply op-amp was considered before the discovery of the TL084's single supply mode operation (TI article), but the other op-amp (LM324) had too low of an input resistance compared to the TL084's high impedance JFET inputs to recognize the small voltage difference produce by the sensing LEDs.

This circuit has a button that will be used as the 'fire' button. It turns an indicator LED that gets activated when the sensor op-amp output goes high. To do this, the sensor portion of the circuit will be connected to an SR-latch. The SR latch is created by using one half of a 4001 quad NOR gate. One of the sensor outputs of the op-amp is connected to the 'set' and a small momentary button is connected to 'reset'. Q is connected to the base of a 2N222NPN transistor that switches on/off the indicator LED ready light. The sensor LED is to be shrouded in black electrical tape and partnered to the white emitting LED, both of which will be extended via 1-1.5' of wire, so the optical elements are free to move for testing and can be remotely located on the go-kart.

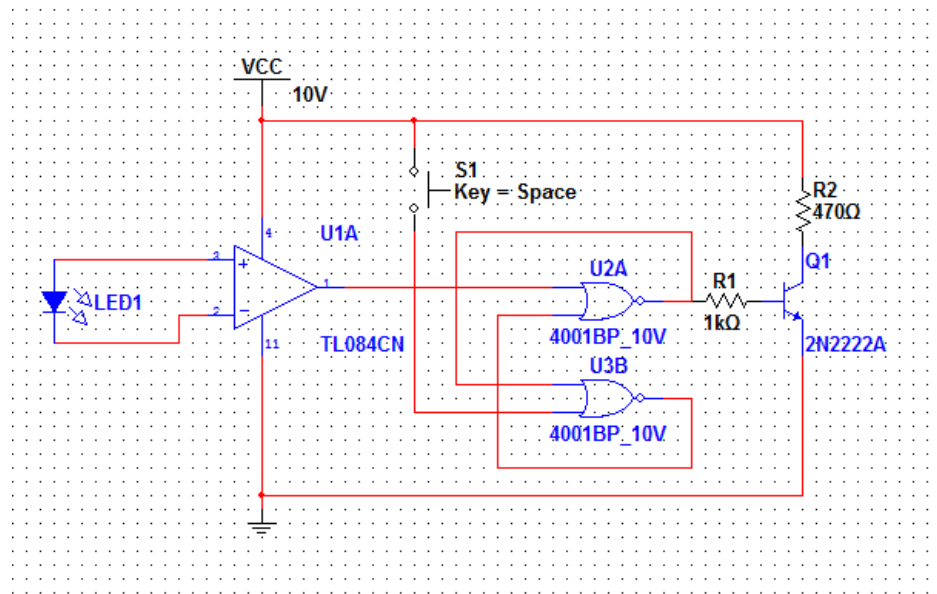


Figure 4.5.4.1: Optical sensor circuit 1

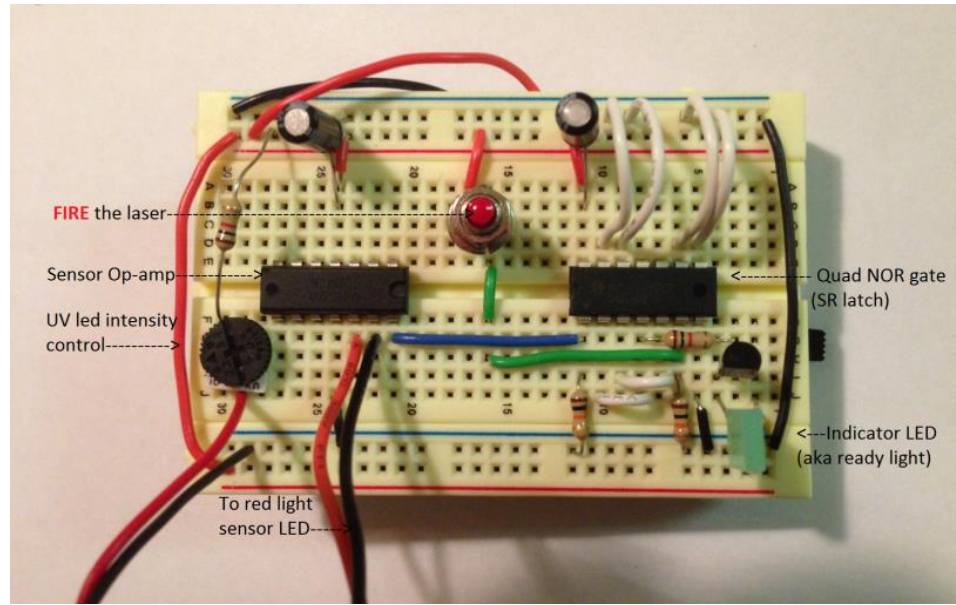


Figure 4.5.4.2: Optical sensor prototype

The circuit is complete and ready to be put to the test. Before using on the go-kart, the test was run on white carpet, which will have similar reflective properties to the white concrete racetrack that the go-karts will be run on. The lone sensor LED chosen was a green LED. The first test was a total failure, because the white LED is constantly shooting white light at the white carpet which reflects white light that is constantly triggering the sensor. The solution to this was peculiar but very interesting. By replacing the white LED with a UV LED, the spectrum of light cast on the ground only reaches the low blue range, so if the sensor is changed to red, it won't detect the blue-violet light that is continuously reflecting off of the ground. But now, the interesting part is the material used as the item marker. Certain fluorescent colored materials are highly reactive to UV light and emit a reflected light with sufficiently high energy (thus the glowing-under-a-black light effect). Neon poster boards reflect very well under UV light and were used as a test material. The red LED responded very quickly to the neon poster board that reflected in the magenta/pink wavelengths (fluorescent reddish-orange under white light). It was time to test a second color and see if the system can differentiate between the two.

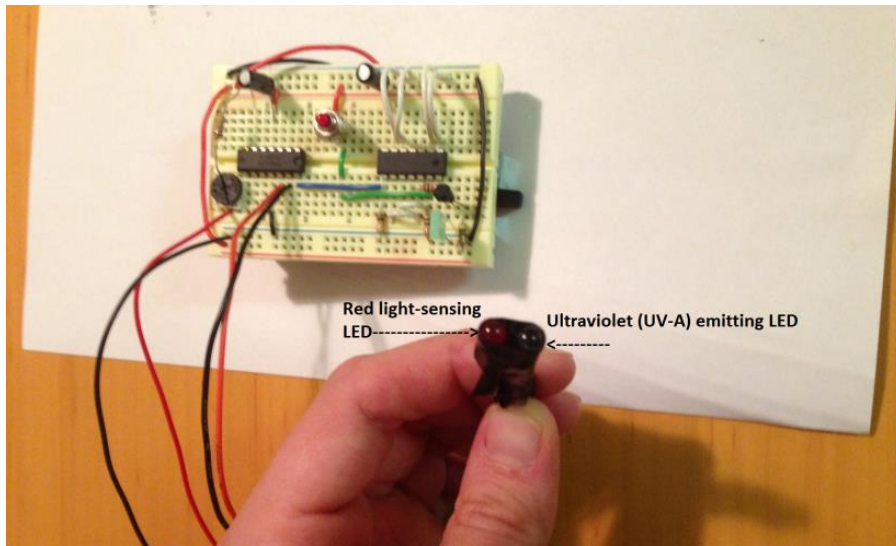


Figure 4.5.4.3: Emitter and sensor LEDs

Adding a second sensing LED (yellow) and its respective SR latch and indicator LED to the circuit was not difficult. The yellow sensor was tested individually first to observe its responsiveness. It responded very quickly to both the neon green and neon yellow poster-board material. As a side note, a yellow highlighter marked on white paper proved to be highly reactive to UV light and allowed for superior response characteristics in the yellow LED. Now the red LED and the yellow LED were both tested together using the neon reddish-orange poster and the neon green poster. The results were not very promising. While the yellow LED responded to the green poster, the red LED didn't initially respond, but if moved slowly enough over the poster, it would respond. A different (unknown origin) red LED was used and the problem was solved. So, bandwidth characteristics vary between LED manufacturers, and it is unclear if perhaps there is a variation between LEDs of the same production batch from the same manufacturer.

4.5.5 Photodiodes/Phototransistors

The solution to multicolor sensing at this point seems to lie in the filtered photodiode or phototransistor circuit. The circuit set up is similar to the previous circuits, but an op amp may entirely be ruled out in favor of connecting the phototransistors into a comparator in a binary light detector set up. This method sets a sensitivity threshold for which the comparator will trip from one state (0V) to the next (5V). An LM339 quad comparator is being tested with two of the channels being dedicated to color filtered light detection and the other channels being configured in a way that may prove to provide an absolute color detection scheme. The hypothesis is that if V_{out} from, say the green light detector, goes high before the red light detector then the output will only be green. This is necessary since both diodes will definitely respond to almost any wavelength, albeit with differing sensitivities, regardless of filtering. However, this difference

due to the filtering will be taken advantage of with this technique. If $V_{out,green}$ is connected to $V+$ on one comparator and then $V-$ on a second comparator, and then $V_{out,red}$ is connected vice versa, then this, in theory would allow the absolute decision of color to be made by the comparator.

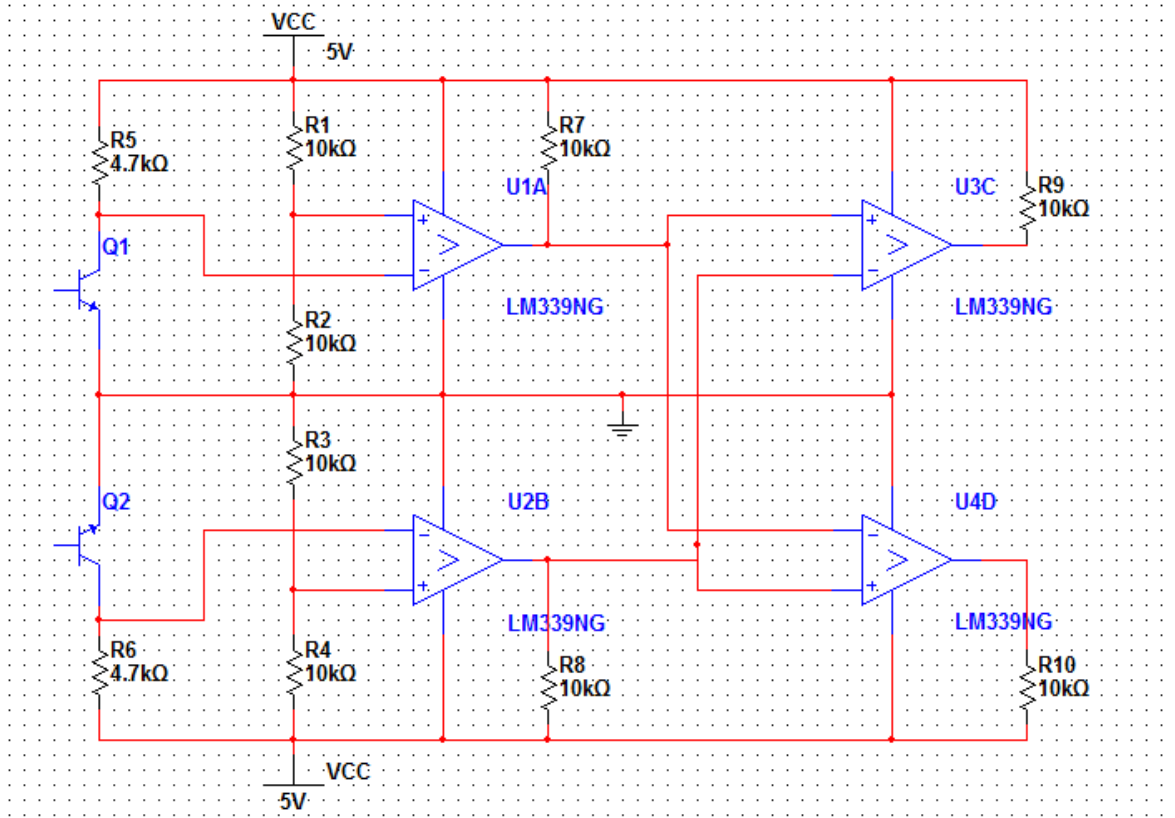


Figure 4.5.5.1

4.5.6 The Final Design

After failed testing of the initial designs, the ultimate design was constructed in which we addressed ambient sunlight interference and multiple color detection. With respect to determining an efficient way to distinguish color, several methods were proposed, but the best solution (which required only one pin on the MCU) relied on a Transimpedance Amplifier (TIA) and Analog-to-Digital Conversion. The TIA converts the current input from a Vishay TEFD4300 PIN photodiode into a voltage on the output, which in turn is fed into an analog input pin on the MSP430. The MSP430's Analog-to-Digital Converter (ADC10) core repeatedly samples the voltage on that pin and triggers an interrupt when the voltage breaches a certain threshold. That threshold was determined empirically to be about 1V. The reason for this is that the photodiode's spectral sensitivity is practically linear in the visible light spectrum, and the TIA feedback resistor was chosen such that the two colors, green and red (~ 525nm and 650nm,

respectively), produced output voltages greater than 1V, with red being roughly 4/3 greater than green.

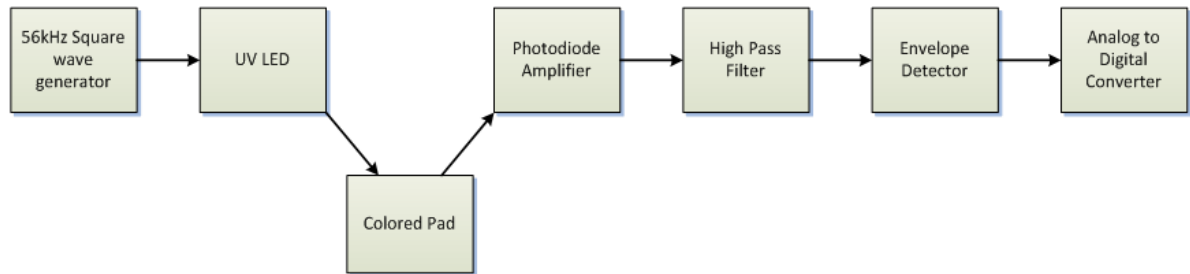


Fig. 4.5.6.1: Simplified block diagram of item pickup subsystem

Since gas-powered go-karting is primarily performed outside, sunlight is often present and will reach underneath the go kart and hit the Photodiode. The interference of ambient sunlight tends to generate unwanted noise current out of the photodiode and can trigger false readings on the ADC10. The reason is that sunlight could add as much as 500mV DC to the signal output and the difference between colors (voltage-wise) is within that tolerance. At this point, the design was expanded to incorporate modulation, ambient light rejection (DC-blocking high-pass filter), and demodulation. Keep in mind that both the UV LED and the photodiode are facing down towards the ground. A TI NE555 timer is configured to generate a 56kHz square wave output which switches a logic-level n-channel MOSFET. Connected to the drain of the Mosfet is the UV LED, which is now flashing at a rate of 56kHz. The UV light source is a ProLight 1 Watt UV LED with a dominant wavelength between 400-410nm and radiometric power of over 475mW, which is more than 15 times more power than a standard 5mm UV LED.

The pulsed light that reflects off of the ground is incident upon the photodiode. The TIA then amplifies the incident light signal and outputs into an active high pass filter (HPF) to reject any low frequency and DC light. The HPF output feeds into an envelope detector, which demodulates the signal into a DC value that is finally sampled by the ADC10. Fig. 4.5.6.2 is a side-by-side comparison of green color voltage (left) and red color voltage (right) output. In each screenshot, the periodic waveform is the output is measured at the input to the envelope detector stage, while the 'DC' value is at its output.



Figure 4.5.6.2

Among other issues that were resolved, it was also necessary to reduce noise throughout the subsystem which was due, in large part, to transient switching noise from the MOSFET caused by stray circuit inductance. The transients are rather high with the uncompensated MOSFET because the UV LED draws a relatively large amount of current at a moderately high switching frequency. A clamper circuit was incorporated which reduced rising edge transient voltage spikes by a factor of 5 (see figure 4.5.6.3). When the Mosfet turns off, the voltage from drain to source (V_{ds}) goes high.

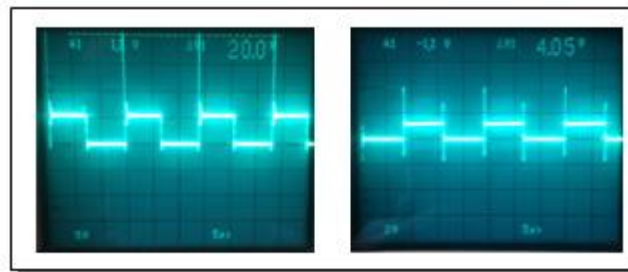


Figure 4.5.6.3

Also a 470uF power supply filter cap was utilized to reduce problematic 56kHz fluctuations of the 5 volt power supply due also to the Mosfet switching. Finally, utilizing an NE555CP (CMOS) timer further reduced the rising edge and falling edge transients by a factor of 2 in comparison to the NE555P (Figure 4.5.6.4). The schematic of the final design is shown in figure 4.5.6.5, and a picture of the final circuit is provided. (Figure 4.5.6.6)



Figure 4.5.6.4

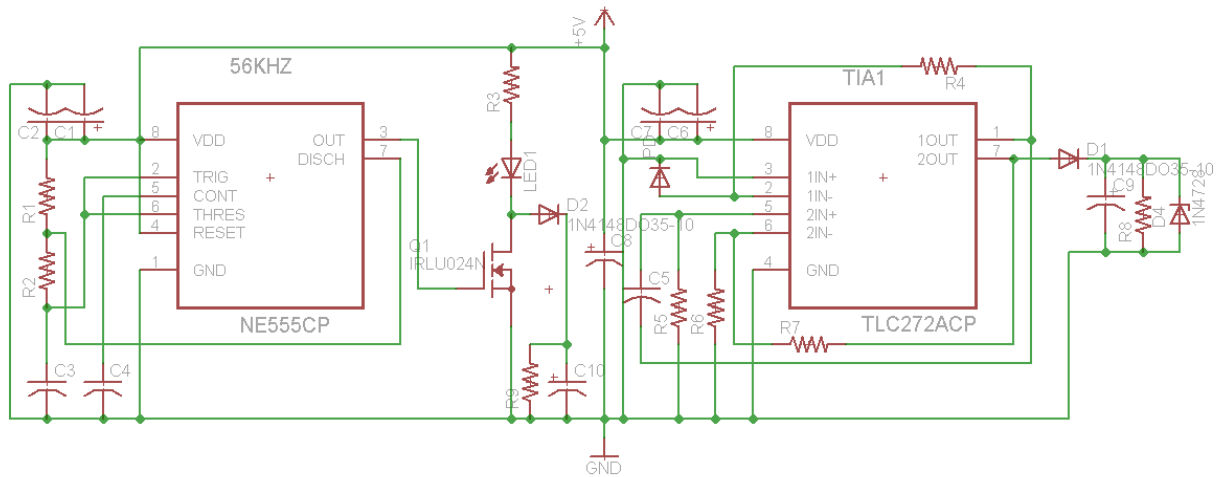


Fig. 4.5.6.5: Item Pickup subsystem schematic

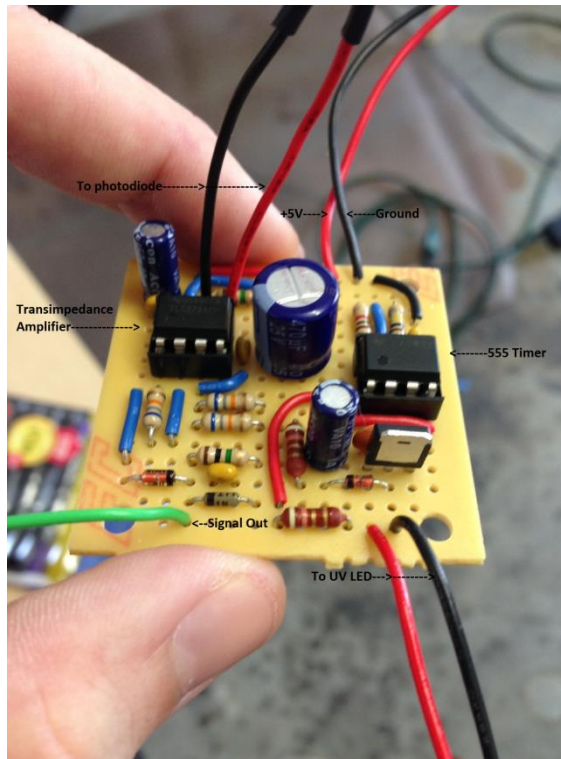


Fig. 4.5.6.6: Physical item pickup subsystem

4.6 Software Design

The MSP430G2553 has a total of 16 KB of Flash memory available to store code. The software will be responsible for reading in various inputs, keeping track various statuses, and controlling the peripherals including LEDs, the servo, and the IR "Lazer".

4.6.1 Headers

The first section of the software will be headers and general setup. It will list the MSP430G2553.h file as an Include. The global variables will be defined as unsigned integers. Global variables can be set and referenced throughout the entire program as opposed to local variables being limited to a single function. Leaving them as unsigned allows for the use of all 16 bits instead of reserving the MSB for signage. These variables will be used to hold the interrupt flags, allow for the random selection of an item, slowly change the length of delay for flashing lights, keep track of which item (Boost or Lazer) the kart currently has ready, and as counters in For loops and such.

4.6.2 Variables

"flags" – As previously described, when a pin on port 1 with interrupts enabled goes from 0 to 1, the corresponding bit in of the P1IFG register is set to 1 and the software skips to the interrupt service routine. At this point, we want the software to be able to recognize which pin originally triggered the interrupt. However, the interrupt register can be changed by other events. Therefore, the first thing we want to do when an interrupt service routine is called is to save the status of the P1IFG register to the variable "flags". Then the code can systematically examine the bits of "flags" without worrying if interrupts are changing the state of the P1IFG bits.

"itemcounter" – The 1st function of the main loop other than waiting for interrupts will be to increment a variable called "itemcounter". When the kart drives over an item pickup spot, the kart should have an equal chance of picking up a laser shot or a speed boost. This randomness keeps the game interesting and pays homage to it's "Mario Kart" roots. To achieve this randomness, the main loop will increase "itemcounter" from 0x0000 to 0xFFFF at a rate of 1 per loop. When an interrupt calls the pickup subroutine, it will examine the LSB of "itemcounter". This bit will sometimes be 0 and sometimes be 1, depending on exactly how long the main loop has been running. On average, this structure should allow for a 50/50 split of boosts and laser shots.

“steptick” - When a kart drives over an item pickup spot, the system should give the appearance of randomly selecting from boost and lazer shot. The items will be represented by a green LED and blue LED, respectively. To achieve an interesting visual effect, the pickup of an item should begin a very rapid alternating of the red and green LEDs. This alternating will slow linearly over the course of about 3 seconds until it stops on the selected item's corresponding LED. Because the interval of time between color changes will slow from nearly instantly all the way to half a second between ticks, the variable “steptick” will be used to hold the delay time instead of a fixed number.

“readyitem” - This variable will be used to represent which item the driver has picked up and is ready for activation. If there is no item available, it will be a 0. Speed boost will be represented by a 1 and a lazer shot will be represented by a 2. This variable will be checked and reset by the trigger pull subroutine.

“i” - This is a general purpose counter variable used in For Loops

4.6.3 Setup

Next, setup routines are ran. This section will include things like setting the port direction, enabling on-chip peripherals, enabling interrupts and timers, and initializing variables. Setup will end with three quick flashes of the green LED so the user knows the program is ready.

4.6.4 Interrupts

Most of the function of the Laser Kart system will be triggered by interrupts. These require a bit of software setup before use. First, the port direction will be set by setting the register PxDIR with 0 for inputs and 1 for outputs. Next, interrupts can be triggered on low to high edge changes or high to low. Our sensors send a high signal upon activation, so port 1 interrupt edge select (P1IES) will be set to 0x0000 for low to high. Then, interrupts will need to be enabled on the pins that need them by setting the corresponding pins of P1IE (Port 1 Interrupt Enable) to 1. Finally, the General Interrupts Enable Register will need to be set (GIE). From here on, state changes from low to high on the enabled ports will cause the interrupt flag for port 1 (P1IFG) to go high and cause the software to skip to the Interrupt Service Routine (ISR).

4.6.5 Timer A

Like the interrupts, the timer used to control the PWM will need to be configured. Many attributes of Timer A are controlled by the control register TA1CCTL. To start with, we will be using output 2, so TA1CCTL2 will need to be set to Output 7 mode. Output 7 mode is the reset/set mode. As explained in the microcontroller

section, the timer will reset the output pin upon reaching the CCR2 value and then set it again when reaching the CCR0 value. Next, the appropriate bits of the control register will need to be set as TASSSEL_2 and MC_1. This selects the sub-main clock as the source of the timer and sets the count mode to UP. Up mode counts from 0x0000 to 0xFFFF. At 0xFFFF, the timer rolls over back to 0x0000. For PWM, we use 19999 for CCR0. This corresponds to a timer period of .02 seconds. The software can then adjust CCR2 to set the pulse width.

4.6.6 Main loop

The main loop is where the program will wait for an interrupt or event to happen. The first thing that will happen in the main loop is the incrementing of the itemcounter variable to allow for a random item selection. Next, the main loop will configure the analog to digital converter to sample the Pickup pin. If the voltage is over 1 volt on that pin, which means that we are driving over a florescent item pickup pad. At that point, the software calls the Item Pickup function. If the voltage on the pickup pin is less than 1 volt, then the program next checks the hit pin. We originally used interrupts for the pickup and hit sensors, but these proved to be too sensitive and were triggering on fluctuations as small as 10 micro volts. To reduce the number of false triggers, we used the ADC to measure the voltage on the pin and react if it exceeds 1 volt.

4.6.7 Interrupt ISR

When an interrupt is detected, the microcontroller will immediately go to the interrupt service routine (ISR). This ISR will first temporarily disable interrupts so the interrupt is not interrupted. Then, the ISR will use IF statements to determine which sensor caused the interrupt. Most interrupts will be caused by pulling the trigger on the dashboard. Once the event has been determined, the ISR will take the appropriate action. Finally, before returning to the main loop, the ISR will reset the interrupt flag register and re-enable interrupts.

4.6.8 Item Pickup

Once the pickup detector has caused pulled the voltage above 1 volt on the pickup pin, the software will begin the pickup function. Steptick will be incremented from 0 to 25000 and the red and green LEDs will cycle with a delay of steptick cycles. Then, the LSB of "itemcounter" will be checked and either a 1 or a 2 will be written to the variable "readyitem". Finally, the main loop will resume.

4.6.9 Hit Detected

When the IR receiver detects a signal from another kart, the kart has been “hit” by the “laser”. When this happens, the circuitry in the brake light will pull the Hit pin up to 3 volts. This will be detected by the software using the ADC. At that point, the Hit function will be run. Here, the software will turn on the brake lights and hit indicator lights by setting that pin high, set the throttle servo using CCR2 to the idle position, wait 5 seconds, and then reset the servo position and the lights. Finally the main loop will resume.

4.6.10 Trigger Pulled

Pulling the trigger will trigger the ISR from the trigger pin. This portion of the ISR will check the status of “readyitem”. If it is 0, P1IFG will be reset and the main loop will resume. If it is 1, the boost routine will be called as described above. If it is 2, the pin controlling the IR transmitter “fire”. The IR transmitter transmits at 56 kHz in a specific pattern. This will be described in detail in the IR section of this report.

4.7 IR Emitters/Receivers

The main lazer system for the LazerKart project will be built using infra-red LEDs and photodiodes.

4.7.1 IR Transmitter

The basic layout is uncomplicated, consisting of a Vishay TSAL6100 high power IR LED operating on a carrier frequency of 56kHz. Using pulse width modulation, a signal will be transmitted that will, when received, inform the receiving unit that it has been hit, and what kart did the shooting. the vital statistics for the LED are shown in figure 4.7.1.1 and taken from the datasheet. Of significant importance is the peak wavelength of 940nm, the angle of half intensity of $\pm 10^\circ$ and the surge forward current of 163mA at 100 μ s. This allows for a high power signal, which will travel an acceptable distance.

PRODUCT SUMMARY						
COMPONENT	I_e (mW/sr)	ϕ (deg)	λ_p (nm)	t_r (ns)		
TSAL6100	130	± 10	940	800		

ABSOLUTE MAXIMUM RATINGS ($T_{amb} = 25^\circ\text{C}$, unless otherwise specified)				
PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
Reverse voltage		V_R	5	V
Forward current		I_F	100	mA
Peak forward current	$t_p/T = 0.5$, $t_p = 100 \mu\text{s}$	I_{FM}	200	mA
Surge forward current	$t_p = 100 \mu\text{s}$	I_{FSM}	1.5	A
Power dissipation		P_V	160	mW
Junction temperature		T_J	100	$^\circ\text{C}$
Operating temperature range		T_{amb}	- 40 to + 85	$^\circ\text{C}$
Storage temperature range		T_{stg}	- 40 to + 100	$^\circ\text{C}$
Soldering temperature	$t \leq 5$ s, 2 mm from case	T_{sd}	260	$^\circ\text{C}$
Thermal resistance junction/ambient	J-STD-051, leads 7 mm soldered on PCB	R_{thJA}	230	K/W

BASIC CHARACTERISTICS ($T_{amb} = 25^\circ\text{C}$, unless otherwise specified)						
PARAMETER	TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
Forward voltage	$I_F = 100$ mA, $t_p = 20$ ms	V_F		1.35	1.6	V
	$I_F = 1$ A, $t_p = 100 \mu\text{s}$	V_F		2.6	3	V
Temperature coefficient of V_F	$I_F = 1$ mA	TK_{V_F}		- 1.8		mV/K
Reverse current	$V_R = 5$ V	I_R			10	μA
Junction capacitance	$V_R = 0$ V, $f = 1$ MHz, $E = 0$	C_j		25		pF
Radiant intensity	$I_F = 100$ mA, $t_p = 20$ ms	I_e	80	130	400	mW/sr
	$I_F = 1$ A, $t_p = 100 \mu\text{s}$	I_e	650	1000		mW/sr
Radiant power	$I_F = 100$ mA, $t_p = 20$ ms	ϕ_e		35		mW
Temperature coefficient of ϕ_e	$I_F = 20$ mA	TK_{ϕ_e}		- 0.6		%/K
Angle of half intensity		ϕ		± 10		deg
Peak wavelength	$I_F = 100$ mA	λ_p		940		nm
Spectral bandwidth	$I_F = 100$ mA	$\Delta\lambda$		50		nm
Temperature coefficient of λ_p	$I_F = 100$ mA	TK_{λ_p}		0.2		nm/K
Rise time	$I_F = 100$ mA	t_r		800		ns
Fall time	$I_F = 100$ mA	t_f		800		ns
Virtual source diameter	Method: 63 % encircled energy	d		3.7		mm

Figure 4.7.1.1

The circuit need to deliver 163A to the LED, which requires a forward voltage of 1.4V. The MSP430 is incapable of delivering this, so the consists of a MOSFET to deliver the PWM signal to the LED. Using our 5VDC rail, that requires a 22 Ω resistor to deliver the proper current. The circuit is shown in figure 4.7.1.2. A PWM signal will be sent consisting of a 2400 μs header and a 5 bit data section indicating the tagging kart. This will allow for up to 32 unique karts to be identified, more than enough for the purposes of LazerKart. This signal can be modified in the future to allow for the optional upgrades. Figure 4.7.1.3 shows an example of a shot from kart number 9. PWM has been unnecessary for the basic application of LazerKart, and may be added in future iterations.

IR Tx

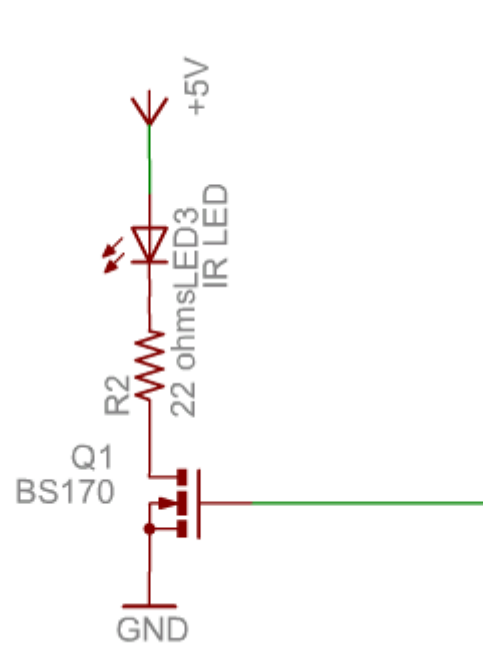


Figure 4.7.1.2

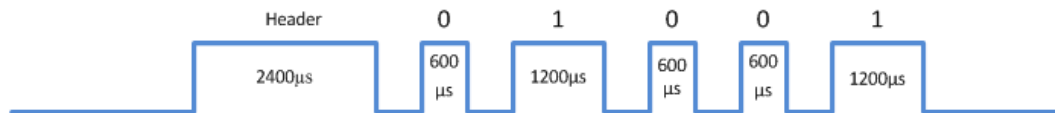


Figure 4.7.1.3

4.7.2 Tagger Housing

The LED needs to be fixed in place, so a housing will be designed out of .75" PVC piping. During the testing phase, the piping length will be determined based on the necessities of game play. The design requires the use of a 25mm diameter, 55mm focal length dual convex lens in order to direct an acceptable amount of power at distance. The housing will be fixed to the top of the Brake Light Housing using a clamp with rubber grommets to ensure stability. Once the appropriate lens setup was determined, the led was permanently affixed with an epoxy resin.

4.7.3 IR Receiver

The IR receiver that was chosen was the Vishay TSOP4856. This is a 56 kHz photo detector and preamplifier that provided an active low signal as an output.

It is well matched to our TSAL6100 emitter, with a high spectral sensitivity near or output wavelength of 940nm and shown in figure 4.7.3.1 which is taken from the product datasheet. The Basic characteristics are shown in figure 4.7.3.1, from the product datasheet.

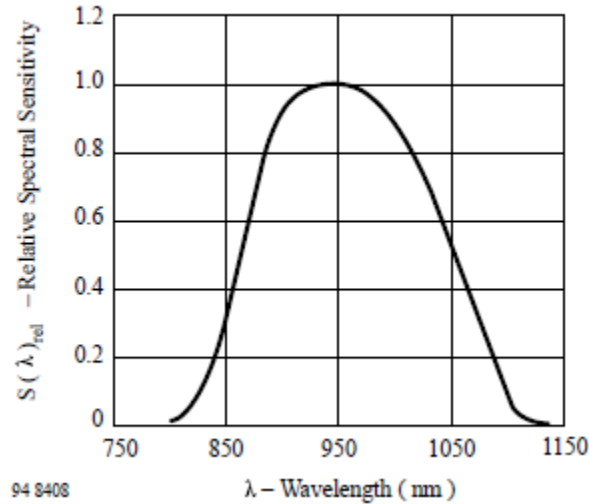


Figure 4.7.3.1

$T_{amb} = 25^{\circ}\text{C}$

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
Supply Current (Pin 3)	$V_S = 5\text{ V}, E_V = 0$	I_{SD}	0.8	1.1	1.5	mA
	$V_S = 5\text{ V}, E_V = 40\text{ klx, sunlight}$	I_{SH}		1.4		mA
Supply Voltage (Pin 3)		V_S	4.5		5.5	V
Transmission Distance	$E_V = 0$, test signal see fig.7, IR diode TSAL6200, $I_F = 250\text{ mA}$	d		35		m
Output Voltage Low (Pin 1)	$I_{OSL} = 0.5\text{ mA}, E_e = 0.7\text{ mW/m}^2$	V_{OSL}			250	mV
Irradiance (30 – 40 kHz)	Pulse width tolerance: $t_{pi} - 5/f_0 < t_{po} < t_{pi} + 6/f_0$, test signal see fig.7	$E_e\text{ min}$		0.2	0.4	mW/m^2
Irradiance (56 kHz)	Pulse width tolerance: $t_{pi} - 5/f_0 < t_{po} < t_{pi} + 6/f_0$, test signal see fig.7	$E_e\text{ min}$		0.3	0.6	mW/m^2
Irradiance	$t_{pi} - 5/f_0 < t_{po} < t_{pi} + 6/f_0$	$E_e\text{ max}$	30			W/m^2
Directivity	Angle of half transmission distance	$\phi_{1/2}$		± 45		deg

Figure 4.7.3.2

The circuit necessary for the receiver consists of the MSP430 mounted on the PCB, with connections for the output and brake light to the Brake Light Dome. The brake light dome will consist of the TSOP4856, and a MOSFET, with a resistor network to transform the active high into low on the MSP 430 pin, until the MOSFET is turned off. A smoothing capacitor is needed to prevent voltage spikes to trigger unwanted interrupts on the MCU resistor and Because the

receiver will be mounted on the rear of the kart, it will also serve as the brake light and hit indicator.

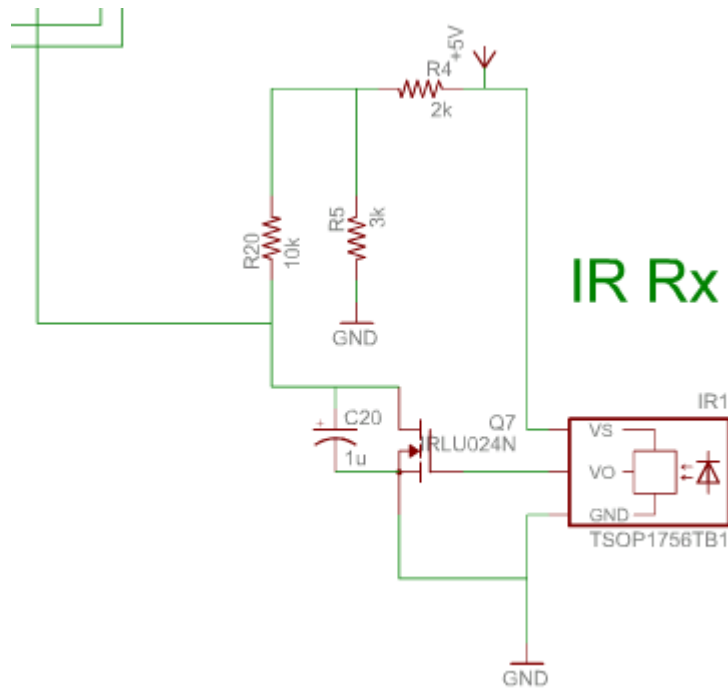


Figure 4.7.3.3

4.7.4 Receiver / Brake Light Housing

The receiver brake light housing will consist of a red dome with the circuit board inside. This will allow for additional protection against interference from outside light sources, as well as protect the system. The dome will house the 2 ultra bright LEDs as well. This domes will be sealed from the elements using a clear epoxy resin. The ultra bright LEDs will be arranged on each side of the dome, for maximum vision.

4.8 Throttle Linkage and Servo

One of the main functions of the Lazer Kart system is its ability to regulate the kart's engine speed. This is what allows for speed boosts due to item pickups. It also allows for the engine to be cut to idle when the kart has been hit by another driver's "lazer". To achieve these responses, the Lazer Kart system includes two servo motors connected to a throttle regulator on the engine.

The karts that our system will be used on are equipped with the Honda GX270 motor. This engine is a small gas powered, 4 stroke motor with one 77x58 mm

cylinder. It has a displacement of 270 cubic centimeters and puts out a maximum of 8.5 horsepower. For engine speed regulation, it uses a centrifugal mass type governor. This governor functions by using a spinning mass inside the engine to move a control arm that is mounted on top of the engine. This control arm is connected to the engine's throttle. It is this control arm that the servos will attach to. In this way, the servos will override the governor and force the engine to either full power or to idle.

4.8.1 The Engine Governor

The engine governor control arm is mounted on top of the engine. It is double sided. The right side (as viewed from the rear of the kart, also the driver's right) is 5.5 inches long and ends in a small connecting hole attached to a push rod that connects to the engine's throttle on the carburetor. The left side is 1.25 inches long. It is attached to a return spring that acts to hold the governor in a neutral position. The arm is mounted on top of a pivot point with a friction adjustment screw on top. This is shown in Picture 4.8.1.1 below.



Picture 4.8.1.1: Top view of the engine governor

4.8.2 Servo Mounting

The servos are mounted using two custom fabricated mounting brackets. Each mounting bracket is a square of metal with a rectangle cut out for the servo to sit in. On either side of the rectangle cutout are two holes to secure the servo using #6 mounting bolts. Additionally, there is a 1/4" hole for the larger mounting bolt that will hold the bracket to the motor.

This is shown in the following two pictures (Figure 4.8.2.1)



Figure 4.8.2.1

4.8.3 Servo Location

Once mounted in the brackets described above, the servos were positioned 5 inches aft of the governor arm as measured in a straight line from the hole currently occupied by the centering spring on the left side of the governor arm. There will be a thin metal cable attached to the end of the governor horn on the right side and to a hole in the custom fabricated extension on the left side. The other end of these cables will be attached to the servos at about 45 degrees from vertical.

4.8.4 Servo and Arm Movement

Attached to the top of the servo will be a 1.25 inch horn, with 0.625 inches extending from the center on each side. The commands for idle and full throttle will rotate the servo ± 45 degrees from center. At this rotation, the end of the horn where the cable is attached, will travel 0.44 inches forward ($\sin(45) \cdot 0.625$) and .18 inches sideways ($0.625 - (\cos(45) \cdot 0.625)$) for a total movement of .475 inches. This nearly half inch movement is more than enough to open the throttle to full or close it to idle.

4.8.5 The Servo

The servo that will move our engine must meet several conditions. First, there are two types of servos. The first and older type is the analog control type servo. This type of servo uses standard pulse width modulation to command a desired

rotation angle. And deviation from this angle will result in torque being applied to reach the desired angle. The standard period for this pulse width modulation signal is 20 μ s. Therefore, that is how long the servo goes between updates. The issue with this that the pulse width is usually between 1 and 2 ms. A short pulse every 20 ms allows for a bit of wiggle room in the servo position. Also, it does not allow for much torque to be applied for small movements.

The other option is a digital servo. A digital servo accepts the same pulse width modulation signal, but it contains a small microcontroller that processes the signal and sends upwards of 300 pulses per second to the servo motor (depending on the model). This will allow for higher torque and faster reactions, but consumes a lot more power. While a standard analog servo may use 0.1 to 0.2 amps while turning, a digital servo can use up to 2 amps. Such a high draw would be undesirable for our Lazer Kart system. Also, small time delays and very slightly off target rotations are not an issue for the Lazer Kart system. Therefore, we have elected to go with an analog servo.

In addition to control types, servos are also sold with different gearing material options. The cheapest hobby servos use nylon or plastic gears for the power train. These are cheap and light weight, but are not very durable. As this project will be used in a commercial application, we require more durability. The next step up is a material by Hi-Tech known as Karbonite. Karbonite is a very durable material marketed as 3 to 4 times stronger than nylon gears and very wear resistant. It is also a brittle material that is prone to shattering at high loads because it has no "give" like nylon. Again, we require higher durability. Finally we come to metal gearing. For a bit more money and weight, servo companies offer servos with all metal gear trains that provide for superb reliability and strength. Metal gears are not always the best product, because they can wear down a bit over time. This can allow a little variance in the rotation angles, but 1 or 2 degrees isn't an issue for our application. Therefore, we have selected a metal gear train servo.

Specifically, we have chosen the Corona 939MG Metal Gear Servo.

Corona 939MG Metal Gear Servo Specifications

Power Voltage:	4.8 – 6 Volts
Max Current Draw at 5 V:	210 mA
Stall Torque:	2.5 kg.cm
Width:	12 mm
Length:	23 mm
Price:	\$4.37 from hobbyking.com

4.8.6 Controlling the Servo

As described above, servos use pulse width modulation for their control. In this application, the pulse width signal will be generated by the MSP430. For this, the MSP430 timer will have to be programmed with a period of 20 ms. Additionally, the servo will require signals that command a neutral position, a clockwise rotation of 45 degrees and a counterclockwise rotation of 45 degrees.

The MSP430 timer operates in terms of clock cycles, so multiplying the sub main clock frequency of 1000000 cycles per second by .02 seconds gives 20,000 clock cycles for the period. Subtracting 1 because the counter will roll over at this point, we load 19,999 into CCR0. See the microprocessor section for more information on the Timer A control registers.

Now, to find the values for CCR2, the range of the servo PWM input signal is divided by the range for that signal. In this case, we subtract 600 μ s from 2400 μ s and divide by 180 degrees to get a pulse width of 0.00001 seconds per degree with a neutral point of 1.5ms. For \pm 45 degrees, the required commands are thus a PWM signal of 1.05 ms duration and 1.95 ms duration, respectively. Multiplying by the clock rate gives a neutral position commanded by 1500 clock cycles and \pm 45 degree positions given by 1050 cycles and 1950 cycles respectively. These are the values to be loaded into CCR2 as described in the PWM subsection of the microcontroller section.

4.9 Optional Modules

4.9.1 8x8 LED Matrix Display

The standard LazerKart implementation will utilize two indicator LEDs located on the steering column of the go-kart to notify the driver that they have acquired an item from the track. A red LED will indicate that the driver has acquired a lazer activating item and a green LED will indicate that the driver has acquired a speed boost from the track. This method of indication is simple and effective, but if time permits, an alternative method would be to utilize an 8x8 RGB LED display to indicate various items and possibly other activities. The display would really benefit from the additional inclusion of a ZigBee network and could display information that might be transmitted to and from another kart, such as a target lock-on or whether a kart was hit by a certain driver. The LED matrix could greatly enhance the LazerKart experience visually.

The 8x8 LED matrix is a single component package that contains a total of 192 LEDs (8x8xRGB). A particular design that could make efficient use of a MCU with limited IO pins will require the use of shift registers. The 74HC595 8-bit shift register is appropriate for consideration in this circuit. This particular shift register can communicate via SPI with a microcontroller, requiring no more than 4 pins. Three 74HC595s would be used to control the RGB rows and one would control

the columns. The microcontroller would apply pulse width modulation (PWM) to each LED in order to create a multitude of colors. Perhaps 4-bit PWM would suffice, as 16 colors would be enough to attract the driver and wouldn't overtax the microcontroller.



Figure 4.11.1.1: Mock-up of 8x8 LED matrix above steering wheel

According to a similar project on instructables.com, the designer was able to implement this configuration using an Arduino MCU and still had 50% of the MCU's resources available to utilize perhaps I²C or serial communication for other peripheral features, thus there it is possible to transmit and receive data to and from the main microcontroller. The LazerKart system will try to implement this type of design using a TI MSP430 MCU if possible. Another similar design was able to use a more advanced Parallax Propeller MCU with no shift registers on a compact PCB with a startup power consumption of 0.6W and a runtime power consumption of 0.275W, so it is feasible to add such a unit onto the LazerKart system in terms of power availability.

The matrix display would be programmed utilizing existing graphics libraries for an Arduino, Parallax, or Atmel microcontroller to cut on development time. The development community is fairly strong in the LED matrix hardware and software design. The total display circuit, including microcontroller, LED matrix, shift registers, passive components, etc., could be incorporated onto its own relatively small PCB and mounted in a weatherproof enclosure within a shock absorbent, cushioned pad bracketed to the steering column.

Possibilities for graphical notification include displaying flashing or animated sprites and/or scrolling text that indicate:

- IR Weapon Activated
- Speed Boost Acquired
- Boost Zone
- Target Lock-On
- Invincibility
- Slow All Other Karts (If ZigBee is used)
- Successful IR Lazer hit/ Hit by IR Lazer
- Scoring/Placement (optional)

A problem could be encountered with daylight visibility, so it may prove to be a financial setback to develop a working prototype for this module just to find out that it isn't very visible during daytime. The RGB matrices themselves cost anywhere between \$8.00 and \$25.00, depending on the vendor, each shift register costs less than \$1.00 and resistors, capacitors, and header pins are relatively inexpensive. A separate PCB would need to be designed thus increasing the price yet again, so the total cost of testing and designing this module could be anywhere from \$35-\$50.00 and that is assuming the MSP430 couldn't handle the requirements and excluding any costs for other MCU development boards. Thus, time and budget constraints seem to be a downside to this otherwise unique enhancement to LazerKart.

4.9.2 Accessory LED lighting

One of the optional modules is to add LED lighting to the go-karts. The idea is that when one of the karts sensors is activated there will be a colorful light display around the driver. The lights will allow the surrounding drivers to see that another driver has acquired a weapon, fired a weapon or have been hit by an opponent. The LED light will add an exciting, aesthetically pleasing addition to the game, attracting customers yet still playing a role in gameplay dynamics.

One option is to build a prototype LED strip from scratch but this would require a lot of unnecessary time and effort spent, considering there are a number of programmable RGB LED strips available on the market and the that LEDs are an addition to the game, not part of the core functionality. A popular strip on the market is the addressable RGB 30-LED Strip made by Pololu Robotics and Electronics® seen in Figure 4.11.2.1.



Figure 4.11.2.1: Addressable 30-RGB LED strip

According to the Pololu website, this particular strip has a driver IC for each LED, allowing the color of the LEDs to be controlled independently. The karts AC coil has a maximum current output of about 3A while the LEDs use about 1.8A, so the number of LEDs installed will have to be limited to only a few. An alternative means of powering the LEDs is through the use of batteries, to avoid overloading the AC coil and for demonstration purposes. The use of batteries will also allow for more strips to be used (Addressable RGB).

The strip has a 5V operating voltage which is a voltage that happens to be available on one of the regulators powering the weapons acquisition circuit so this system will be easy to incorporate into the power system. Some additional features of the LED strip are listed below (Addressable RGB).

Features include:

- 24-bit color (8-bit PWM channel);16.8million colors per pixel
- One wire communication
- Waterproof
- 3M adhesive backing
- Data input/output connector

The protocol for the LED strip involves using a high-speed one-wire connection using a series of high pulses where $0.7\mu\text{s}$ in duration, represents a zero, while long pulses $1.3\mu\text{s}$ in duration are representative of a one. The time the signal needs to stay low after sending high pulses, is $2.5\text{-}9.0\mu\text{s}$. There is a large range of acceptable pulse widths that will still register as a one or zero, reducing the amount of precision needed to display the colors. After sending the serial bits the line is then held low for $24\mu\text{s}$ to send a reset command, which updates the colors displayed. The timing for the strip is shown in Figure 4.11.2.2

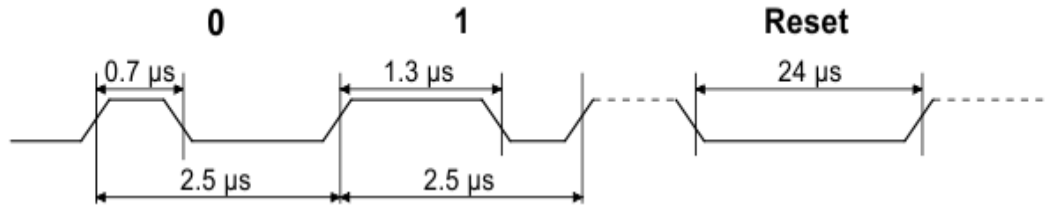


Figure 4.11.2.2: pulse timing diagram for LED strip

Each color is encoded as three red, blue, green LED brightness level using 8 bits each. The MSB of the 24-bit number is sent first. The first 24-bit number, before a rest period is sent, is for the first LED, each 24-bit number sent thereafter is for the next LEDs and so on. If all 30 LEDs are to be updated the numbers should be sent consecutively without the 24μs reset time, sending a total of 720-bits. Additionally, constant updates are not necessary because the LED strip can hold its state indefinitely as long as power remains connected. A bit placement is shown in Figure 4.11.2.3 (Addressable RGB).



Figure 4.11.2.3: RGB 24-bit placement.

The desired displays will include three different light sequences, one for each of the three laser kart's primary functions; (1) the weapons acquisition; (2) using the weapon acquired; (3) being hit by a weapon.

The light effect for when a rider picks up a weapon will look as though the kart is charging up with light "energy". This effect will go from dim to fully bright in a 5 second period and remain bright until the user chooses to fire the weapon. The final color of the light can vary from kart to kart so that there is a clear distinction between riders, giving the game a more colorful appearance.

The display for when the rider fires their weapon will appear as though the shot is running along the sides of the kart. The LEDs closest to the back will light first then each consecutive light will turn on until the light nearest the front is lit before the sequence starts over. Again, this display will last a few second.

The third light effect for when an opponent is hit will be a sequence of red flashes using all the LEDs, appearing as though the kart has malfunctioned.

The next important feature to consider is choosing microcontroller. One option is to use the MSP 430 since it is already available on the kart's PCB. The MSP 430

has plenty of processing power to perform the light display and is inexpensive, however, the one currently on the PCB only has one pin available so using multiple strings of LEDs on the kart may be difficult to implement. Another option is to use I2C and purchase another MSP 430 used solely for the LED display. A third and more costly solution to running the LED display is to use an Arduino MCU. The lines from the weapons acquisition and IR transmitter and receiver can be used as inputs on the Arduino to create the light display eliminating the need for I2C. There are many similar projects using the Arduino and available libraries for programmable LED displays. Example code can be found at Pololu.com, including step-by-step instructions describing how to use install and the libraries. The time and effort spent will be on getting the lights to display in the three patterns previously described.

The example code in the libraries include a color gradient display that allows you to see the various colors in sequence along with a color tester sample code which allows you to choose any to display any color. The samples will be a useful tool when trying to learn the programming processes. As mentioned before the LED strip takes around 2ms to update all the lights in a single strip. The library disables interrupts using in order to accurately update the LED strip, however, this function causes issues with other programs using interrupts. The library contains an 'interruptFriendly' command that allows the library to coexist with other programs using interrupts but the LED strip will interpret any interrupt longer than 8µs as a reset signal, causing unwanted flashes in the lights so any interrupts must be for a short duration making it even more necessary to use a separate MCU in addition to the MSP430 (Addressable RGB).

As previously stated, the various colors are encoded using 24-bits. The available libraries define a type named 'rgb_color', used to represent colors. The colors are defined as three numbers between 0 and 255 for the red, blue and green respectively, where 255 is the brightest value (Addressable RGB).

The library uses a 'pin' template parameter that is used to define the pin that the LED strip's data input line is connected to on the MCU. There are many user friendly commands and definitions such as the ones listed above that will allow for relatively hassle free programming should the Arduino be used.

It should be noted that the accessory LED display goes hand-in-hand with another optional module, the 8x8 LED graphics display. If the display is built, both the accessory LEDs and the 8x8 graphics will easily fit on the same Arduino board.

Addressable LED strips cost anywhere from \$10.00 to \$40.00 depending on length and the manufacturer. The total cost of adding the accessory LEDs is around \$50.00 if the MSP 430 cannot handle the additional but may be as little as \$20.00 if the only additional hardware needed is the LED strips themselves.

4.9.3 ZigBee Mesh Network

One of the core optional additions will be the wireless communication module to be added upon the successful implementation of the basic game system. For this, a ZigBee mesh network has been selected.

After consideration, the module chosen was the Telegesis ETRX2-PA. This module allows for configuration as a ZigBee End Device (ZED) Router (R) or Communicator (C). This device comes with an integrated antenna, and with an overall dimension of 37.5 x 20.5 x 3.2 mm will be able to be integrated onto the existing PCB with I²C. Using the 2007 ZigBee Alliance protocol, gives the added benefit of self-healing mesh networking and improved point to multipoint message transmission through source-routing. This will aid in the multi-kart control aspect of the project. An operating supply voltage range of 2.7 -3.5 VDC fits well with the power available to the project. Figure 4.9.3.1 shows the hardware diagram from the Telegesis datasheet.

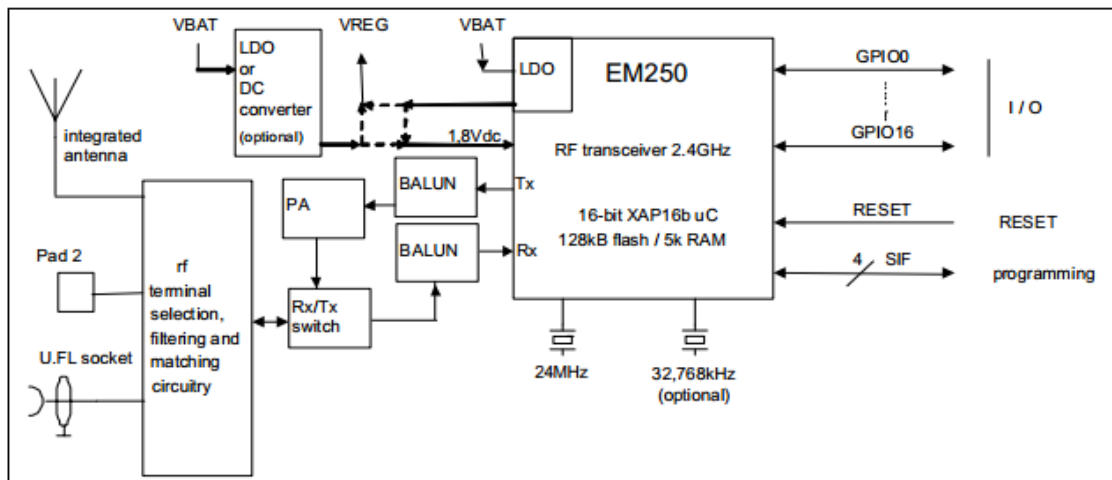


Figure 4.9.3.1

4.9.4 Audio Components

4.9.4.1 Sound Effects Concept

One feature that will allow for project scalability is the use of audio components to add sound effects to a game of Lazer Karts. Like the LED light effects, this module will play a short .wav file when the microcontroller senses a weapon/boost acquisition, the driver fires the weapon or if the kart is hit by an opponent. Each function will address a different .wav file. Like the LED strips this module will only be built considering there is enough time and available budget to do so.

When a driver picks up a weapon/boost the desired sound will be a “power up” effect that gets louder to give the driver the feeling they are speeding up or that the lazars are charging and ready to be used. Another desired sound will be the “power down” effect that goes from louder to quieter when the Kart is hit by an

opponent. The third sound effect “firing” will be played when the driver uses the laser. These sounds will play simultaneously with the LEDs responding to the same in game functions.

A second option is to add vocal sound effect, either by themselves or at the same time as the corresponding sound effects described above depending on if the shield can play multiple .wav files at once or not. The vocals could include “charging lazer!” or “weapon acquired!” when a lazer is picked up. Alternatively, the vocal effect could include “firing lazars!” or “speed boost!” when either a weapon or boost is used respectively. When a kart is hit by an opponent the vocal sound effects could say “malfunction!” or “system failure!”.

4.9.4.2 Software/Hardware

Since adding sound effects to a project from scratch is a difficult task the use of available wave shields will be considered. This will cut down on development time but still give the designer the opportunity to learn new audio software and hardware integration methods. One source that has detailed information on how to build, use and install this type of project is Adafruit Industries (Adafruit). The website offers tutorials, open source libraries, required equipment, file conversion steps, and steps-by-step instructions on how to assemble the parts board. Listed below are some of the key features of the audio shield.

- The shield comes with an Arduino library for easy use
- Can play any uncompressed 22KHz, 16bit, mono Wave (.wav) files of any size. While it isn't CD quality, it is certainly good enough to play music, have spoken word, or audio effects.
- Output is mono, into L and R channels
- Standard 3.5mm headphone jack and a connection for a speaker that is switched on when the headphones are unplugged.
- Files are read off of a FAT16/FAT32-formatted SD/MMC card
- Included library and examples makes playing audio easy
- The library bulky, requiring 10K of flash and more than 1/2 K of RAM for buffering audio. It works fine using an yATmega328-based Arduino

There will have to be considerations regarding the amount of power the speakers will require. The recommended size of the speakers for this module is 3 inch diameter, 8 ohm, 1 watt speakers. Since the sound effect are mono then the system will work well with only one speaker but since the sound effect will be played at the same time as the LED lights, microcontroller processing and use of the IR Tx/Rx module there will be more than 3W being drawn from the AC coil. To include the sound effects it will almost certainly require the use of batteries. These issues will be addressed when testing the audio components.

There is an issue with the amplitude of the sound that this system can output as it will be competing with the noise produced by the engine possibly making it necessary to increase the size of the speakers. An alternative solution could be

to use a pair of headphones that can be mounted on the kart for use while driving cancelling the majority of the sound produced by the engine, however, this will add additional cost to the project. The use of headphones will only be considered if the budget permits and if the engine is in fact too loud for the speakers to be heard. Again, the use of audio components to make sound effects is only an addition and is not part of the core Lazer Kart system.

This module is relatively low cost if there is no need for an additional microcontroller. The module is only \$22.00 making it an affordable add-on to the project.

4.9.4.3 Sound Results

Although the Sound Module was not included in the final design for the presentation, a proof-of-concept was developed using a TI MSP430 Launchpad with a g2553 MCU. A laser sound, a shutdown sound, and turbo sound were all generated using PWM via TimerA to an output pin that fed into a gain of 200 LM386 amplifier circuit with a 2W speaker as the audio output. This design method is a departure from the aforementioned design in that the system resources are conserved (less memory is used) and only 1 pin is utilized and the audio is merely square wave sound effects for “old-school video game” – style sounds rather than realistic sounds.

4.9.5 No Bumping Sensor and Warning

4.9.5.1 Motivation

While researching this project, our group made several visits to Fun Spot. We spoke with the owner, the mechanics, and the track operators. We discovered that one of their biggest concerns is reckless driving, specifically drivers bumping into other karts. These karts travel at speeds up to 20 miles per hour. Reckless ramming into other karts is not only a safety issue; it is also a maintenance issue. Repeated impacts are rough on the karts, the steering linkages, and the power train. These must all be adjusted by maintenance on a regular basis and constantly banging into other karts increases this work. There are “No Bumping” warnings posted all around the track as well as on the karts, but we are told by Fun Spot staff that they are mostly ignored. Therefore, a possible addition to the Laser Kart system at some point in the future is a Bumping sensor integrated with the microcontroller.

Our No Bumping warning system would use an accelerometer to detect if a driver has rammed into another kart. When this is detected, the microcontroller will illuminate a sign reading “No Bumping!” and then cut the kart's engine's throttle as if it had been hit by another driver's laser.

4.9.5.2 Accelerometer Requirements

The only additional hardware required for the No Bumping sensor will be an accelerometer. This accelerometer need only detect acceleration in a single axis as it will only be looking for rapid speed changes in the karts forward speed. It will also require a small g sensing range. Personal testing has shown that most bumping induces a negative acceleration of no more than 2-3 g's. The exact g value will be refined with additional testing once the unit is installed. An accelerometer with a range of +/- 5 g's should be sufficient without losing too much resolution. The biggest choice in accelerometers is analog or digital. Analog accelerometers output a voltage proportional to the load on them. Digital accelerometers output serial data that can be read and decoded by a microcontroller. While digital units are more accurate and the data can be read directly by the microcontroller, they require polling by the microcontroller. In our application, we hope to not ever use them so frequent polling would be wasteful. A better option is to use the analog output of an analog accelerometer to trigger an interrupt in the microcontroller code. Therefore, our system will use an analog accelerometer that outputs a voltage proportional to its loading.

4.9.5.3 Selection

After looking at several options, the Analog Devices ADXL325 accelerometer was chosen for this application. It operates on 3.3 V Vcc, has a range of +/- 5g's, a low power draw of 350 μ A, and an analog output. It is a 3 axis accelerometer, but is very inexpensive at only \$6.25 from digikey.com. There are several single axis accelerometers available on the market, but they are nearly all designed for higher loads in the 25 – 200 g range. They are also quite expensive. It has become industry standard to include three accelerometers in a single inexpensive package. In fact, the sensor uses one structure to measure all three accelerations. So, in this case, it is more cost efficient for this project to use a three axis accelerometer and only use one of the three outputs.

4.9.5.4 Output Voltage

The datasheet of the ADXL 325 states that at zero g's, the output of the accelerometer will be one half the source voltage, which in this case will be 3.3V. Therefore, the zero g voltage will be 1.65 Volts. The voltage dV/dg is 190 mV when Vcc = 3.3 volts. That means that an "x" g deceleration will be indicated by $1.65 - (.19 \times x)$ Volts. Again, the exact g force experienced during a collision will need to be refined by testing.

4.9.5.5 Interaction with Microcontroller

As just described, the accelerometer will output an analog voltage depending on the acceleration experienced. The microcontroller could read this voltage through an analog to digital converter port, but that would require a lot of polling of the port, and even then, a quick bump might be missed because the

microcontroller was doing something else. A better solution is to once again use an interrupt. As an example, we will assume a -2 g deceleration here. This value may change, but it is just a matter of changing the resistor values to compensate. A voltage corresponding to a -2 g bump should trigger an interrupt on one of the microcontroller's input pins. To do that, however, a comparator is required. A comparator will output either a high level or low level depending on if the V+ or V- is higher. In this application, Vcc will be 3.3 volts. As described above, a -2g bump will cause a voltage of 1.27 volts. Means that when the input voltage on the following comparator circuit is less than 38% ($1.27/3.3 = 38\%$) of Vcc, a -2g bump has occurred and the output going to the input pin will go high triggering an interrupt.

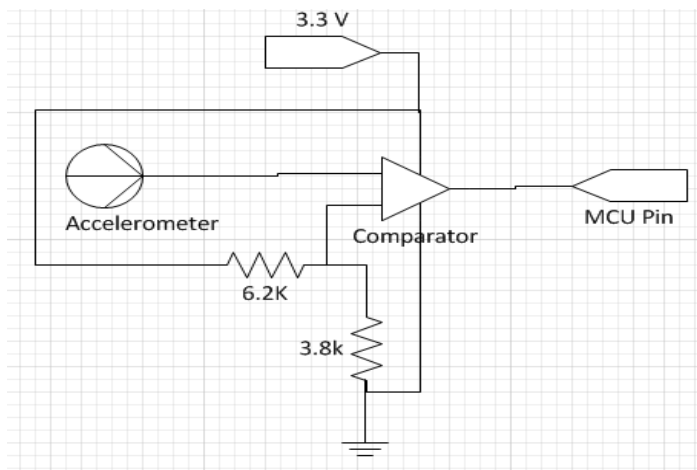


Figure 4.9.5.5.1: No Bumping Schematic

Once the interrupt is triggered by output of the comparator going high, the interrupt service routine will be called that will set the servo to the “idle” position for 5 seconds and light a small NO BUMPING sign in front of the driver.

The intent is for this system to reduce the amount of reckless driving, increase safety, and reduce wear and tear on the karts.

4.9.6 Hand Held IR Transceiver

The Laser Kart system is designed to be used by multiple karts, all equipped with identical systems that interact with each other as they race around the track. As such, the system had to be fully tested using multiple karts before it is deployed. However, that will not be the only testing done. To test multiple karts interacting, multiple karts would first have to be built. If a flaw is discovered after multiple karts have been built, it is more expensive and time consuming to go back and fix all the karts. The flaw should have been detected earlier. As such, we first built just one kart and then tested it with simulated signals from other karts. That is, instead of building a second or third kart for testing purposes, we built and used a

small, hand-held IR testing tool. It will consist of an IR receiver, an LED to indicate reception status, an IR transmitter, and a MSP430 all mounted on a development board.

The primary means of interaction between karts will be the infrared transmitter and receivers. As such, our hand-held testing units consist of two units, one to transmit and one to receive.

To aid in development, troubleshooting, and final testing, we have developed two stand alone infrared systems that will allow us to simulate the IR transmitter and receivers of other karts. This was a necessity because so much of this project is about interacting with other karts.

4.9.6.1 IR Receiver

Just like on the kart itself, the IR testing transceiver will use the Vishay TSOP IR receiver configured for 56 kHz reception. As described in depth in the IR Transmitter and Receiver's section of this report, the IR receiver is tuned to detect a 56 kHz signal and pull the output low while a 56 kHz signal is being received. All of the complicated signal processing is done inside the receiver for a nice, clean Vout of either Vcc or ground depending on if a 56 kHz signal is being received. While that will be used on the actual kart system to trigger an interrupt, on the testing platform we will only use it to turn off an LED to indicate the reception of the signal.

To test that our IR transmitter is generating the correct signal, we built a standalone IR receiver box. It contains a battery pack and a simple circuit consisting of an IR receiver identical to the one on the kart, a large LED, a power switch, and a MOSFET to source power to the LED. When the box is turned on, the LED will glow until a 56 kHz IR signal is seen by the receiver. When the LED turns off, we know the receiver is sensing the IR signal.

4.9.6.2 IR Transmitter

The lazer kart system will use the Vishay TSAL6100 high power IR emitter as the transmitter or "lazer". As discussed in the IR Transmitter and Receiver's section of this report, the TSAL6100 will need to operate on a carrier frequency of 56 kHz. To achieve this, the IR transmitter will be controlled by another MSP430 in the testing unit. The MSP430 will be connected to a push button that will act as the trigger. Whenever the button is pressed, the MSP430 will call a function that will output a 2 second 56 kHz signal. The testing system will need to send pulses with period $1/56000$ seconds for the duration of 600 microseconds. This works out to:

- Period of Carrier Frequency: $1/56000 = 1.78e-5$ seconds

This carrier frequency is a square wave with amplitude varying between fully off and fully on. As such, the time of being on will be one half the period:

- Length of “on” time: $.78 e-5 / 2 = 8.93e-6$ seconds

The MSP430 in the testing unit will be running at 16 MHz. To find the number of clock cycles the “on” command should be given:

- Cycles for each pulse: $16e6 * 8.93e-6 = 142.85$ cycles

Obviously, we can’t do anything for 0.85 clock cycles, so this will be rounded to 143 cycles. This will actually give an on time of

- $.0006 / 1.78e-5 = 8.9375e-6$

And a period of

- $8.9375e-6 * 2 = 1.7875 e-5$ seconds

For a frequency of:

- $1/1.7875 e-5 = 55.944$ kHz

As described in the previous subsection, this will be close enough to the nominal 56 kHz rate for successful reception by the receiver. It is worth mentioning here that the rise and full times of this LED are around 800 ns. This is not long enough to material affect the transmit rate. These low times are one of the reasons we selected this IR LED.

Now that we know we will be turning the IR LED on for 143 cycles, then off for 143 cycles to generate a carrier frequency of 56 kHz. This will need to be repeated for as long as we want to be transmitting a “lazer” shot. We have chosen a 2 second time period for this although this may be adjusted during play testing.

The other IR feature that needed extensive testing is the IR receiver on the back of the kart. To facilitate this, we re-purposed a plastic toy dart gun into an IR transmitter. To ensure the receiver on the kart responds predictably, we built into

the toy gun the same components used on the kart's IR transmitter. We used the same IR diode connected to the same MOSFET and driven by an MSP430 using very similar code. The optics were also identical. When the trigger on the toy gun is pulled, as switch is closed that tells the MSP430 to active the 56 kHz pulse width signal. This signal drives the MOSFET which in turn controls the current through the IR diode.

4.9.6.3 Transmitter Power

The Vishay 6100 IR emitter is rated for a surge current of up to 200 mA for a duration less than 0.0001 seconds (100 us) at 50% duty cycle. Our pulses will be much shorter (about 0.000009 (9 us) seconds) in length, so there should be no issue with running .2 A through this LED. This is, however, more current than the MSP430 can source. The MSP430's output pins are limited to around 40 mA (depending on voltage). Therefore, an N-Channel MOSFET controlled by the microcontroller will be used to power the transmitter.

4.9.6.4 Receiver Circuit

As shown below in Figure 4.9.6.1, the IR receiver is powered by 3.3 Volts. The output voltage will be 3.3 volts until something is received. This will be indicated by the LED. The current on the output pin must be limited to 5 mA. The LED has a 2 volt forward voltage, so the resistor must be

$R = V/I = (3.3 - 2) / 0.005 = 260 \text{ ohms}$. This will protect both the LED and the IR receiver.

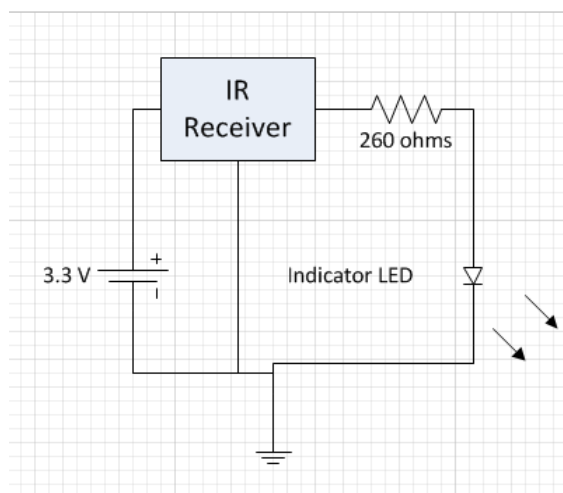


Figure 4.9.6.4.1: IR Receiver Schematic

4.9.6.5 Transmitter Circuit

The TSOP6100 has a forward voltage of 1.5 volts when 200 mA is allowed through. When placed on a 9 volt source, it will need a resistance in series with it to prevent over current.

$$R = 9 - 1.5 / .2 = 37.5 \text{ ohms.}$$

The MSP430 can only source 40 mA at 3.3 Volts, so instead of a direct connection, the MSP430 will control a MOSFET that will act as a switch for the IR LED in the 9V circuit. This is shown below as Figure 4.9.6.2.

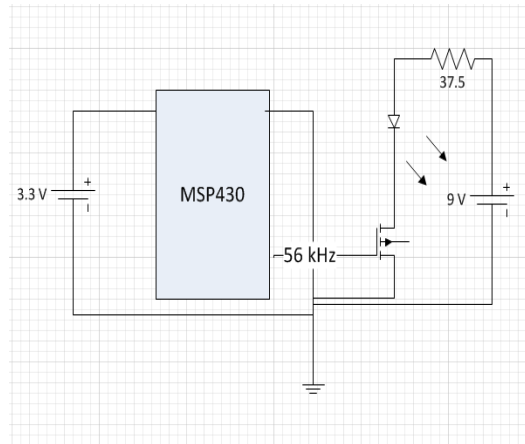


Figure 4.9.6.2: IR Transmitter Schematic

5.0 Design Summary

5.1 Flow Charts

5.1.1 Hardware Block Diagram

The Laser Kart system is based around an MSP430 microcontroller. It communicates with input devices and LEDs. The inputs and outputs are shown below with grey blocks. It also controls two servos via a pulse width modulated signal. We've left room to expand with the wireless communication system via UART protocol. The power regulator distributes 3.3V and 5V power to the microcontroller and all of the other systems. Power distribution is shown in red. Data paths are shown in green and blue. AC components are shown in yellow. Driver inputs are shown in orange. Figure 5.1.1.1 illustrates this system.

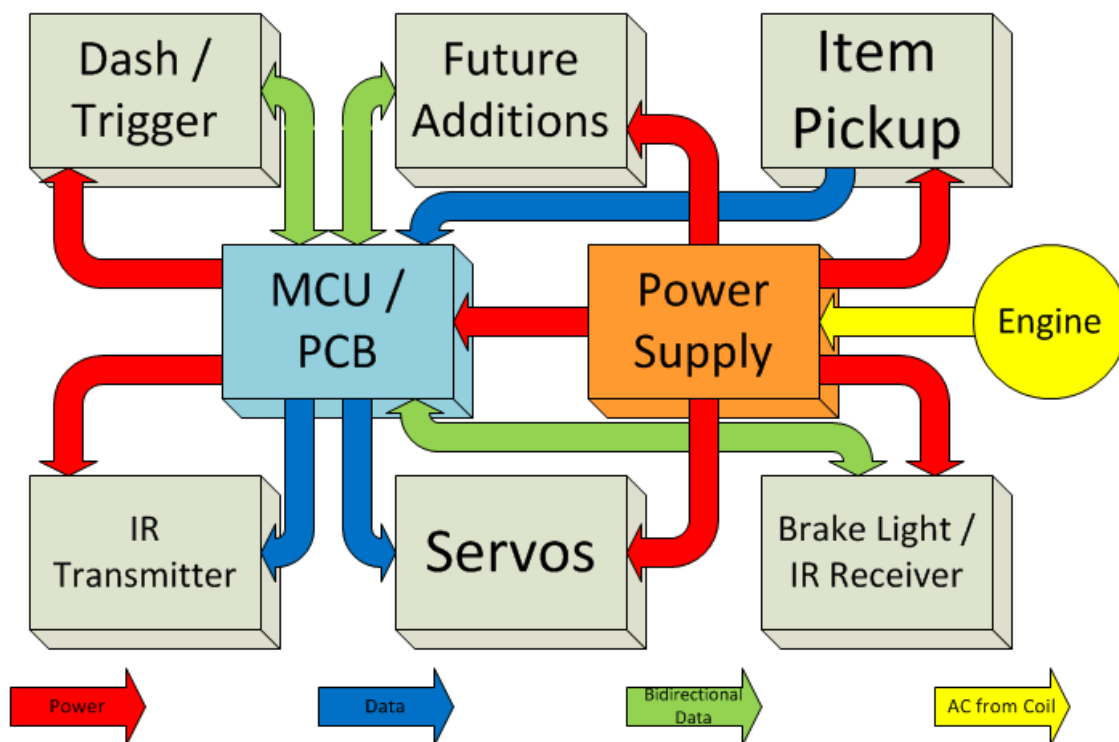


Figure 5.1.1.1

5.1.2 Software Flow Chart

The flowchart shown (Figure 4.1.2.1) is how we are going to implement the game logic for LazerKart. It contains an initialization procedure and a main loop that is interrupt driven and monitors the subsystems for action. Play testing may alter the design in the future.

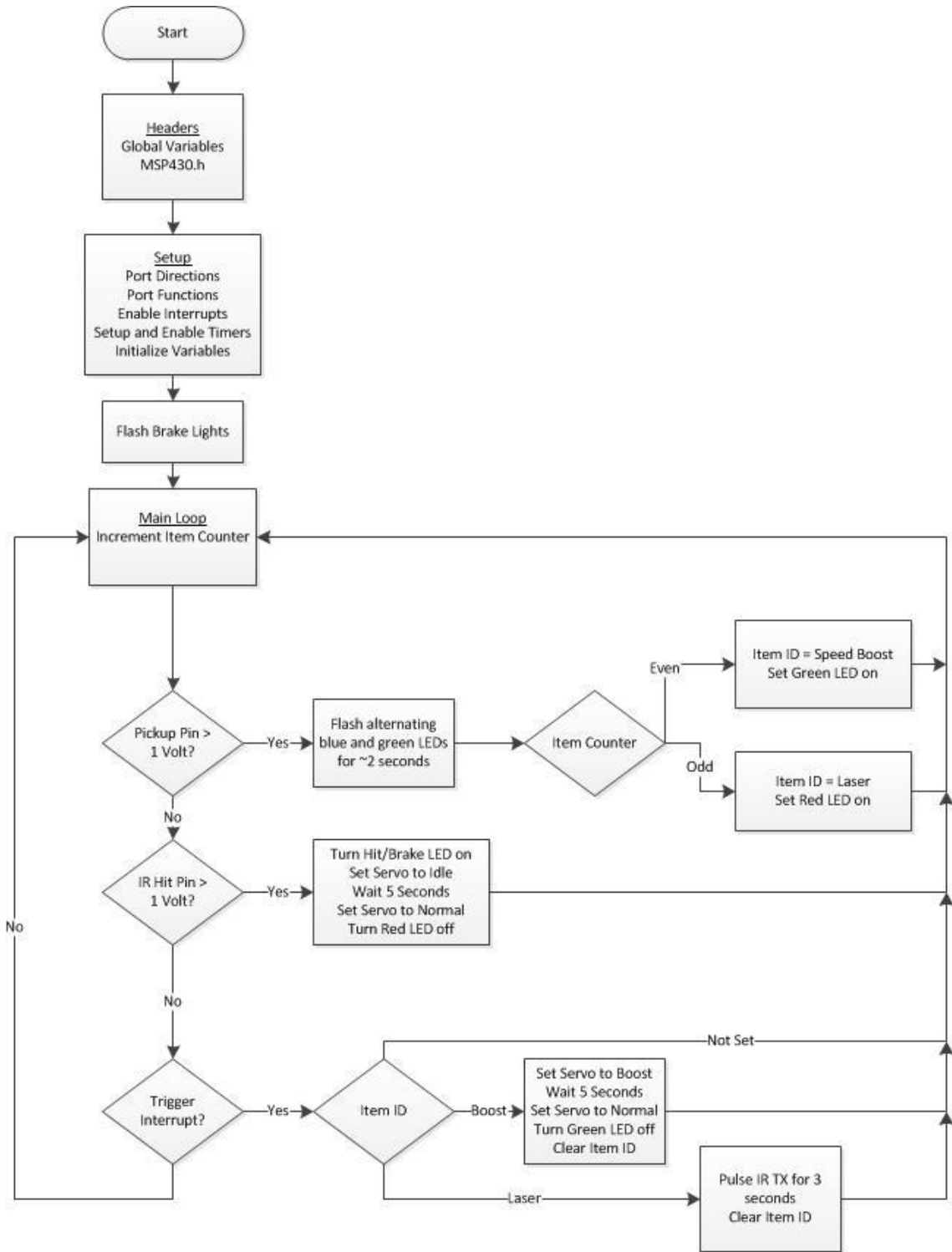


Figure 5.1.2.1

5.2 Hardware Design Summary

5.2.1 Power System

Given the number of subsystems that can be applied to the project, the power systems needed to cover a wide range of possible configurations and requirements. The power system for lazer karts focuses on delivering the necessary DC voltage and current required by each component. The subsystems include the weapons pick up circuit and UV LED, MSP430 microcontroller, brake light, IR Tx/Rx, user dash/trigger LEDs, and the boost and cut servos, as well as the projected additional modules including the programmable LED lighting, no bumping sensor and warning, ZigBee wireless module and sound effects (to be added). Ideally, all systems are expected to be powered using an AC coil that is stock on each Honda GX270 engine.

The biggest challenge faced when designing the power system was the conditioning of the AC source output of the coil. Special consideration was necessary when converting this output to obtain a stable signal due to its high voltage values produced and the large differences in amplitude and frequencies produced between idle and boost. The output to the coil needed to be conditioned to a steady DC value that was then voltage and current regulated as needed by the subsystems being powered. The design required to condition the signal produced by the AC coil uses the GBU601 full-wave bridge rectifier which was put in parallel with multiple external components such as capacitors, in order to produce a steady ripple voltage. Once the ripple voltage was obtained it was used as the input to a LM2576HVT switching buck voltage regulator to provide a 12V output and currents between 240 μ A to 2A which is then used as the input to the LM1084-5 and UA78M33C LDO linear regulators. Table 5.2.1 shows the voltage, current and power requirements of the main modules in the design.

There are several regulators that met the requirements of the systems to be powered. One regulator chosen for MSP430 is the LT3008 series low dropout linear regulator based on the fact that the MSP430 requires very little power. This regulator does not need feedback protection which is important when considering the AC coil on the Honda GX270 will be changing frequency and amplitude quickly when the throttle is undergoing rapid changes in position.

The regulator chosen for the weapons pickup circuit and UV LED is the LT3014 - 20mA low dropout micro power linear regulator. This system, like the MSP 430, requires very little power and needs to be protected from any feedback produced by the AC coil which is also a feature of the LT3014. While these regulators would in fact work if the output of the coil was a more regulated AC waveform, they are however, not the ones used in the final design.

The use of batteries was a possibility and was commonly used during the initial testing and was considered, at one point, to be used for demonstration purposes.

There were several types of batteries that were considered such as lithium-ion, nickel-metal hydride and alkaline batteries. Since the systems each have their own power requirement they could potentially use different batteries. An alkaline battery will be used for the IR Tx/Rx system due to the high power consumption. The MSP 430 and weapons pickup op-amp can be powered by a small lithium-ion battery as well as the other subsystems on the Kart. When a battery was used for testing we used common 9V and AA batteries as well as a 18V drill battery when much more power was needed.

The power systems hardware for the optional modules such as the accessory lighting and sound effects was considered on an as needed basis. For now it is only necessary to have the hardware chosen for the core systems seen below.

Module Part	Supply Voltage	Operating Current	Power
IR Rx TSOP4856	5.0 V	1.5 mA	7.5 mW
IR Tx TSAL6100	3.3 V	1.5 A (surge @100us)	3.9 W(surge)
Pickup sensor UV LED (2)	5.0V	40mA	0.2W
User trigger	5.0 V	20 mA	0.1W
MCU MSP430G2553 (2)	3.3 V	230 uA	0.8mW
Servo motors HS-311 (2)	5.0 V	200 mA	1W

Table 5.2.1: Voltage, current and power requirements of each system

5.2.2 Item Acquisition

The Item Acquisition subsystem is simple in concept, but tricky to implement in reality. Through exhaustive research and moderately successful iterations of a working design, the final design of this subsystem entails modulating a UV LED light source, incorporating a Transimpedance Amplifier (TIA) with a photodiode as its current source, a high-pass filter to reject low frequency light-fluctuations and ambient sunlight, and a simple envelope detector to maintain a steady DC value to feed into the Analog-to-Digital Converter (ADC) in the MSP430 MCU.

The UV LED is turned off and on by an N-channel Mosfet, modulated at 56kHz by a 555 timer. The light reflected off of the ground by way of the UV LED generates a current in the photodiode (located very close to the light source) which turns into a modulated voltage at the output. A High pass filter at the output of the amplifier rejects DC and low-frequency light. The signal gets

demodulated by the envelope detector for a steady DC signal into the ADC. When on the road, the reflection of the pavement generated less than 300mV at the output, but when a neon-colored surface is present under the UV LED, >1V output is generated at the output that feeds into the ADC. See Figure 5.2.2.1 for a schematic of the item pickup circuit.

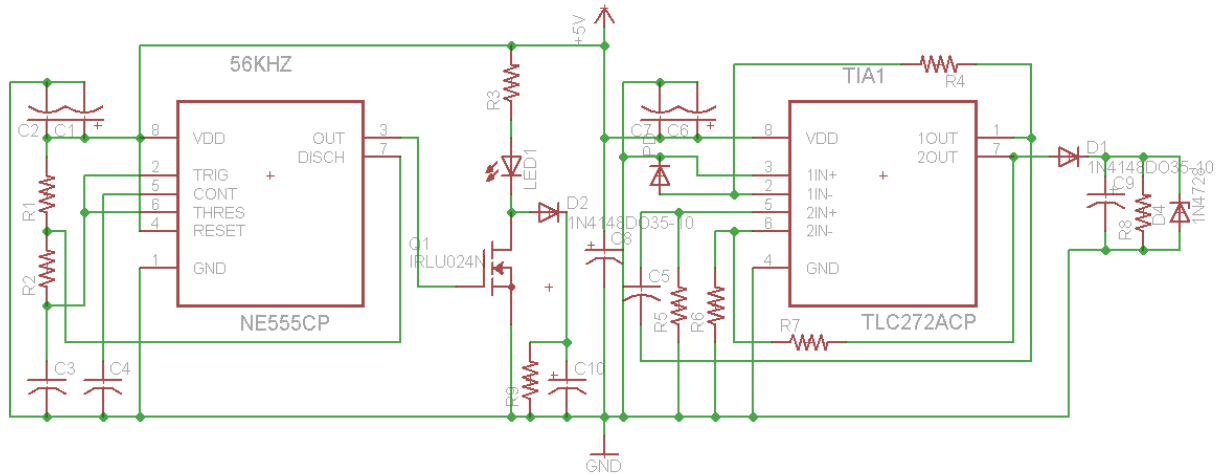


Figure 5.2.2.1: Item Pickup Schematic

5.2.3 PCB

The MSP430 will be mounted on a printed circuit board along with the power system components. The pins on the MSP430 that are actually utilized by this system will be connected to wire terminals at the edges of the board for connection to the various other modules. The MSP430 will be able to read and control many of the other features directly, but the infrared transmitter and the brake lighting system will require more power than the MSP430 can source from a single pin. Therefore, the printed circuit board will also have two MOSFETs connected to the IR transmitter and the brake lights. There will also be a small LED to indicate that the power is on. The MSP430 itself will be mounted in a 20 pin DIP socket that will be solder to the printed circuit board. Mounting the controller in a socket instead of soldering directly to the board will ease in programming, debugging, and upgrading the system later.

5.2.4 Servo

The kart engine will be controlled by an all metal hobby servo connected to the throttle regulator. The servo will be mounted to a large heat shield that is already in place on the top of the engine. Between Lazer Kart events, the engine will run normally. When something on the Lazer Kart system commands either full throttle or idle, the servo will rotate and either boost the power of the engine or cut the power to idle, depending on the event.

5.2.5 LED Accessories

The LEDs will be placed in various locations on the karts, including on either side of the driver and around the roll bar above the drivers head. The programmable LEDs will be controlled by either the available pins on the MSP 430, the use of I2C or an entirely separate Arduino MCU depending on the requirements, time and budget constraints of the project. The LEDs will perform different lighting displays depending on the event occurring in the game. For example, when a driver is hit by an opponent, the LEDs will flash red for a few seconds, giving the effect that their kart is malfunctioning or if the driver fires their weapon the LEDs will display a cascading effect from back-to-front as though the weapon is being discharged.

5.2.6 IR Transmitters and Receivers

The IR Transmitters and receivers are the main race combat simulator for LazerKarts. They will operate on a 56kHz PWM carrier signal with a wavelength of 940nm. The transmitter will be incorporated into a barrel system mounted on the front of the brake light box, the receiver will be combined with the braking and hit light system, and mounted on the rear of the kart. Drivers will use the IR lazer system to tag other drivers to facilitate passing during the race. This system will connect to the main unit with removable plugs for easy replacement

5.3 Software Summary

The Lazer Kart system will be controlled by the MSP430. Because the events that make up the game will happen relatively infrequently, the software is largely interrupt based. It will use global variables to keep track of interrupt flags, items picked up, items used, and general counters. The Main loop on the software program only increments an item counter. Changing the value of this counter every clock cycle allows for randomized item pickup. As the different sensors and modules of the Lazer Kart system detected events, they will trigger interrupts and the associated interrupt service routine. These are summarized here:

5.3.1 Item Pickup

Once the pickup detector has caused pulled the voltage above 1 volt on the pickup pin, the software will begin the pickup function. Steptick will be incremented from 0 to 25000 and the red and green LEDs will cycle with a delay of steptick cycles. Then, the LSB of "itemcounter" will be checked and either a 1 or a 2 will be written to the variable "readyitem". Finally, the main loop will resume.

5.3.2 Main Loop

The main loop is where the program will wait for an interrupt or event to happen. The first thing that will happen in the main loop is the incrementing of the itemcounter variable to allow for a random item selection. Next, the main loop will configure the analog to digital converter to sample the Pickup pin. If the voltage is over 1 volt on that pin, which means that we are driving over a florescent item pickup pad. At that point, the software calls the Item Pickup function. If the voltage on the pickup pin is less than 1 volt, then the program next checks the hit pin. We originally used interrupts for the pickup and hit sensors, but these proved to be too sensitive and were triggering on fluctuations as small as 10 micro volts. To reduce the number of false triggers, we used the ADC to measure the voltage on the pin and react if it exceeds 1 volt.

5.3.3 Hit Detected

When the IR receiver detects a signal from another kart, the kart has been “hit” by the “laser”. When this happens, the circuitry in the brake light will pull the Hit pin up to 3 volts. This will be detected by the software using the ADC. At that point, the Hit function will be run. Here, the software will turn on the brake lights and hit indicator lights by setting that pin high, set the throttle servo using CCR2 to the idle position, wait 5 seconds, and then reset the servo position and the lights. Finally the main loop will resume.

5.3.4 Trigger Pulled

Pulling the trigger will trigger the ISR from the trigger pin. This portion of the ISR will check the status of “readyitem”. If it is 0, P1IFG will be reset and the main loop will resume. If it is 1, the boost routine will be called as described above. If it is 2, the pin controlling the IR transmitter will “fire”. The IR transmitter transmits at 56 kHz in a specific pattern. This will be described in detail in the IR section of this report.

5.3.5 Interrupt ISR

When an interrupt is detected, the microcontroller will immediately go to the interrupt service routine (ISR). This ISR will first temporarily disable interrupts so the interrupt is not interrupted. Then, the ISR will use IF statements to determine which sensor caused the interrupt. Most interrupts will be caused by pulling the trigger on the dashboard. Once the event has been determined, the ISR will take the appropriate action. Finally, before returning to the main loop, the ISR will reset the interrupt flag register and re-enable interrupts.

6.0 Prototype Construction and Coding

6.1 Building the Modules

One goal of the project is that the go karts are easily maintainable. It was expressed by the project sponsor that each kart is already requiring regular maintenance, leaving little time or resources for additional maintenance. To reduce the amount time required to fix or replace any of the modules they can be attachable or detachable, making the modules easy to swap in and out with a working module. The systems that are either located in a specific location on the kart similar to the weapons acquisition sensor or the IR Tx/Rx sensors are modulated.

6.1.1 Connectors

One way to isolate the modules can be through the use of board-to-board, wire-to-board or wire-to-wire connectors. There are a number of distributors carrying a wide variety of these multi-wire connectors such as Molex. When selecting a connector there are many options such as the number of wire positions available, contact area and thickness, housing material, right or vertical circuit connection.

The weapons acquisition sensors will only needs power and ground running to three different sensors under the kart, so the number of wire positions will be 6. This circuit is very low power, only needing about 30mA of current so the connection area will be minimal. For accessibility, the connector will be located near the PCB. With this in consideration the weapons acquisition sensors only require a wire-to-wire connector as long as it is in close to proximity to the PCB. One connector will be needed for providing power to the PCB from the coil, having two positions for high and ground. The connector will need to be large enough for 14 gauge wire. There will also need to be a connector for the ready-light button on the steering wheel with only 2 positions. There will be a wire-to-wire connector running from the IR Tx/Rx, one coming from the back of the kart (Rx) and the other from the front of the kart's seat (Tx). Wire-to-wire connectors will be used for the LED accessory lighting to the PCB, 1 on each side of the kart. The chosen LED strips only require a VCC and ground wire, so this connector will only need 2 positions as well. Their will need to be a connector for the servo motor that is near the engine block the only requires two wire positions as well. If ZigBee is used this system will also require a connector.

The option of wire-to-board connectors are a possibility but the issue with this approach is that these connectors require a lot of real estate and add more cost to the fabrication of the PCB then does the additional costs of the wire-to-wire connectors. A typical connector is low cost but it should be considered that the modules will be exposed to dust, oil, vibration and water regularly so the best selection of connectors will seal the wires from the elements. A family of

connectors that meets these requirements is the Mizu-P25™ Miniature Waterproof Connectors (Sealed Connectors). Table 6.1.1.1 shows some of the key features of these connectors. Even though the system could operate perfectly without the connectors, they are in fact the best approach to reducing the amount of time it will take to repair the karts, should any of the components fail or get broken.

Certified for IP67 rating	Complete dustproof and waterproof protection
Compact size	Space saving for tight packaging applications
Integral seal stopper feature	Waterproof protection
Spring-beam terminal design	High pressure and small deflection for high-vibration applications
Raised-body male terminal design	Provides polarization to prevent mismatch
Positive locks	Secure mating retention

Table 6.1.1.1: Mizu-P25™ Miniature Waterproof Connector Details

6.1.2 PCB Housing

Due to the exposure to the elements and the threat of being damaged by riders, the use of a durable waterproof housing for the PCB is an important preventative measure. There is a number of off the shelf containers that would be suitable for the PCB. The dimensions of the whole PCB are 3.5 x 2.5 in. One option is to have the box custom manufactured by one of the many companies specializing in this line of work; however, the cost is high. Another option is to purchase an off-the-shelf enclosure. A manufacturer of these enclosures is TEKAM Enclosures®. Customers can specify cases with flat end panels for handheld or portable use, or end panels with integrated wall mounting ears. They are available in sizes from 2.75 x 2.36 x 1.22 to 6.89 x 4.17 x 1.81 in (Extruded Aluminum Enclosures) and come with 2 molded rubber cases gaskets for sealing. There will be a need to drill holes into the casing so that the various connections can be easily disconnected when they need to be replaced. Each hole drilled will have gaskets or some form of sealant to protect the PCB from the elements. An image of the enclosures can be seen in Figure 6.1.2.1.



Figure 6.1.2.1: PCB housing (Extruded Aluminum Enclosures)

6.1.3 Servo Mount

The group considered having a custom mount built for the servo but the quote was out of the available budget so instead the servo mount will be made using multiple layers of sheet aluminum sandwiched together to increase rigidity and strength. Before sandwiching the layers of aluminum together each layer will be worked on separately. Each layer will require a rectangular hole in the center large enough for the servo to slip into. The servo will be screwed down to the sheets of aluminum using small tap con screws, thus connecting the layers of aluminum together. The mount will then be attached to the engine block using bolts.

6.1.4 Weapons/Boost Pickup Sensor

Besides putting the sensors in a convenient location (discussed in the installation section) the sensor underneath the kart is protected from dirt and debris that could potentially cause the sensor to fail. A thin sheet of acrylic is screwed in place over the open hole in which the UV LED is exposed. The location of the sensor is easily accessible on the kart such that the acrylic can be wiped down if any grease or mud from the track gets on it.

6.2 Installation

The LazerKart subsystem modules and sensors are installed in various locations including the go kart frame, engine block, and steering column. The installation procedure will have to take into account areas that are subject to driver interference (getting in and out of the kart), high vibration, heat from the engine/exhaust manifold, line of sight (for IR subsystem), and under-kart shade (item pickup) among others. The installation of each subsystem will be explained in detail accompanied by pictures to enhance the descriptions.

These preliminary installation descriptions are subject to change once the finalized modules are physically on hand and ready to be mounted.

6.2.1 Throttle Control Servo

The Throttle Control Servo is mounted onto a bracket that will be fabricated from an 8"x2" aluminum plate bolted through the two mounting arms extending from the engine block as show in Figure 6.2.1.1. The boost spring and the slow spring link the servo arm to the throttle regulator as indicated by the arrows. After shock testing the mount, any necessary steps to increase the stability of the bracket and/or lessen vibration issues will be taken into consideration.

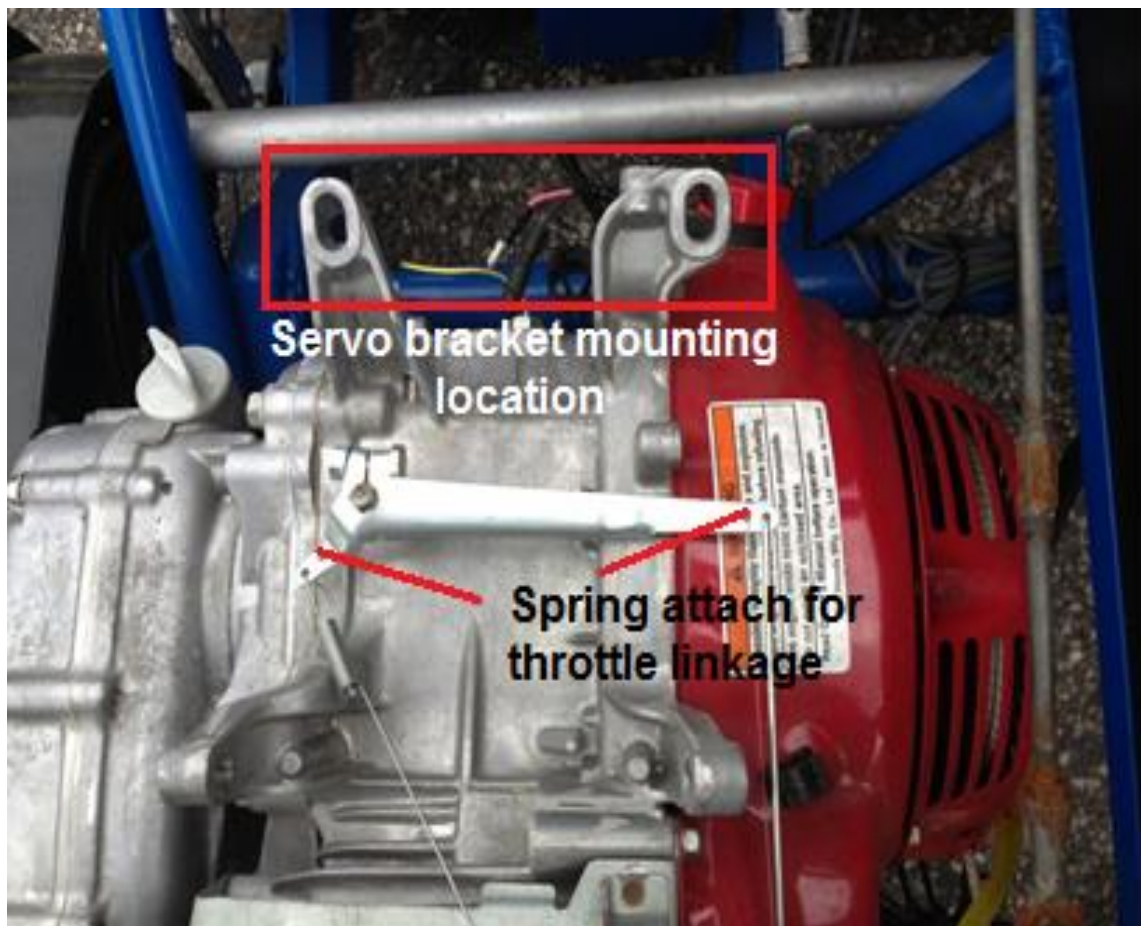


Figure 6.2.1.1: Throttle Control Servo mounting location

6.2.2 LazerKart Main Module

The main module will be housed in a weather-proof box that will be mounted behind the drivers seat on the left side of the kart (Figure 6.2.2.1). This is a relatively centralized, easy-to-access location for all of the modules to connect to and no new brackets will have to be fabricated. Shock-testing was performed on all modules. However, it is notable that the KARTROL module can only be replaced if the LazerKart main module will incorporate the ZigBee communication system that will effectively allow for overriding the control of the throttle from a remote location by the staff of the go-kart venue.



Figure 6.2.2.1: Main Module mounting location

6.2.3 Item Pickup Sensor

The Item Pickup Sensor is remotely located from the main module, into the area on the go kart frame floorboard (Figure 6.2.3.1). The circuit is housed in a 3"x2"x1" black box with the UV LED and the photodiode mounted on the bottom surface of the box. The bottom of the box is 1 5/8" from the ground which proves to be plenty of clearance for any typical go-kart track.



Figure 6.2.3.1: Item Pickup Sensor mounting location

6.2.4 IR Transmitter/Receiver

The IR laser tag receivers were mounted up high on the backing plate of the roll bar. This way, the receiver will be easier to hit with the IR transmitter. The roll bar plate is approximately 1/8" thick, so a mounting solution was to use high strength double sided tape to attach a metal plate to the front of the backing plate and then directly bolt the module onto it, secured with nuts and washers. This is displayed in figure 6.2.4.1



Figure 6.2.4.1: IR Receiver mounting location

6.2.5 Dashboard

The concept behind the dashboard is straight forward and relatively easy to implement. The idea is that there needed to be some kind of obvious indicator of what is occurring in the game at any given time that can be easily interpreted by the driver of the go kart. To do this we designed the dash to display three different colors, red, blue and green, for the different functions of the game. More specifically, when the LazerKart passes over a pickup sensor on the track the dashboard flashes the blue and green LEDs to indicate that an item was in fact detected (blue light indicates a laser and green light indicates a boost). The blue and green LEDs alternate back and forth until only one light will remain on, indicating that they have acquired either a boost or a laser. That color will remain on until the driver pushes the trigger which will then either cause acceleration or fire the laser at their opponent. Once the trigger has been pushed the blue and green LEDs will remain off until the LazerKart goes over another item. The third color red will only light up when the user is hit by an opponent.

The dashboard uses a total of 9, 15mA LEDs in parallel, 4 of which are multi-color green/blue LEDs and 5 red LEDs in an "X" configuration. Each set of colored LED's cathode is in series with an LU024N HEXFET power MOSFET, of which the gate is connected the appropriate pins on the MSP430 controller to complete the circuit to ground when the dash is supposed to light up. The trigger is simply connected to an output pin on the MSP which is floating until the trigger is pulled and the circuit is completed to an input pin on the controller that is waiting for a signal from the Driver to activate the transmitter or the boost servo motor. Figure 6.2.5.1 shows an image of the dashboard with all the LEDs lit.



Figure 6.2.5.1: Ready light mounting location

6.2.6 Trigger

The item/boost trigger mechanism or “fire button” is located on the portion of the dashboard box where the right thumb tends to naturally rest. It will require an aluminum bracket that is mounted on the dash. All connecting cables are interior to the dash box. Figure 6.2.6.1 shows the location.



Figure 6.2.6.1: Trigger mounting location

6.2.7 Brake light/Stop Lamp Switch

The main brake light would be incorporated into the module for the IR receivers on the roll bar (Figure 6.2.7.1). The signal for the brake light will come from the rear of the brake lever assembly. (Figure 6.2.7.2).



Figure 6.2.7.1: Brake Light mounting location

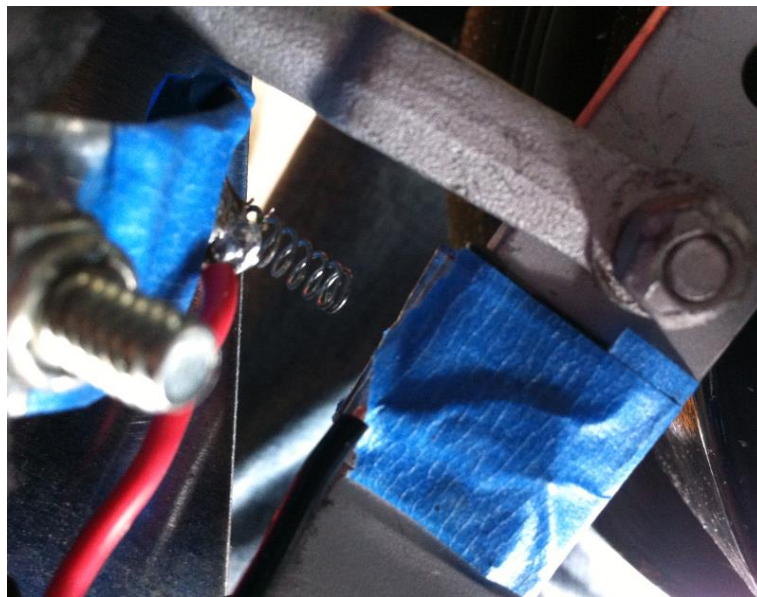


Figure 6.2.7.2: Stop Lamp Switch mounting location

6.2.8 Accessory Lighting

The accessory lighting LED strips will need to be located in such a fashion as to minimize the chances of a driver accidentally making physical contact (i.e. kicking) with them when entering and exiting the kart. Ideally, the LED strips that activate with the firing of a lazer would run along the side rails (Figure 6.2.8.1) of the kart so they would be visible to the driver, however that may be a bad location due to the traffic of drivers' feet entering and exiting the kart and brushing up against them. To alleviate this, the LED strips may need to be laid

under a thick protective clear plastic strip (similar to rope light) that could take the abuse

Like all the other modules, the wires will be concealed within heat shrink tubing and will hug the frame with zip ties.



Figure.6.2.8.1: Accessory light mounting location

6.3 Software Development

Complex embedded software is best written incrementally. When actually developing this project, the code went through several iterations that got increasingly complex. Lower level functions were developed and tested before additional functionality is added to the code. To test the code, a small testing platform was used.

6.3.1 Testing Platform

Because most of the software development will take place away from the actual project kart, there needed to be a way to quickly test and troubleshoot the software code. The MSP430 Launchpad comes with two LEDs, but that is not sufficient for testing complex code. For this, a small development board was used. On this testing board, 6 LEDs were mounted, each with their own current limiting resistors. The LEDs have a forward voltage drop of approximately 2 volts and the MSP430 uses a 3.3 volt signal as a logical high. The LEDs have a current limit of 20 mA. To find the proper resistor value for current limiting:

- $V = I * R$
- $(V_{msp} - V_{led}) = I * R$
- $(3.3 - 2.0) = .020 * R$

- $R = (3.3 - 2.0) / .02$
- $R = 1.3 / .02$
- $R = 65 \text{ ohms}$

As 65 ohms resistors are not widely available, any value from 65 to 100 may be used. A higher resistance will mean lower current. The LED would not glow quite as brightly, but that isn't a concern for testing, we are just trying to verify if pins on the MSP430 are going high or low at the proper times.

In addition to the 6 LEDs used for testing, we will use another board with 3 small buttons. These are single pole, single throw buttons that were used to simulate the inputs to the Laser Kart system. The three simulated inputs will be the driver's trigger, the item pickup, and the hit detector. As discussed in the software section, the interrupts for these three actions are triggered by a low to high level change on the input pins. Therefore, these buttons will be connected with a pull down 10k resistor.

The MSP430 Launchpad development platform is equipped with male headers for each pin. To ease development, each LED and switch on the testing platform was connected to a short length of wire ending in a female header. This allowed for the easy connecting of the testing platform to the Launchpad and speed development. In this way, all interrupts, inputs, and outputs were able to be tested in the lab before being taken to the kart for final testing.

As mentioned above, writing the code was done incrementally. Each function was tested on the test platform before the additional functionality was added to the code. First, the setup routines were written and basic port direction was verified. Then, the interrupt setup code was written and the interrupt service routine was written. To test this, the test platform was connected with the push buttons connected to the input pins for trigger, item pickup, and hit detect. The LEDs were connected to the item indicator pins, the brake light pin, and the IR transmitter pin. Each button was pressed and each interrupt and function was verified. Then, once the interrupts are known to be working, Pulse Width Modulation for the servo control was added. This involved setting up Timer A and adjusting CCR2 to set different angles for the servos. Finally, the IR transmitter will need a 56 kHz pulsed signal. This was configured using software delays for toggling the IR TX output pin. This was tested using the hand held IR testing equipment described earlier in this report.

Once all the software code for all the different functionality was written and tested on the test platform, the MSP430 was loaded with the complete code and taken to the actual kart for installation and final testing.

7.0 Testing

7.1 Subsystem Tests

7.1.1 Item Pick-up Sensor Testing

Testing of the item pick up sensor was simple in format: drive the go-kart over colored markers and make sure the sensor differentiates between the road and the markers consistently. While the subsystem can distinguish between multiple colored markers, only one is demonstrated for the purposes of the project.

Testing was performed by placing fluorescent poster board upon a paved area, slowly positioning the kart directly over the marker to where the item pickup sensor is reading it and measuring the voltage on the output of the circuit. The testing was run with the sun in different positions in the sky and in complete darkness. This is where we determined that ambient sunlight was a major issue and was skewing the desired output by as much as 500mV.

Once the circuit was redesigned for ambient sunlight rejection, we re-tested the system and the results were consistently accurate for any kind of ambient light scenario. The bright orange-red neon marker generated a solid 1.5V output from the circuit no matter what time of the day it was.

At that point we tested the speed of the system with the output connected to the ADC of the microcontroller. The ADC is looking for any voltage that is higher than 1V in order to trigger the item pickup algorithm. Naturally, we used the orange-red, neon marker again and drove over it at full speed (~17MPH) countless times without a single glitch or misread. For good measure, testing done at varying slower speeds proved just as successful.

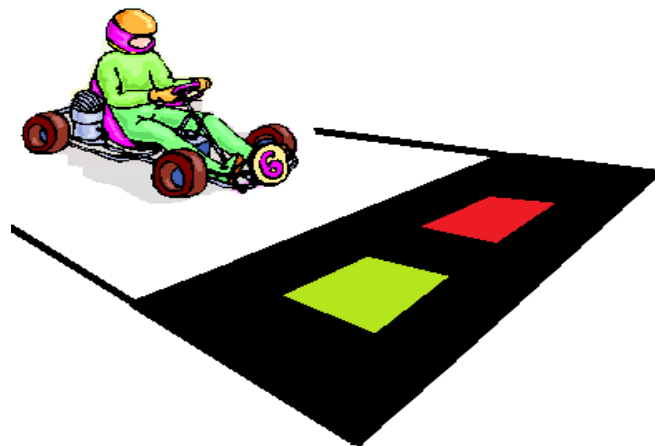


Figure 7.1.1.1: Item pickup/boost zone with fluorescent markers

7.1.2 Boost-zone Sensor Testing

The Boost zone testing phase will address several calibration procedures required to allow for a noticeable, yet controlled speed increase in the go kart. The first issue is sensing the boost-zone, then determining an adequate throttle threshold, and lastly, adjusting the duration of the speed boost.

The sensing portion of the Boost-zone tests will be similar to the item pick up tests. A specific color, probably yellow or green will be chosen for the Boost-zone marker. Whichever method that works the best for the item pick-up, whether it be the duct tape or the painted mats will be the same for the Boost-zone.

The donor go kart is throttle-limited by an adjustable nut and bolt “stopper” that is placed behind the gas foot-pedal. With the stopper in place, the top speed is roughly 17 mph. The stopper was removed completely to determine if speed gains were noticeable. While top speed wasn’t greatly improved, the acceleration from the “stopped” throttle point to the unlimited point was very noticeable. This will allow for an enjoyable speed boost even at full throttle. However, this was done purely on speculation and guessing with one’s foot. The true test will come when the servo physically pulls the throttle to the desired position from the limited threshold. The servo will be linked to the throttle by a spring. Pre-emptive measurements were taken as to determine spring length, however, these trials will be an opportunity to test varying spring strengths and lengths to determine the optimal choice.

Lastly, the duration of the speed boost will need to be adjusted, however, these adjustments need only be preliminary. The best way to determine whether a speed boost is too long or too short will be in an actual play test with other karts.

7.1.3 Microcontroller Testing

Once assembled and installed, one of the most important areas to be tested was the microcontroller. It controls nearly all of the functions of the Lazer Kart system and had to be tested thoroughly for both normal operation and resistance to anticipated potential failure modes. Some of these tests were repeats of individual system tests, but are necessary to ensure the system is working properly as a whole.

7.1.3.1 Item Pickup

Purpose:

The item pickup subroutine is the first step in the software process. It is important to make sure that this routine is reliably being run when an item pickup indicator is driven over.

Procedure:

To test the item pickup ability, drive the kart over an item indicator at maximum speed.

Expected Results:

The red and green item lights should alternatively flash and then settle to a single light. It should select a Boost roughly half the time and a Lazer half the time. Do at least 8 tests at various speeds and make sure at least 2 items are selected from each item.

Actual Results:

The pickup was successfully detected at all speeds.

7.1.3.2 Boost Item

Purpose:

Once an item has been picked up, the next step in the Lazer Kart process is to use it. The two items will be tested individually, starting with the Boost Item.

Procedure:

With a Boost Item ready, depress the trigger. Static testing of this should first be done with the kart on jack stands.

Expected Results:

The kart should noticeably speed up for 5 seconds and then return to normal speed. Verify the servo rotates to 45 degree counterclockwise for 5 seconds and then returns to neutral position.

Actual Results:

Servo rotated as expected, Figure 7.1.3.2.1 shows the trail runs for the adjustment of the boost mechanic.

Run	Max Unboosted RPM	Change	Max Boosted RPM
1	2800	Guess	3400 Adam
2	2800	2 bolt turns	3450 Ryan
3	2800	neg 1/8" cable	3650
4	2800	pos 1/8" cable	3500
5	2800	2 bolt turns	3580

Figure 7.1.3.2.1

7.1.3.3 Lazer Item

Purpose:

The other item to be tested will be the Lazer Item.

Procedure:

Testing the Lazer will require the use of the Handheld IR Testing Unit. The Lazer will be tested both statically and while the kart is moving. Details of the IR system testing will be described in full later in a following section.

Expected Results:

If the IR receiver is picking up the IR transmission, then the microcontroller's function is verified to be working.

Actual Results:

- 105ft consistent maximum
- Greater range possible depending on conditions
- 160 degree receiver reception
- 3 degree transmitter angle

7.1.3.4 Boost Pad

Purpose:

Because the Boost Pad is attached to a different pin and calls a different subroutine than the Item Pickup Pad, it should be tested individually.

Procedure:

To test the Boost Pad routine, the kart will be driven over a Boost pad at full speed.

Expected Results:

The kart should speed up for 5 seconds and then return to normal speed.

Actual Results:

The Boost Pad dynamic has not yet been incorporated into the track implementation.

7.1.3.5 Lazer Hit

Purpose:

Testing being hit by another driver's lazer incorporates IR testing with the microcontroller. Here we test them working together.

Procedure:

Begin by activating the IR transmitter in the handheld unit while pointing at the kart. This should first be done with the kart on jack stands and with the IR transmitter at a distance and angle as described in the Specifications section. Once proper static operation has been verified, repeat the previous steps while the kart is driving away at 3 different speeds ranging from coasting to full speed.

Expected Results:

The microcontroller should detect the IR signal, turn the brake and hit lights on, and rotate the motor control servo 45 degrees clockwise for 5 seconds before returning to neutral and turning off the brake and hit lights.

Actual Results:

This was tested in conjunction with the Lazer Item testing, the results are shown above in section 7.1.3.3.

7.1.3.6 Possible Failure Causes

7.1.3.6.1 Vibration and Loads

Purpose:

Lazer Kart is designed to be a rugged, dynamic system that can take the abuses inherent to tourists and teenagers driving go-karts. This ruggedness will need to be verified before deployment.

Procedure:

After full installation, the kart should be driven as aggressively as possible to simulate the actual operating conditions the system will be used in. A series of full power accelerations followed by slamming on the brakes to a full stop will test linear durability. The tracks these karts will be driven on are very curvy, so a series of sharp turns at full speed should be made in alternating directions to try to shake the system loose. Next, combining rapid acceleration and deceleration with sharp turning will test the limits of the system. Finally, driving the karts over a bumpy road will simulate rough track conditions that may be encountered.

Expected Results:

Areas to inspect after this test include all of the solder joins on the PCB as well as the cable connections connecting the parts. After all of this abuse, the whole system should be re-tested as described in the Normal Operations Testing section above.

Actual Results:

After thorough testing, the system has proven to be extremely robust.

7.1.3.6.2 Shock

Purpose:

In addition to harsh driving conditions, drivers will occasionally hit something. This may be the sidewall of the track or another kart. For safety reasons, we will not recreate full speed crashes. Our goal is not to test the structural integrity of the kart to failure. However, abrupt stops by bumping into a barrier at moderate

speed will be done to ensure survivability of the Lazer Kart system and identify any weak points in our mechanical connections.

Procedure:

Abrupt stops by bumping into a barrier at moderate speed will be done to ensure survivability of the Lazer Kart system and identify any weak points in our mechanical connections.

Expected Results:

Areas to inspect after this test include all of the solder joins on the PCB as well as the cable connections connecting the parts. After all of this abuse, the whole system should be re-tested as described in the Normal Operations Testing section above.

Actual Results:

No issues found.

7.1.3.6.3 User Damage

Purpose:

Another type of shock that can be expected to be encountered is going to be caused by the operator's limbs. Excited drivers climbing in and out the karts are bound to kick, step on, bump, and knock with their arm any possibly exposed component.

Procedure:

To test for this, the driver's dashboard, external IR sensors, and the servo mount will be tested by kicking with moderate force to ensure secure mounting.

Expected Results:

After all the shock tests are done, the whole system should be re-tested as described in the Normal Operations Testing section above.

Actual Results:

No Issues Found.

7.1.3.6.4 Water

Purpose:

It is the operator's policy to discontinue kart races in the event of rain, but this being Florida, our system will eventually get wet.

Procedure:

To test weatherproofing, 8 oz. of water will be poured onto each component of the system from above to simulate rain.

Expected Results:

After the rain test, the system will need to be completely retested as described in the Normal Operations Testing section above.

Actual Results:

During testing in rain, no issues were found, however, driving over puddles can cause a pickup trigger, due to the high reflectivity of the standing water.

7.1.4 Servo Testing

Purpose:

As the only moving part of the Lazer Kart system, extra testing should be done on it to verify proper operation. The servo is moved by both Boost events and Idle/ Cut events from IR hits from other karts.

Procedure:

As such, both directions should be tested. Boost and Cut movements should both be tested at idle, half power, and full power. This is because the return springs on the engine governor will be applying different forces depending on the throttle position. Finally, tests should be done where both Boost and Cut signals are applied when the kart is at different speeds. These tests will be done at a full stop, middle speed, and at full speed.

Expected Results:

The servo should set the engine to the desired throttle position regardless of the kart's speed or the driver's throttle position.

Actual Results:

Testing the servos at different speeds indicated a fairly consistent boost based primarily on the tension of the connection, not the current speed of the kart.

7.1.5 IR TX/RX Testing

The IR LED tagging system is designed to facilitate the combat aspect of the racing game. For best effect it will be necessary to calibrate the transmitters and receivers in a way as to make the race enjoyable and challenging. Typical lazer-tag systems employ a lens system to produce narrow high power beams that can score hits over 200 yards away. For the Lazer karts game purposes, this range is unnecessary, and potentially detrimental to the game play. Ideally the maximum registerable range is on the order of 100 feet.

In order to accomplish this goal an off kart version of the tagger and receiver is built and tested different ranges. The receiver was fixed to a vertical surface, and the tagger was fired at the receiver several times, while increasing the distance from the receiver. Initial testing determined that lensing was needed and a

25mm DCX lens with a 55mm focal length was chosen to match the physical characteristics of the tube, and the IR LED being used

After the initial run through of the lens testing, the entire process with be repeated for different lighting conditions. Direct sun lighting is the condition most likely to cause problems with the lazer system. We were able to achieve consistent hits up to 100 ft with greater ranges possible depending on conditions. At 10 ft, we achieved a range of 160° which diminished to 80° at 100 ft.

7.1.6 Power Systems Testing

The power system required multiple stages of testing. Simulations were run on the circuits but they only provide results of an ideal environment and operating conditions. Some of the variables and conditions that needed to be seen in an actual game of Lazer Karts include high ambient temperature, moisture, vibrations and long term wear and tear. Although some of these conditions cannot be considered when designing a prototype they are still worth noting, as they all have an impact on the longevity and performance of the overall system. These tests will be run multiple times in a sequential manner as needed while component values such as resistances and capacitances are changed

7.1.6.1 AC Coil Testing

Purpose:

The first stage of testing is determining the characteristics of the signal produced by the Honda engine's AC coil. The following steps were taken when analyzing this signal.

Procedure:

- Measured peak voltage value while at idle
- Measured peak voltage value while throttle is open
- Obtained frequency of AC signal at idle
- Obtained frequency of AC signal while throttle is open
- Recorded any unexpected characteristics of AC signal i.e. shape and/or changes in signal produced due to RPM of engine
- Recorded all values and potential causes for unexpected signal characteristics
- Saved images of signals displayed on oscilloscope for each scenario

Results:

When testing the AC coil signal it would have been ideal if the signal produced turns out to be a sine wave for all throttle positions. It was also expected that the frequency has a 1-to-1 ratio with the RPM of the engine, i.e. when the throttle is in the idle position with a rate of 1200 RPM the frequency of the coil is around 20

Hz and when the RPM of the engine is high around 3200 RPM the frequency of the signal is around 50Hz.

Note: It was necessary to do some research on the internal workings of the Honda GX270 engine's AC coil because the signal measured showed many unexpected characteristics.

7.1.6.2 Rectifier

Purpose:

Measure the output of the GBU601 full-wave bridge rectifier circuit when connected to the output of the AC coil.

Procedure:

- Applied power to input of rectifier circuit
- Measured output with respect to "low" node while at idle
- Measured output while throttle is fully open
- Checked output with and without coupling capacitors to understand rectified signal and ripple voltage individually
- Ran tests with several capacitor and load resistance values to obtain optimal ripple voltage
- Saved images displayed on oscilloscope for further analyses
- Recorded and provide potential explanations for results obtained
- Obtained results when using different the 1N4148 diodes and Schottky diodes

Results:

The output of the rectifier with and without the coupling capacitors was a purely positive rectified signal and a rippled DC voltage respectively. The DC peak-to-peak value of the ripple voltage output only varied by a small amount when the throttle position was changed from idle to fully open however the base DC value itself changed drastically based on the throttle position.

7.1.6.3 Regulators

Purpose:

This test was run to determine the output of the various regulator circuits built. Each regulator was tested without connecting the actual component it was design for as this was a precautionary step taken to avoid destroying them. Instead a load, resistors and LEDs were be used giving a good approximation to the operating resistance and current requirement of each system.

Procedure:

- Connected the input pin of each regulator, with appropriate capacitors and adj. resistors necessary to simulate device, to the output of the full-wave bridge rectifier.
- Measured the output voltage and current of each regulator
- Found the experimental resistance needed to obtain desired voltage and current while adjusting the throttle position
- Recorded all results and DC values displayed on oscilloscope

Results:

When running the tests on the regulators it was expected that the DC voltage and current are the ones required by each subsystem. These values were approximately the values seen in Table 4.1

As stated before, these tests needed to run multiple times, requiring large amounts of research between each test to redesign a circuit, specifically the rectifier, or choosing a different regulator to obtain the desired results. The power system was particularly unpredictable due to the wide ranges of values produced by the AC coil, making the testing process time consuming and tedious. This system underwent large amounts of further testing when it was connected to the actual devices it was designed to power to ensure that these components operated as expected. Additionally, the systems were also tested with the discussed batteries to determine the amount of time between charges and operation performance.

7.1.7 Optional Module Testing

7.1.7.1 Accessory LEDs

Before the LEDs can be installed it is important that they function properly. Testing the LEDs will involve two stages; determining how many LEDs can be on at once and how it will affect the power output of the Honda GX270 AC coil and other components; making sure that the LEDs respond to the microcontroller for the correct function and they show the correct display.

Stage 1

Purpose:

The first test will be run to determine how much power the LEDs will be consuming when they are at their dimmest and brightest.

Procedure:

The LED strip is spec'd to have a max current draw of around 1.8A. The light displays for lazer karts will only need short intervals of maximum current draw if at all. After the software has been completed it will be modified to test the LEDs.

One test will turn a single LED on while the current is measured. Another test will be performed to measure the current while all the LEDs are lit. Several intermediate programs will be written to measure the amount of current when the number of LEDs increases or when all of them are adjusted from off to a brightness value of 255. The current values will be multiplied by the 5V operating voltage giving a range of power consumption. These values will be plotted and added to the maximum power consumption of the other modules, then subtracted from the maximum power output of the AC coil. By collecting this information it will be easy to calculate the maximum number of lights that can be on at any given moment based on the “worst case scenario” or when all modules are drawing maximum current at the same time.

Results:

When testing the strips it is expected that they will not draw too much power when all LEDs are lit simultaneously. The maximum power output of the AC coil is around 75W and just one LED strip has a max power consumption of 9W allowing for multiple strips to be used, reserving batteries as a backup plan.

Stage 2

Purpose:

The LEDs are supposed to display specific patterns for the three functions of the kart. This test will check for the correct functionality of each lighting display based on the signal sent by the microcontroller.

Procedure:

After uploading the code to the microcontroller, the lights will be tested for correct functionality when; a weapon is acquired; a driver fires their weapon; the kart is hit by an opponent.

Expected Results:

- Driver fires weapon: All LEDs should light one at a time from back to front down both sides of the kart multiple times for the correct interval of time.
- Kart hit by opponent: The lights display a series of red flashes for the correct interval of time.
- Driver acquires weapon/boost: The lights will go from off to fully lit, slowly going through the different brightness values from 0-255. The color of the lights will be specific to that kart.

7.1.7.2 Audio Components

Before installing the audio components it is important that they function properly. Testing the sound effects will entail several steps. The testing will be very similar to the steps taken when testing the LEDs since both functions are going to be called by the microcontroller at the same time. Determining how loud the

speakers are with respect to the Honda engine is also an important factor to consider. It will be necessary to know how much power will be drawn from the Honda GX270 AC coil and how this will affect other components. Finally it is important that sound effects respond to the microcontroller for the correct corresponding events, weapons/boost pickup, using the weapon/boost and being hit by an opponent.

7.1.7.2.1 Power Consumption

Purpose:

The first test will be run to determine how much power the speaker(s) will be consuming when either using the speaker at full volume or the suggested on-kart headphones at full volume.

Procedure:

Using the multi-meter, a range of current values will be measured while adjusting the volume. Two separate tables will be made, one for the current values measured using the 3 inch speaker and one for when using the headphones. These values will be multiplied by 3.3V (operating voltage for the audio module) to get an estimate of how much power it requires. As done when testing the LEDs the wattages will be added to the power consumption of the other modules to obtain a “worst case scenario”. These values will be subtracted from the maximum power output AC coil to determine if batteries will be needed.

Expected Results:

When testing the speakers it is expected that they will not exceed the power output of the AC coil, which is around 75W, when operating simultaneously with the other function based modules including the LED, IR Tx/Rx.

7.1.7.2.2 Sound Effects

Purpose:

The speakers are supposed to play the .wav files when one of the three functions of the kart is processed. This test will check for the correct functionality of each sound based on the signal sent by the microcontroller.

Procedure:

After programming the microcontroller, the speakers will be tested for correct functionality when; a weapon is acquired; a driver fires their weapon; the kart is hit by an opponent.

Expected Results:

- Driver fires weapon or acquires boost: speakers should play chosen sound effect i.e. “firing lazer”

- Kart hit by opponent: speakers should play chosen sound effect i.e. “malfunction” or “powering down” effect
- Driver acquires weapon/boost: speakers should play chosen sound effect i.e. “charging lasers” or “powering up” sound effect

7.1.7.3 No Bumping Testing

Purpose:

As mentioned in the No Bumping section, the Bump Detecting subsystem will consist of an accelerometer, a comparator, and a voltage divider as shown below in Figure 7.1.7.3.1.

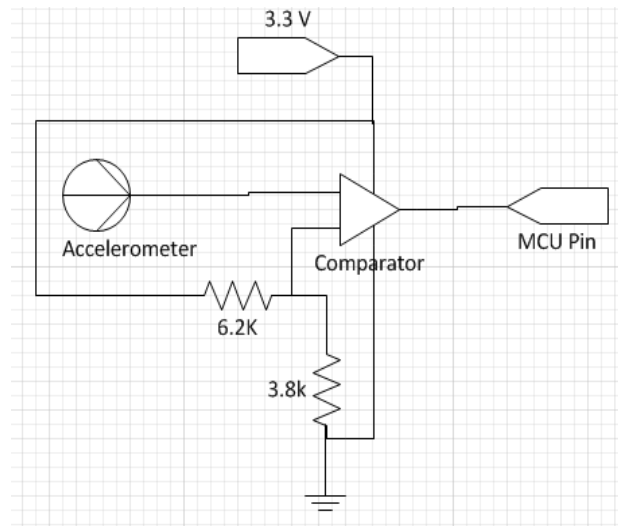


Figure 7.1.7.3.1

As discussed in the No Bumping section, an “x” g deceleration will be indicated by $1.65 - (.19 \times x)$ Volts on the accelerometer's output. We are estimating that the force of a bump will be around $-2g$. This could be wrong and will need to be tested.

Procedure:

To test this, one kart will be driven forward at full speed, followed by a second kart with the No Bumping system installed at set to detect a force greater than $-2g$. The kart to do the test bump will follow at a distance of 10 feet. From observing kart races at Fun Spot, we determined most following is done at or around this distance. Then, the driver of the first kart will suddenly idle the engine and coast by taking his foot off the gas pedal. The second driver will continue at full speed into the back of the first kart.

Expected Results:

If a bump is not detected, the resistor values will be adjusted so that the interrupt is triggered by -1.5g and the test redone. This will continue until we find a value that reliably detects bumps at reasonable collision speeds.

Actual Results:

This subsystem has not yet been added to the LazerKart system. Further development is required.

7.2 Single Kart Tests

Once the tagger setup was chosen, the single kart tests took place. The goal of this was to determine optimum placement of the added components, and was the first test of a fully functioning system.

7.2.1 Transmitter / Receiver location

The transmitter and receiver is located centered on the rear above the drivers head. This location has proven ideal, as it is centrally located and behind the driver, which limits contact. During driving, attention will be paid to foot location relative to the transmitter, and testing to determine ease of contact with the transmitter. It is likely that while some contact may occur, it will be lessened by this location.

While there are no anticipated problems with the location of the transmitter and receiver, it is best to resolve any issues that occur before mounting the system on multiple karts. The hand held unit was vital in determining the playability of the game. Distance and accuracy for hits were tracked. The full mount is shown in figure 7.2.1.1



Figure 7.2.1.1

7.2.2 Photo-detection Location

The location of the photo detection sensors have proven critical to the success of the game. Reliable item and boost zone recognition enhances the game play. The sensors are placed under the forward part of the kart, allowing the driver to have a better sense of the area needed to drive over in order to get the item or boost. The location chosen is shown by the green oval in figure 7.2.2.1. Alternate locations are shown by red ovals.

For the single kart trials, colored heavyweight paper squares will be placed on the ground and crossed at varying speeds by the kart. A success rate of greater than 95% at all speeds was achieved. The extensive testing of this part also tested the durability of the sensors to the road conditions. Attempts were made to approach the mats on straight roads as well as while making sharp turns. The undercarriage of the kart will provide some protection, and if damage is occurring to the sensors, a special housing will need to be devolved based on the results of the testing, however none has been seen.

With the expectation that the project is going to be produced for commercial use, durability of this part is crucial, as it is a key aspect of the game. With this in mind, a significant portion of play testing time will be devoted to it. Once a

suitable location and housing was determined, it can be replicated for use in multi kart testing.



Figure 7.2.2.1

7.2.3 Triggers and Item Lights

The main point of interaction for the driver will be the triggers. The trigger needs to be durable and easily accessed. As can be seen in figure 7.2.3.1, the ideal location for a thumb mount trigger would be just outside of the protective padding on the upper bar of the steering wheel. The locations of the thumb buttons are marked in red. Alternatively, a gun style finger pull trigger could be mounted lower down on the sides of the wheel, as shown in green. An extra effort will be made to expose the triggers to non-typical levels of torque, to ensure their durability. After play testing, the right thumb button location was chosen



Figure 7.2.3.1

The item lights were mounted in a dashboard box above the safety padding of the steering column, as shown in figure 7.2.3.2. This location keeps the LEDs mostly free from driver interference, yet still is highly visible. For testing purposes, attention was paid to the accuracy of the item lights, which will also tie into the pickup testing section of the single kart testing. An effort was made to dislodge the lights, to simulate treatment by drivers.

The durability again will be a key part of the testing of these parts of the system, specifically since these are the main contact points between the drivers and the game. Failure of these parts will render the kart unable to participate in the races and excessive downtime is unacceptable to the commercial viability of the game.



Figure 7.2.3.2

7.2.4 Speed Control Testing

The throttle linkage portion of the single kart testing is tied into all of the preceding tests. Because this is not a part of the system that the driver has much contact with, durability testing will be limited to mechanical workings of the servo system. Attempts were made to overwork the servo by continuously engaging the speed boost and by registering hits on the receiver. Much of this testing occurred in tandem with the item pick up and transmitter/receiver testing. One major physical test was the ability of the mounting unit to hold up under real world conditions.

Once the kart has been shown to operate correctly and over a long period of time, a second kart will be acquired and a new phase of testing can begin. Multi kart testing will be required to develop a working system.

7.3 Multi Kart Testing

Multi kart testing will allow the development of the game play mechanics and allow fine tuning of the systems. Two kart testing will followed by four kart testing, and if successful a full 16 kart game implementation.

7.3.1 Two Kart Testing

The main focus of two kart testing will be lazer acquisition and system durability when subjected to the inevitabilities of bumping during the racing. Two kart testing will take place off of the track, again with painted mats for item pick up

and boost zone testing. This is also where rough tuning will be done to the speed boost duration timers, as well as weapon length timers and throttle cut timers. Ideally any bonus should allow a clean pass, and different scenarios will be observed. Also critical is to ensure that all karts are being affected by the bonus's in the same manner. Care will be taken to ensure that all examples of the kart are as closely matched as possible.

The lazer systems will be fine tuned in this phase of testing. Due to the difference in height, of the transmitter and receiver, care will have to be taken to make the proper adjustments. Distance and accuracy of the lazer system will be again observed and recorded.

With the addition of the second kart, new variables will be taken into account. Bumping will be tested extensively, to ensure the reliability of the components and mounting brackets. One again the handheld unit will be utilized to add an extra layer of testing, it will allow reaction times to be tested from the drivers dealing with outside sources affecting the flow of the driving.

7.3.2 Four Kart Testing

With the successful completion of two kart testing and additional two karts will be equipped with the lazer system. This will be the first testing done on the Fun Spot race track and will heavily influence the game mechanics. The track will be outfitted with several temporary moveable colored mats for the item pick up and boost zones.

The focus of four kart testing will be on passing opportunities in race situations. By now the pick-up, lazer and speed control systems will have been thoroughly tested. More fine tuning will be done with the timing lengths of the speed changes as well as the lazer firing time. The colored mats will be moved around the course to determine where the best locations are for game enjoyment. Initial placement can be seen in figure 7.3.2.1. Green for boost zones, red for item pick up.



Figure 7.3.2.1

7.3.3 Full Race Testing

Once the best set up has been determined with the four kart testing, the remaining race karts will be equipped with the lazer kart system. This will be the ultimate test of the commercial viability of the game. The track will become more crowded, more bumping will occur, and jockeying for position will create different scenarios which will need to be monitored.

The main focus of this round of testing will be safety. By now, the system should be demonstrated to be functionally sound and durable. Tracking collisions when compared to races without the system will be done. It is expected that even though speed changes will occur more frequently, the ability to pass without the need for bumping will reduce the number of major collisions.

At the completion of full race testing, a determination will be made on permanent track implementation. At this point the LazerKart game system will be considered fully implemented, and work can begin on adding subsystems to increase the attraction to the Fun Spot ownership and customers.

7.4 Game Play Mechanics Testing

Once the final multi-kart testing is finished, the overall game play will continue to be fine tuned. The overriding goal from a commercial aspect of the LazerKart project is to get people to want to return to the race. It is at this point where rider feedback becomes important. With the ability to have up to 16 karts on the course at once, it will be possible to collect a large amount of data in a small time frame. During the initial implementation process, the team will be present for the race testing by the general public. Each rider will be asked to answer questions about the impression of the new system and to compare it to standard go-karting. The team will also be able to collect more ideas and suggestions for future improvements.

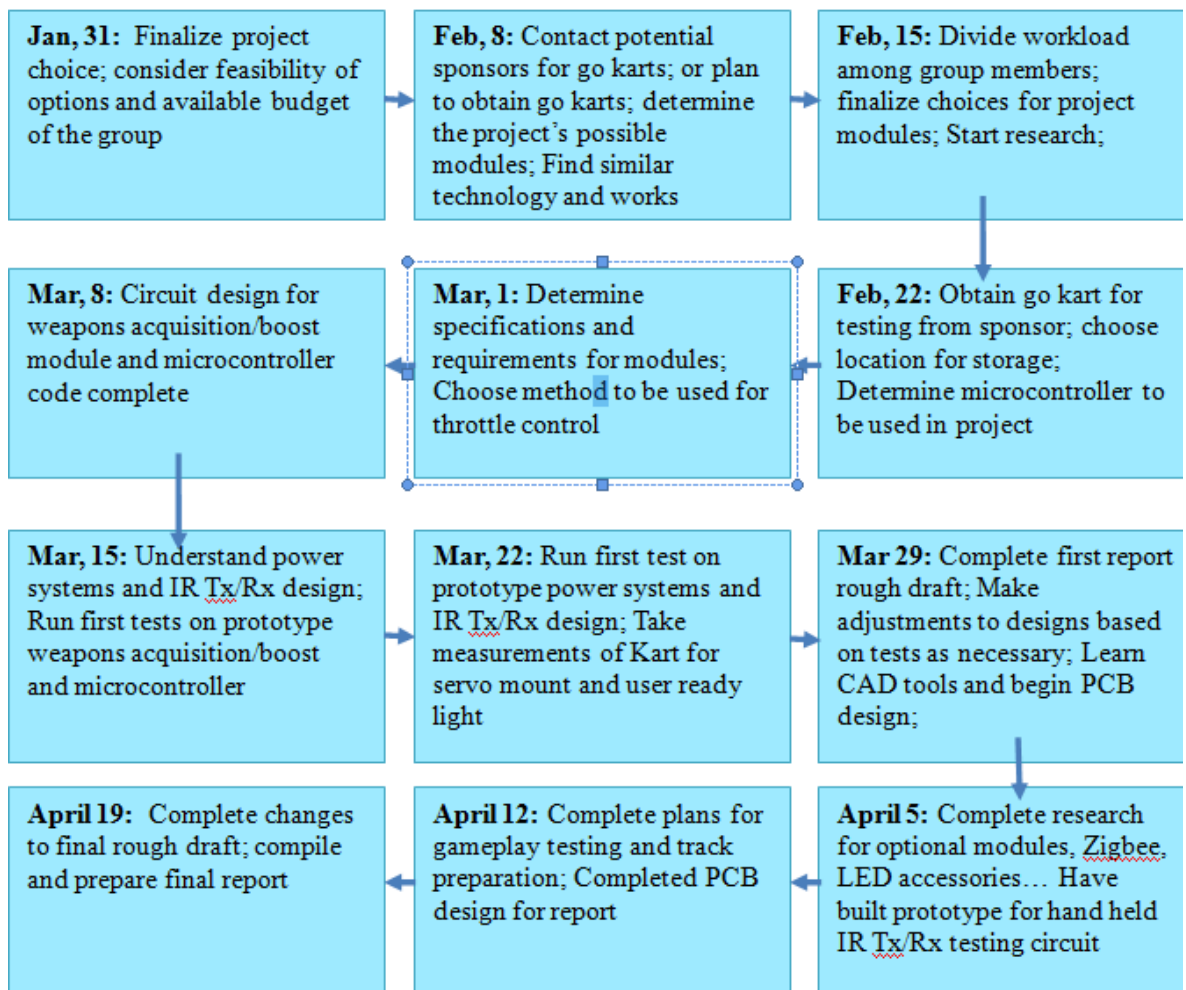
With the permanent track markings in place, the primary focus of the game play testing will be the manipulation of speed control timings, and lazer system fine tuning. With the addition of the optional ZigBee network, after initial implementation, new weapon modes may be added and play tested. Of interest would be a weapon that would disable all other cars on the track, and one that automatically disables the nearest car with ought having to aim, and one that disables the car with the most points. All of these weapons require the additional network module and display unit.

8.0 Administrative Content

8.1 Project Milestones

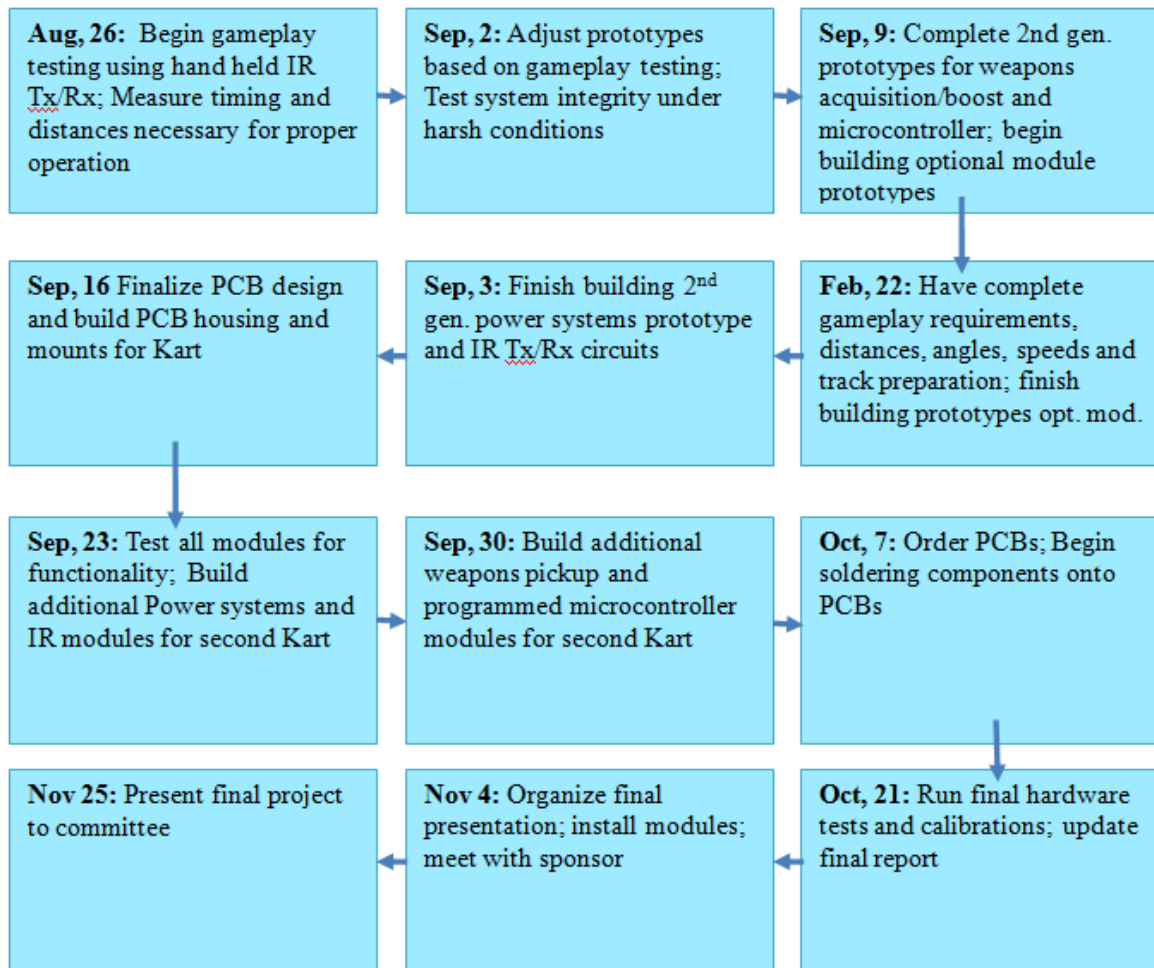
Project milestones are significant events or changes in the development of the project and were chosen to incorporate parallelism in order to achieve as much progress in research, design, testing and building as possible. The group subdivided the project into sections in order to achieve this time efficiency.

8.1.1 Spring 2013 – Senior Design I



8.1.2 Fall 2013 Senior Design II

The main focus of the fall semester was building, testing the systems, installation, prototype iterations track design and preparation. Originally we thought there will multiple karts to build which would take time and top priority, however, due to time constraints and budget this was not possible and the final design and demonstration was carried out using only one Kart as well as a few handheld devices to act as stand-in karts to be shot and to activate a hit. Once PCBs were ordered and the core system had been built the group focused on installing the optional modules for a post-graduation demonstration at FunSpot™



8.2 Equipment

- Tektronix CDM-250 Multi-Meter
- Tektronix 2465A 4-channel oscilloscope
- Bread-boards
- 6 gauge setting wire cutters
- 14 gauge wire

- 15' tape measurer
- Honda GX270 4-stroke engine
- 3/8' tapcon screw
- 19.5V drill
- 1/4' nut and bolts
- Servo arm throttle attachments springs
- Soldering kit, solder, solder pump etc.
- Tin Snips
- Dremel Tool and attachments

8.3 Accessories

- 30 RGB LED strip
- Waterproof terminal connectors
- Rubber mats
- 2-gal paint
- Zip ties
- Arrow marker stencil
- Aluminum sheeting
- Servo motor
- Hand held IR Tx/Rx
- TI Launchpad
- Laptop running TI Code Composer Studio
- PCB Enclosure and mounting hardware

8.4 Consultations

On several occasions we spoke with our professors for their opinion and insight regarding a module or the project in general. Before deciding to design lazer karts we wanted to know about the feasibility of the weapons pick up concept. We decided to speak with Dr. Xun Gong about the cost, maturity and availability of technologies that would best fit the requirements of the weapons pick up system. First we described the project to Professor Gong and pointed out that the go karts would have a velocity of about 17mph and would need to detect the weapons on the track from approximately 6 inches away. Initially we had considered using RFID technology as means of detecting weapons on the track. We discussed the possibility of designing our own RFID tags to meet the requirements such as range and speed but found this to be more of a physics project rather than an electrical engineering project due to the complex electromagnetic field computations and material specifications that would be required as well as the fact that there are already many mature RFID

technologies available for purchase. Once we ruled out designing our own RFID tags we then further discussed what types of technologies we could purchase.

The first technology discussed was the possibility of using a system similar to the electronic toll collection (ETC) used on highways, since these systems are used at high speeds and can detect tags from long distances. Professor Gong pointed out that the ETC systems are very high power and costly. We took the liberty of further exploring similar technologies and found that they are in fact costly, did not seem practical for the application we would be using them for and did not compete with other solutions such as the LED/photodiode approach.

On several occasions we spoke with Dr. Arthur Weeks. The first time meeting with him was to ask him for advice on where we should start as far as choosing parts for the power systems since there are so many available. Professor Weeks recommended that we look at the LT and TI website for rectifiers and regulators that meet the specifications of the power systems input and output. He pointed out that we could use TI's WEBENCH® in order to get an idea of what options are available as well as what we can design ourselves.

On another occasion we met with Dr. Weeks to further discuss the power systems in detail. After running our first test of the full-wave bridge rectifier we found that the diodes were burning up and needed to consult Dr. Weeks about a possible explanation and solution to this issue. He asked us to describe some of the characteristics of our power supplies signal such as what the shape frequency and amplitude are. Based on our description he said that the diodes are not able to handle the reverse bias current and that we would need to change them to Schottky diodes which can handle the rapid changes and in turn avoid burning them up. He also pointed out that we would need to change the capacitor values we were using in order to rectify the AC signal at the given frequencies.

Our last consultation with Dr. Weeks was to discuss the op-amp and LEDs as sensors. He described exactly what would happen in this configuration that matched the exact results obtained in testing. He declared that such a setup using LEDs as sensors, while fine for hobby use is not reliable for a functioning electrical engineering design. His recommendation was to use photodiodes set up in a current-to-voltage configuration with colored filters.

8.5 Budget

The projected budget (Figure 8.5.1) takes into account the assembly of one LazerKart system, and the preparation of a track for testing. We made this spread sheet as we were in the R&D stages and many of the costs did not actually end up being used on the kart itself. After the kart was finished we made a separate budget spreadsheet that only included the costs associated with the parts that were actually used on the final design as seen in Figure 8.5.2

Module	Item	Cost/item	Qty (1 kart)	Purchased	Sub-total	Total
Power systems	Inductor	\$0.46	1	Sky Craft	\$0.46	
Power systems	Caps	\$1.50	2	Sky Craft	\$3.00	
Power systems	Regulators	\$4.00	2	LT/TI	\$8.00	
Power systems	Schottky diodes	\$0.59	4	Spark Fun	\$2.36	
Power systems	Resistors	\$0.15	6	Radio Rhack	\$0.90	
Power systems	AC coil terminals	\$0.40	2	Home Depot	\$0.80	
					\$15.52	\$15.52
Weapons pickup	Photo transistors	\$3.00	2	Vishay	\$6.00	
Weapons pickup	2-chnl Op-amp	\$0.50	1		\$0.50	
Weapons pickup	2-chnl Comparator	\$0.55	4		\$2.20	
Weapons pickup	Resistors	\$0.15	10		\$1.50	
					\$10.20	\$10.20
IR Tx/Rx	TSAL6100 LED	\$0.55	1	Vishay	\$0.55	
IR Tx/Rx	TSOP4856 Photo Module	\$1.17	1	Vishay	\$1.17	
IR Tx/Rx	ultrabright LED	\$0.95	8	Spark Fun	\$7.60	
IR Tx/Rx	Resistors	\$0.15	4		\$0.60	
IR Tx/Rx	PVC Pipe	\$2.83	1	Home Depot	\$2.83	
IR Tx/Rx	IR Filter	\$6.50	1	Edmund Optics	\$6.50	
IR Tx/Rx	Clear Dome	\$4.00	1	Surplus Shed	\$4.00	
					\$23.25	\$23.25
Microcontroller	MSP 430G2553	\$2.79	1	Digikey	\$2.79	
Microcontroller	Launchpad Programmer	\$4.30	1	TI	\$4.30	
					\$7.09	\$7.09
Fab	PCB enclosure	\$15.95	1	OKW Enclosures	\$15.95	
Zigbee					\$15.95	\$15.95
PCB		\$31.88	1		\$31.88	\$31.88
Core					\$0.00	
						\$103.89
Additional Costs						
Track	Paint	\$35.00	2	Home Depot	\$70.00	
Track	Rubber mats per foot	\$5.00	3	Home Depot	\$15.00	
Testing	Gas	\$10.00	3	Mobil	\$30.00	
Fab	shop work per hour	\$20.00	1	UCF wrk shp	\$20.00	
Accessory	30 RGB LED strip	\$20.00	3	Pololu	\$60.00	
Accessory	Water proof connectors	\$1.00	5	Molex	\$5.00	
Accessory	8x8 RGD display	\$35.00	1		\$35.00	
Servo	Corona 939MG	\$4.37	1	Hobby King	\$4.37	
Servo	Servo Mount	\$5.00	1	Home Depot	\$5.00	
No Bumping	Resisitrs	\$0.15	2		\$0.30	
No Bumping	ADXL325	\$6.25	1	DigiKey	\$6.25	
No Bumping	LM393	\$0.55	1	DigiKey	\$0.55	
PCB	2 Pin PCB Terminals	\$1.00	12	Radio Shack	\$12.00	
PCB	3mm LED	\$0.35	1	Spark Fun	\$0.35	
PCB	20 Pin DIP Socket	\$0.11	1	Spark Fun	\$0.11	
PCB	MOSFET	\$0.95	2	Spark Fun	\$1.90	
PCB	Resisitrs	\$0.15	2		\$0.30	
	Wire (20AWG)	\$8.99	1	Radio Shack	\$8.99	
					\$275.12	\$275.12
						\$379.01

Figure 8.5.1

System	Part	Quantity Per Kart	Cost Each	Cost Per Kart	Source
Servo	5V Servo	2	\$14.00	\$28.00	Radio Shack
Servo	Servo Mounting Plate	2	\$0.00	\$0.00	Built
Servo	Mounting Bolt/Nut	2	\$2.50	\$5.00	Home Depot
Servo	Connecting Wire	2	\$0.00	\$0.00	Supply
Servo	Connecting Clips	4	\$0.50	\$2.00	Walmart
Servo	Servo 3 Pin Leads	2	\$1.50	\$3.00	Hobby Store
Servo	Governer Extender	1	\$0.00	\$0.00	Built
Computer	MSP430	1	\$2.50	\$2.50	DigiKey
Computer	Socket	1	\$0.50	\$0.50	Radio Shack
Computer	PCB	1	\$10.00	\$10.00	Osh Park
Computer	Computer Case	1	\$5.00	\$5.00	Radio Shack
Computer	Connector Sockets	6	\$0.50	\$3.00	Mouser
Computer	Resistor	1	\$0.07	\$0.07	Supply
Computer	FET	1	\$1.00	\$1.00	DigiKey
Pickup	TI TLC555CP Timer	1	\$0.74	\$0.74	Element14
Pickup	TI TLC272ACP Op-amp	1	\$0.45	\$0.45	Element14
Pickup	1W Pro-Light UV LED	1	\$7.00	\$7.00	SuperBrightLED
Pickup	1M ohm Resistor 1/4W	2	\$0.07	\$0.14	Supply
Pickup	100k ohm Resistor 1/4W	1	\$0.07	\$0.07	Supply
Pickup	68k ohm Resistor 1/4W	3	\$0.07	\$0.21	Supply
Pickup	1k ohm Resistor 1/4W	1	\$0.07	\$0.07	Supply
Pickup	4.3 ohm Resistor 1W	2	\$0.03	\$0.06	Element14
Pickup	470uF Electrolytic Cap	1	\$1.04	\$1.04	Digikey
Pickup	10uF Electrolytic Cap	2	\$0.10	\$0.20	Supply
Pickup	0.1uF Ceramic Cap	2	\$0.10	\$0.20	Supply
Pickup	0.01uF Ceramic Cap	4	\$0.10	\$0.40	Supply
Pickup	IRLU024N Mosfet	1	\$0.35	\$0.35	Element14
Pickup	1N4728 3.6V Zener Diode	1	\$0.03	\$0.03	Element14
Pickup	1N4148 Diodes	2	\$0.05	\$0.10	Supply
Pickup	TEFD4300 Photodiode	1	\$0.25	\$0.25	Element14
Pickup	8-pin IC Socket	2	\$0.12	\$0.24	Element14
Pickup	2"x2" PerfBoard	1	\$2.50	\$2.50	Radio Shack
Pickup	3"x2"x1" Project Box	1	\$3.50	\$3.50	Radio Shack
Power Supply	GBU601 Bridge Rectifier	1	\$1.33	\$1.33	DigiKey
Power Supply	220 uH Inductor PE-53116NL	1	\$4.11	\$4.11	DigiKey
Power Supply	Schottky Diode MBR360G	1	\$0.55	\$0.55	DigiKey
Power Supply	Buck Regulator LM2576HVT-12	1	\$5.80	\$5.80	DigiKey
Power Supply	5V Regulator LM1084IT-5	1	\$2.79	\$2.79	DigiKey
Power Supply	1000 uF Capacitor P11280	3	\$1.70	\$5.10	DigiKey
Power Supply	10 uF Capacitor P5148	4	\$0.20	\$0.80	DigiKey
Power Supply	470 uF Capacitor	2	\$1.04	\$2.08	DigiKey
Power Supply	LED	1	\$0.25	\$0.25	Radio Shack
Power Supply	Switch	1	\$3.00	\$3.00	Radio Shack
Dashboard	90 Degree EMT Conn.	1	\$2.50	\$2.50	Home Depot
Dashboard	1/2" Red Momentary Button	1	\$2.00	\$2.00	Skycraft
Dashboard	3" Corner Brace	2	\$3.50	\$7.00	Home Depot
Dashboard	5mm RGB LED	4	\$2.00	\$8.00	Radio Shack
Dashboard	5mm Red Led	5	\$1.00	\$5.00	Radio Shack
Dashboard	6"x4"x2" Project Box	1	\$6.50	\$6.50	Radio Shack
Dashboard	3"x2" PerfBoard	1	\$2.25	\$2.25	All Electronics
Dashboard	IRLU024N MOSFET	3	\$0.35	\$2.10	Element14
Dashboard	5mm LED Holders	9	\$0.20	\$1.80	Radio Shack
IR System	IR LED TSAL6100	1	\$0.55	\$0.55	Element14
IR System	220ohm resistor	1	\$0.07	\$0.07	Element14
IR System	IRLU024N MOSFET	2	\$0.35	\$0.70	Element14
IR System	IR Rec. TSOP4856	1	\$0.95	\$0.95	Mouser
IR System	1uF Tantalum Capacitor	1	\$0.25	\$0.25	Supply
IR System	2k Resistor	1	\$0.07	\$0.07	Supply
IR System	3k Resistor	1	\$0.07	\$0.07	Supply
IR System	10k Resistor	1	\$0.07	\$0.07	Supply
IR System	2"x3" PerfBoard	1	\$2.25	\$2.25	All Electronics
Brake Light	IRLU024N MOSFET	1	\$0.35	\$0.35	Element14
Brake Light	1 Watt White LED	2	\$4.00	\$8.00	Skycraft
Brake Light	4.7 ohm resistor	2	\$0.25	\$0.50	Skycraft
Brake Light	470uF	1	\$1.04	\$1.04	Digikey
Brake Light	Custom Switch	1	\$1.00	\$1.00	Self-Made
Brake Light	PVC enclosure	1	\$2.25	\$2.25	Lowe's
Brake Light	25mm Diam. 55mm Focal Length	1	\$4.00	\$4.00	Surplus Shed
Brake Light	3"x5" Project Box	1	\$5.50	\$5.50	Radio Shack
Brake Light	Various Mounting Supplies	1	\$3.00	\$3.00	Lowe's
Brake Light	Brake Light Enclosure	1	\$3.50	\$3.50	Lowe's
Miscellaneous	Solder	1	\$10.00	\$10.00	Radio Shack
Miscellaneous	18ga Wire (Red, Green, Black)	1	\$8.00	\$8.00	Radio Shack
			Total	\$192.70	

Figure 8.5.2

9.0 Commercial Implementation

9.1 Track Preparation

9.1.1 Track Selection

During initial play testing, the three operational tracks at Fun Spot were tested to determine which track would be best suited for a first track to implement the system on. Things that were looked at included; areas for passing, track width, and appropriate areas for boost and weapon zone placement. The initial run was taken on the "Quad Helix" track. This track has several long straight-a-ways, as well as long sections of circling curves. The track width was consistent throughout. The next run was done on the "Conquest" track, which is smaller than the previous track, with a very steep downhill straight-a-way and a long circular climb. The final track tested was the "Thrasher" track which is considered a slick track, designed on one level and featuring many hairpin turns and varying widths of track.

After an initial run through of the tracks it was decided that the Thrasher was not suitable for the game purposes, due to the nature of the driving. Several more runs were taken on each of the other two courses. These subsequent runs involved simulated lazer fire and braking, to test the length and times needed to allow for passing. Attention was put into the location of the passing, straight versus curved track, and uphill versus downhill. The results of this play testing concluded that the best option would be the Quad Helix track. The track was well suited for constant throttle racing, which should lend itself well to the game. The Commander track hill was determined to have been a possible safety concern for the game. Future play testing on all tracks is possible, but focus will be placed on the Quad Helix.

9.1.2 Game Setup

The main purpose of the game is to allow for the increase in passing, thereby making the experience more enjoyable for the rider. The setup chosen was designed to maximize these opportunities. In a typical go kart race, very little of the track is used if the drivers are even a little experienced. By placing the boost zones on the outside of the track, as indicated below by the green markings in Figure 9.1.2.1 more of the track will be used, and drivers can now weigh the benefits of taking the longer path to getting the speed boost. Timing of the boosts will be set to give the driver an good chance at passing the kart in front.

The red lines in Figure 9.1.2.1 indicate the positioning of the weapon pick up points. These are located so as to give the kart the ability to shoot while on the straight track, increasing the chance of a hit, and again, the opportunity to pass.



Figure 9.1.2.1

During play testing the locations of the zones will undoubtedly change, as more data becomes available. Initial track setup for testing will be done using movable zones, until an optimum setup has been chosen. Cardboard with the appropriate colors can be affixed to the track to hold enough for play testing will be removed for the permanent setup.

The final setup will consist of painted florescent stripes of appropriate color and width to be determined by play testing. Florescent paint is available at a cost of \$35 a gallon, and one gallon of each color should be sufficient to create the zones needed for the track. Track preparation will begin upon completion of the single kart play testing, for use in multiple kart play testing.

9.2 Staff Training

9.2.1 Game Operation Training

The ride operators at Fun Spot typically work in pairs, one operator at the beginning of the track, and one stationed in the middle of the track observe for unsafe conditions. The initial training will consist of explaining the new kart additions and what can be expected to change with the pace of the ride. The initial set up of the Lazer Kart will be a simple press of the reset button, which will enable game play. The ride operators will be instructed as to the location of the reset button.

The initial design is intended to be a simple version of the final product. As new features are added to the karts, the ride operators will be given instruction on their uses. Remote control of Karts and scoring will be additions which the game operators will be trained on.

9.2.2 In-Race Troubleshooting

During the course of play, it is inevitable that problems will occur with the system. The ride operators will be instructed on what common symptoms might occur, as well as possible solutions. The ideal situation is to fix the problem without removing the car from the track, and often the solution will be a simple reset of the unit. Staff will be trained to recognize when a more serious problem has occurred and when it is advised to remove the kart from the race.

9.2.3 Off Track Troubleshooting

The maintenance department will be trained more thoroughly than the ride operators, and will be given detailed instructions on the operation of the entire system. These personnel will be provided with circuit and wiring diagrams for the entire system, as well as a hands on walkthrough of the system by the design team. After initial implementation, it will be the maintenance department which will continue training new track operators on the proper operation of the system. As new revisions happen throughout the course of the design, the maintenance department will be re-trained to account for the changes.

9.3 Maintenance Training

The maintenance staff at Fun Spot will be given adequate training to ensure the proper operation of the LazerKart system. The basic troubleshooting flowchart shown below in figure 9.3.1 will be the first step towards maintenance and repair of the system.

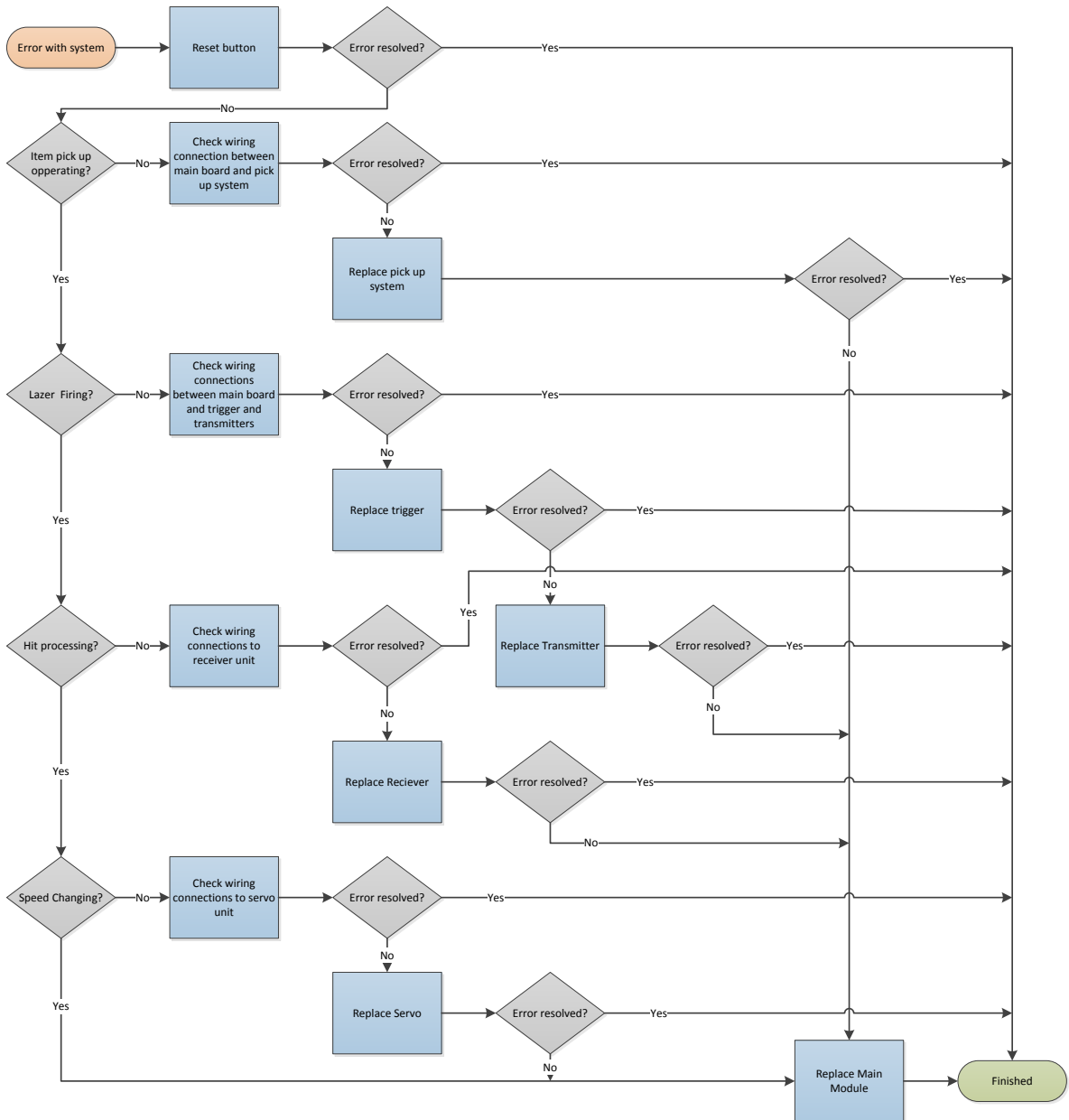


Figure 9.3.1

9.4 Stocking and Ordering Spare Parts

Fun Spot has a team of mechanics available to make repairs to and replace individual units of the LazerKart system. It is not expected that they will need to do any major troubleshooting, as the individual modules of the whole system are designed to be easily replaced, and relatively low cost. By following the flow chart given in section 9.3, it will be easy to determine the nature of the fault, and repairs will be quick.

With the initial plan to support one race track with the LazerKart system, a supply of 5 replacement components for each module will be sufficient. Because of the modular nature of the construction, no component level parts will need to be stocked, only fully built modules. In order to keep Fun Spot supplied with 5 working units, the team itself will be required to have parts on hand for the building of an additional 5 units. When the design is finalized, it is estimated that a lead time of no longer than one week would be necessary to resupply a fully functioning system.

If the system is shown to have a commercial appeal, distribution and resupply becomes a bigger piece of the puzzle. Effort will be made to standardize parts suppliers, to ensure consistency throughout the product line. With continued expansion, more data will become available to system longevity, and supply can be adjusted accordingly.

10.0 Summary and Conclusions

The culmination of this project, LazerKart, lies in the harmony of all subsystems and graceful execution of all gameplay mechanics. Through exhaustive research, extensive testing, and careful production, LazerKart has proven to be a stellar product that exceeds all expectations. The engineering team has brought a multitude of technologies together for a design that not only impresses those who are technically inclined but also brings a smile to the average person who knows little of the inner workings involved.

Everything from wireless communication, embedded microcontroller programming, and power distribution to LED light displays and sound effects can potentially be employed in LazerKart, for a demonstration of a vast understanding of a multitude of technologies. The implementation is two-fold: not only is there an academic reflection in LazerKart, but also a possibility for a marketable platform that could be low-cost and easy to maintain. The collective group feeling about the potential for LazerKart has been nothing short of positive and passionate, which has thus far helped to drive the progress in developing the concept further without getting discouraged.

Everything has seemed to fall into place at this point, with the sponsor, Fun Spot™, graciously donating a pristine go-kart to the group and Dixon Wheels and Sound of Sanford, Florida allowing the kart to be stored, tested, and developed on site. Furthermore, there is ample power to supply to all of the basic subsystem components and inexpensive parts were used that allow these components to function as intended.

Appendix A

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Appendix B

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- Hunter Smith (Waterloo Labs)

From: Jeremy Feliciano [jeremy@pololu.com]
Sent: Thursday, April 18, 2013 2:52 PM
To: evan brown
Subject: Re: Letter of Consent

Hello, Evan.

Thank you for your interest in our products. You are welcome to use the text, files, and images from our website in your work as long as you give credit to us.

Please let me know if you have any additional questions or concerns.

Sincerely,
Jeremy Feliciano
(702) 262-6648
www.pololu.com

.....
Pololu Corporation
920 Pilot Rd.
Las Vegas, NV 89119
USA

From: John Hamburger [jhamburger@linear.com]
Sent: Monday, April 15, 2013 12:09 PM
To: evanb88@knights.ucf.edu
Cc: bscott@linear.com; treimund@linear.com
Subject: FW: Letter of consent

Evan,

You are welcome to use the specs and schematic for the regulators in your senior design project. You may consider this email as a permissions letter. Please credit Linear Technology Corporation for use. Thanks for your interest.

John Hamburger

John Hamburger
Director, Marketing Communications
Linear Technology Corp

-----Original Message-----

From: bscott@linear.com [mailto:bscott@linear.com]
Sent: Sunday, April 14, 2013 8:42 PM
To: jhamburger@linear.com
Cc: treimund@linear.com
Subject: Fw: Letter of consent

I imagine you have a standard letter of approval citing copyright, trademark etc., considerations to reply to this.

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Mr. Evan Brown
University Of Central Florida
404 Timberglen Court
Winter Springs, FL 32708

Dear Mr. Brown

Our Ref: TEKAM.13.04.19

Date: 4/19/13

Hi Evan,
Thank you for the inquiry.

Please accept this letter as confirmation to use the Tekam image in your project. We are very interested in how our cases are used. Please if possible send us a picture so we can share with TEKO.

Yours sincerely

Ray Toubo
Office Manager
rayt@okwenclosures.com