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

By

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Contents

Acronyms & Pre-Requisite Information

- Infantry - branch of a military force that fights on foot.
- I.F.F. - Identification Friend or Foe
- PWM - Pulse Width Modulation
- PCB - Printed Circuit Board
- R.F. - Radio Frequency
- RTC - Real Time Clock
- NEP - Noise-equivalent Power

1 Introduction

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.

In order to reduce the amount of friendly fire accidents in modern combat, a Infantry I.F.F. (Identification Friend or Foe) will be designed and constructed which will notify a soldier bearing a weapon whether or not their target is friendly.

Several I.F.F. systems exist for aircraft, however not many reliable systems have been constructed to suit infantry that incorporate fast response times and LEDs for indication.

The system will mount to the side of any weapon, send out queries, ask if a target is friendly, and upon receiving a successful (friendly) reply, will notify the operator.

This will be accomplished through a laser transmission system mounted to the rail (weaver mount) of a weapon. If the friendly personnel receives any of this signal (via phototransistors), it will respond with "acknowledgement" that it is friendly. Once the interrogator receives notice that the target is friendly, the dot sight will turn to a different color.

It is important to note that, in order to have a laser communicate "friendly" for a swath the size of a person, there either need to be multiple photodetectors or a large beam from the laser. Because hundreds of photodetectors is not feasible, our design will use optical adjustment to create a large beam.

Encryption plays a large role in a system like this, and for this reason must be emphasized heavily in the design process. Pulse Width Modulation will be used to transmit a unique I.D. of the interrogator pointing their sights at a friendly target, and upon receiving this laser transmission, the target will respond with an RF signal. This RF Isotropic Signal will be encrypted with a passphrase that is generated using a method similar to a "Time-based one-time password" algorithm.

The benefit of a system like this are the following:

- 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

The cost of a system like this will be heavily emphasized throughout the design phase. The team has proposed a schedule dating from February 8th - May 2nd of this semester. This gives the team ≈ 3 weeks for design, ≈ 7 weeks to assemble, test, and refine, and ≈ 3 weeks to document. The cost and schedule are both expanded upon in Section 5 in this document.

2 Design

2.1 Block Diagram

The design of a system like this is very flexible and can be implemented in several ways. The team decided to break this up into two subsystems with individual sub-components. These will be referred to the "friendly interrogator system" and the "friendly target system".

1. Friendly Interrogator System
    - Laser Transmission (Transmit Query)
    - RF Receiver (Receive Acknowledgement)
2. Friendly Target System
    - Photoreceiver (Receive Query)
    - RF Transmitter (Transmit Acknowledgement)

Below is a block diagram containing all subsystems that will be designed and constructed this semester. The red dotted line is referring to the Laser Subsystem which is essentially a adjustable laser that will reach the desired distance along with a photodetector to detect these signals. The blue dotted line is the R.F. Subsystem which will serve as the "acknowledgement" to the laser signal to notify the interrogator that the target they are pointing their weapon at is friendly. The green dotted line is referring to the Friendly Interrogator and the Friendly Target Subsystem which will be expanded upon in the following pages.

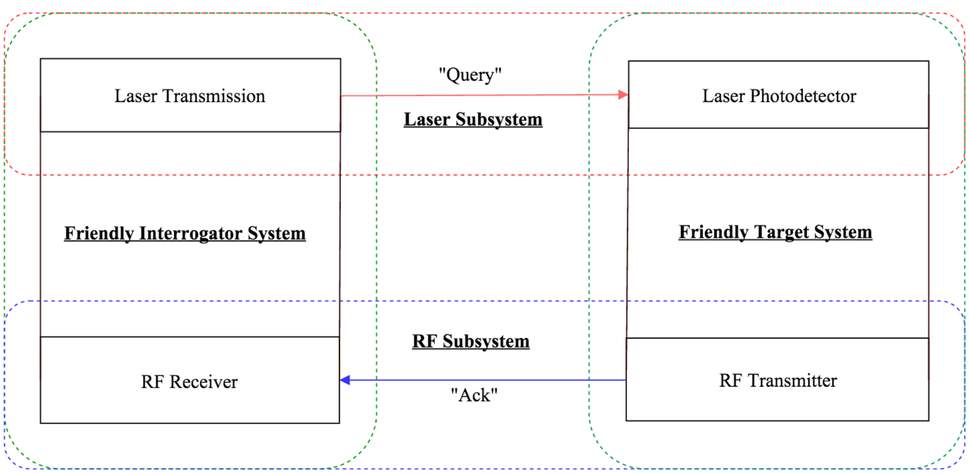

Figure 1: I.F.F. Subsystem Diagram

2.2 Block Descriptions

Friendly Interrogator System

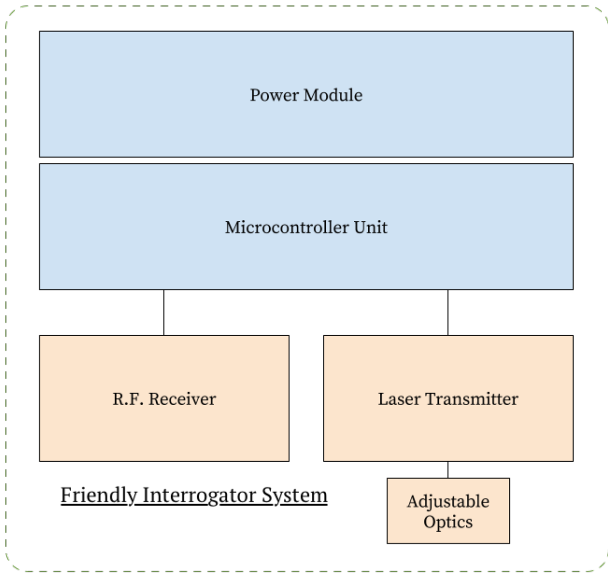

Figure 2: Interrogator System Diagram

Laser Transmission

- Optical adjustment to achieve:
  - Short Range (Close Quarters) : 0 - 50 meters
  - Medium Range (Urban Setting) : 50 - 150 meters
  - Long Range : 150 - 300 meters
- At the extreme of each range, the diameter of the light spot from the laser should be 5-6ft; around the size of a person.
- P.W.M Signal to transmit signal attached with a unique I.D. of interrogator.
  - Ability to adjust state of laser to transmit information.
  - Preamble followed by unique I.D. of transmitter (in 2 byte packets).

R.F. Receiver

- Receives "acknowledgement" signal from friendly target.
- Must have ability to verify passphrase with common clock (Real Time Clock - RTC).
- If successful (i.e. system identifies target as friendly), then indicator (LED) will change color from red to green.

Friendly Target System

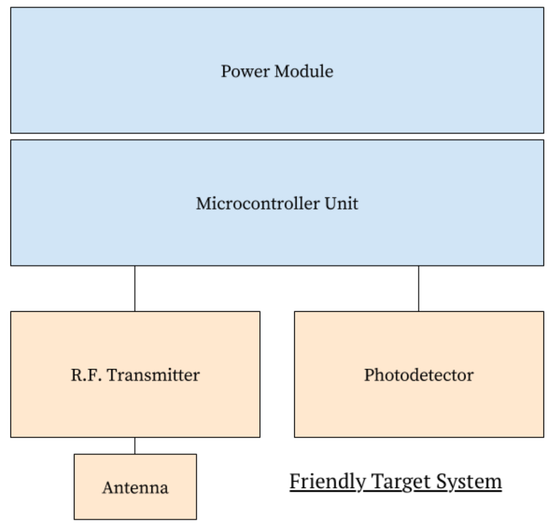

Figure 3: Target System Diagram

Laser Photodetector

- Couse staff and resources provided on Wiki will help narrow down options in the design phase.
  - https://courses.engr.illinois.edu/ece445/wiki/?n=Topics.LaserDiodeAndPhotodiodeIntroduction
- Photodiode that must be engineered to receive the wavelength and intensity of the laser transmission at maximum range.
- Photodiodes will be mounted on the wearer's helmet, weapon, and/or chest to detect incoming transmissions.

R.F. Transmitter

- Isotropic R.F. Radiator to acknowledge query sent by laser on interrogator.
- Ability to reach up to 300 meters.
- Encrypted Passphrase
  - Password generated based off of common clock (RTC).
  - Clocks will need to be synced with a common clock source periodically.

3 Requirements and Verification

The requirements for this semester are as follows:

System	Module	Requirement	Verification	Points
Friendly Interrogator System	Laser Transmitter	Must be able to achieve 20mW of power at source with a wavelength in the infrared spectrum from 700 nm - 1400 nm. See Tolerance Analysis for the source of the 20mW power requirement Light from the beam must span a range of 5-6 ft at the following distances, with optical adjustments allowed: - Short Range (50 m) - Medium Range (150 m) - Long Range (300 m)	Verify with a multimeter that power is 20mW at source. Verify that a photodiode optimised for 700 nm - 1400 nm registers the light from the laser source by pointing the laser towards, and then away from the photodiode. Field Test - Verify laser transmission at distances for three ranges. See Tolerance Analysis section for greater detail.	*20*
	R.F Receiver	Ability to detect an R.F. signal of up to 300 m away in the frequency range of 315 - 450 MHz.	Field Test - R.F. Receiver must receive 90% of packets from R.F. Transmitter placed 300 m from receiver. Verify frequency with oscilloscope.	15
	Power Module	Must maintain a constant DC power source of 5.0V ± 5%. Must maintain constant supply of power while equipped with friendly interrogator personnel for 8 hours ± 10%.	Attach power module to digital multimeter in parallel and measure output voltage with and without load components attached. Attach battery pack to friendly interrogator module and test for a period of ~8 hours to determine if it supplies a constant power.	2.5
	Microcontroller	Ability to control laser transmitter to send digital data by alternating the state of the PWM laser pulse at a predefined time period of ~ 100μs. Ability to process signal from R.F. receiver and decode it to match the passphrase with 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.	10
Friendly Target System	Photoreceiver	Ability to detect a PWM signal up to 300 m of the same wavelength as the laser transmitter. At least 90 % of packets must be received properly when the laser is aimed at the photoreceiver.	Field Test - Photoreceiver must be feeding correct voltage dependent on specifications/datasheet to MCU.	*10*
	R.F. Transmitter	Ability to transmit digital data up to 300 m away in the frequency range of 315 - 450 MHz.	Field Test - R.F. Transmitter must transmit 90% of packets generated from microcontroller to 300 m from transmitter	15
	Power Module	Must maintain a constant DC power source of 5.0V ± 5%. Must maintain constant supply of power while equipped with friendly target personnel for 8 hours ± 10%.	Attach power module to digital multimeter in parallel and measure output voltage with and without load components attached. Attach battery pack to friendly interrogator module and test for a period of ~8 hours to determine if it supplies a constant power.	2.5
	Microcontroller	Ability to generate an encrypted signal containing passphrase that is based on internal Real Time Clock (RTC) with an precision of ± 10 minutes ± 10%.	Sample packets sent to microcontroller and verify time with that of a local known source.	15
System	System	Speed - The average human reaction time for visual stimulii is 190 milliseconds[3]. A friendly target at 300 m should be marked friendly within 190 milliseconds so that, to a human user, it seems nearly instantaneous.	Measure time from when initial interrogator points weapon at friendly target to when the acknowledgement is received.	10

Figure 4: Requirements and Verfication Table

4 Tolerance Analysis

The signal transmission from the friendly interrogator to the friendly target will be a critical aspect of this project. The extremes of this transmission must be tested; ensuring that it has bot the range and signal span required.

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 and processed by the MCU. 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 2.5 - 3 feet of the receiver and still register friendly.

The team must transmit a signal over a distance of 300 meters that has the ability to be accurately received by a photo-detector and processed by an MCU.

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.
- Aim and verify the signal is also received when aiming 2.5ft to the right, top, and bottom of the receiver.
- Repeat these steps for 50 m and 150 m.

Ensuring that the laser can broadcast over this distance, with divergence, requires a careful selection of parts; including a sensitive photodiode and a powerful laser.

Because photodiodes are generally cheaper and consume less power than lasers, our starting point for selection criteria was to choose a sensitive photodiode. As such, the team has selected the PIN photodiode.

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.[1]. The best photodiode, then, will have the highest detectivity for the infrared wavelength.

Figure 5 illustrates the specific detectivity ranges of photodiodes. The interrogation laser is in the infrared range; therefore, the matching photodiode is of type InGaAs. Using this type of photodiode, the detectivity is between 10^{12} and 10^{13} $\frac{Hz^{\frac{1}{2}}}{W}$.

The equation to get the NEP from the detectivity is $\frac{A^{1/2}}{NEP}$. The NEP, then, for a 5mm photodiode is $\frac{\sqrt{.0025^2 * \pi}}{10^{12}} = 4.431 * 10^{-15} \frac{W}{Hz^{1/2}}$. Assuming the laser is operating in the IR wavelength, lets say the frequency is $4 * 10^{14} Hz$. This means the amount of power incident on the photodiode to cancel noise is $\sqrt{4 * 10^{14} Hz} * 4.431 * 10^{-15} \frac{W}{Hz^{1/2}} = 8.862 * 10^{-8} W$.

Taking the power to include the area of the photodiode, it takes $\frac{8.862 * 10^{-8}}{.0025^2 * \pi} \approx 0.0045 \frac{W}{m^2}$ for a signal to cancel out the noise. Broadcasting a PWM signal means producing a signal that registers as more than noise. As such, we will up the theoretical required energy by 100%. Assume $0.009 \frac{W}{m^2}$ is necessary to broadcast a PWM signal.

Now, assume the laser comes out of a diverging lens in the form of a cone. Neglecting dissipation from light reflecting off of air, we can assume that the loss in power per unit area of the laser happens with respect to the area of the light spot. That is, a 5mW laser diverged to a 5 ft diameter will have much less power per area than a concentrated 5mW laser with an inch diameter.

The laser must cover a diameter of 5.5ft (1.6764 m) at 300 m. Let P be the laser power needed. $\frac{P}{0.8382^2 * \pi} = .009 \frac{w}{m^2}$

This means the required power, P, is 18 milliwatts.

Please note that the work being performed in the tolerance analysis sections takes up a total of 30 points in the requirements/verification table.

5 Cost & Schedule

The schedule and budget of this project will be analyzed in the sections below.

5.1 Schedule

Please refer to Figure 6 for the brief timeline of this project highlighting the milestones and approximate duration of each phase. Refer to Figure 7 for an extended week-to-week description of what the team wishes to accomplish over the duration of the semester.

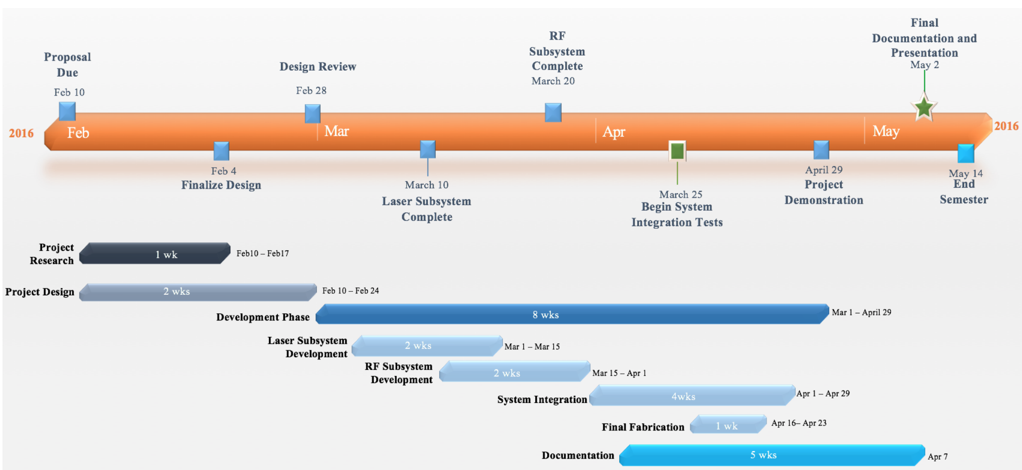

Figure 5: Timeline with Milestones

Wk #	Week	Task	Responsibility
1	2/8	Finish and Submit Proposal	Eric & Noah
		Research R.F. Transmitter and Receiver Modules	Eric
		Research Optical Adjustment Techniques/Theory	Noah
2	2/15	Research Laser Transmitter and Photodetector Modules	Noah
		Research MCUs and Power Module	Eric
		Develop encryption algorithm and communication protocol	Noah
3	2/22	Develop circuit for photodetector and R.F. Modules	Eric
		Select and Buy Parts/Sensors	Eric & Noah
		Finalize Design Review Documentation	Eric & Noah
4	2/29	Finish and Submit Design Review + Presentation	Eric & Noah
		Construct basic laser transmission circuit with protoboard	Noah
		Construct basic R.F. circuit with protoboard	Eric
5	3/7	Establish communication between both Laser Transmitter and Photodetector	Noah
		Establish communication between R.F Transmitter and R.F. Receiver	Eric
		Implement PWM with laser	Eric & Noah
6	3/14	Implement RF Encryption Algorithms on MCU	Noah
		Test and Debug	Eric & Noah
		Finalize Any Construction before Spring Break & Plan	Eric & Noah
7	3/21	Spring Break (NO SCHOOL)	----
8	3/28	Assemble Friendly Interrogator System	Noah
		Assemble Friendly Target System	Eric
		Test and Debug	Eric & Noah
9	4/4	System Integration Tests	Eric & Noah
		Test Tolerance Analysis	Eric & Noah
		Revisions for PCB	Eric & Noah
10	4/11	Sign up for Presentations	Eric & Noah
		Final Revision PCB	Eric & Noah
		Field Test and Verify Requirements Met	Eric & Noah
11	4/18	Test System Integration	Eric & Noah
		Finalize Construction	Eric & Noah
		Prepare Presentation and Demonstration	Eric & Noah
12	4/25	Friendly Interrogator System Documentation	Eric
		Friendly Target System Documentation	Noah
		Finish Final Report/Documentation	Eric & Noah
13	5/2	Prepare Presentation	Eric & Noah
		Final Report/Presentation	Eric & Noah
		Check-in Supplies	Eric & Noah

Figure 6: Extended Schedule Week-by-Week

5.2 Cost & Labor

This appears to be a fairly demanding Senior Design project. The team has approximately 12 weeks to design, implement, and fabricate this project. Each member of the team will likely work at least 15-20 hours/week on the project. This means ≈ 200 hours per team member for the semester.

The following is a rough cost analysis of the project:

Name	*Hourly Rate*	*Total Hours Invested*	*Total*
Noah Prince	$31	200	$15,500
Eric Meyers	$31	200	$15,500
		Labor Sub-Total:	**$31,000**

Part	*Unit Cost*	*Quantity*	*Total*
Industrial IR Laser	$13.26	1	$13.26
16-bit PIC MCU	$10.00	2	$20.00
Resistors and Capacitors	$0.40	10	$4.00
Battery/Power Module	$15.00	2	$30.00
Photodiodes	$1.00	2	$2.00
PCB Printing	$30.00	2	$60.00
RF Transmitter	$7.00	1	$7.00
RF Receiver	$7.00	1	$7.00
Indicator LEDs	$0.40	2	$0.80
			$144.06
			× 2 for redundancy:
		Parts Sub-Total:	**$288.12**

Grand Total :	*$31,288.12*

Figure 7: Labor and Cost Analysis Table

The labor cost was calculated as follows:

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

The parts estimate is not final by any means, this is just a rough estimate of what the team can expect during the design review.

References

[1] O. Bisi, *Silicon-based Microphotonics: From Basics to Applications.* IOS Press, 1999.

[2] R. S. Quimby, "Optical components and optics," 2006.