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.

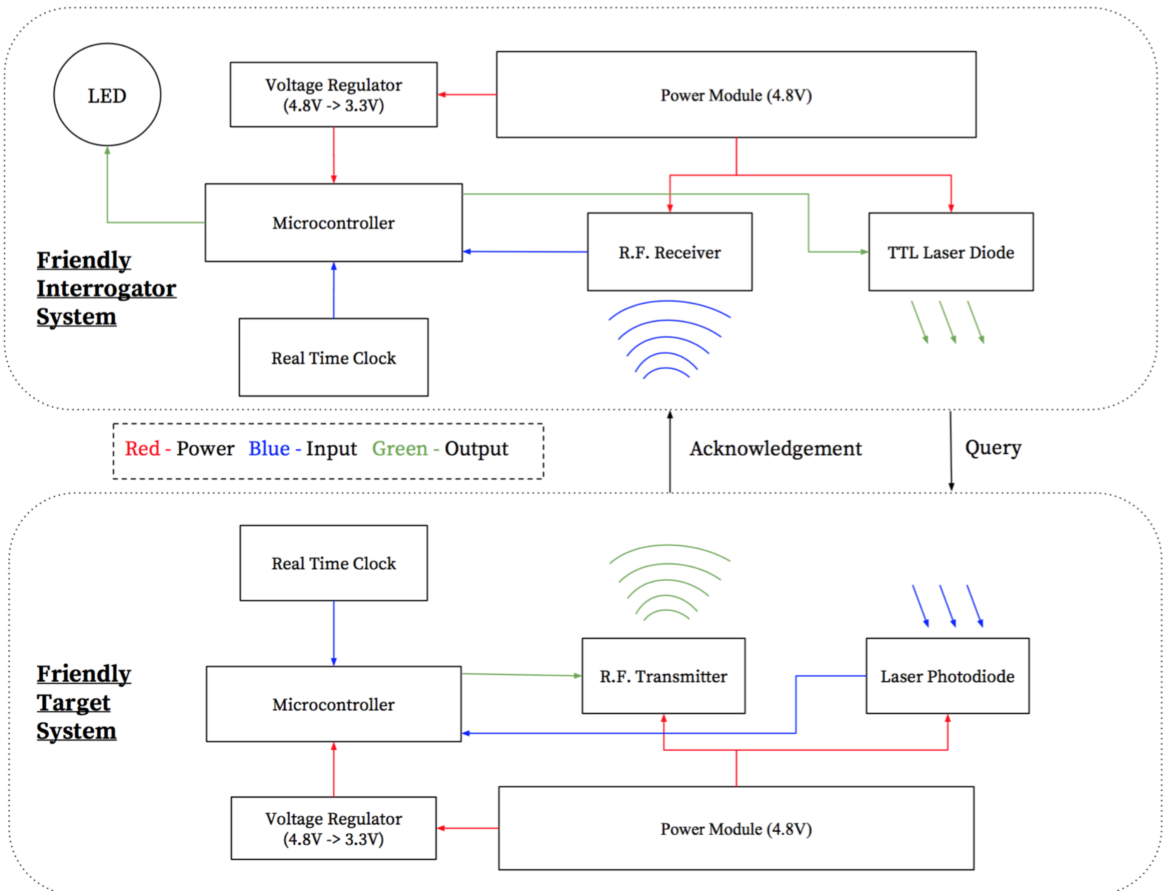

Figure 1: System Block Diagram

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.

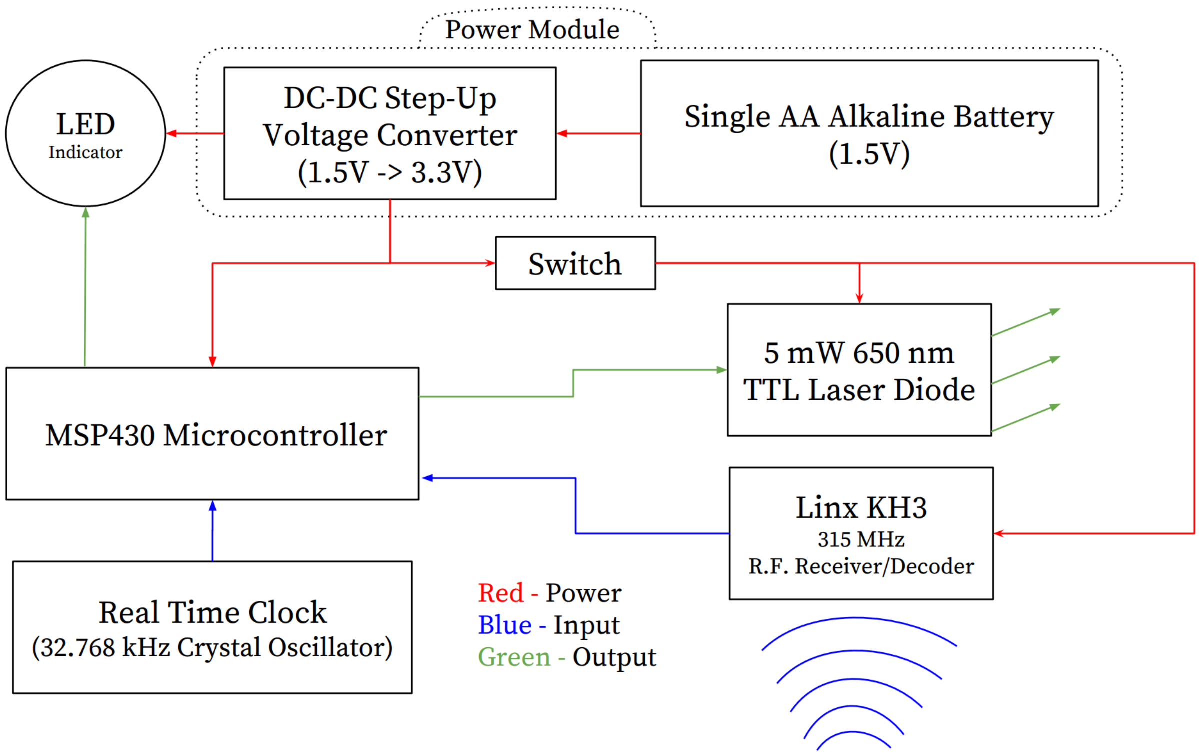

Figure 2: Block Diagram of Friendly Interrogator Unit

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 ____.

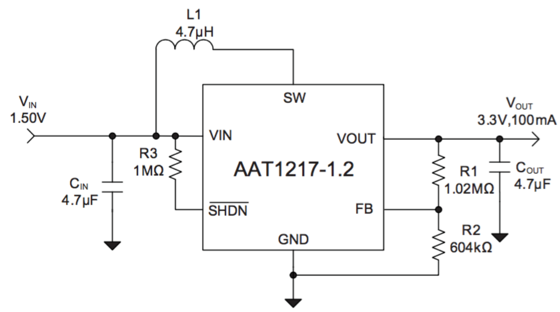

Figure 3: AAT1217 Circuit Schematic

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 IO
9	2.1/TAINCLK/SMCLK/A1/OA0C	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

For safety reasons, the maximum allowable power for the laser diode is $5mW$; which registers as a Class IIIa laser. The laser diode must also fall in the visible range, so that it will trigger a person's blinking reflex before eye damage occurs. Specifically, the team will use a red ($650nm$) laser. See section 3.2 for more on safety of the laser.

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.

To save cost and time, the team will be purchasing an adjustable focus laser. This laser will allow for optical adjustments to achieve the beam diameter at all required distances. The team will ensure the purchased laser meets these requirements, and will adjust the lens if necessary.

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

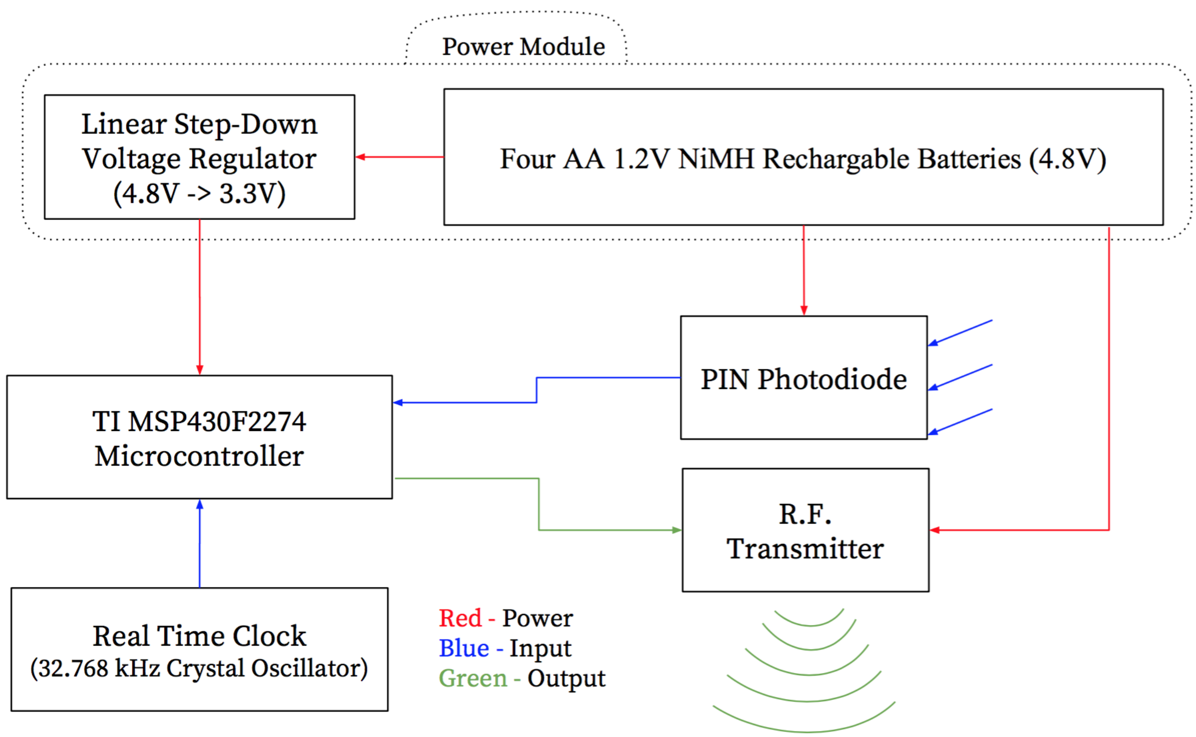

Figure 5: Block Diagram of Friendly Target System

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.

Photoreceiver
Power-In: N/A
Power-Out: N/A
Input(s): Laser Transmitter
Output(s): MCU

A network of four photodiodes mounted on the friendly target will report incoming laser signals to the MCU. The photodiode signals will be boosted via an operational amplifier, and passed through a low-pass filter. The $40kHz$ signal that passes through the filter will be sampled and processed by the MCU.

For a detailed analysis of the choice of the photodiodes, see section 3.1

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

2.2 Circuit Schematics

2.2.1 Friendly Interrogator Unit

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

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

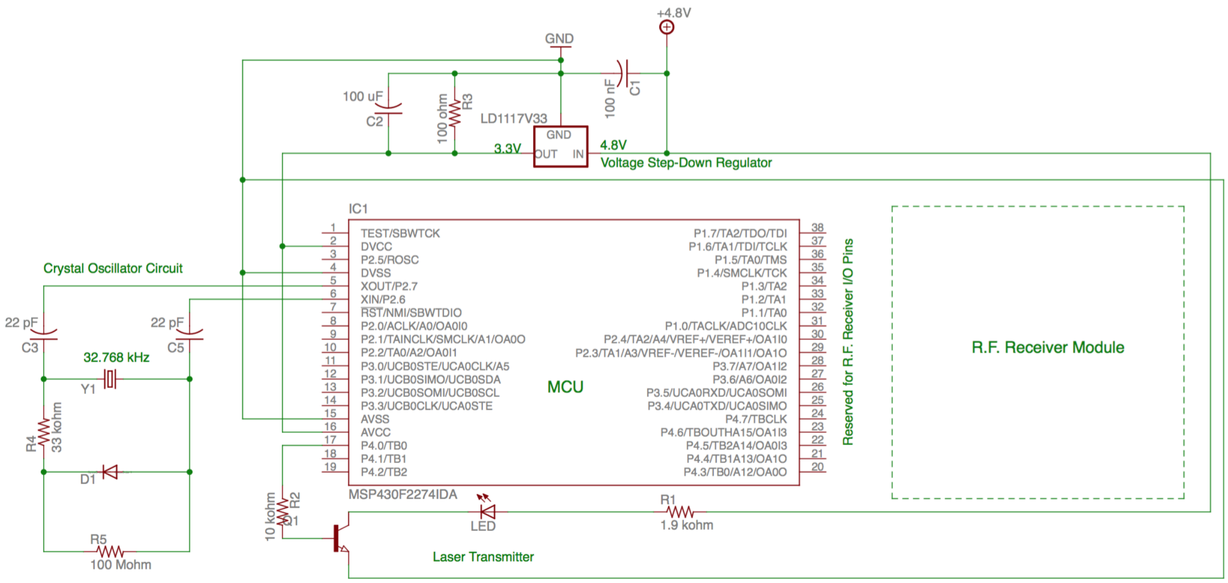

Figure 6: Circuit Schematic of Laser Transmitter

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.

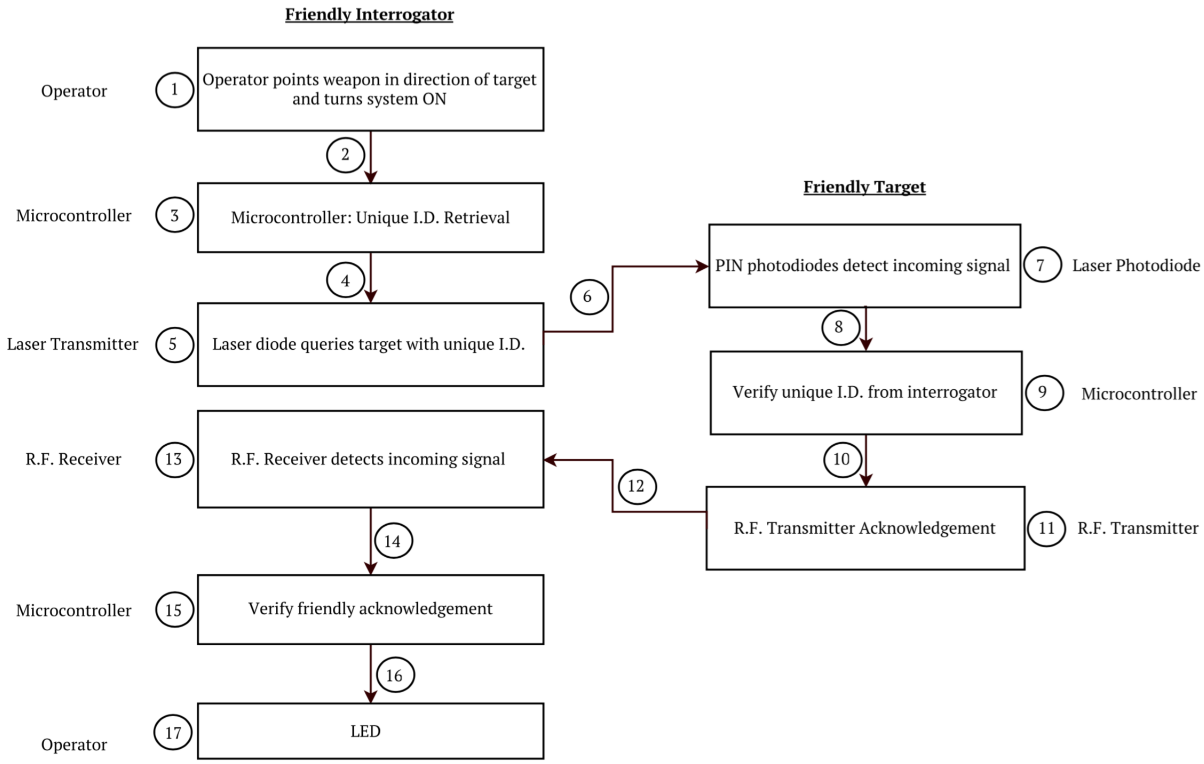

Figure 7: Flowchart for Functionality

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:

$$\mathrm{I}_{\mathrm{Total}} = 270\mu A + 25mA + 5.9mA + 0.7\mu A$$

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 and Photodiode

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).	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
		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)	Field Test - Verify laser transmission at distances for three ranges.
	Power Module	Must maintain a constant DC power source of 4.8V ± 5%.	Attach power module to digital multimeter in parallel and measure output voltage with and without load components attached.
		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 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.	Verify using oscilloscope connected to output generated by MCU and measuring period time in µs.
		Must maintain its own internal clock to a precision of ± 10 minutes ± 10%.	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

The inherent limitations of laser power for safety means that the performance is in the hands of the photodiode. The starting point for selection criteria was to choose a photodiode type. There are three main photodiode types: normal, PIN, and Avalanche; the team chose PIN photodiodes as they have a high sensitivity and speed. A normal photodiode would not be sensitive enough to register a wide divergence $5mW$ laser, and an Avalanche photodiode requires high voltage.

The next selection criteria is the material with which the photodiode is made. This includes materials such as Si, InGaAs, and InA. The optimum wavelength is dependent on the material selection.

With photodiodes, Noise-equivalent Power (NEP) is a measure of the incident power required to generate a response signal equal to the noise level of a detector system. Detectivity is the reciprocal of the NEP normalized for the active area of the photodiode.[?]. The best photodiode, then, will have the highest detectivity for the visible wavelength.

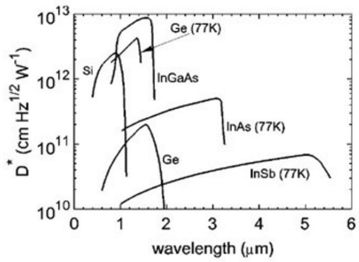

Figure 9: Specific Detectivity for Photodetector Materials [?]

Figure 9 illustrates the specific detectivity ranges of photodiodes. The interrogation laser is in the visible range; therefore, the matching photodiode is of type Si. Using this type of photodiode, the detectivity is between 10^{10} and 10^{13} $\frac{Hz^{\frac{1}{2}}}{W}$. The following calculations will use a conservative value, $10^{12}\frac{Hz^{\frac{1}{2}}}{W}$, as the detectivity. In realty, because the wavelength is less than 1 µm, the detectivity is somewhere between 10^{12} and 10^{13} $\frac{Hz^{\frac{1}{2}}}{W}$

The equation for NEP from detectivity, D^*, and photodiode active area, A, is

$$NEP = \frac{\sqrt{A}}{D^*} \ [\frac{W}{Hz^{1/2}}]$$

The incident irradiance, E_i, to cancel noise is

$$E_i = \frac{NEP*\sqrt{f}}{A} = \frac{\sqrt{Af}}{AD^*} = \frac{f}{D^*\sqrt{A}} \ [\frac{W}{m^2}]$$

The NEP measures the incident irradiance to cancel the noise on the photodiode. To register a signal on the MCU, the incident irradiance must be higher than the noise. To be conservative, define the required incident irradiance as

$$E_{req} = 2E_i \ [\frac{W}{m^2}]$$

Multiplying the area of the laser's spot by the required incident irradiance at the photodiode gives the necessary power. Thus, the radius of the spot in terms of the power of the laser and required incident irradiance at the photodiode is

$$r = \sqrt{\frac{P}{\pi E_{req}}} \ [m]$$

Note that the power contained in the laser's spot does not depend on distance from the source, as atmospheric reflection is negligible at $300m$.

The radius, in terms of the detectivity, frequency, and sensor active area is

$$r = \sqrt{\frac{PD^*\sqrt{A}}{2\pi f}} \ [m]$$

The proposal listed $0.8382m$ as the ideal radius of the laser's spot. Unfortunately, with the $5mW$ red laser, this would require a sensor with a massive active area. The largest sensor the team could find, at a reasonable price, has a $100mm^2$ active area.

For the $100mm^2$ active area photodiode operating at $650nm = 4.6121910^{14}Hz$

$$r = 0.608721m \approx 61cm$$

Refining the proposal requirements, the team has set a new requirement of a $50cm$ laser spot radius, making the diameter of the beam $1m$ at distances of $50m, 150m$, and $300m$ with optical adjustment.

Capturing these requirements, the team must transmit a signal to a photo-detector at the following ranges:

- Short Range (0 - 50 m)
- Medium Range (50 - 150 m)
- Long Range (150 - 300 m)

The team should then verify that the signal was received. Furthermore, the team should verify that the signal spans the width of a human chest. More concretely, that a sighted-in laser transmitter can be aimed at any point within $50cm$ of the receiver and still register the transmitted signal.

Test Procedure:

- Mount the receiver 300 m downrange of the transmitter
- Aim the laser transmitter directly at the receiver, using a mount (like a vice grip) to keep it stable.
- Verify the signal is received via the probe point on the PCB
- Aim and verify the signal is also received when aiming 25 cm to the right, top, and bottom of the receiver.
- Repeat these steps for 50 m and 150 m.

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

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

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

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

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:

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

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.