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# Power analysis and message decoding of laser engagement systems

Joshua Trujillo

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Dr. Paul DeRego

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**POWER ANALYSIS AND MESSAGE DECODING OF LASER  
ENGAGEMENT SYSTEMS**

**by**

**JOSHUA JOSEPH TRUJILLO**

**BACHELOR OF SCIENCE, COMPUTER ENGINEERING,  
UNIVERSITY OF NEW MEXICO, 2006**

**THESIS**

Submitted in Partial Fulfillment of the

Requirements for the Degree of

**Masters of Science  
Computer Engineering**

The University of New Mexico

Albuquerque, New Mexico

**December, 2012**

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## **Dedication**

*This thesis is dedicated to my amazing wife, Ali.*

*God has surely blessed me with a partner in life who is so supportive of all that I do.*

## **Acknowledgments**

I would like to thank my advisor and committee chair, Dr. James Plusquellic. I would also like to thank Dr. Nasir Ghani, for being on my committee. My special thanks to Dr. Paul DeRego, for being on my committee, as well as helping with document editing and advisement. My thanks go out to everyone at Honeywell FM&T, for their help in supporting my graduate education.

I would also like to thank my parents, Samuel and Kathryn Trujillo, for encouraging me and supporting me my whole life.

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## **Abstract**

Laser engagement systems are used for training by many military and security organizations around the world. Advanced laser engagement systems communicate using coded bursts which contain a multitude of information. These bursts must be sampled precisely in order to be correctly decoded. It is important to be able to correctly decode the messages from the laser transmitters when developing a decoder, or even just for verification of correct transmitter operation. Power measurements can be calculated from the sampled waveforms, but require proper sampling rates to ensure accurate power calculations. Calculating power accurately is important when verifying transmitter power, which is often measured to ensure that a transmitter is not operating above safe levels that can cause ocular damage. The aim of this work is to obtain a test setup that will accurately sample the waveforms of the transmitted coded bursts for proper decoding and power measurement calculations. Digitizer selection will be discussed, as well as an analysis of the algorithmic method used for decoding the messages from the bursts.

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## **1.0 Introduction**

### ***1.1 Overview***

Laser engagement systems are used for training by many military and security organizations around the world [9], as well as for entertainment and recreation in the private sector using laser tag gaming systems [8]. Advanced laser engagement systems communicate using coded bursts which contain a multitude of information. These coded laser bursts are sent to receivers worn by the player that capture the data sent for later analysis.

Because of the nature of lasers, there are always concerns about eye safety [10], especially in a laser engagement system where the goal is to fire the laser at another human being. While the laser in an engagement system is not designed to be powerful enough to cause harm to a human, safe operating procedures should still be followed at all times. Lasers should especially never be aimed directly towards anyone's eyes because a malfunctioning laser could cause permanent eye damage.

Safety is important to my employer, Honeywell FM&T, and it is for this reason that I was tasked with designing and building a test system to ensure that our laser transmitters are functioning properly and are not lasing at an unsafe level. In addition to the added safety, another benefit of a properly operating laser transmitter is accuracy. If the laser power is set too high or too low, then the effective range of the laser transmitter will not correctly simulate the weapon being used trained on. For example, a laser set too high on a small handgun might be able to trigger a target over a mile away, which is unrealistic.

In addition to calculating laser power, the system is also able to decode the messages from the transmitters. This is useful for technical troubleshooting of transmitters, as well as

verification of proper transmitter functionality. Laser transmitter encoding methods will vary by manufacturer.

Due to the fact that the actual test system I built is for Honeywell FM&T, which is a government contractor, I am unable to reveal certain details that pertain to our systems. Therefore, the concepts in this document will be described in terms that apply to all laser engagement systems, including recreational systems available to the public [14].

## ***1.2 Thesis Goals***

The goal of this thesis is to show the development of a system that can be used test and measure laser energy in a laser engagement system, as well as to provide the necessary background information to understand the underlying technologies.

## ***1.3 Thesis Outline***

First, the background will be covered, which includes lasers, photodetectors, digitizers, and sampling. This will be followed by implementation methodology and implementation results. Finally, the thesis will end with the conclusion and a list of references.

## 2.0 Background

The definitions in this section give the foundation to better understand the technologies presented in the rest of this thesis. Topics covered include lasers, photodetectors, and digitizers.

### 2.1 Lasers

Lasers are devices that emit beams of highly coherent and nearly monochromatic light. The term 'laser' is an acronym that stands for Light Amplification by Stimulated Emission of Radiation.

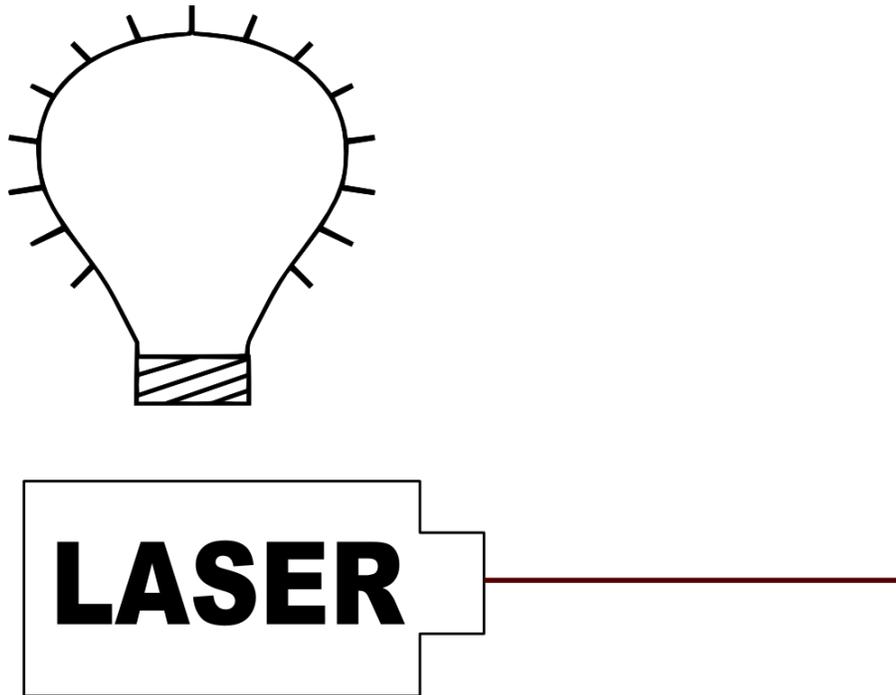
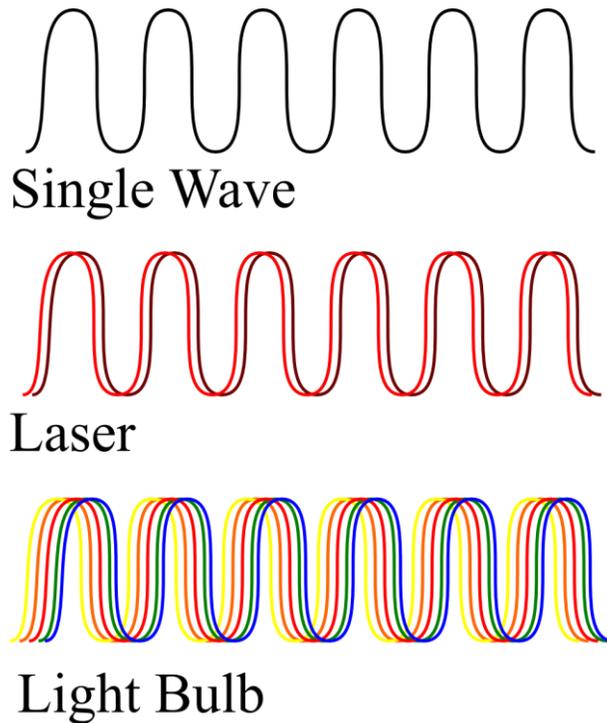


Figure 1 – Collimated Laser Light

In Figure 1, we see that a light bulb radiates light in almost every direction, whereas the laser emits light coherently in a single direction. Although focused in a single direction, the laser

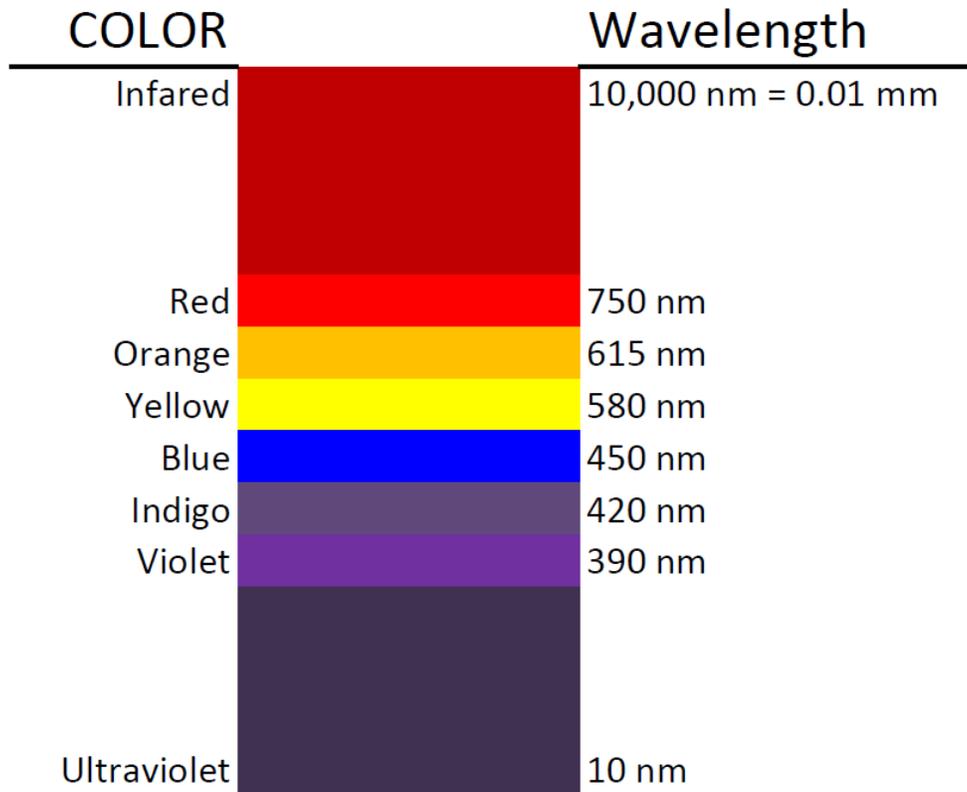
is not perfectly collimated, as can be seen at long distances, but for most applications the laser beam collimation is adequate.



**Figure 2 - Coherent Versus Incoherent Light Waves**

The phases of the laser light waves are synchronized, which makes them coherent [3]. Light bulbs emit wide bandwidth light [6], which is incoherent, as can be seen in Figure 2. In most laser applications, narrow bandwidth light approaching a single wavelength is used. Lasers are available in several different wavelengths, throughout the electromagnetic spectrum. Figure 3 shows the most relevant section of the electromagnetic spectrum in regards to lasers. Although infrared ranges from 750 nm to 10,000 nm, it is not common to find commercial infrared lasers

above 1500 nm. Similarly, ultraviolet ranges from 10 nm to 390 nm, but most commercial lasers are above 200 nm.



**Figure 3 - Spectrum Most Often Used By Lasers**

Since laser light is monochromatic, it will have a very narrow bandwidth, unlike visible light, which is spread out across the visible spectrum from approximately 390 nm to 750 nm. In a red laser, such as those used for laser pointers, a very narrow bandwidth frequency centered around 750 nm is used [7]. Figure 4 illustrates this point by showing a single wavelength next to the entire visible spectrum.

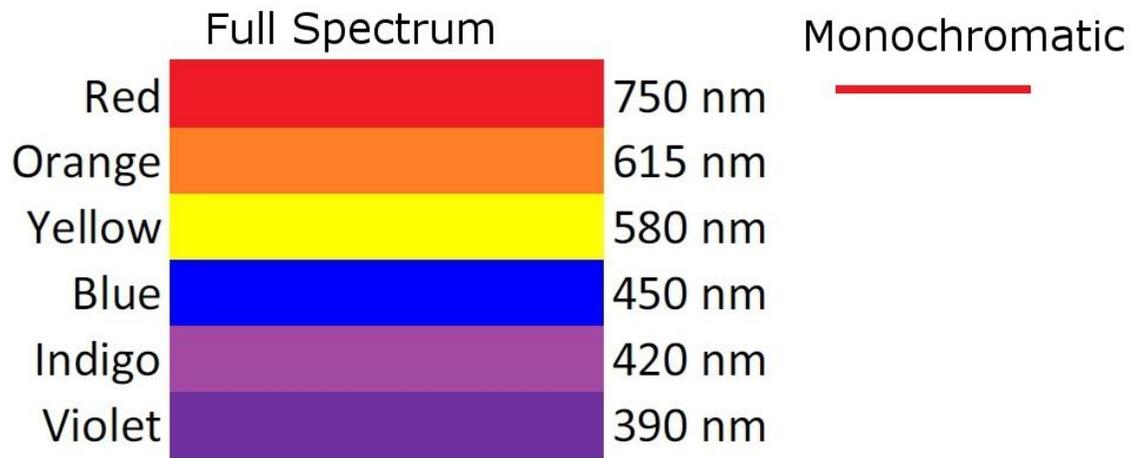


Figure 4 - Monochromatic Laser

Often times, choice of laser wavelength will be limited since manufacturers usually make available lasers with wavelengths that have properties that are ideal for the application that they are developed for. This helps to be able to focus on other parts of the system, without having to research how different wavelengths will affect your system. However, it is still very advantageous to become familiar with rudimentary laser physics in order to have a more well-rounded understanding of all of the components in the system being designed and built.

One very important aspect of lasers is laser safety [10]. Lasers are very useful, but are also very dangerous. Lasers are used in LASIK systems to reshape the cornea of the eye to improve vision [11]. What we don't want is for people to misuse lasers and harm their vision, or even cause complete blindness.

We saw in Figure 3 that lasers are available in wavelengths that are outside of the visible spectrum. What this means is that a laser can be lasing directly into your eye without you being aware of it. Infrared lasers are included in the group of lasers that are not visible by the human

eye, which is dangerous because the blink reflex does not work with infrared light, so a human will not naturally blink when an infrared laser is lasing into his or her eye. Often times, people injured by infrared lasers become aware of damage when they hear a popping sound coming from his or her eyeball. That noise is the sound of the retina boiling, and is associated with permanent blind spots being created.

## 2.2 Photodetectors

Photodetectors, also known as photosensors, are devices that detect light or other electromagnetic energy. There are several types of photodetectors, including photodiodes, photomultipliers, optical detectors, and light-dependent resistors [12]. Each of these photodetectors is very different. One of the more common photodetectors is the photodiode. Because of the popularity of the photodiode, we will assume that is what we are using in our examples that describe photodetectors. An example of a photodiode can be found in the solar cell of a typical solar panel. Figure 5 shows the circuit schematic symbol for the photodiode.

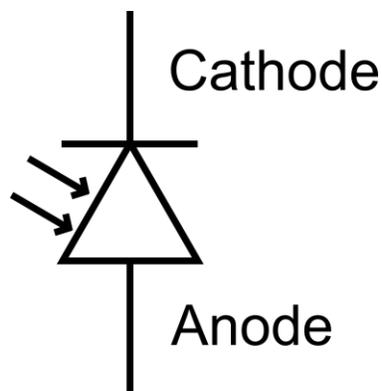


Figure 5 - Circuit Symbol for the Photodiode

Photodiodes operate using the photovoltaic effect, which is the production of voltage or current that is a measure of the intensity of incident radiation [2]. The voltage that is produced is then measured using a digitizer. The photodiode manufacturer supplies the parameters of the photodiode which are then used to calculate the laser energy, based on the readings that are recorded by the digitizer. When selecting a photodiode, it is necessary to verify that the

wavelength range of the photodiode is adequate to capture the light that the system is being designed to detect. Another important attribute of the photodiode to be mindful of is the rise time. Using a photodiode that has a fast enough rise time ensures accurate readings.

## 2.3 Digitizers

Digitizers convert analog signals into digital signals. In our case, the digitizers we are interested in convert analog voltage levels from the photodetector into digital waveform data [4]. An example of a digitizer can be seen below in Figure 6.



Figure 6 - Digitizer from Agilent

The most basic feature of a digitizer is the input port. In Figure 6, we can see that there are four BNC inputs on the front of the device. Each input is a channel, so this is a four-channel digitizer. The BNC connector is very common, including on photodetectors, which is very convenient since the photodetector can be hooked up directly to the digitizer using a BNC cable.

Oscilloscopes are specialized versions of digitizers because of their ability to view the waveforms on a display. Low-end, analog oscilloscopes may not have the ability to capture data from the device under test, which is an important and necessary feature when trying to analyze the data from a photodetector. Digital storage oscilloscopes (DSOs) digitize the signal coming in from the input using an analog-to-digital converter (ADC). The ADC samples the incoming signal and stores it in the memory of the DSO in digital form. This allows the stored, sampled data to be sent to a computer for further processing. Many DSOs have on-board processing using

very fast field programmable gate arrays (FPGAs) or digital signal processors (DSPs), which can significantly speed up the processing of the sampled data. Figure 7 shows where the ADC is located in the DSO workflow.

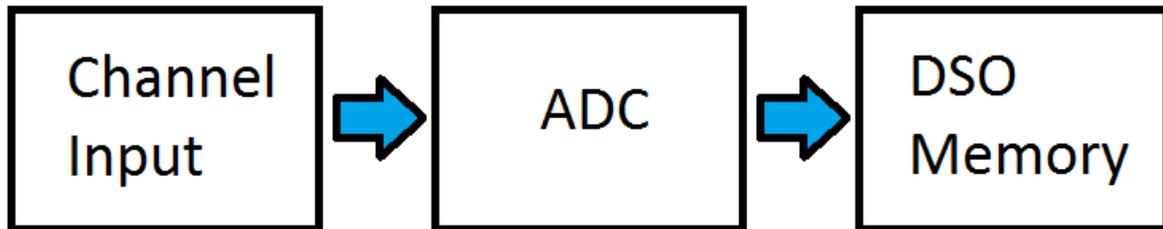
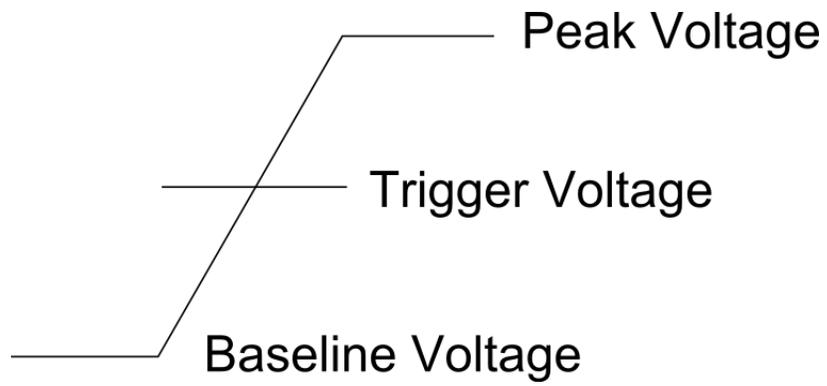


Figure 7 - ADC in DSO Workflow

An important feature on a digitizer is trigger control. Triggering allows you to set a threshold value that is used to initiate data capture when an event occurs. One example of using triggering is when we try to capture a pulse event. In order to successfully capture the pulse, we must determine what voltage level we will see on the edge of the pulse. It is very common to set a rising edge trigger, which is the voltage threshold that we tell the digitizer to look out for as the pulse rises from the baseline voltage to the peak voltage of the pulse [4]. Figure 8 shows the rising edge of a pulse.



**Figure 8 - Rising Edge Triggering**

There are other methods of triggering, such as pulse-width triggering, but for communication using pulses, rising edge triggering works well.

## 2.4 Sampling

Sampling is the process of converting a continuous signal to a discrete signal. This task is performed by the ADC in the digitizer. It is very important to capture the signal accurately enough to be able to recreate the signal from the digitized waveform [1]. In order to do that, a proper sampling rate must be used. The sampling rate is how frequently the digitizer is recording a sample of the signal [5]. Figure 9 shows a signal, with points along the signal at which samples are taken.

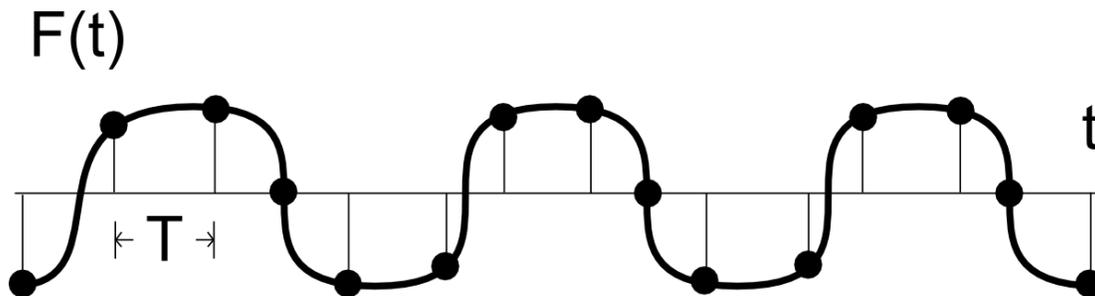


Figure 9 - Sampling

As we can see in Figure 9,  $T$  represents the time between samples, which is called the sampling period or sampling interval [13]. This relates to the sampling frequency in the following equation:

$$f_s = \frac{1}{T} \quad (1)$$

The unit for measuring sample frequency is Hertz (Hz), but often samples per second is used (Sa/s). Modern digitizers are capable of very high sample rates. For instance, the Agilent digitizer in Figure 6 is capable of up to 2 GSa/s.

Bit depth is the amount of memory used to measure each sample. For example, with a bit depth of 8, there are 256 possible values for each sample. Because of the way the sample data is stored, we must be aware of the digitizer vertical scaling. With the digitizer vertical scaling set to 1 Volt per division, and with 8 divisions total, we know that a value of 32 from the digitizer is equal to a 1 Volt measurement. We can see this more clearly in Figure 10.

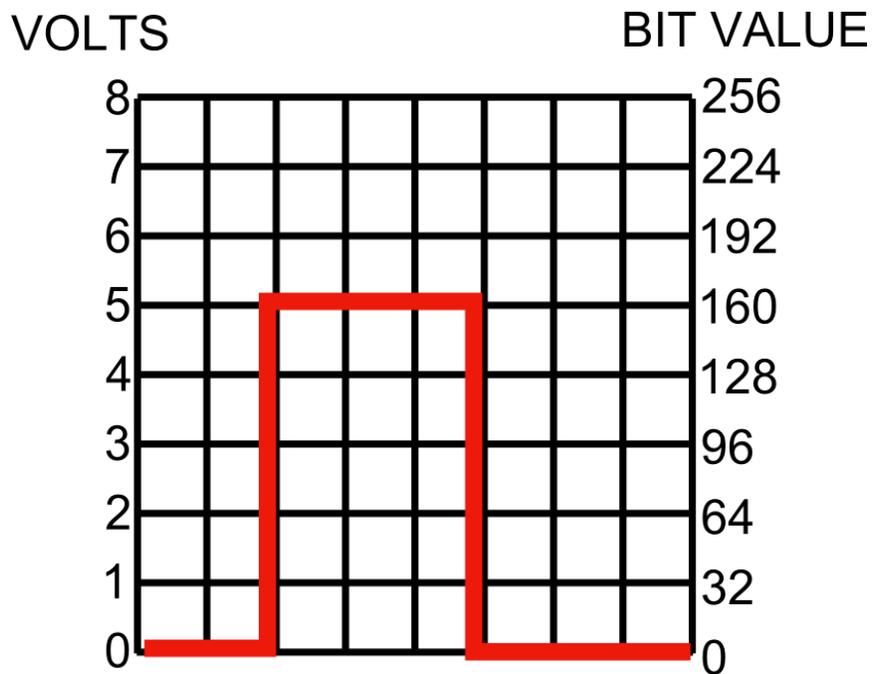


Figure 10 - Bit Depth

### **3.0 Implementation Methodology**

The methodology in this section is based on a system I designed and built at Honeywell FM&T. Again, because of the nature of our national security mission, I am unable to give specific details regarding protocols and actual message decoding algorithms used. However, because laser engagement systems used for entertainment purposes (such as laser tag) [14], the methodology presented here can be presented in a more general sense, while still offering enough technical details to contribute to engineers and scientists working in specific field of engineering.

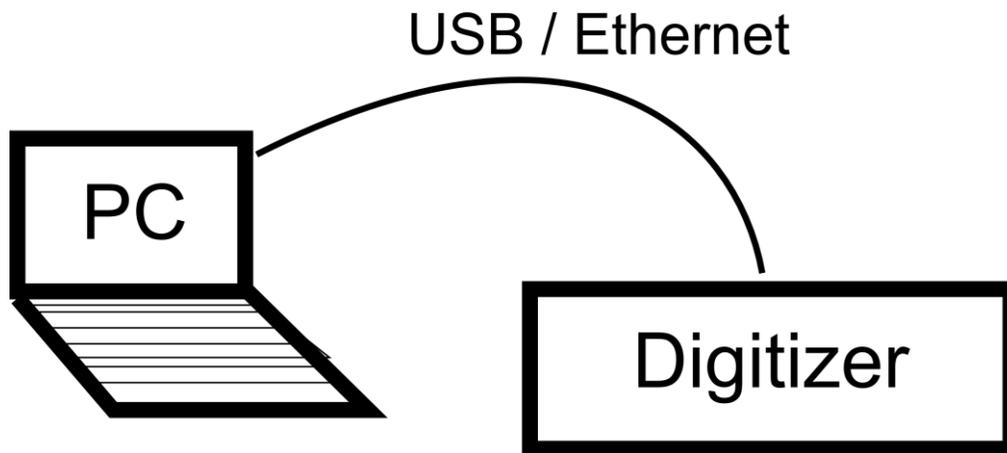
#### **3.1 Hardware**

Without hardware, there is no software to run code on, so we will begin by reviewing the hardware setup. The primary component in the system is the digitizer. As mentioned in the Background section of this document, the sample rate is an important requirement when choosing a digitizer. Based on the pulse width of the laser transmitter, I determined the minimum sample rate needed in order to sample the pulse accurately.

Next, I determined what environment the digitizer would be used in, and how it would be used by the users in their daily workflow. Since the users of the system wanted portability, I decided to use a laptop computer, as opposed to a desktop computer. This design decision effected the digitizer selection because the digitizer would need to be able to connect to a laptop. For instance, an internal PCI digitizer card would not work in this situation because a desktop computer would be necessary for the internal PCI card.

I simultaneously looked at laptops and digitizers to determine what connectors are available on laptops, while keeping in mind the connection options available on the digitizers on the market. Some of the connectors I looked at were USB (1.0 / 2.0 / 3.0), Firewire (400 / 800), Ethernet (10Base-T / 100Base-T / 1000Base-T), PCI Express Cards, and several others. I researched speed, reliability, and market adoption.

Market adoption was important because it is often easier to implement a component when example code from the manufacturer exists, or if others in the field have been successful and can share their experience, and sometimes even their code. This helps tremendously when developing any type of product.



**Figure 11 - PC and Digitizer**

As you can see in Figure 11, up to this point the system components included a laptop PC and a digitizer. Based on what was available, I made the design decision at this point to use either USB or Ethernet to connect the laptop to the digitizer. I learned that it is important to get a

solid foundation when designing a system, as opposed to trying to select every component in the system, tie it all together, and see if it works. The next task was to try to get a system diagram of all of the components, now that I felt confident with my solid foundation. The remaining components in the system are the transmitter and the photodetector.

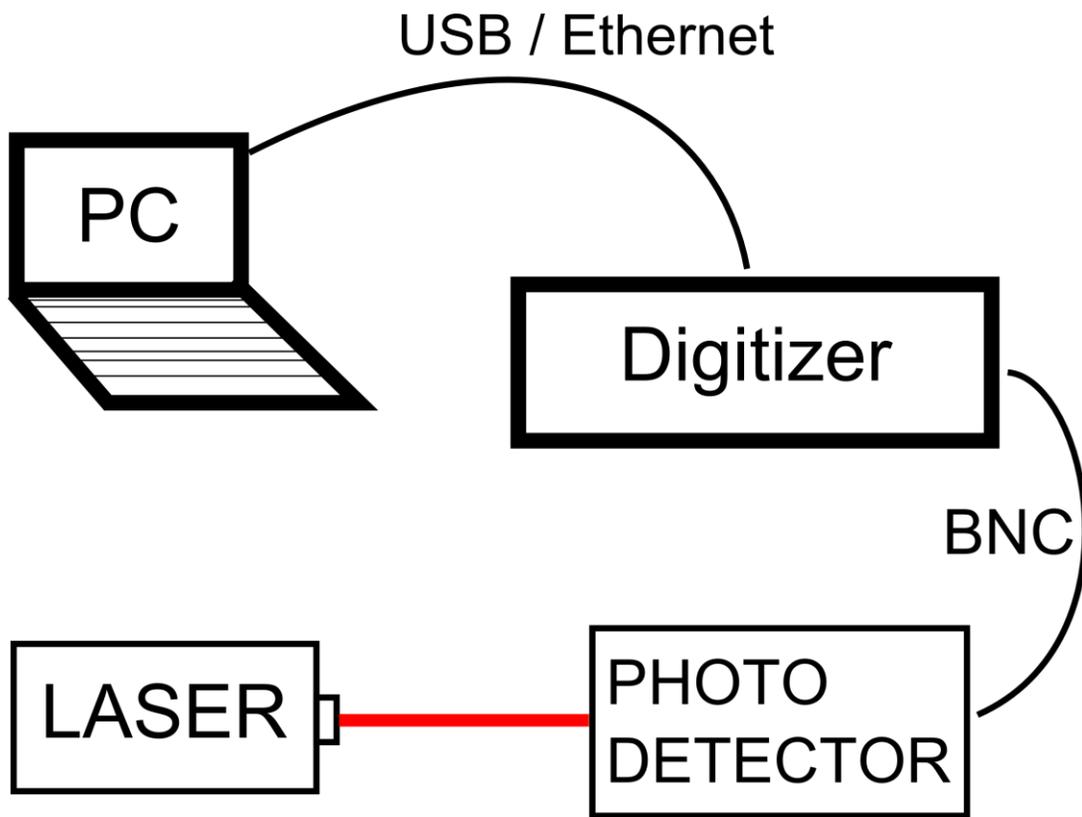


Figure 12 - PC, Digitizer, Laser, Detector

In Figure 12, the system diagram shows all of the major components of the system and how they are interconnected. In order to ensure proper measurements that are both accurate and repeatable, it is advisable to build a test fixture to mount the transmitter and receiver to. In fact,

there is a large selection of laboratory tables available that are threaded, that are designed with the laser physicist in mind. For my test setup, I decided to use a custom built housing for all of the components in the system.

### **3.2 Software**

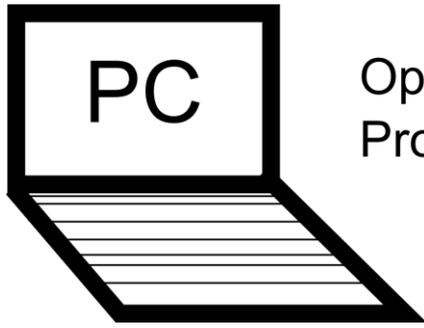
With the hardware chosen, the next step is the software. As you can see in Figure 12, the only component in the system that directly interfaces with the PC is the digitizer. The manufacturer of the digitizer made available several drivers for interfacing from the PC directly to the digitizer. Based on the drivers and developer documentation available from the manufacturer, the best choice of driver was for Microsoft .NET. The documentation and sample code for both C# .NET and Visual Basic .NET (VB.NET) made .NET the clear choice.

There is a possibility that the .NET libraries could have been run on Linux using Mono, but since this is a production system, the choice with the least risk and best chance of succeeding was Microsoft Windows.

At this point, it has been decided that Microsoft Windows will be the operating system, and the .NET libraries will be used. The next question was around what programming language to use. While both languages are very capable, C# was chosen due to the fact that it is a variation of C. In industry, I have seen that it is much easier for a software developer who knows C++ or Java to learn C# than it is for him or her to learn any version of Visual Basic, including VB.NET.

I had prior experience with both C# and VB.NET, but my personal preference was C#. My preference, in addition to knowing that someone working on my code down the road will most likely know Java or a variation of C, led me to the decision to choose C# as the

programming language for the system software. Figure 13 shows the operating system and programming language choices.



Operating System: Microsoft Windows  
Programming Language: C#.NET

**Figure 13 - Operating System and Programming Language**

## 4.0 Implementation Results

After carefully examining the specifications for a digitizer that looked like a good fit for this application, I asked several other engineers at work to verify that this digitizer would in fact work well, based on the documentation available from the manufacturer. With a unanimous vote to proceed with the purchase, I placed the order for the digitizer.

As soon as the digitizer arrived, the first task was to attempt to capture pulses from the laser transmitter. After searching through the developer documents and even speaking with field engineers from the manufacturer, it became apparent that there was a problem. The digitizer did not have segmented memory, which was required to store multiple pulse waveforms. This digitizer was not going to work for this application.

The lesson learned here was that even though several engineers carefully evaluated the digitizer, we ended up with a product that did not meet the needs of the project. Fortunately, I was able to trade in the digitizer for another digitizer that had the proper segmented memory that could capture all of the pulses. The digitizer that I finally ended up using did not have this feature enabled from the factory and had to be purchased as an add-on, but I was aware of that fact beforehand and purchased the add-on when I placed the order for the digitizer.

Once the digitizer with segmented memory arrived, I set it up and was capturing pulses. I gave my hardware designers the go-ahead to proceed with the hardware fixture design, using the new digitizer and all of the other components we use for our test setup. The completed hardware setup can be seen in Figure 14 below.



**Figure 14 - Completed Hardware**

As you can see, the hardware fixture was designed with modularity and functionality in mind. The frame is made of aluminum and is very sturdy. In Figure 15 you can see a snapshot of the software that I developed to control the digitizer. Both Figure 14 and Figure 15 are low-resolution images, but they still show the high quality that went into their design and build. There are many factors that went into this hardware design, but that is outside the scope of this document.

Figure 15, below, shows a snapshot of the software used to interface to the digitizer. This software was designed to be user-friendly, with special attention given to software reliability. The software uses a database to store the waveforms, which are displayed automatically as waveforms are captured, and can be recalled from the database and displayed at a later time as well.



**Figure 15 - Completed Software**

The software was also designed with modularity in mind. The Model-View-Controller (MVC) design pattern was used in order to separate the code for the graphical user interface (GUI) from the rest of the code, like the digitizer driver software. Using MVC when developing software helps with reliability, as well as readability, because of the way the code is separated, which also helps with maintainability.

For power calculations, I integrated the area underneath each pulse and added those values from all of the pulses together. This new test system I built is replacing an older test system that was built several years ago. I used the data from the older test system to verify that my power calculations were correct. When building a new system, it is very convenient to have a standard in place to compare results against.

## **5.0 Conclusion**

In conclusion, I am very pleased with the way the system turned out. I received positive feedback from the users of the system, as well. I started out this project with just the knowledge I gained in my undergraduate and graduate courses up to that point. Thanks to the research required to complete this project I was able to broaden my knowledge in all of the areas covered in this document.

## 6.0 References

- [1] Oppenheim, A., et.al. (1997) Signals and Systems. 2<sup>nd</sup> Ed. Prentice Hall. Upper Saddle River. Pp-514-555.
- [2] Wilson, J., et.al. (2009) Test and Measurement. 1<sup>st</sup> Ed. Elsevier. New York. Pp-281-293.
- [3] Young, H., et.al. (2000) University Physics. 10<sup>th</sup> Ed. Addison Wesley Longman. San Francisco. Pp-1251-1254.
- [4] Evaluating Oscilloscope Fundamentals [online] available from <http://cp.literature.agilent.com/litweb/pdf/5989-8064EN.pdf> [22 October 2012].
- [5] Evaluating Oscilloscope Sample Rates vs. Sampling Fidelity [online] available from <http://cp.literature.agilent.com/litweb/pdf/5989-5732EN.pdf> [22 October 2012].
- [6] Wikipedia (2012), “Light”, <http://en.wikipedia.org/wiki/Light> [Accessed: 10 October 2012].
- [7] Wikipedia (2012), “Laser”, <http://en.wikipedia.org/wiki/Laser> [Accessed: 10 October 2012].
- [8] Wikipedia (2012), “Laser tag”, [http://en.wikipedia.org/wiki/Laser\\_tag](http://en.wikipedia.org/wiki/Laser_tag) [Accessed: 10 October 2012].
- [9] Wikipedia (2012), “Multiple Integrated Laser Engagement System”, [http://en.wikipedia.org/wiki/Multiple\\_Integrated\\_Laser\\_Engagement\\_System](http://en.wikipedia.org/wiki/Multiple_Integrated_Laser_Engagement_System) [Accessed: 10 October 2012].
- [10] Wikipedia (2012), “Laser safety”, [http://en.wikipedia.org/wiki/Laser\\_safety](http://en.wikipedia.org/wiki/Laser_safety) [Accessed: 10 October 2012].

- [11] Wikipedia (2012), “LASIK”, <http://en.wikipedia.org/wiki/LASIK> [Accessed: 10 October 2012].
- [12] Wikipedia (2012), “Photodiode”, <http://en.wikipedia.org/wiki/Photodiode> [Accessed: 18 October 2012].
- [13] Wikipedia (2012), “Sampling (signal processing)”,  
[http://en.wikipedia.org/wiki/Sample\\_\(signal\)](http://en.wikipedia.org/wiki/Sample_(signal)) [Accessed: 20 October 2012].
- [14] Lazer Tag – Hasbro (2012), <http://www.lazertag.com/> [Accessed: 22 October 2012].