I.F.F. (Identification Friend or Foe) System

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Contents

1 Introduction

1.1 Statement of Purpose

There have been several friendly fire incidents in recorded military history, accounting for an estimated 2% to 20% of all casualties in battle[?]. Using attire to identify friend vs enemy is problematic in situations when both sides are clad in the same camouflage pattern, or are obscured by obstacles.

The purpose of this project is to create a system that quickly and accurately identifies friendly targets among military personnel on foot. Similar systems exist for aircraft, however not many exist for infantry.

The idea is to develop a two-way communication system so that when a soldier aims their weapon in the direction of a friendly target, they will receive notification through an LED that the target is, indeed, friendly and not an enemy. Throughout this document the infantry unit with the weapon will be referred to the "friendly interrogator" and the target will be referred to as the "friendly target".

This communication protocol can be

1.2 Objectives

1.2.1 Goals and Benefits

- Reduce number of friendly fire accidents during combat [?]

- Reduce number of misfires accidents during combat [?]

- Notify friendly personnel location of particular friendly target when aiming

- Other applications including but not limited to:

    – Paintball or Airsoft
    – Arcade Laser Tag

1.2.2 Functions and Features

- Laser diode on friendly interrogator to transmit unique I.D. of friendly interrogator.

- Photodiodes on friendly target to detect unique I.D. and verify it is a valid signal.

- R.F. Transmitter on friendly target to send acknowledgement back to interrogator.

- R.F. Receiver on friendly interrogator to verify that the target is friendly.

- LED on friendly interrogator to indicate to the operator the status of the target.

2 Design

2.1 Block Diagrams and Descriptions

2.1.1 System Overview

The following figure represents the system as a whole, including both the friendly interrogator unit and the friendly target unit. Both units will be expanded upon in further detail below.
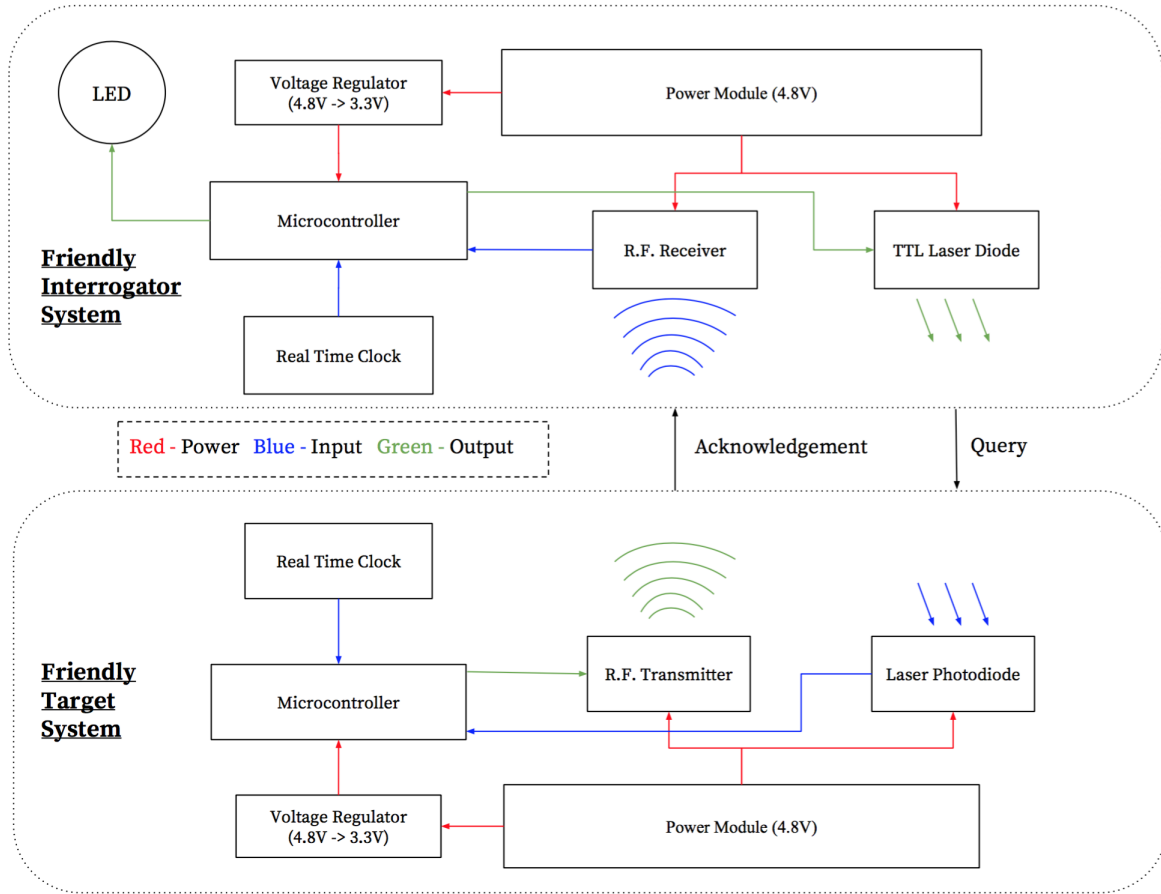

Figure 1: System Block Diagram

2.1.2 Friendly Interrogator Unit

The following diagram shows the friendly interrogator unit *only*. The interconnections in red represent power, interconnections in blue represent input to a block and interconnections in green represent output to a block. These inputs and outputs are described below under each block description.
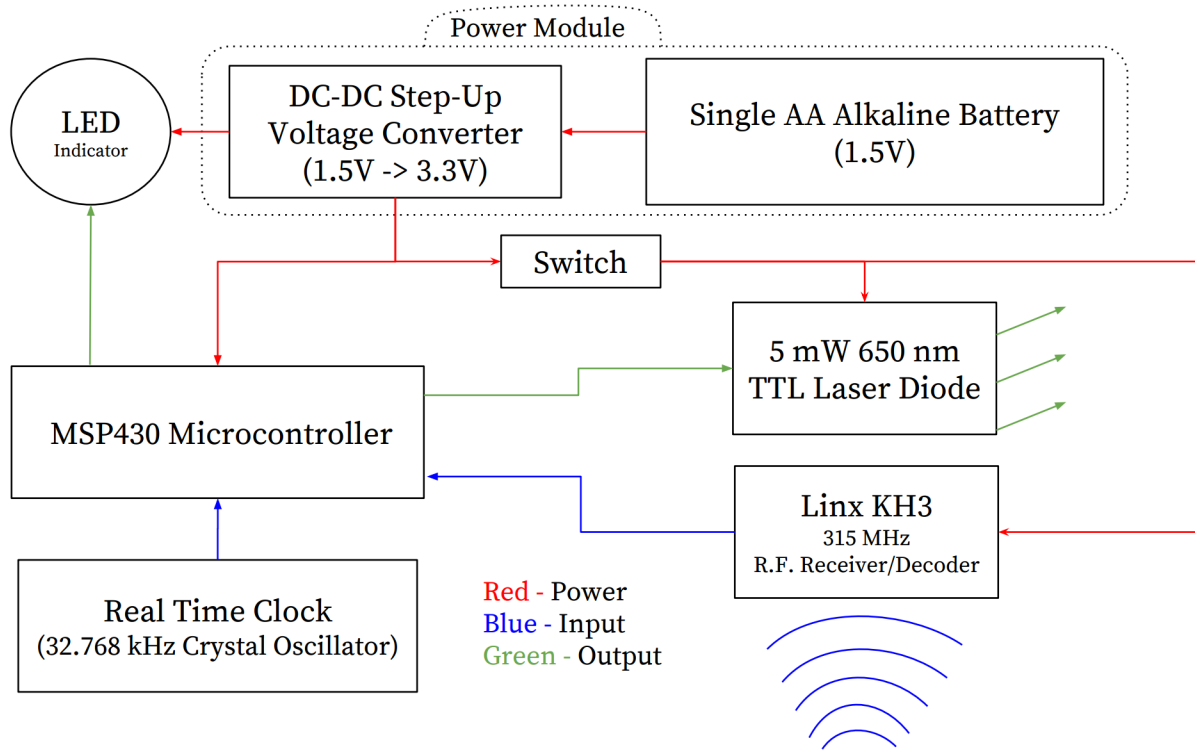
Figure 2: Block Diagram of Friendly Interrogator Unit

Power Module
Power-In, , N/A
Power-Out: MSP430 Microcontroller Unit (Pin ___), Laser Diode, R.F. Receiver (Pin ____), LED Indicator
Input(s): N/A
Output(s): N/A

The power module will consist of a single standard alkaline AA battery (no specific brand/part name is necessary) which will lead into a Skyworks AAT1217 DC-DC step-up voltage converter. This will step the voltage up to 3.3V with a maximum current output of 100 mA which is sufficient enough to power the MCU, laser transmitter, and the R.F. receiver. Please refer to Section 2.5 for these calculations regarding power delivery to this unit.

As noted on the block diagram, in between the power module and the R.F. receiver/laser transmitter, there is a switch to control the power given to these two modules. This switch exists for two reasons: (1) to decrease power consumption and (2) to limit the amount of time the laser transmitter is sending data. This design choice will be expanded upon in Section ___.

The circuit to operate the DC-DC step-up converter is shown in Figure 3.

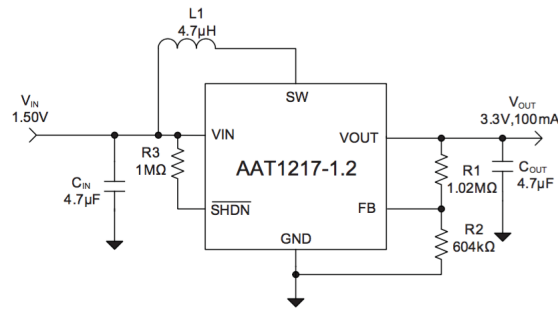The battery will be mounted to the PCB through a standard mount shown in Figure ___.

Figure 3: AAT1217 Circuit Schematic

MSP430 Microcontroller

Power-In: 3.3V (from Power Module)

Power-Out: ??

Input(s): Received R.F. Signal, Real Time Clock (32.768kHz Crystal Oscillator)

Output(s): LED, 5mW 650nm Laser Diode

The team chose to work with an T.I. MSP430F2274 Microcontroller Unit [1] due to its compiler simplicity, its availability in the ECE445 Senior Design Labs (inventory) and the number of GPIO Pins on board (compared to other options, this model had several I/O pins and was the most inexpensive). Compared to many other MCUs on the market, the MSP430 is relatively well documented and there exist several support forums on the internet to assist the team throughout the duration of the project.

The board requires a 3.3V power supply which is why the voltage regulator is necessary as stated before.

Please refer to Section 2.3 to view in-depth discussion about the functionality of the MSP430F2274 Microcontroller Unit and how it will be used throughout this project.

INDICATE WHICH PINS ARE ACTIVE AND WHICH PINS ARE NOT BEING USED Indicate what the overall block layout of this is, i.e. show the Power Pins, the RX Pins, and the Laser Diode Pins

Pin #	Label	Description
1	TEST/SBWTCK	Selects test mode for JTAG pins on Port 1. The device protection fuse is connected to TEST. Spy-Bi-Wire test clock input during programming and test
2	DVCC	Digital Supply Voltage
3	P2.5/R_{osc}	General-purpose digital I/O pin / Input for external DCO resistor to define DCO frequency
4	DVSS	Digital Ground Reference
5	XOUT/P2.7	Output terminal of crystal oscillator General-purpose digital I/O pin / General-purpose digital I/O pin
6	XIN/P2.6	Input terminal of crystal oscillator General-purpose digital I/O pin / General-purpose digital I/O pin
7	~RST/NMI/SBWTDIO	Reset or nonmaskable interrupt input / Spy-Bi-Wire test data input/output during programming and test
8	P2.0/ACLK/A0/OA0I0	General-purpose digital I/O pin ; ACLK output ; ADC10, analog input A0 / OA0, analog input I0
9	2.1/TAINCLK/SMCLK/A1/OA0O	General-purpose digital I/O pin ; Timer_A, clock signal at INCLK ; SMCLK signal output / ADC10, analog input A1 ; OA0, analog output
10	P2.2/TA0/A2/OA0I1	General-purpose digital I/O pin ; OA0, analog input I1 / Timer_A, capture: CCI0B input/BSL receive, compare: OUT0 output ADC10, analog input A2
11	P3.0/UCB0STE/UCA0CLK/A5	General-purpose digital I/O pin ; USCI_B0 slave transmit enable / USCI_A0 clock input/output ADC10, analog input A5
12	P3.1/UCB0SIMO/UCB0SDA	General-purpose digital I/O pin ; USCI_B0 SPI mode: slave in/master out / USCI_B0 I2C mode: SDA I2C data
13	P3.2/UCB0SOMI/UCB0SCL	General-purpose digital I/O pin ; USCI_B0 SPI mode: slave out/master in / USCI_B0 I2C mode: SCL I2C clock
14	P3.3/UCB0CLK/UCA0STE	General-purpose digital I/O pin / USCI_B0 clock input/output USCI_A0 slave transmit enable
15	AVSS	Analog Ground Reference
16	AVCC	Analog Supply Voltage
17	P4.0/TB0	General-purpose digital I/O pin / Timer_B, capture: CCI0A input, compare: OUT0 output
18	P4.1/TB1	General-purpose digital I/O pin / Timer_B, capture: CCI1A input, compare: OUT1 output
19	P4.2/TB2	General-purpose digital I/O pin / Timer_B, capture: CCI2A input, compare: OUT2 output

Pin #	Label	Description
38	P1.7/TA2/TDO/TDI	General-purpose digital I/O pin ; Timer_A, compare: OUT2 output / Test Data Output or Test Data Input for programming and test
37	P1.6/TA1/TDI	General-purpose digital I/O pin ; Timer_A, compare: OUT1 output / Test Data Input or Test Clock Input for programming and test
36	P1.5/TA0/TMS	General-purpose digital I/O pin ; Timer_A, compare: OUT0 output / Test Mode Select input for device programming and test
35	P1.4/SMCLK/TCK	General-purpose digital I/O pin / SMCLK signal output ; Test Clock input for device programming and test
34	P1.3/TA2	General-purpose digital I/O pin / Timer_A, capture: CCI2A input, compare: OUT2 output
33	P1.2/TA1	General-purpose digital I/O pin / Timer_A, capture: CCI1A input, compare: OUT1 output
32	P1.1/TA0	General-purpose digital I/O pin / Timer_A, capture: CCI0A input, compare: OUT0 output BSL transmit
31	P1.0/TACLK/ADC10CLK	General-purpose digital I/O pin Timer_A, clock signal TACLK input / ADC10, conversion clock
30	P2.4/TA2/A4/VREF+/VeREF+/OA1I0	General-purpose digital I/O pin ; Timer_A, compare: OUT2 output ADC10, analog input A4 / Positive reference voltage output or input OA1, analog input I/O
29	P2.3/TA1/A3/VREF−/VeREF−/OA1I1/OA1O	General-purpose digital I/O pin ; OA1, analog input I1 ; OA1, analog output ; Negative reference voltage input / Timer_A, capture CCI1B input, compare: OUT1 output ADC10, analog input A3
28	P3.7/A7/OA1I2	General-purpose digital I/O pin ADC10 analog input A7 / OA1 analog input I2
27	P3.6/A6/OA0I2	General-purpose digital I/O pin ADC10 analog input A6 / OA0 analog input I2
26	P3.5/UCA0RXD/UCA0SOMI	General-purpose digital I/O pin / USCI_A0 UART mode: receive data input ; USCI_A0 SPI mode: slave in/master out
25	P3.4/UCA0TXD/UCA0SIMO	General-purpose digital I/O pin / USCI_A0 UART mode: transmit data output USCI_A0 SPI mode: slave in/master out
24	P4.7/TBCLK	General-purpose digital I/O pin / Timer_B, clock signal TBCLK input
23	P4.6/TBOUTH/A15/OA1I3	General-purpose digital I/O pin ; OA1 analog input I3 / Timer_B, switch all TB0 to TB3 outputs to high impedance ADC10 analog input A15
22	P4.5/TB2/A14/OA0I3	General-purpose digital I/O pin ; OA0 analog output I3 / Timer_B compare: OUT2 output ADC10 analog input A14
21	P4.4/TB1/A13/OA1O	General-purpose digital I/O pin ; OA1 analog output / Timer_B, capture: CCI1B input, compare: OUT1 output ADC10 analog input A13
20	P4.3/TB0/A12/OA0O	General-purpose digital I/O pin ; OA0 analog output / Timer_B, capture: CCI0B input, compare: OUT0 output ADC10 analog input A12

Figure 4: Pin Layout Table

Real Time Clock

Part Name: Power-In: N/A

Power-Out: N/A

Input(s): N/A

Output(s): MSP430 Microcontroller Pins 5 & 6 (X_{in} and X_{out})

The Real Time Clock is not entirely necessary for the operation of the Laser Transmitter Subsystem, however it will be necessary for the operation of the R.F. Receiver and thus must be included in the MCU circuit. It will operate using a 32.768 kHz Crystal Oscillator (as recommended by T.I. [2]) with an accuracy of +/- 20 PPM (deviates between 32.7673 kHz and 32.7687 kHz).

Laser Diode

Power-In:

Power-Out:

Input(s): MSP430 Microcontroller Pins __ & __ (List Pin Labels Here)change

Output(s): 5mW Laser Beam

The 5mW laser diode will operate on 3.3V at 25mA so a 1.3kΩ (confirm?) resistor is necessary to drop the current being supplied to the diode down to this threshold.

Due to safety and ethical considerations, the requirements have changed for the divergence of the beam. The proposal stated a requirement of a 5-6 ft diameter beam at 50, 150, and 300 m (with optical adjustments allowed). This was assuming the team was using a 20mW laser diode which is now not the case (this design choice will be discussed in both Section 3.2 and Section 2.5 as appropriate). Instead the team will be using a 5 mW laser which will produce a beam divergence of 2.5-2.75 feet at ____ feet.

Again, please refer to Section 3.2 and Section 2.5 to view an in-depth discussion about these design choices.

R.F. Receiver

Power-In: 4.8V (from Power Module)

Power-Out: N/A

Input(s):

Output(s):

A Linx 315 MHz LR Series R.F. Receiver will be used for this project along with a Linx 315-SP Splatch PCB Mounted Antenna.

Parameter	Typical Value
Receiver Frequency	315 MHz
Receiver Sensitivity	-112 dB
R.F. Input Impedance	50 Ω
Receiver Turn-On Time	7.0 ms

Table 1: Notable Datasheet Values for Linx 315 MHz LR R.F. Receiver
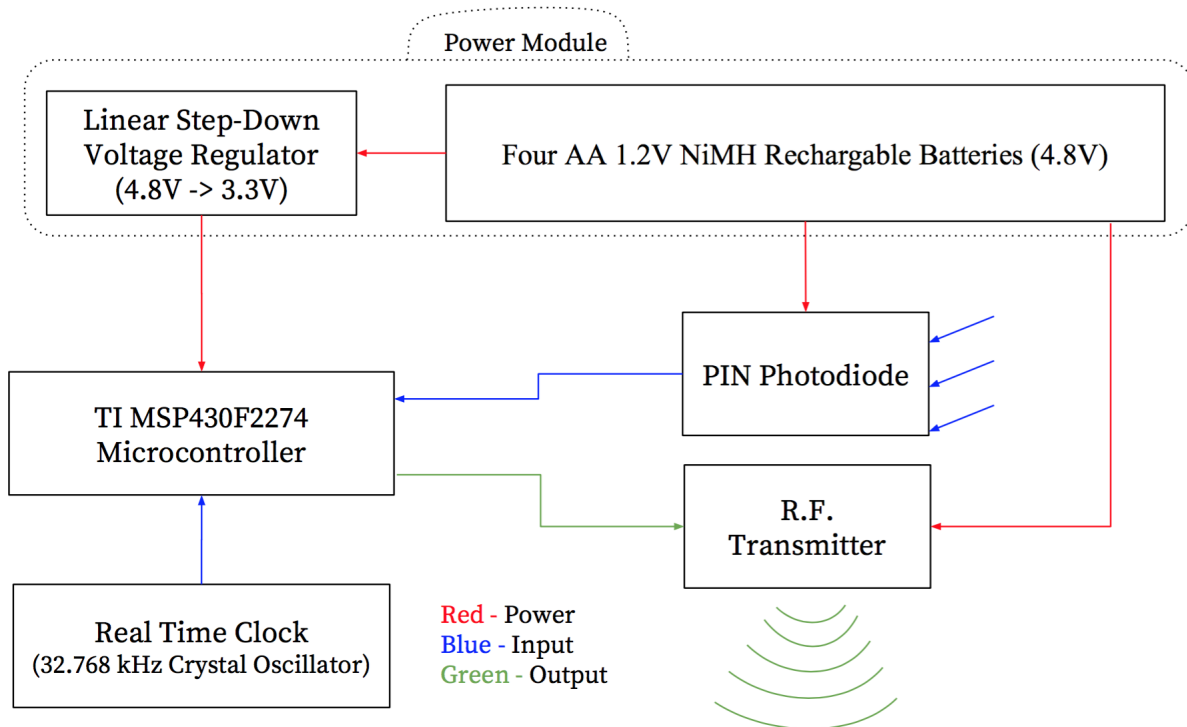
2.1.3 Friendly Target Unit

Figure 5: Block Diagram of Friendly Target System

Power Module

Power-In: N/A

Power-Out:

Input(s):

Output(s):

The power module on board the Friendly Target Unit will be the same as the Friendly Interrogator Unit. Th Please reference that section to get all details pertaining to the power module.

Microcontroller

Power-In:

Power-Out:

Input(s):

Output(s):

INDICATE WHICH PINS ARE ACTIVE AND NOT

Real Time Clock

Power-In:

Power-Out:

Input(s):

Output(s):

The Real Time Clock on board the Friendly Target Unit will be the same as the Friendly Interrogator Unit. Please reference that section to get all details pertaining to the Real Time Clock.

Laser Photodiode

Power-In:

Power-Out:

Input(s):

Output(s):

R.F. Transmitter

Power-In:

Power-Out:

Input(s):

Output(s):

A Linx 315 MHz LR Series R.F. Transmitter will be used for this project along with a Linx 315-SP Splatch PCB Mounted Antenna. This is an identical setup to the receiver end on the friendly interrogator unit as discussed before.

The

Parameter	Typical Value
Transmit Frequency	315 MHz
Output Power	4 dB
Data Rate	10,000 bps
R.F. Output Impedance	50 Ω
Transmitter Turn-On Time	1.0 ms

Table 2: Notable Datasheet Values for Linx 315 MHz LR R.F. Transmitter

2.2   Circuit Schematics

2.2.1   Friendly Interrogator Unit

The circuit schematic is shown below for the Friendly Interrogator Subsystem.
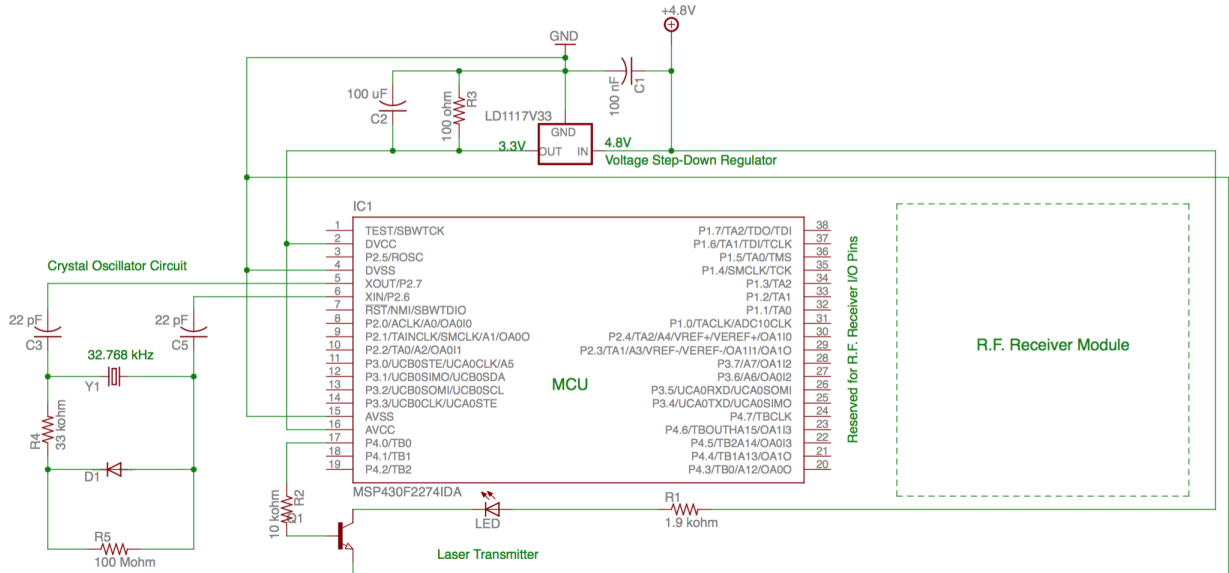

Figure 6: Circuit Schematic of Laser Transmitter

2.2.2   Friendly Target Unit

2.3   Functionality

Do we need any setup procedures? This section is to explain the overview of how each part interfaces with another and the protocol used to transmit data from both the friendly interrogator unit to the friendly target unit. The below diagram is a flowchart representing the flow of events that occur to identify a target as friendly. Each individual label will be explained in extensive detail below.
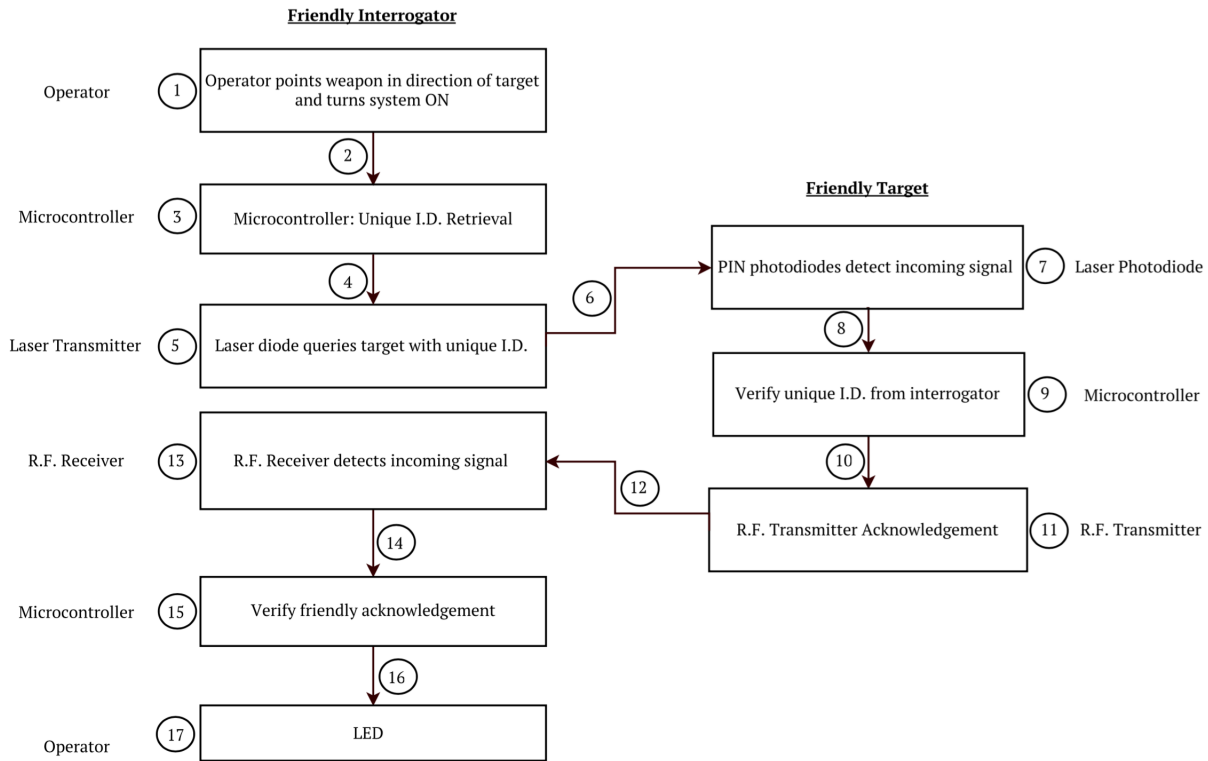
Friendly Interrogator

Figure 7: Flowchart for Functionality

The left side of this diagram are all events that occur within the friendly interrogator unit, and the right side represents all of the events that occur on the friendly target side. This flow diagram also assumes that both the interrogator operator and the friendly target operator have powered on their respective units.

Event #1 - Operator points weapon in direction of target and turns power ON
The operator will trigger the power of the friendly interrogator unit which will then send a signal to the

2.4 Software Flowcharts

2.5 Numerical Analysis and Simulations/Plots

2.5.1 Calculations

Power Module (Friendly Interrogator Unit)
The following section is intended to backup the design choices made for the power module on the friendly interrogator first shown in section 2.1.2.

The team placed a strict requirement (shown in section ___) regarding the operation time of the friendly interrogator unit (at 8 hours of operation time $\pm$ 5% verify).

In order to select parts that satisfied this requirement, the active current consumption on the entire unit must first be calculated. The main power consumption modules on board the friendly interrogator unit are the MSP430F2274, the 5mW 635nm TTL laser transmitter, and the Linx KH3 R.F. receiver. These values were received from each of the respective datasheets. The following table displays the active current

consumption of each unit.

Module	Active Current Consumption	Standby Current Consumption
MSP430	270 μA	0.1 - 0.7 μA
Linx KH3 R.F. Receiver	5.9 mA	0 mA
5 mW Laser	25 mA (max)	0 mA

Table 3: Notable Datasheet Values for Linx 315 MHz LR R.F. Receiver

Because the R.F. receiver and the 5mW laser will only be powered when the operator designates, the standby current consumption of these units will be 0.

Therefore, with this information, the maximum possible active current consumption will be:

$$I_{\text{Total}} = 270\mu A + 25mA + 5.9mA + 0.7\mu A$$

Assuming the team uses a standard Alkaline AA 1.5V Battery, these typically produce anywhere from 1800mAh to 2500 mAh insert reference here. Therefore, the average of these two values will be used as the capacity of the battery: 2150 mAh. Since all of the components being used requires 3.3V, this battery must be fed into a voltage step-up converter as stated previously. The team is using the AAT1217 step-up converter this boosts the voltage up from 1.5V to 3.3V with a 75% efficiency insert reference here.

Using energy conservation laws, the equivalent capacity can be determined after stepping this voltage up from 1.5V to 3.3V. Since Energy = Power * time, we can use a ratio of the energy produced per hour of the standard alkaline battery to the output voltage of the converter. This calculation can be shown below:

$$TotalCapacity = \frac{P_{\text{battery}} * time * V_{\text{battery}}}{V_{\text{converter-output}}} * ConverterEfficiency$$

$$TotalCapacity = \frac{2150mAh * 1.5V}{3.3V} * 75\% = 732.95mAh * 0.75 = \textbf{14.95 hr active use}$$

This result shows that a single standard alkaline AA 1.5V disposable battery will be more than sufficient enough to satisfy the requirements of 8 hours of active use time.

Power Module (Friendly Target Unit)

Laser Diode

With some tolerance, the PIN photodiode used in the friendly target system can register an irradiance of 9 $\frac{W}{m^2}$. The laser required to achieve this irradiance is a function of the laser power and the radius of the beam. With relatively short distances of 0-300 m, atmospheric deflection of light is negligible.

Using trigonometry, the power as a function of radius is given by $P = \pi r^2 E_{req}$, where r is the radius (in meters) and E_{req} is the required irradiance of 9 $\frac{W}{m^2}$.

For a diameter equal to the one stated in the proposal ($\approx 1.6764m$), a $\pi(0.8382)^2(9) \approx 20mW$ laser is needed. A $20mW$ laser is a Class 3B laser, and is considered dangerous. For the scope of this senior design project, a $5mW$ laser will be used instead.

The radius achieved using a $5mW$ laser is given by $\sqrt{\frac{P}{E_{req}\pi}} = 0.420522m$. This is approximately a $2.75ft$ diameter beam, which is still the size of a person's chest.

2.5.2 Simulations/Plots

INSERT PLOTS/ANY SORT OF ANALYSIS HERE

3 Requirements and Verification

Block/Subsystem	Module	Requirement	Verification
Friendly Interrogator System: Laser Transmitter	Laser Diode	Must be able to achieve 5 mW of power at source with a wavelength in the visible light spectrum from 620–750 nm (red). Light from the beam must span a range of 10-15 inches at the following distances, with optical adjustments allowed: - Short Range (50 m) - Medium Range (150 m) - Long Range (300 m)	Verify with multimeter that the laser is producing 5 mW at source. Verify the laser is in the visible light spectrum from 620-750nm using a Field Test - Verify laser transmission at distances for three ranges.
	Power Module	Must maintain a constant DC power source of 4.8V ± 5%. Must be able to supply 4.8V for a period of 8 hours ± 5%.	Attach power module to digital multimeter in parallel and measure output voltage with and without load components attached. Attach power module to digital multimeter in parallel and measure output voltage over a period of time.
	Voltage Regulator	Must be able to output a constant voltage of 3.3V with ± 0.3V deviation (i.e. 3.27V < Vout < 3.33V), with a current supply of max 75mA.	Attach power module to digital multimeter in parallel and measure output voltage with and without load components attached.
	Real Time Clock (RTC)	Must oscillate at a frequency of 32.768 kHz with a precision of ± 20 PPM.	Attach oscilloscope to outputs of crystal oscillator circuit and measure frequency
	Microcontroller (MCU)	Ability to control laser transmitter to send digital data at a frequency of at least 30 kHz. Must maintain its own internal clock to a precision of ± 10 minutes ± 10%.	Verify using oscilloscope connected to output generated by MCU and measuring period time in μs. Sample packets sent to microcontroller and verify time with that of a local known source.

Figure 8: Requirements/Verification for Laser Transmitter System

3.1 Tolerance Analysis

NEED TO INCLUDE IN DEPTH ANALYSIS-
Tolerance analysis is part of the DESIGN process. The tolerance analysis is not an experiment to see what the limits of your project are after it has been designed and built. The tolerance analysis is an exercise in working backwards from what your goal is, and then figuring out how precise a specific hardware component must be. "We will stress the device until it no longer works as intended and look at the results" is not a tolerance analysis. "Given that we have a goal of X, The accuracy of component Y must be Z to achieve X properly" is a tolerance analysis. It should involve math and design equations. For example, in amplifier design there is usually a bias circuit that includes a resistor network. Resistor values in real life are not exact and have an advertised tolerance (10%, 5%, 1%). Find how accurate your resistors must be to meet your gain or bandwidth requirements in the worst case scenario. If it is lower than 10%, you have just concluded that your design will require parts with a tighter tolerance.

3.2   Safety

Laser Diode

As stated previously, the proposal requirements would have required a $20mW$ IR laser. However, in the State of Illinois, a 20mW laser is considered a Class 3B laser and must be registered with the Division of Nuclear Safety in the Illinois Emergency Management Agency. This would have required the team to file the correct paperwork and pay a registration fee of $50. This paperwork would have likely caused delays in receiving parts and construction of this project. A 20 mW laser would have also needed much more pre-caution and safety mitigations than a much less powerful laser.

For the reasons stated above, the team will instead use a $5mW$ visible red laser. $5mW$ visible lasers have a low chance of injuring the eye, as the blinking reflex will save a victim from permanent damage; as opposed to IR lasers which can go unnoticed for several seconds.

The following is a calculation for the nominal ocular hazard distance (NOHD) of our laser, as defined by the ANSI Standard [3].

The maximum permissible exposure (MPE), as defined by the ANSI Standard [3] is the highest power or energy density of a light source that is considered safe, i.e. that has a negligible probability for creating damage. This MPE for a pulsing laser is calculated as the minimum of the following three rules:

1. Any single pulse in the train must not exceed the MPE for the pulse exposure time.

2. The exposure from any group of pulses delivered in time T must not exceed the MPE for time T, where T is 0.25 seconds (from the blinking reflex), for a visible laser.

3. For thermal injury, the exposure for any single pulse within a group of pulses must not exceed the single-pulse MPE multiplied by a multiple-pulse correction factor

The laser will pulse at a rate of 40 kHz. Assuming at most a 50% duty cycle, each pulse will be of max length $1.25 * 10^{-5}s$. The divergence of the beam is smallest for the longest range; a lower divergence is more restrictive in terms of safety, so this calculation uses $300m$. The divergence of the beam for 300m is 2.79 mrad and the beam waist is approximately $4mm$.

Following the ANSI Standard [3], the Rule 1 calculation is

$$5 * 10^{-3} * \left(\frac{2.79}{1.5}\right) = 0.0093 \frac{J}{m^2}$$

The Rule 2 calculation is

$$\frac{18(.25^{0.75})(\frac{2.79}{1.5})}{.25 * 40000} = 0.0011837 \frac{J}{m^2}$$

The Rule 3 calculation is

$$(.25 * 40000)^{0.25} * 5 * 10^{-3} * \left(\frac{2.79}{1.5}\right) = 0.093 \frac{J}{m^2}$$

The most restrictive of all the rules is Rule 2, which gives us an MPE of $0.0011837 \frac{J}{m^2}$.

At $5mW$ with a pulse width of $1.25 * 10^{-5}$, the power of the laser is $6.25 * 10^{-8} J$.

The NOHD is defined as

$$\frac{\sqrt{\frac{4*P}{\pi*MPE}} - 2w}{\theta}$$

Where P is the power of the beam ($6.25 * 10^{-8} J$) and w is the waist of the beam ($1mm$). This gives an NOHD of

$$\frac{\sqrt{\frac{4*6.25*10^{-8}}{\pi*0.0011837}} - 2(0.004)}{0.00279} = 0.0713m$$

The team will avoid eye damage by not working with their eyes inside of 8 cm from the laser. If it is necessary to get this close to the laser, the team will wear eye protection or simply power off the laser.

3.3   Ethical Issues

4 Cost and Schedule

4.1 Cost Analysis

The labor cost was calculated as follows:

$$\text{Labor Cost} = \text{Worker Salary (\$/hour)} \times 2.5 \times \text{Time (Hours) Invested In Project}$$

COMPILE PARTS LIST, SUM UP TOTAL, ADD TO LABOR COSTS - SAME AS PROPOSAL

4.2 Schedule

EDIT SCHEDULE CREATED IN PROPOSAL

References

[1] "Mixed Signal Microcontroller MSP430F22x4," Web, Texas Instruments, accessed February 2016. [Online]. Available: http://www.ti.com/lit/ds/symlink/msp430f2274.pdf

[2] "Using the Real-Time Clock Library," Web, Texas Instruments, accessed February 2016. [Online]. Available: http://www.ti.com/lit/an/slaa076a/slaa076a.pdf

[3] "American National Standard for Safe Use of Lasers," ANSI Z136.1-2000.