Laser Modulation Development for Interplanetary Transponding Applications

A Research Paper

Presented to the

Science Department

Eleanor Roosevelt High School

In Partial Fulfillment

Of the Requirements for

Research Practicum

By

Callen Rain

May, 2011

Laser Modulation for Ranging Applications Abstract

Callen Rain May 11, 2011

This project aims to develop a set of lab electronics into a working model of a synchronous laser transponder for use in interplanetary ranging. The proposed set of lab electronics will demonstrate the concept and feasibility of a photon counting synchronous laser transponder. The system will employ such concepts as signal generation, detection, and location of the ranging signal in the presence of noise. In practice with a spacecraft around Mars, the proposed system will fire laser pulses from a ground station to the spacecraft in question. When the spacecraft receives the data, it returns the signal straight back to the ground, where the elapsed time is measured. Simple multiplication by the speed of light gives the distance. The project proposed would test this methodology on a lab scale, between two setups less than a meter apart. Several filters restrict the number or photons allowed to pass through the detector, thus simulating the high loss of data with a ranging system to Mars. The existing attenuation is about 10^6. The current lab setup is an arrangement constructed where the laser pulse is filtered, reflected, and finally returned to a detector, where the signal is processed. This project will not dismantle this existing arrangement, but will add a laser generating system and a data input system to the receiver to complete the two-way transponder. The construction of such a laser transponder will require a variety of tools and techniques. The circuits need to be finalized and created, which will require soldering, testing, and cabling different parts together. In addition, there may be some Virtual Instruments in LABView that will have to be modified or created to fit the specifications of the project.

Once all the hardwiring and setup is complete, the instrument will need to be tested thoroughly. Most of this testing will be done with a gap between the receiver and transmitter being only a few centimeters. The test will change the distance the ranger has to measure only slightly, and see how the system responds. After it is certain that the setup is working properly, the laser pulses could be shot out of a window at a nearby building, and the distance between them could be calculated as a trial run. Both tests involve PCs equipped with Multiscalar Time of Flight (TOF) cards.

Acknowledgements

I would like to extend thanks to NASA Goddard for the existence for my research opportunity. Without my mentors, Dr. Xiaoli Sun and Mr. Dave Skillman, the final project could never have been completed. They helped me when I was confused, clarified when I was wrong, and always gave me a new task when I was not busy. I would also like to thank several members of Building 33 Floor 4 like Mr. Ray DiSilvestre and Mr. Bill Hasselbrack for their assistance in mechanical and electrical engineering design problems. My RP teacher, Mrs. Alexis Donoghue, was also integral to my research practicum experience. Her guidance and patience were of the utmost value. Last, I would like to heartily thank my classmates for their upbeat positivity and assistance when they knew what was going on and I did not. Their attitude largely reflected positively on mine. Thank you all.

Biographical Outline

Personal Data
- Name: Callen Rain
- Date Of Birth: 09/01/1993
- Place of Birth: Lewisburg, PA
- City of Residence: Hyattsville, MD
- College Attending: Swarthmore College
- Major: Engineering

Academic Achievement
- Accepted into the Science and Technology Internship Program at NASA for 12th grade
- Honor Roll all Quarters
- National Merit Commended Scholar
- Maryland Distinguished Scholar
- AP Scholar with Honors
- Received the Harvard Book Award for outstanding academic achievement
- Accepted into the PG County All County Band
- Director's Award for Outstanding Musical Achievement Junior Year
- Superior Ratings at MMEA Solo and Ensemble Festival for multiple years at county and state levels

Activities
- Sports
    - Varsity Lacrosse Goalie (Captain)
    - Varsity Swim Team
- Mock Trial
    - Senior member and Lawyer
- Music (French Horn)
    - Wind Ensemble (1st Chair)
    - Wind Quintet
    - Symphonic Orchestra
- Pep Band (Mellophone)
- Custom Computer Building and Programming
- Circuitry and Wiring

- Quaker Young Friends Conferences
- Intern in the Applied Optics and Detection Lab at NASA Goddard Remote Sensing Department
- Satellite and ArcGIS data collector in Accra, Ghana (2008)

Table of Contents

List of Tables and Figures

Chapter One

The Problem and Its Setting

Introduction to the Problem

Laser remote sensing is a rapidly growing and increasingly useful field for developments in geography, astronomy, and physics. Particularly, interplanetary ranging is integral to the pursuit knowledge regarding the Universe and humanity's existence in it. Currently, missions conducted by the National Aeronautics and Space Administration (NASA) have done ranging with various celestial bodies in the solar system. Some of these missions include the Lunar Orbiter Laser Altimeter (LOLA) aboard the Lunar Reconnaissance Orbiter (LRO), the Mercury Laser Altimeter aboard the MESSENGER spacecraft, and the Mars Orbiter Laser Altimeter (MOLA) aboard the Mars Global Surveyor (MGS). All three of these applications have used laser assemblies and computer systems to collect data about surrounding planets. Mars laser ranging is going to be addressed in this project. Currently, the development of a two-way synchronous laser transponder is underway at NASA, and this project seeks to achieve it the completion of a working demonstration of this system. The goal can be summarized in a simple concept. The transponder will send a small laser pulse to a distant spacecraft, which will receive and process the data, re-encode it, and send it back. In the laboratory, sets of filters will simulate the immense signal breakdown associated with such a long time of flight. The working model will be sending several million photons per pulse, and thousands of pulses per second.

Statement of the Problem

This project aims to develop a set of lab electronics into a working model of a synchronous laser transponder for use in interplanetary ranging.

Description of Proposed Engineering Design Solution

With a spacecraft in orbit around Mars, the proposed system will fire laser pulses from a ground station to the spacecraft in question. When the spacecraft receives the data, it returns the signal straight back to the ground, where the elapsed time is measured. Simple multiplication by the speed of light gives the distance. The project proposed would test this methodology on a lab scale, between two setups less than a meter apart. Several filters restrict the number or photons allowed to pass through the detector, thus simulating the high loss of data with a ranging system to Mars. The existing attenuation is about 10^6. The current lab setup is an arrangement constructed where the laser pulse is filtered, reflected, and finally returned to a detector, where the signal is processed. This project will not dismantle this existing arrangement, but will add a laser generating system and a data input system to the receiver to complete the two-way transponder.

Limitations and Assumptions

The greatest limitation of this study is the premature nature of it. Never in this project will a spacecraft actually receive a laser pulse or will a photon travel tens of millions of kilometers. The farthest the pulse will travel is a few kilometers, but in all practicality, most testing will be to the scale of the meter. This property of the project limits its usefulness in determining real world variables and properties of actual space flight. However, this “limitation” allows for greater control over a number of variables. By adjusting several mechanisms within the device, the precise number of photons that are expected can be produced, because the given attenuation is known and exact, unlike that of retro reflection off Mars.

Testing Procedures and Development

The construction of such a laser transponder will require a variety of tools and techniques. The circuits need to be finalized and created, which will require soldering, testing, and cabling different parts together. In addition, Virtual Instruments in LABView will have to be modified or created to fit the specifications of the project.

Once all the hardwiring and setup is complete, the instrument will need to be tested thoroughly. Most of this testing will be done with a gap between the receiver and transmitter being only a few centimeters. The test will change the distance the ranger has to measure only slightly, and see how the system responds. After it is certain that the setup is working properly, the laser pulses could be shot out of a window at a nearby building, and the distance between them could be calculated as a trial run. Both tests involve PCs equipped with Multiscaler Time of Flight (TOF) cards.

Definitions of Terms and Abbreviations

1. Attenuation – the gradual loss of the strength of a signal as it passes through a medium.
2. Asynchronous Transponder – A laser transponder in which the laser pulses sent from the spacecraft and ground are not timed concurrently or consecutively. Rather, each MET is measured and calculations proceed from there.

3. Detector – also called a photon counter; a device that uses a photomultiplier tube to excite electrons on a photocathode and use the accelerated electrons to detect incident light.
4. LABView – Laboratory Virtual Instrumentation Engineering Workbench; a visual programming language environment developed by National Instruments.
5. Laser -- Light Amplification by Stimulated Emission of Radiation; laser pulses are made up photons released by a laser diode supplied with an electric current.
6. Laser remote sensing – the acquisition of data, involving the use of laser technology, pertaining to objects or bodies that are not in physical contact or range of the collecting device.
7. Multiscalar Time of Flight (TOF) Card – a highly advanced peripheral card equipped with a multiscalar processor capable of comparing the sync between two clock oscillators.
8. Photon – an elementary particle; the basic unit of light and electromagnetic radiations; moves at 10E8 m/s.
9. Synchronous Transponder – A laser transponder in which a laser pulse is fired from the spacecraft to the ground when it receives a pulse from the ground station; the mission elapsed time can be determined from the whole trip, unlike an asynchronous transponder.

Chapter Two

The Review of the Related Literature

Introduction

Lasers can be used for the acquisition of information from objects and applications that are not available for tangible observation. Specifically, a technology called LIght Detection and Ranging (LIDAR) measures the properties of incident light to find the range or other information about a distant target. LIDAR is used in several fields, from military applications to biology to meteorology. In the proposed project, LIDAR is employed for the uses of remote sensing. This field seeks to use such laser technology to develop techniques and instruments for scientific measurements of the Earth and planets. Early remote sensing applications began in the 1970s with the National Aeronautics and Space Administration. Their efforts included the development of proprietary airborne solutions to future space borne problems. NASA's primary objective with these studies was to examine the composition of air and ocean water, measuring quantities of gases, particles, and vegetation. These objectives evolved as scientists applied the land based laser technology they had been using and created new instruments for outer space. Such applications are seen in the development of laser altimeters and similar equipment onboard research vessels sent to the Moon, Mars, and several other planets and celestial bodies (Zuber, Smith, & Solomon, 2008).

Laser technology is most useful because of the speed of the electromagnetic wave and the existence of computer systems capable of keeping up with such potential. The most evident precursor to LIDAR uses is Radio Detection And Ranging (Radar). Ultimately, newer LIDAR solutions are more precise and efficient, but the older radar systems are smaller and cheaper, often more useful for applications that do not require such precision. Laser transponders, especially those destined for use in outer space, definitely necessitate the utmost accuracy, an undertaking that would be almost impossible with the noise and imprecision associated with radar over such long distances.

Transponders

A laser transponder is a device that communicates by way of laser pulses between a transmitter and receiver. In space, the distance between the two devices can be many hundreds of millions of kilometers. Specifically, the distance between Earth and Mars varies from 55 million kilometers and 400 million kilometers. Such a variation results from the elliptical orbits of Earth and Mars around the Sun.

To measure this distance, the goal of an interplanetary laser transponder, a satellite in space must communicate, by way of laser pulses, with a ground telescope on Earth. This communication can occur in two main ways. The transponder can either be synchronous (echo), or asynchronous (Degnan, 2006). A synchronous transponder sends a laser pulse from the transmitter to the receiver. The receiver accepts the pulses and processes the data, time tagging the arrival time and the data from the photon, after which the computer encodes new data to modulated laser and sends the signal back to the transmitter. The time lapse of the encoding in the receiver is measured under carefully calibrated conditions and factored into final calculations. An asynchronous transponder operates differently and is used more commonly in interplanetary ranging applications that it's synchronous equivalent. Because it fires the laser pulses independently, the two clocks do not have to be firing laser pulses at the same time, making calibration simpler. Despite this, a synchronous laser transponder is the source of this study (Degnan).

Lasers

Originally, the word laser came from the phrase Light Amplification by Stimulated Emission of Radiation. This stimulation process occurs in the valence shell of atoms. When an electron receives or loses enough energy, it can change its place within the atom. Added energy results in the electron moving from a lower electron shell to a higher electron shell, and released energy results from the electron moving the other way, from an outer shell to a lower one. When it makes this move, it emits a specific amount of energy, dependent on the type of atom it is attached to and the shells between which it is moving. The released energy is contained in the form of electromagnetic radiation (EMR). EMR is a type of energy propagation that manifests in the form of a wave. It consists of an electric field and a magnetic field oscillating orthogonally to one another. The properties of these waves are governed by their frequency. This attribute results in a spectrum of different values and qualities. For example, only EMR that has a frequency of 400–790 THz can be seen by human eyes. However, the speed of all electromagnetic waves remains constant. They all travel at 3E8 meters per second. This value, known as *c* is a fundamental constant of physics ("wavelength selected cw,").

Lasers are generally differentiated by their gain medium, the substance in the device that provides an optical gain for the stimulated emission. This medium can be a variety of substances, such as gases, liquids and solids. Although lasers made from semiconductors are solids, they are generally classified differently from most solid-state lasers. Semiconductor lasers are operated with a device called a laser diode. The diode is a combination of an N-type and a P-type semiconductor that has been doped to create an area of impurity between them. For example, this impurity would put electrons in a P-type area and holes in an N-type area. When an electrical current is applied across this junction, known as a diode, the electrons that have been forced into the positive area from doping move to the opposite side, creating a depletion zone devoid of charge carriers. Eventually, positive holes and negative electrons are attracted enough to annihilate each other, releasing energy as a result of the electron being dropped in energy level. This energy is released in the form of a photon, which is the output of a laser diode ("wavelength selected cw,").

However, this reaction is spontaneous and must be regulated to ensure that the released photons are of the same frequency. Temperature is the largest factor that can manipulate the frequency, so one must work hard to maintain a constant temperature, whatever it may be. This is done with a temperature controller, which employs a thermoelectric cooler (TEC) and thermistor control loop. A steady current is pumped through the TEC and the thermistor. Special qualities of the TEC force it to maintain a temperature difference across its surface. This fact ensures that the device route heat away from the diode. If the thermistor, which is a resistor that varies resistance with temperature change, senses a high temperature at the diode, it will increase resistance.

An increase in resistance at a constant current will drop the voltage accordingly. The temperature controller will account for this voltage drop and push more current through the TEC, thus lowering the temperature. This feedback loop ends up keeping the diode at a very stable temperature ("Mpt series instruction," 2009).

Detectors

Detection of incident light is integral to the proper function of the laser transponder. With such a high attenuation of the signal, an accurate photon-counting detector can make data processing much cleaner and without noise. The most basic component of a photon counter is a photomultiplier tube (PMT). A PMT consists of a photocathode, an electron multiplier, and an anode. When light enters the photocathode of the PMT, photoelectrons are emitted from the photocathode. These photoelectrons are multiplied by a secondary electron emission through the dynodes and then collected by the anode as output pulses (Becker, & Bergmann).

One important factor in photon counting is the quantum efficiency. It is the production probability of photoelectrons being emitted when one photon strikes ht photocathode. In the single photoelectron sate, the number of emitted photoelectrons per photon is only 1 or 0 ("Photon counting using,"). Therefore, QE refers to the ratio of the average number of emitted electrons from the photocathode per unit time to the average number of photons incident on the photocathode. Photoelectrons emitted from the photocathode are accelerated and focused onto the first dynode to produce secondary electrons. However, some of these electrons do not strike the dynode or deviate from their normal trajectories, so they are not multiplied correctly. This efficiency of collecting photoelectrons is referred to as the collection efficiency. In addition, the ratio of the count value to the number of incident photon is called the detection efficiency or counting efficiency (Becker, & Bergmann).

<u>Oscillators, Modulation, and Data Processing</u>

For a laser pulse to carry data such as the time tag for its departure, the data stream must be encoded into an electrical signal, modulated, and fed into the laser diode. This setup requires a few precise devices.

The first of these devices is called the laser diode driver (LDD). The LDD provides the final output current to the laser that it receives before it sends out light. The LDD is powered by an external power source and has two inputs. The first input is the low drive current. This current simply runs the driver and is completely constant. The second input is a modulated voltage with the data encoded on it. These electrical signals are combined in a device called a bias tee. A bias tee consists of an inductor and a capacitor, which each restrict their signal to either pure AC or DC. The currents are then combined and sent to the laser. The drive current is mostly insignificant because its only use is the physical operation of the diode, nothing more. A modulated signal could not run the diode by itself. However, the modulated signal represents the most important computing system in a transponder ("Modulating laser diodes,").

The entire computer system responsible for accurate time tagging, encoding, decoding, and phase shifting is based around a clock. The specific clock being used is called a hydrogen maser. A hydrogen maser consists of a small storage bottle of molecular hydrogen. This bottle leaks a controlled amount of gas into a discharge bulb. Molecular hydrogen consists of pairs of atoms bound together. The molecules are disassociated in the discharge bulb into individual hydrogen atoms by an arc of electricity. This atomic hydrogen passes through a collimator, which selects certain speeds of hydrogen atoms, and a magnetic state selector, which selects certain magnetic states. The atoms are thereby selected for the desired state and passed on to a storage bulb. The storage bulb is roughly 20 cm high and 10 cm in diameter and made of quartz. Its inside is coated with Teflon, allowing many collisions of the atoms with the wall without perturbation of the atomic state, and slows the recombination of the hydrogen atoms into hydrogen molecules. The molecules of hydrogen oscillate at exactly 1,420,405,752 Hz, making a hydrogen maser the most accurate oscillator in existence.

The accuracy of the maser is so important because it provides accurate oscillation for other parts of the system. The maser feeds a 20MHz signal to the clock synthesizer, a clock that computes time intervals accurately. This synthesizer is responsible for encoding and decoding the data. The maser also provides oscillation to the timer, a device in charge of timing the departure and return of laser pulses.

So far, in this chapter, encoding and decoding have been mentioned in name only, not in detail. Each time it needs to be send by laser pulse, the data must be converted from the digital signal consisting of binary numerals to an analog oscillation between two voltages. This process is called encoding. The data that is encoded and modulated consists of two separate but equally important parts. The first part of the data stream is not data at all. The first section of the waveform, often called a sync pattern, serves as a flag for the detection that happens later on. This sync pattern identifies the data as a data and not noise, which is very plentiful in the detector. After the sync pattern comes the actual data stream, containing information about how about when the pulse is leaving so that the spacecraft side of the transponder can record it when it reaches there. Decoding is slightly more complicated because the computer cannot tell which photons belong to the data stream and which ones are noise (Horowitz, Yang, & Sidiropoulos). This confusion did not exist in the encoding process, because all of the data were known and there was no noise involved. To get around this problem, the system will stack all of the incoming photons as incidents on a chart. As the data flows in, certain photons will arrive at specific time intervals because the same data set is being looped repeatedly. As thousands upon thousands of photons appear, it becomes clear which photons are being sent from the transmitter and which photons are simply noise. This method of determining the pertinent information in a data set with extraneous values is called histogramming. After the data stream has been identified by the histogrammer, the computer uses a control loop called a phase locked loop (PLL). Since the phase of the outgoing waveform has deteriorated since it was sent, the PLL strives to lock on to the correct phase of the data. This is very important because without the correct phase of the data, the computer can do nothing to determine its content. This whole process has to be repeated every time incoming photons are detected.

Because the nature of this study is aimed at creating a model set of lab electronics that future projects can work off of and use for actual outer space, certain freedoms can be taken. Because the clocks that would ordinarily be millions of kilometers apart are less than a few meters away, it makes the data collection more accurate to keep these two clocks in sync. This is done with a Multiscalar Time of Flight Card. This advanced card has a processor much faster than that of any commercial personal computer, and can analyze the phase difference between the two clocks accurately. This is important because there is no other way to synchronize the clocks without directly connecting them or combining them, but that step would less productive to the final product than using the TOF cards.

Summary

Laser communication and ranging is and will continue to be one of the hallmark areas of geophysics for years to come. The diversity of the study, seen in its integration of optical physics, computer science, and signal modulation, makes transponders complex and useful for a plethora of applications. Additionally, the data gleaned from the study of laser ranging can assist mankind in its study of the universe.

Chapter Three

Materials and Methods

Introduction

This chapter serves to document the scientific procedure used to solve the problem. The indicated problem is the fabrication of lab electronics into a small scale laser transponder capable of handling high frequency bursts. All research was done at NASA Goddard Space Flight Center, in Building 33, in the Laser Remote Sensing and Detection Lab. This chapter will be a formal analysis of exact procedures and techniques used in design and development of the selected solution.

Materials

- Laser System
    1. JDSU S29 660 mW Fiber Bragg Grating 980nm Pump Laser Module
    2. National Instruments MPT5000 Temperature Controller
    3. National Instruments MPL250 Laser Diode Driver
    4. Thor Labs LM14S2 Butterfly Laser Diode Mount and Bias Tee
    5. Power One HC15-3-A Power Supply
    6. Power One HC5-6 Power Supply
    7. Thor Labs RBX32/M Rack Box Chassis
    8. Assorted Copper Wires and Ribbons, Screws, and Zip Ties

9. Several Surface Mount Resistors, Capacitors, and Inductors
10. RS232 Connectors for Cable Interface
11. Self-Fabricated Circuit Board Test Plate

- Optical Equipment
  1. Newport 1835-C Optical Meter
  2. Thor Labs PDA8GS - 9.5 GHz Amplified Photodetector
  3. 980nm FC/APC Single Mode Fiber Optic Cables
- Computer Equipment
  1. (2) Atlanta Vision Computers Velocity Workstations
  2. Cyber Research Workstation with GPIB peripheral interface
- Electrical Equipment
  1. Pace MBT High Power Soldering Iron
  2. HP Infinium 1.5 GHz Oscilloscope
  3. Existing TTL Logic Transponder Circuit
  4. (2) Stanford Research Systems CG635 2 GHz Synthesized Clock Generator
  5. Agilent Technologies E3630A 35 W Triple Output Power Supply
  6. Assorted 50 Ohm Impedance Transmission Cables
  7. Fluke 87V Industrial Multimeter

Methods

This project can be generally broken down into three distinct phases. The first phase involves the preparation of the laser system, involving assembly of the temperature control apparatus and the current driver. The second stage is the modulation of said laser. It involves the testing of several modulated signals separate from the rest of the system and ones directly from the TTL signal used by the transponder. The third and final stage of the project is the assembly and testing of the completed transponding system.

The first steps taken in the fabrication of the laser system were the gathering of the necessary hardware. A laser diode was obtained, as well as a temperature controller, a laser diode driver, and a laser diode mount. First, product manuals and data sheets were collected for the hardware in question. Important data and information from the manufacturer were noted, and settings for the boxes were selected based on necessary constraints. Several diagrams were made with Microsoft Visio to illustrate wiring between the boxes. Original diagrams were made to house one power supply. As it became clear that two were needed, however, these diagrams were updated. These drawings were checked and rechecked by several professionals to confirm their accuracy and effectiveness in the system. When it was certain that the wiring system was essentially flawless, steps were taken to create final diagrams. Making the cables to connect the various boxes was done with a soldering iron and several RS232 connectors. Once they were soldered and labeled, the cables were checked with a multimeter to confirm their accuracy. One mistake was made with a power cable to the laser driver connector. The wire was desoldered and repaired. After the cables were all done, the boxes were connected and attached to the mounting board. Additionally, two power supplies were mounted to the same board with aircraft grade mounting hardware, ensuring stability through any kind of unexpected movement. Wires were soldered to the plug on the case, and the case was grounded to the main power line. These exposed solder points were covered with nonconductive tape to make certain that the high voltages would not harm anyone working with the box. The sensing points on the power supplies were shorted, and the correct jumpers were connected to the main cable. At this point, the cables were unplugged and a multimeter was used to confirm correct voltages on the input pins for the boxes. After this was ascertained, the boxes were plugged in. At this point, it was learned that the current and voltage at the mount could not be checked without a laser installed because the boxes determine an open circuit and shut off until they detect a diode plugged in. Instead, a resistor was installed instead and correct voltages were found. After the resistor was removed, the laser diode was installed using anti static equipment. The diode current was raised until light was seen on a UV light card. Temperature voltage was monitored and controlled during this time to ensure consistent temperature levels.

After the unmodulated laser successfully produced light, it became necessary to modulate the laser with a bias tee to achieve data modulation. It became obvious at a point that the laser obtained for the product did not have an inductor inside. The mount was shipped with a bias network system, but it only could work with a preinstalled inductor. The bias network consisted only of a 26 ohm resistor and a small capacitor. It became necessary to install an inductor on the circuit board of the laser mount. A design was made to cut several copper traces and connect them in a way to combine the modulated signal with a base DC signal for basic operation of the laser. The traces were cut and wires were soldered to the board, an inductor was added, and the resistor was replaced with a 49 ohm resistor. The intended resistance was 50 ohm, but such a resistor was not available. Instead, two resistors were combined in parallel to create an equivalent resistor of 49 ohm. When the bias tee was connected, a small resistor was put in place of the laser to make sure the DC loop was still intact. After this, a time synthesizer was configured to produce a 1 MHz frequency and 10 ns pulse. The pulse peaked at 2V. The modulated signal was inputted to the bias tee network and the output was connected to a photodetector. The photodetector was then attached to an oscilloscope. The recovered signal, through various manipulations, could be as short as 800 ps, from fifty percent rise to fifty percent fall. These manipulations included the adjusting of the bias current level and changing the amount of light available to the photodetector. The latter was done to ensure that the photodetector was not in any way saturated with light.

After it was hooked up to the time synthesizer and it successfully produced clean pulses, it became necessary to connect the laser system to the output signal generated by the simulated spacecraft. The TTL output was connected to the laser system but was too slow in rise time for the purposes of transponding. There were several factors involved with this failure, but a few big ones included the length of the drive cable serving as a capacitor and messing up the circuit. In addition, the power output was simply too low to drive the laser effectively. There ended up being a large amount of noise and unpredictable scatter on the scope. Several solutions were proposed and a few were implemented. The one with the greatest success was connecting an amplifier to the output signal to boost the amplitude, but the rise time still ended up being far too large. It was then decided to use a pulse generator with an external trigger to generate clear wave pulses for the system, thus bypassing the poor performance of the TTL circuit. A program for this pulse generator was obtained, and it was tested with an oscilloscope using the internal trigger.

In this way the third phase was reached, in which the laser system and pulse generator were inserted into the larger transponder system. The path of the data went from the ground station circuit to a laser through several filters for attenuation purposes, to a detector. The detector sends the signal to a spacecraft circuit, which processes the electrical pulse and outputs it to the laser created in this project, which is then received by a photon counter on the ground. The circuits on each side are monitored with PCs with multiscalar cards installed in them. Data is collected with these computers. If the distance between the laser and the detector is changed, the data will indicate this change between the comparisons of several variables.

Chapter Four

Data

This project explored the fabrication of a laser modulation system and its addition to a larger and more complex laser transponder. Results were collected in two distinct phases. The first area was the development of the laser assembly and its modulation. The second was the addition of the laser into the greater transponder system. The data generated from the first part was engineering type data. Different methods were tried and noted as to whether they worked or not. As a result, the data was the completed product and the failed attempts made along the way.

Conversely, when the modulated laser was added to the transponder system, the most important information gleaned was the data that determined the accuracy of the laser parts added. There was also, however, some engineering data obtained from the second phase off the experiment. This chapter is partitioned into these two sections to isolate their independent significance.

Data

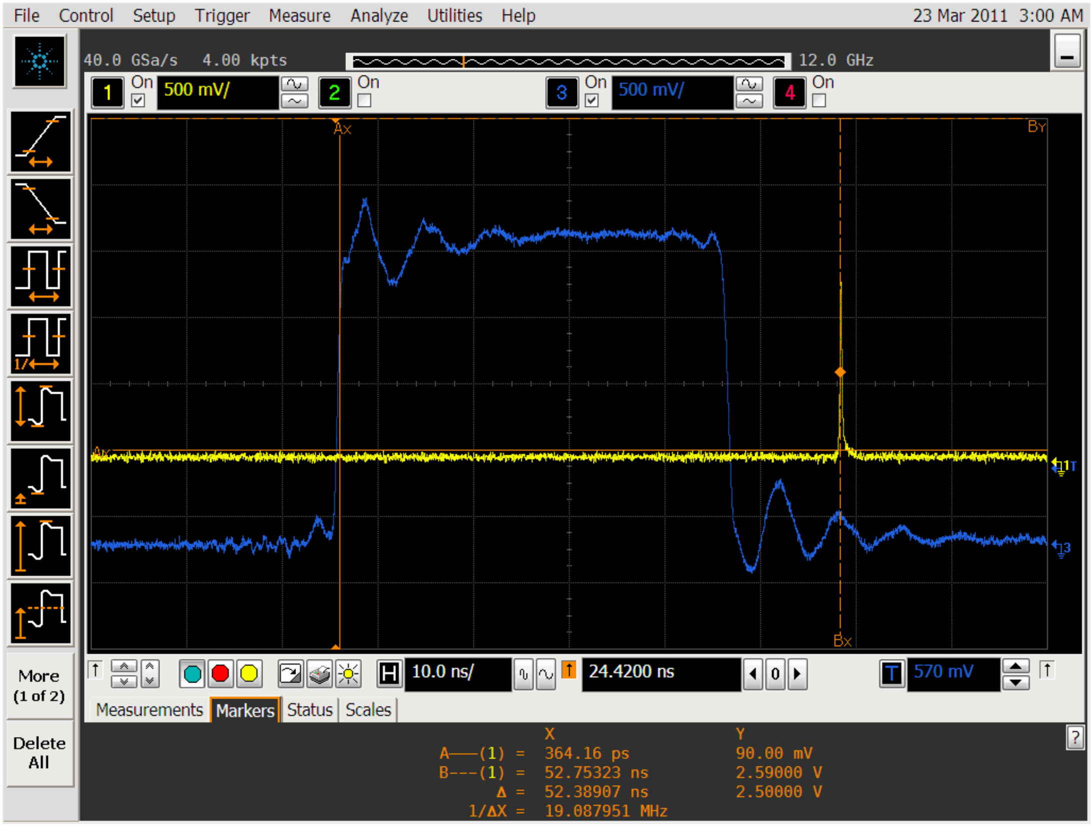
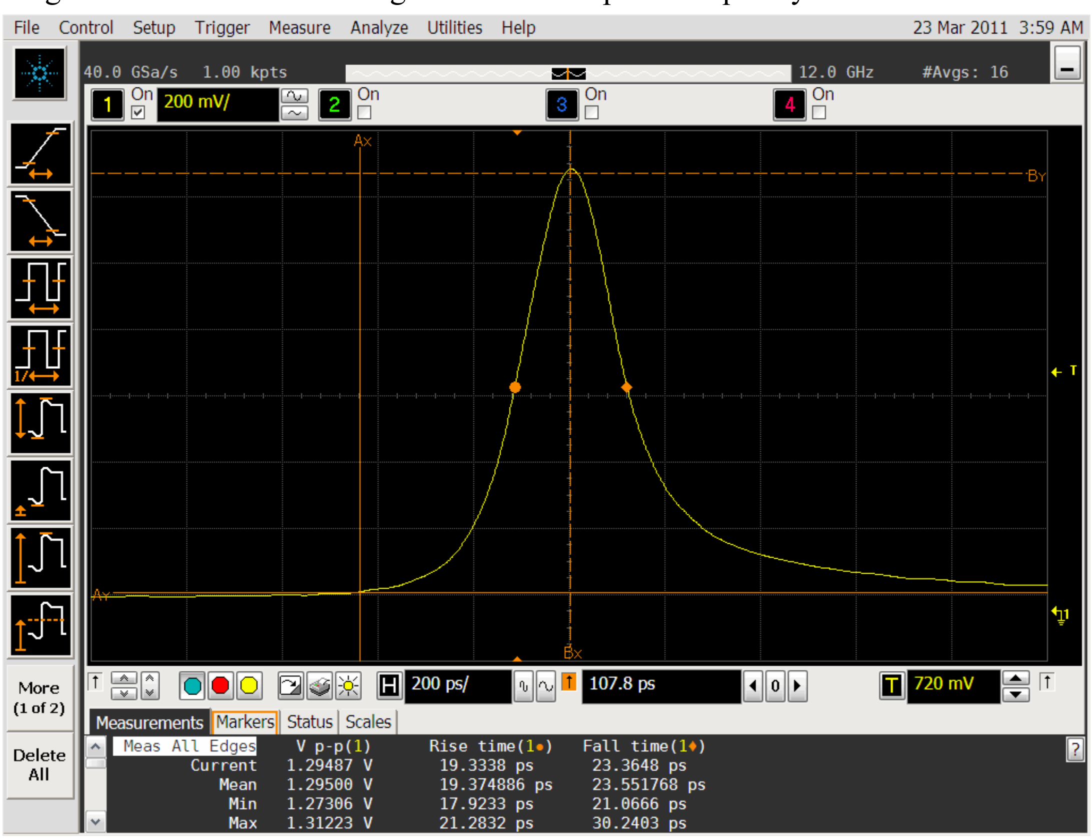


Figure 1 – The laser trigger frequency

Figure 2 – Markers measuring the basic laser pulse frequency



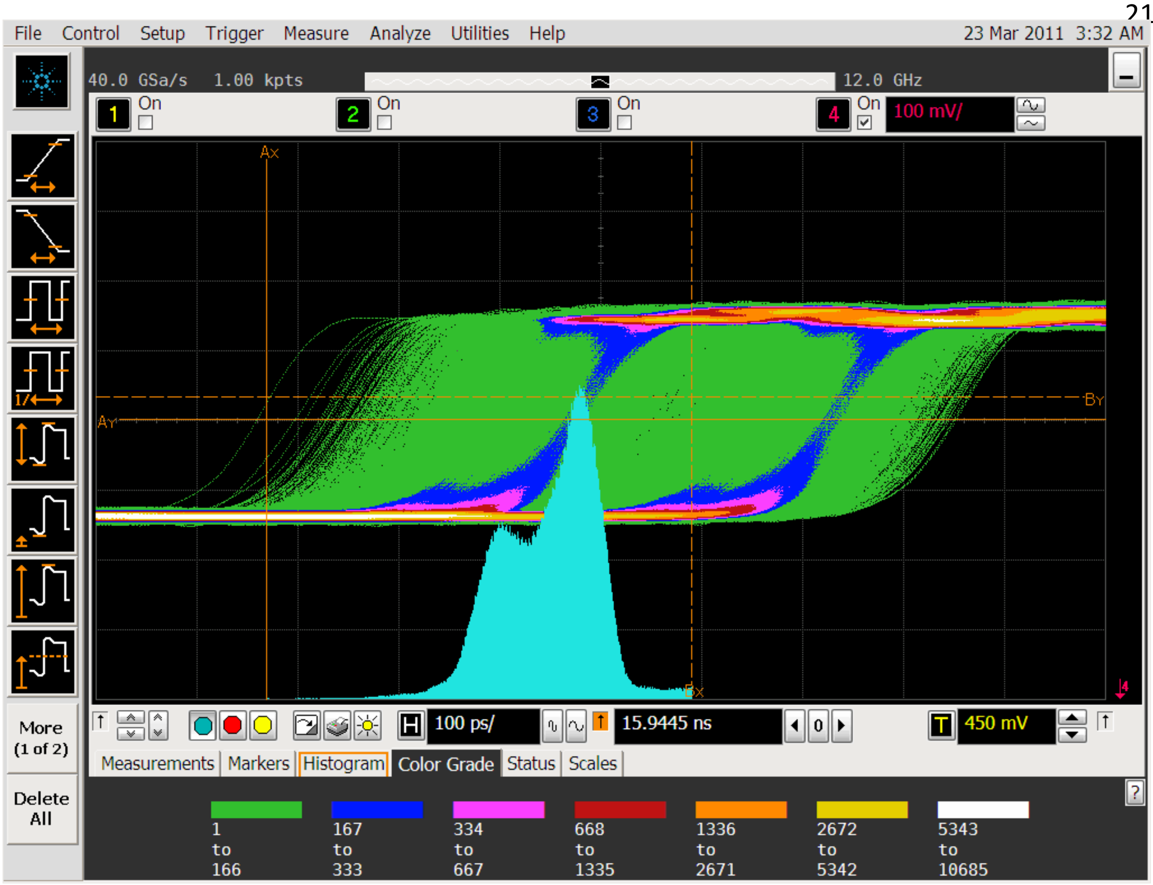
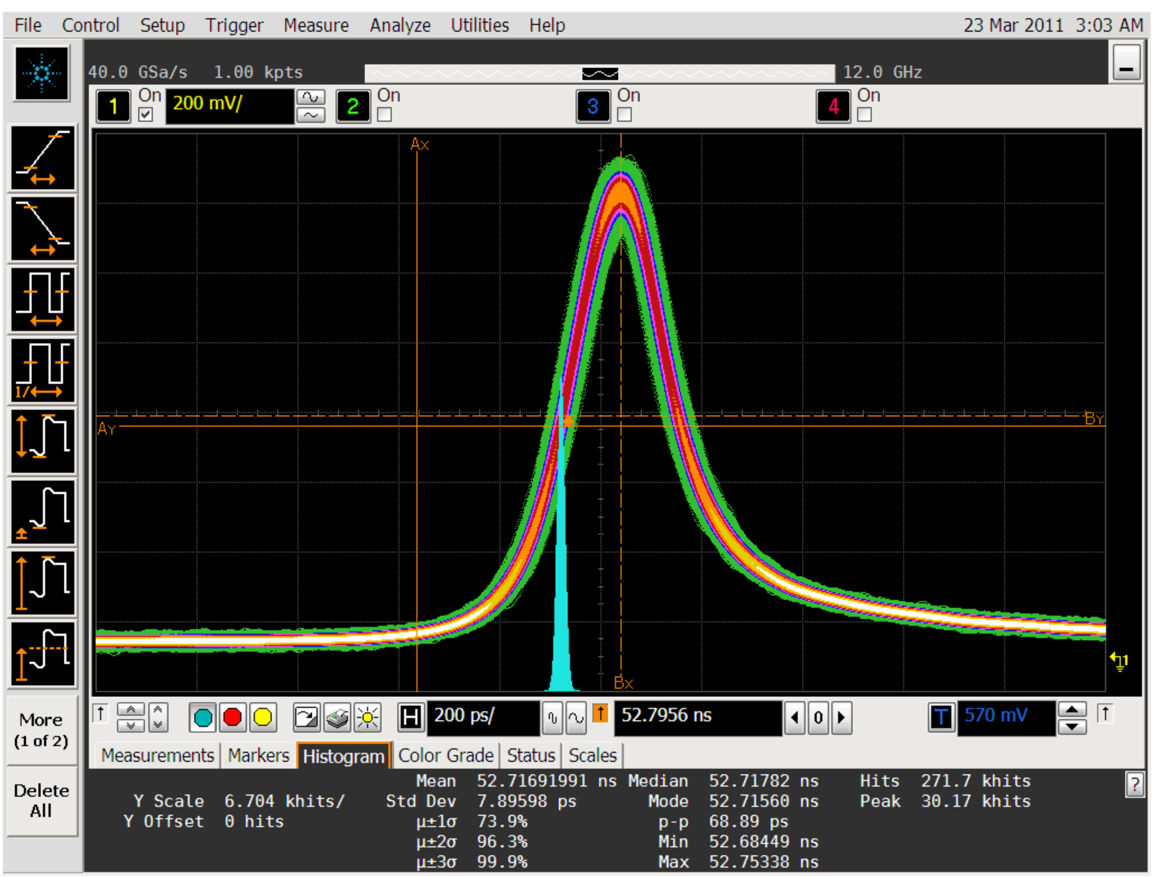


Figure 3 – Clock color density chart and histogram

Figure 4 - The isolated laser diode jitter histogram



Data Analysis – Electrical and Grounding Designs

After all the boxes were connected with cables and turned on, design considerations with more impact had to be made. The issue of grounding was an important one to discuss. The two methods of grounding include a spider method in which separate points in the circuit tie back to a common grounded point in the circuit. A separate method involves tying to a single heavy ground wire that is present throughout the circuit. The latter method was used in this project. A large braid was arranged through the circuit and each part of the circuit was tied to it. The spider technique proved to be too complex for such a simple circuit like the one at hand. In addition to the grounding techniques used in this project, the method by which the inductor was added to the circuit board was a significant design consideration. It was decided to use the mount circuit board as a location for the added inductor. Traces were cut and an inductor was soldered to the device as noted in the figure below.

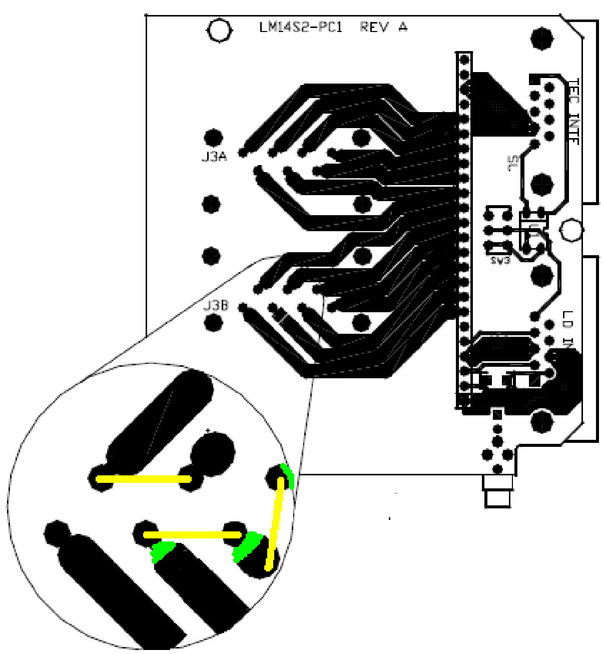


Figure 5 - Circuit Board of the Laser Diode Mount with traces cut and wires added indicted.

Data Analysis – Jitter Measurement

The jitter measurement was done in reference to two points in the transponder system. The first one was done by measuring the jitter of the laser in reference to the time synthesizer, which would produce a value for the jitter of the laser alone. The second was triggered by the laser in reference to the much faster spacecraft clock. The pulse generator was configured to produce a sub nanosecond signal by careful changes made to the DC bias and the amplitude of the trigger pulse. The jitter measured between the pulse generator and the output from the detector provided values for delay times and overall accuracy. The measurement for the distance between peaks of the trigger signal and the laser pulse, which was about 52ns, indicated the delay between the pulses. This can accurately be factored out of the final distance calculations for the transponder as a whole. The standard deviation of this measurement is the timing jitter, a value that indicates the accuracy of the system. For the experiment, this jitter was 7.067ps. The jitter of the clock relative to the laser was about 47ps, which is much less accurate than the laser alone. Future research could remedy this problem by eliminating the bimodal nature of the clock jitter. Additionally, the root sum squares of the jitters for each component will be taken to finally determine a jitter measurement of the entire system. If <100ps jitter can be achieved, that results in a 3cm error range. Higher accuracy transponders result in better mapping and data collection, which in turn improves the extent to which scientists can interpret and use the information they are given.

Chapter Five

Conclusions

Laser transponding is the use of laser communication to transfer information between distant sources. The hypothesis proposed was indeed proven valid, as the jitter measurements obtained were within required values. Since the nature of this study is purely proprietary, the most evident conclusions are made about the success of the design considerations. This study confirmed that a pump laser could be used for high-speed modulation despite its intention to be used otherwise. This end goal can be achieved by setting a DC bias at the takeoff point for the laser. This point is measured with a power meter that finds the minimum current necessary to produce visible light. The bias is then set here and the voltages are modulated from that point. It has also been found that the type of pump laser that was used can be used without an internal inductor. Most telecom lasers made for biasing are included with an integrated inductor and a resistor and capacitor on the outside. The project proved that it is possible to install an inductor and maintain a 1MHz pulse frequency.

Using a capacitor to force a cleaner signal output proved successful in the testing stages of the laser modulation. The low value of the capacitor resulted in a smaller time constant, which succeeded in differentiating the front of the signal, resulting in a very steep edge and short rise time. Additionally, it was concluded that a photodiode is not necessarily useful in such an application because of the problems it causes. If the photodiode and laser diode are grounded to a common ground, multiple problems can occur. Conversely, if the laser diode is grounded to earth and the photodiode is not, the voltage on the photodiode can run away and produce a negative floating circuit. This causes several problems. Instead of doing either of these, a constant current mode was selected and the photodiode was just never set to constant power mode.

In terms of the transponder system, several assumptions were made in the beginning in the engineering stages that proved to be successful in the end. After the TTL output signal was determined to be not consistent enough, it was possible to use an externally triggered pulse generator to complete the circuit. This was an unforeseen circumstance as it was expected that the raw signal was going to work by itself. Even an externally powered amplifier did not raise the amplitude and power enough to significantly change the rise time of the pulsed signal.

The implications of this research are far reaching. Laser modulation is needed in almost every industry, from communication to research and development. The most likely path that this particular laser assembly will take is that of a laser transponder for interplanetary ranging. With the low bit rate of the signal and the high speed of its transfer, distance calculation is most naturally suited to it. The laser would most likely be part of a synchronous transponder with high-powered lasers at each end, making error much more forgiving and less common. The laser system would be attached to a hydrogen maser that would maintain highly accurate oscillations for the clock synthesizers. The data would be encoded, shot from the laser, and detected. What would follow would be a phase locked loop that would match the oncoming phased pulse to existing pulses via a histogrammer. Then the data would be decoded and read. With high speeds, this data collection could compile massive amounts of distances that could be used for many mapping applications. This research could be applied to NASA applications such as LOLA ranging and the ATLAS project. The LOLA ranging involves having a separate, smaller telescope pointing at Earth to essentially communicate its position to NASA stations on Earth. This application of the research would prove to be especially significant and useful.

Literature Cited

1. *Becker, W, & Bergmann, A`. Detectors for high-speed photon counting. Becker & Hickl, 01-22.*

2. Degnan, J. Design and test of a breadboard interplanetary laser transponder. *NASA Goddard Space Flight Center* ,

3. Degnan, J. J. (2006). Asynchronous laser transponders: a new tool for improved fundamental physics experiments. *Sigma space corporation*,

4. Horowitz, M., Yang, C. K., & Sidiropoulos, S. High speed electrical signalling: overview and limitations. *Stanford University*, 01-29.

5. *J.R.Barry, E.A.Lee, D.G.Messerschmidt, Digital Communication, Kluwer Academic Publishers, 2004.*

6. Modulating laser diodes. *ILX Lightwave*, 01-08.

7. Mpl series instruction manual. (2002).*Teamwavelength*, 01-08.

8. Mpt series instruction manual. (2009).*Teamwavelength*, 01-10.

9. Photon counting using photomultiplier tubes.*Hamamatsu*, 01-26.

10. Sun, X. . (2006). Mars 1064nm spectral radiance measurements determined from the receiver noise response of the mars orbiter laser altimeter.*Applied Optics*, *45*(17),

11. wavelength selected cw dfb laser module data sheet.*Fitel*, 01-04.

12. Zuber, M., Smith, D., & Solomon, S. (2008, July 4). Laser altimeter observations from messenger's first mercury flyby . *Science*, *321*, 77-78.