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Near Infrared Imaging System

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Near Infrared Imaging System

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Abstract

This senior project is to design and fabricate a near infrared imaging system using laser diodes for imaging biological tissues. The device will have three major sections comprising the signal source, detection and data analysis sections.

In the source signal section, a circuit would be designed and built which will contain two laser diodes with different wavelengths (780nm and 830nm). Each of the two laser diodes will modulated at different frequencies to enable a spatial coding system. The detection section of the device will have an optical detector channel which will be designed to detect signals from all the laser diodes and reveal their spatial locations. The device will have the photodetectors(avalanche diodes) placed next to each laser diode to detect the back-scattering off of biological tissue, and ultimately convert that analog (optical) signal into an electrical signal. In the data analysis component of the device, an amplifier will be incorporated into the design to strengthen the signal from the photodetectors for proper processing through a data acquisition device, which will be connected to a computer and monitored with LABVIEW® software. This software will programmatically detect the states of each diode and filter any noise using a bandpass filter. The filter will be designed to sort out the specified frequencies and separate multiple frequencies that might be detected by the photodetectors, placing each separate signal on a graph that is displayed on an interactive user interface.

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1. Introduction

1.1. Background

The Near Infrared Imaging System (NIRIS) is a research based device that will help the client in her research on imaging of cancerous tissues. The client Dr. Zhu is a Professor in the Department of Electrical and Computer Engineering at the University of Connecticut in Storrs CT. Professor Zhu is a leading researcher in combining ultrasound and near infrared (NIR) imaging modalities for clinical diagnosis of breast cancers.

The primary concept behind the NIRIS for imaging biological tissue stems from the discovery that the transmission and absorption of near-infrared light by biological tissue can provide information about hemoglobin concentration changes. By employing several wavelengths and time resolved (frequency or time domain) and/or spatially resolved methods, blood flow, volume, and oxygenation can be quantified. These measurements are a form of oximetry, which is used in the detection and assessment of breast tumors.

The project to be designed aims to create a near-infrared imaging system using laser diodes for imaging biological tissues as requested by the client Dr. Zhu. Although there are similar products on the market for this task, this design presents a cheaper, more portable and more user and patient friendly option. The design is based on the analysis of the optical properties of pertaining to cancerous tissues such as hemoglobin concentration, blood O_2 saturation, and tissue light scattering and absorption.

1.2. Purpose

A diagnostic imaging modality based on near-infrared (NIR) radiation offers several potential advantages over existing radiological techniques. First, the radiation is non-ionizing, and therefore reasonable doses can be repeatedly employed without harm to the patient. Second, optical methods offer the potential to differentiate between soft tissues, due to their different absorption or scatter at NIR wavelengths that are indistinguishable using other modalities. And third, specific absorption by natural chromophores (such as oxy-hemoglobin) allows functional information to be obtained. NIR imaging research has focused on a variety of possible clinical applications. Potentially the most important is the development of a means of screening for breast cancer, particularly if a specificity and sensitivity exceeding that of x-ray mammography can be achieved. Screening demands a spatial resolution of a few millimeters or better in order that tumors can be distinguished from surrounding healthy tissue while they are still small in size before metastasis occurs and treatment becomes more difficult. Using a NIRIS will be a better and more patient-friendly method of imaging.

1.3. Previous Work by Others

1.3.1. Products

There has been significant research and work done in the area of NIR imaging. One product that has been designed is a portable near infrared system for topographic imaging of the brain of babies. This device provides real time temporal and spatial information about the cortical response to stimulation in unrestrained infants. This product was designed and made by Vaithianathan et al from University College London.

A previous device "Near Infrared Diffusive Light Optical Imaging for Biomedical Applications" was designed by students from the electrical engineering department of the University of Connecticut. This device incorporates near infrared light and ultrasound waves to measure the interior optical properties of human tissue pertaining to cancerous growth, such as hemoglobin concentration, blood O2 saturation, and tissue light scattering and absorption.

Another product that has been created which utilizes NIR imaging is a hand-held laser breast scanner (LBS) which can accurately distinguish between malignant and benign tumors, potentially providing an easy-to-use, non-invasive technique to see whether breast tumors warrant further aggressive treatment. The scanner works by measuring metabolism in breast tumors and normal breast tissue. The LBS provides detailed functional information by measuring hemoglobin, fat, and water content, as well as tumor oxygen consumption and tissue density.

1.3.2. Patents

Patent #7689258: Device and Method for Determining Optical Characteristics of Biological Tissue

This is an appliance for examining biological tissue, comprising of a light injection means for injecting visible and/or close infrared light into the biological tissue, a detector for converting light signals that exit the biological tissue into detection signals, and an output device allocated to the detector for outputting information that depends on the detection signals.

Patent #7347365: Combined Total-Internal-Reflectance and Tissue Imaging Systems and Methods

The system includes an illumination source, a platen, a light detector, an optical train, and a computational unit. The platen is disposed to make contact with a skin site of an individual. The optical train is disposed to provide optical paths between the illumination source and the platen, and between the platen and the light detector. The combination of the illumination source and optical train provides illumination to the platen under multispectral conditions. The computational unit is interfaced with the light detector and has instructions to generate a total-internal-reflectance image of the skin site from a first portion of light received from the skin site, and to generate a tissue image of the skin site from a second portion of light received from the skin site.

1.4.Map of Report

The remainder of this report will investigate the design for the project and how the optimal design evolved into the final prototype.

The optimal design will provide a detailed look at each subunit and the proof that each subunit will work. The realistic constraints of the project will also be discussed and the safety issues that must be addressed. The impact of the engineering solution as well as the learning that has occurred will also be reviewed. The section after engineering solutions is life-long learning. This section is more of a personal growth section where the new material learned is discussed as well as new knowledge gained in familiar subjects.

2. Project Design

The project design consists of three alternative designs and one optimal design. The alternative designs will be overviewed in this report, and the specifics of the optimal design will be discussed. All of the subunits in the optimal design will be analyzed and the reasons for choosing the optimal design will also be explained. Figures will be used to illustrate the optimal design.

Alternative Design 1

The first alternative design deals with making our system portable by programming all filters and analytic functionality onto a microcontroller. This microcontroller will be packaged into a box with the near-infrared laser imaging system and an LCD screen to display the user interface. In terms of marketing, this design is highly beneficial for its application in clinical use. Potential clients, such as hospitals, favor devices that can easily be transported from one room to another. Portability means less equipment to deal with and more time to work with, and that is exactly the business model that fits into the ecosystem of a hospital-like environment. Our original design would require a separate data acquisition device to process the signal from analog to digital, and then send that digital signal to a computer. From there, further processing would need to be done by LabView® with the guidance of the user. With a portable device such as an

integrated microcontroller, the data acquisition and all following processing can be done in one independent unit.

There are some advantages and disadvantages to this design. One major advantage is portability. Due to the nature of the device, it will be very light and easy to carry from one location to another. The operability of the device will on par with the original computer-based design. Another advantage is its marketability. In terms of aesthetic appearance, a portable tablet-like device is in-line with current technological trends. Portable devices have been outselling their stationary counterparts for the past three years, and it seems as if this pattern is not going to change anytime soon. One last advantage, and a very big one at that, is the cost. For our client specifically, this advantage does not hold true, since they already have a data acquisition device that will be able to handle our original stationary design. When considering a broader market, beyond our intended client, it is important to note that many hospitals and clinical environment do not house industry standard data acquisition devices, such as the National Instruments one. Not having LabView®, on the other hand, is not an issue, due to the fact that LabView® supports the creation of standalone executable programs. The microcontroller in question is the ARM926EJ-S CPU Board, as seen in the Figure 1.0.

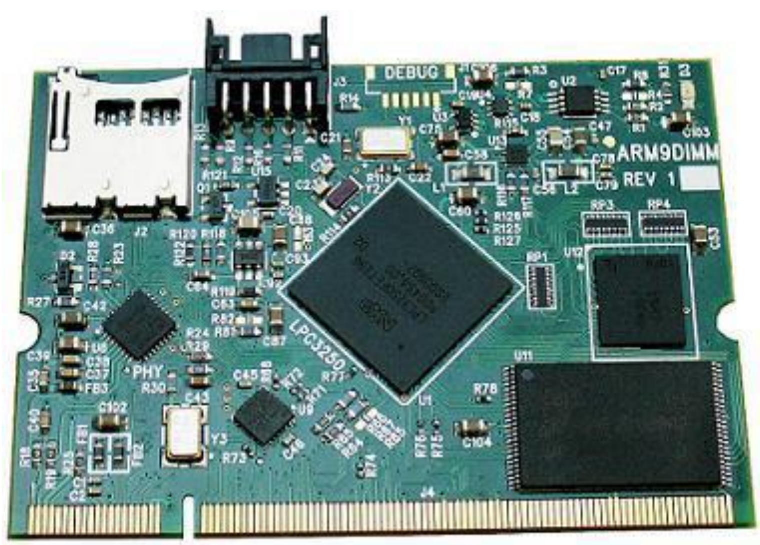

Figure 1. ARM926EJ-S

The onboard Linux drivers support LCD frame buffers and touchscreen capability, giving this specific piece of hardware very high potential. Optimally, an LCD touchscreen will be used in tandem with the microcontroller to output the user interface, giving the client a keyboard-less and intuitive design to work with. This all adds to the usability of the product.

In terms of costs, the microcontroller itself would retail at $120. The LCD touchscreen (capacitive) would cost roughly $200. That would be it for the additional costs of this alternative design, due to the fact that LabView® has a software development kit (SDK) specially targeted to ARM microcontrollers. This would mean the program would still be coded in LabView®, but with slight modifications to the user interface and with a little less functionality. This reduced functionality though does not impose on the intended functionality of the program, since all signal analysis VI's are included in the LabView® microcontroller SDK. And if this doesn't suffice, LabView® has a C Code Generator module that will port our algorithms to any ARM processor.

Alternative Design 2

The second alternative design would be implemented within the filtering aspect of our near infrared imaging system. As with any transmitted signal there will be a noise associated with the desired signal. Even if noise reduction techniques are used the noise level can never really be reduced to zero. With this fact to get a readable or clean signal a method would be to take the signal and clean it up by filtering out noise. An easy example of an unwanted signal would be the 60 Hz frequency given off by land line power. To combat this unnecessary signal the total signal is taken and placed through a filter to filter out the 60 Hz frequency. Originally the plan was to take the transmitted signal from the laser diodes and allowing a software interface to filter out the signal. This alternative design removes the filtering done by the software and instead uses hardware within of the near infrared imaging system to filter the noise out before sending the data to the computer.

There are two basic types of filters that can be used within circuit design. The Low-pass filter and the High- pass filter. The low-pass filter allows low frequencies to pass while the high pass filter allows high frequencies to pass. They both can be built using a resistor in series with a capacitor. The type of filter produced would depend on the orientation of these two components and the exact frequency filtered out is dependent on the values of the resistor and capacitor. A simple low-pass 1st order filter can be seen in Figure 2.

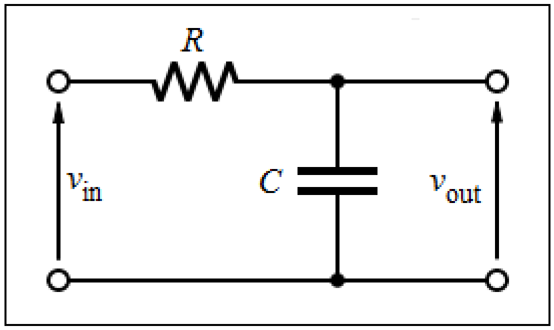

Figure 2. First Order RC Low Pass Filter

With a low pass filter from the input voltage we first have a resistor then a capacitor which feeds to ground. The signal would be produced between the resistor and capacitor with reference to ground. An example of a high-pass filter can be seen in Figure 3. The high-pass filter is similar to a low-pass filter however the orders of the components are simply swapped.

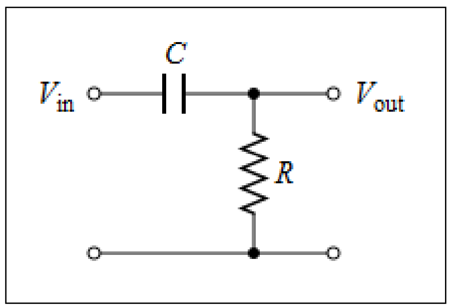

Figure 3. First Order High RC Pass Filter

With these two filters in combination a third type of filter can be produced. This filter will be the filter implemented into the circuit design. This is a band-pass filter. Figure 4 demonstrates how a band-pass signal is constructed.

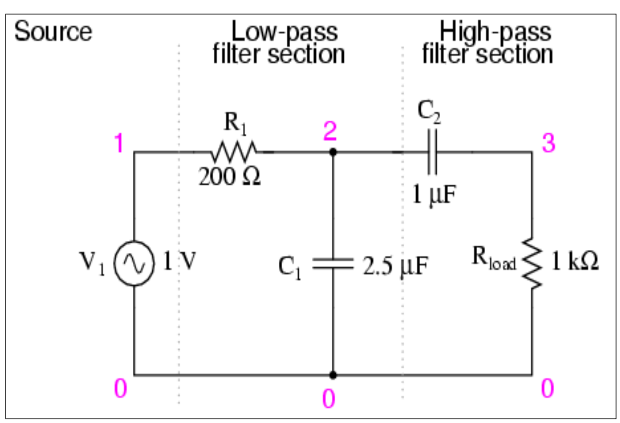

Figure 4. Band Pass Filter

A band-pass filter has a low-pass filter component in addition to a high-pass filter section. This allows for a particular frequency range to be accepted through the filter with all other frequencies rejected from the signal. Figure 5 shows how a band-pass filter works.

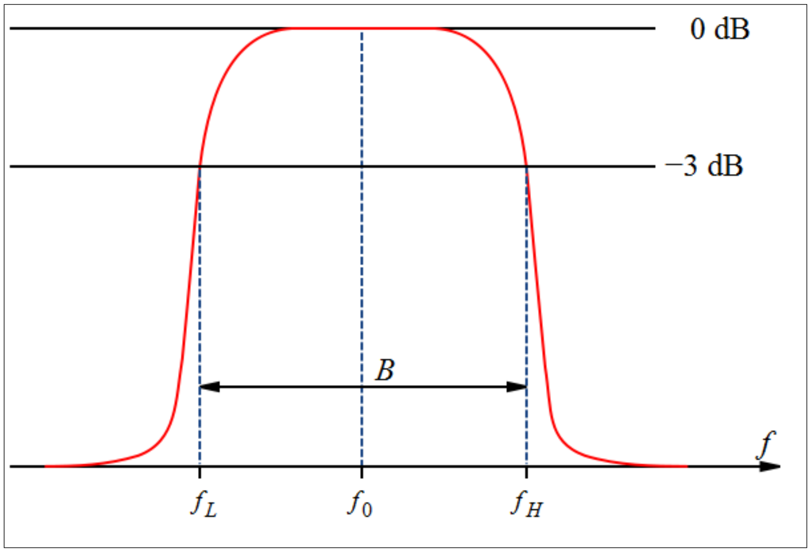

Figure 5. Band Pass Filter Signal

Figure 5 demonstrates how a band-pass filter works on a graph of magnitude transfer versus the frequency. The bandwidth of the filter is just the different between the upper and lower cutoff frequencies respectively FH and FL within the graph. With this band-pass filter component values can be chosen to specifically cut out the 60 Hz land line frequency by having a higher lower cutoff frequency then 60 Hz. Also knowing the modulated signals that will go through the signals the specific frequency range can be chosen to filter out everything else which should be noise.

Benefits to a filter built within the circuit instead of using a software filter would relate to timing issues. The circuit takes an AC signal and directly filters the noise out of this signal before sending to the computer. If relying on a software filter the signal would have to be received by the PC which involves an Analog to Digital conversion before any filtering can be done. Also another important benefit would be the ability of the circuit to filter out noise before amplifying the signal. If the data isn't filtered before being amplified, when it is amplified this would include an amplified version of the noise with the signal. Drawbacks to having a circuit filter instead of a software filter are that the filter values are set unless components are physically changed. With a software filter the restrictions of the filter range can easily be changed by modifying the formula used to filter the signal.

Alternative Design 3

The third design option involves changing the type of photodetector used. Phototransistors will be used to collect backscattered light from the laser diodes instead of avalanche photodiodes. Phototransistors are a type of photodetector that contains an internal gain. Similar to photodiodes, they take optical signal from a light source (laser diodes in this case) and convert it into an electrical signal. Here, light striking the base of the phototransistor replaces what would ordinarily be voltage in the case of a regular transistor. The phototransistor amplifies variations in the light striking it. This internal gain is a desired property of the phototransistor since the signals involved are of small magnitudes.

In terms of cost, the phototransistor is a more economical alternative then avalanche diodes and photomultiplier tubes. An additional advantage of phototransistors is that in comparison to another self-amplifying unit, the avalanche photodiode, the phototransistor produces a lower level of noise. One of the main disadvantages of the phototransistor is the fact that it does not have a particularly good high frequency response. This occurs because of the large capacitance associated with the base-collector junction. This junction is designed to be relatively large to enable it to pick up sufficient quantities of light.

In this design, a common-emitter phototransistor will be used in conjunction with an amplifying circuit (Figure 6) to generate an output that transitions from a high state to a low state when light in the near-infrared range is detected by the phototransistor. The wavelength range for light in the near-infrared region is about 650 nanometers (nm) to 1100 nm. The output is created by connecting a resistor between the voltage supply and the collector pin of the component. The output voltage is read at the terminal of the collector. It is called an amplifier circuit because the current generated in the phototransistor when light is detected is very small. However, the phototransistor has an internal amplifier which magnifies this current to useful levels.

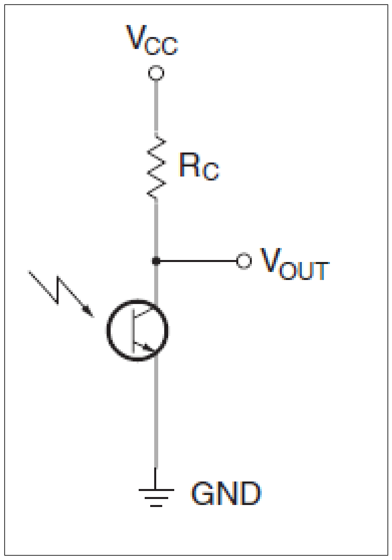

Figure 6. Common Emitter Amplifier

Since the design requires the detection of two different frequencies, the phototransistor will be operated under active mode. In the active mode the base connection of the transistor is left open or disconnected because it is not required. If the base of the phototransistor is used to bias the transistor, the collector current flow would mask any current flowing from the photo-action itself. This is unwanted because we want the photo-action from the laser diodes to control the transmitted signal not current from the collector of the transistor.

For operating conditions, the bias conditions are quite simple. The collector of an n-p-n transistor is made positive with respect to the emitter of a p-n-p transistor. In this mode, the phototransistor will generate a response proportional to the light received by the component up to a certain light level. When the amount of light surpasses that level, the phototransistor becomes saturated and the output will not increase even as the light level increases. This mode is useful in applications where it is desired to detect two levels of inputs for comparison.

2.1. Optimal Design

2.1.1. Objective

The project to be designed aims to create a near-infrared imaging system using laser diodes for imaging biological tissues as requested by the client Dr. Zhu. Although there are similar products on the market for this task, this design presents a cheaper, more portable and more user and patient friendly option. Referring to alternate designs proposed, this approach contains a combination of the different desirable aspects of the designs that fits the client's requests. The design is based on the analysis of the optical properties of pertaining to cancerous tissues such as hemoglobin concentration, blood O_2 saturation, and tissue light scattering and absorption, as seen in Figure 7 below

The primary concept behind the NIRIS for imaging biological tissue stems from the discovery that the transmission and absorption of near-infrared light by biological tissue can provide information about hemoglobin concentration changes.

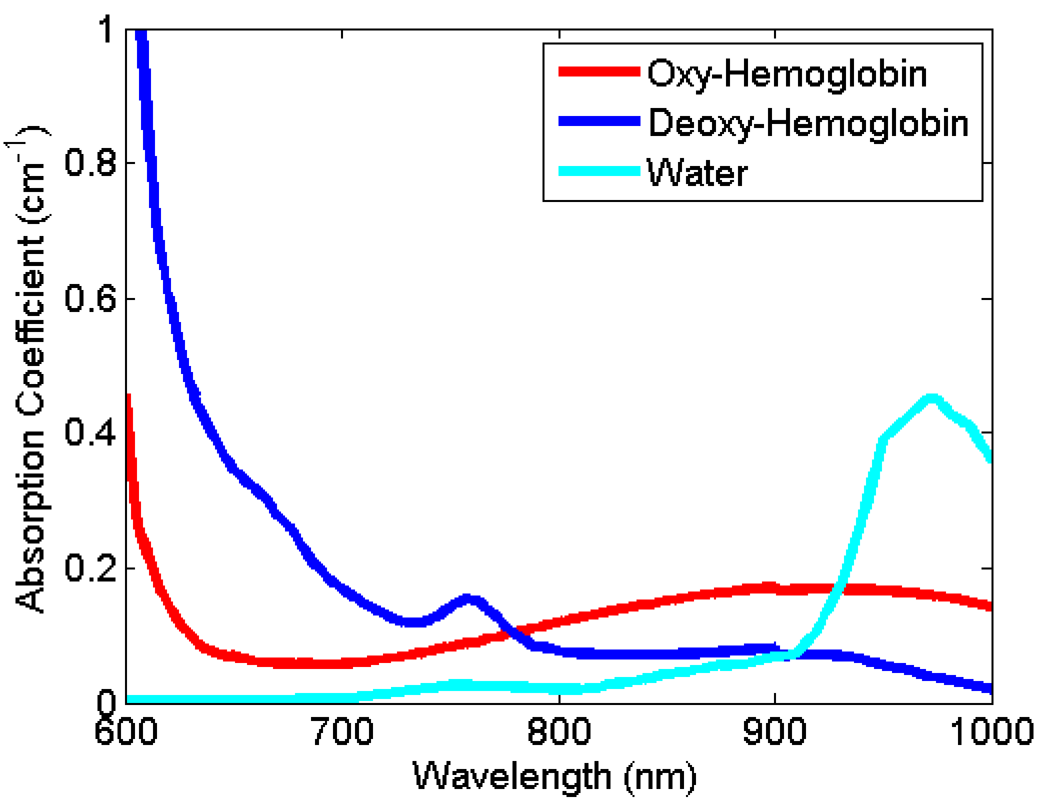

Figure 7. Absorption Spectra of Oxygenated and Deoxygenated Hemoglobin and Water

The device will provide multiple inputs from a probe of 10 centimeter in diameter that contains multiple laser diodes. The client wants the diodes to be able to operate at two different optical wavelengths, 780nm and 830nm, and the probe to potentially contain up to eight different laser diodes. To operate at these wavelengths the system will be operating in according to the International Commission on Illumination (CIE) at IR-A infrared radiation or near-infrared wavelengths.

The device will have each of the laser diodes modulated at different frequencies to enable a spatial coding system and an optical detector channel will be designed with this device to detect signals from all the laser diodes and reveal their spatial locations. The device will have a system that would be able to identify the states of the laser diodes in either an on or off state. The device will have phototransistors as photodetectors placed next to each laser diode to detect the back-scattering off of biological tissue, and ultimately convert that analog signal into an electrical signal. An amplifier will be incorporated into the design to strengthen the signal from the photodetectors for proper processing through a data acquisition device, which will be connected to a computer and monitored with LabView® software. This software will programmatically detect the states of each diode and separate multiple frequencies that might be detected by the phototransistors. Separate signals will be plotted on a graph that is displayed on an interactive user interface. Prior to conversion of analog to digital signals, signals from photodetector are filtered to remove any noise using a band pass filter.

2.1.2. Subunits

2.1.2.1. Laser Diode Circuit

The first component to implement would be the laser diodes. There will be two laser diodes used each operating at different wavelengths. These two diodes will also operate at two different modulated frequencies to ultimately differentiate between the two, but that is a problem to be solved later. At this point we are only concerned with supplying the laser diodes with adequate current to operate when necessary and not provide currents beyond its maximum ratings. If current ever surpasses the laser diodes maximum current capabilities the diodes burn out. Since operating in the small milliamps range the precision of the current is very important.

Figure 8 shows the circuit diagram for the transmitting side of the circuit. D1 and D2 represent the two laser diodes. V_{DD} is set at a constant DC voltage of 9 volts. This will power all

integrated chips within the circuit including the amplifier and the current driver. Within the laser diode driver pins 11 and 12 are connected to the negative input of the laser diode. Pins 10 and 9 are tied to ground. Pins 8 and 7 are tied to the negative pin of the second laser diode. Pin three is the reset pin and is active low. This means that the device is turned on when it is grounded. Pin 4 is the first input from the function generator and pin 6 is the input for the second input. Both of the function generators are tied together to the same ground separate from the DC ground. This ensures that there isn't any noise interfering and the input functions are clean of noise.

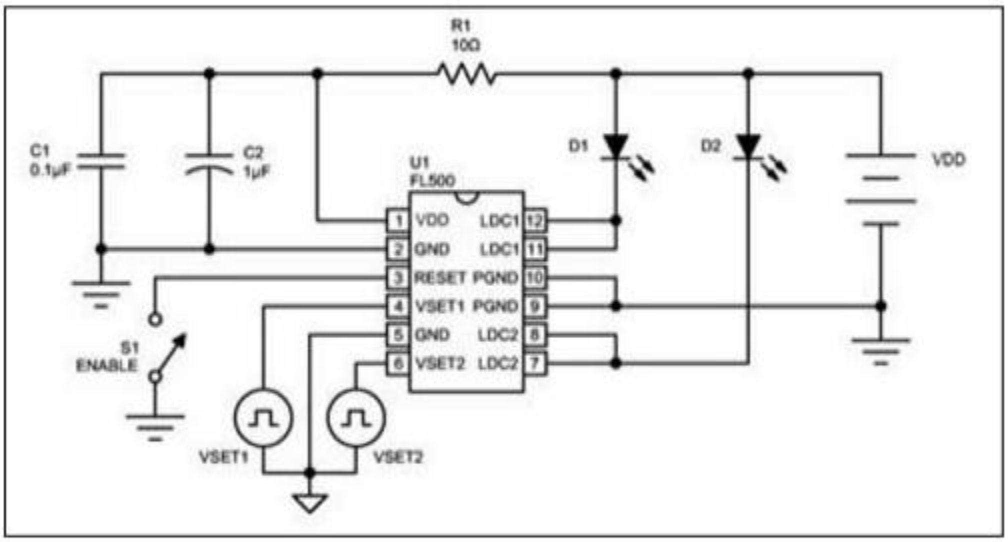

Figure 8. Transmitting Circuit Diagram

2.1.2.2. Photodetector

A photodetector is a component that takes optical signals and converts it into electrical signals. There are many different types of photodetectors including photodiodes, phototransistors, and photoresistors. With this design the type of photodetector being used is the Avalanche Photodiode (APD). The most important factor of using an avalanche photodiode over other photodetectors is that the APD provides a greater level of sensitivity. Also the APD has a self-amplification which amplifies the initial received signal. A big disadvantage to the APD is that because it is so sensitive it creates a higher level of noise then other types of photodetectors. This would require filter devices to be used to remove as much noise from the signal as possible.

The APD's structure is more complicated than that of ordinary photodiode devices. It consists of four layers, the n+, p, un-doped, and p+ regions. Light is absorbed through the un-

doped region which is a relatively thick region. An example of the layers of an avalanche photodiode can be seen in Figure 9.

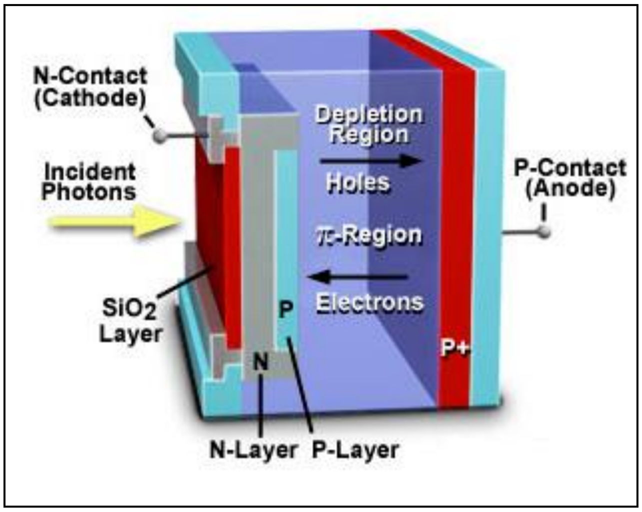

Figure 9. Avalanche Photodiode Regions

The avalanche region occurs between the n+ and p regions. When light enters the un-doped region it causes generation of hole-electron pairs. Under the action of the electric field the electrons then migrate towards the avalanche region. Here the electric field causes the velocity of the electrons to increase which creates collisions with the crystal lattice. This effect creates further whole electron pairs. This process allows than a single electron created by light in the un-doped region to produce many more electrons with the collisions with the crystal lattice. This in fact is how the self-amplification of the APD works.

The specific APD necessary would be either one made of Silicon or a combination of Indium, Gallium, and Arsenide because these two are able to operate within the limits of the laser diodes of 700-900 nm. The downside to using these two types of APDs are that the level of multiplication of the self-amplification is lower than that of Germanium, however Germanium can only operate from 800-1700 nm which excludes the 730 nm diode.

Figure 10 shows the photodetector circuit and the pins corresponding to the photodetector itself.

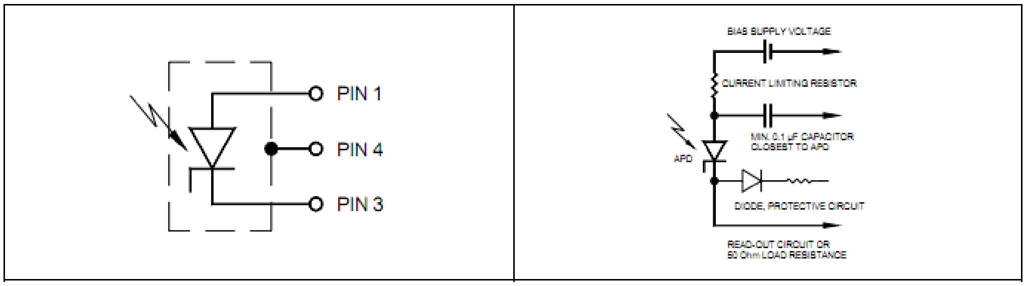

Figure 10. Photodetector Pin Configuration and Circuit

Pin 1 is the anode pin of the photodetector and pin 3 is the cathode. Pin 4 is a ground for the device. Within the circuit a bias voltage of 9 volts is applied to the anode of the pin with a capacitor to handle fluctuations from the bias voltage. The cathode side of the photodetector provides the output and also a diode running to ground. This is a protective function to the photodetector if a positive voltage is ever for any reason applied to the cathode of the photodetector it will have a path to ground not reverses biasing the photodetector and potentially breaking it down. The output of the photodetector circuit is fed into the amplifier circuit.

2.1.2.3. Amplifier

Figure 11 demonstrates the AC amplifier built. The amplifier consists of an op-amp at its core with a non-inverting build to control the amplification of the signal. C2 within the diagram removes the DC bias from the signal amplifying only the AC component of the input. Since the DC component is removed the signal oscillates around zero volts.

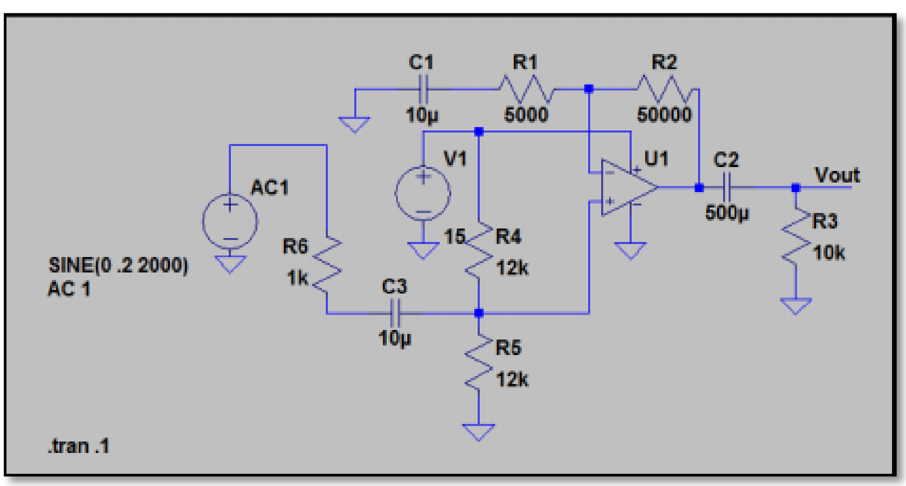

Figure 11. AC Amplifier

The gain for the system is $Gain = 1 + \frac{R_2}{R_1}$ however if the output voltage approaches greater than 6 volts the signal is clipped. Knowing this dependent on what the voltage response will be with the avalanche photodiode the gain can be adjusted to provide the maximum amplification for the signal without clipping any information. Figure 12 shows the amplification with software design and 13 shows amplification with the built prototype.

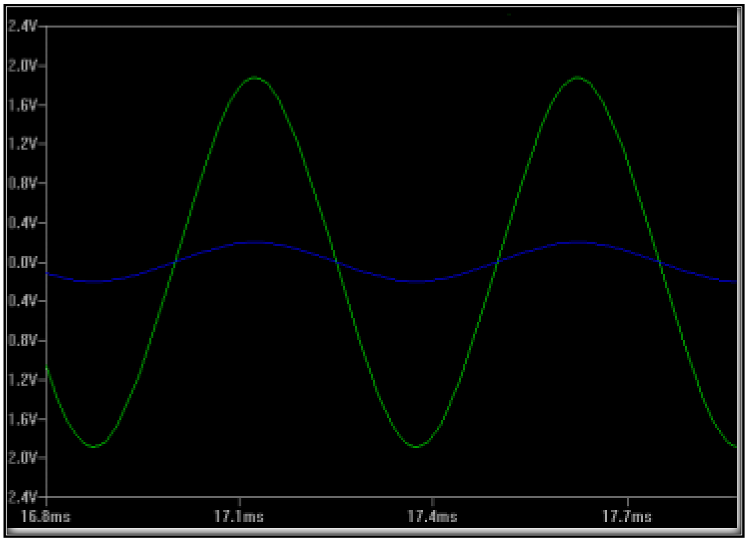

Figure 12. Digital Design Gain

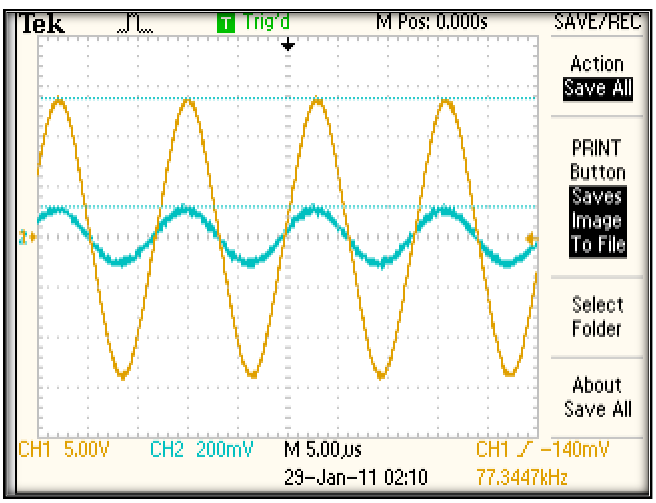

Figure 13. Prototype Gain

2.1.2.4. Data Acquisition Device

In order to analyze the signal being generated by the photodetectors, the NIRIS will be connected to a National Instruments Data Acquisition Device, Model PXI-5114. This specific device is a high-speed digitizer featuring two 250 MS/s simultaneously sampled input channels, each with 8-bit resolution, 125 MHz bandwidth, and up to 256 MB of memory [4]. The whole circuit is integrated into a 3U peripheral component interconnect (PCI) extension for instrumentation (PXI). The unit is ideal for a wide range of application areas including communications, scientific applications, military/aerospace, and consumer electronics. The optimal design will utilize the PXI-5114 for its digitizing abilities. To fully utilize this device, it is important to understand how it digitizes the analog signal and sends to as a readable format to LabView® for further analysis.

Bandwidth describes the difference between limiting frequencies within which the input signal can pass through the system with minimal amplitude loss — from the input at the tip of the probe or test fixture to the output data [8]. In the case of the NIRIS design, the bandwidth will be the signal that will be sent to the PXI-5114 from the circuit through a BNC connection. The limiting frequencies that determine the bandwidth include both a high and a low frequency that are specified as the frequency (in Hz) at which a sinusoidal input signal is attenuated to 70.7% of its original amplitude. This point is known as the -3 dB point. Figure 14 below shows a graphical representation of this point.

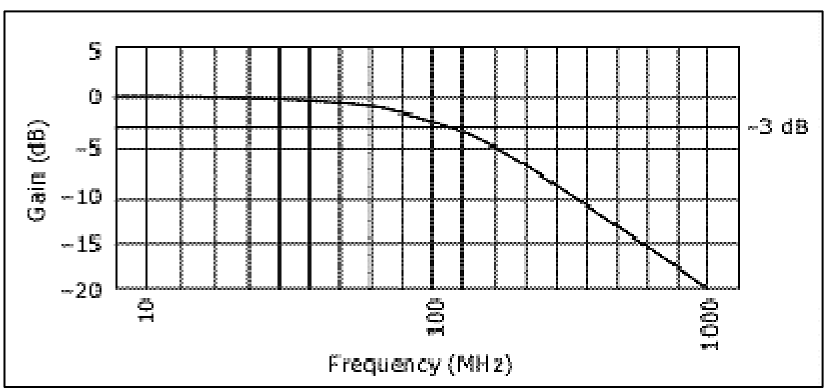

Figure 14. -3 dB Point

Another aspect of the signal to understand is flatness. Flatness is an effect on the acquired waveform that is frequency dependent [8]. As the frequency rises, the amplitude slowly falls toward the 3 dB cutoff point of the bandwidth. When signals are composed entirely of frequencies below this cutoff point, the measured signal can appear slightly different than the input signal. The higher frequency components of the signal are attenuated more than the lower frequency components, changing the overall signal. Flatness describes how well the analog front end passes signals of different frequencies. A maximally flat front end passes all frequencies with the same amount of attenuation, so the measured signal looks like the input signal. However, in the real world, as the frequency rises, the measured input signal slowly falls toward the 3 dB point.

Once the fundamentals of the signal is understood, such as the bandwidth and the flatness effect, it is important to look into how the digitizer would interpret the input signal, and whether it will be able to read it at all. This concern is addressed by the resolution of the digitizer. Resolution is the smallest input voltage change a digitizer can capture. Resolution can be expressed in bits (LSB), in proportions, or in percent of full scale. For example, a system has 12-bit resolution, one part in 4,096 resolution, and 0.0244% of full scale. Resolution limits the precision of a measurement. The higher the resolution (number of bits), the more precise the measurement. An 8-bit ADC, such as the PXI-5114 used in this design, divides the vertical range of the input amplifier into 256 discrete levels. With a vertical range of 10 V, the 8-bit ADC cannot ideally resolve voltage differences smaller than 39 mV. In comparison, a 14-bit ADC with 16,384 discrete levels can ideally resolve voltage differences as small as 610 µV. Figure 15 below shows the block diagram for the PXI-5114 [4].

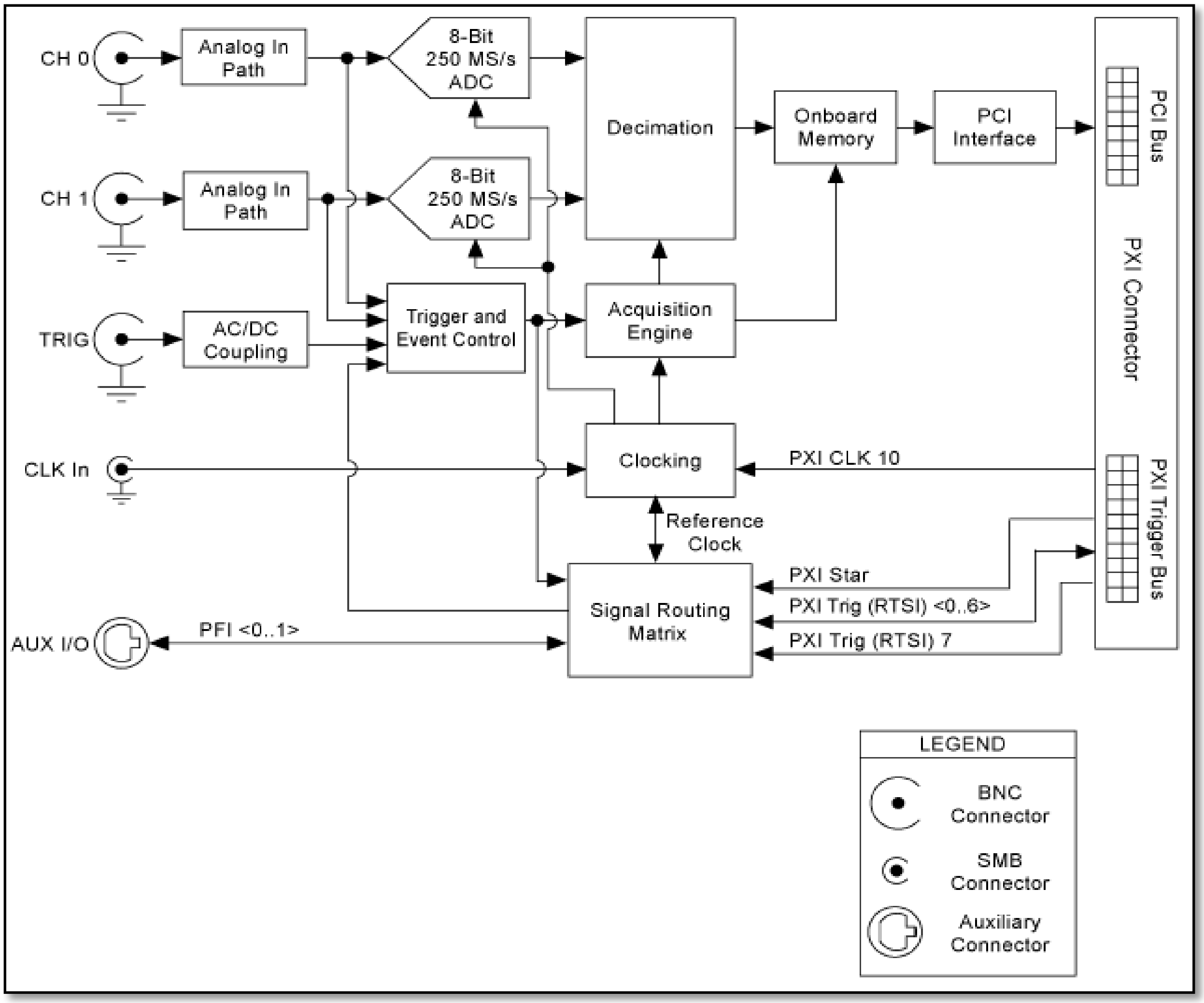

Figure 15. PXI-5114 Block Diagram

In above image, we can see both BNC channels, CH 0 and CH 1. Using one of these channels, the analog signal will be transmitted from the photodetectors into the digitizer. From the analog in path, the signal will be transferred to the 8-bit 250 MS/s analog-to-digital converter (ADC). An ADC is a device that converts a continuous quantity to a discrete digital number. As described before, resolution is an important factor of the ADC. Due to the fact that the signal is decimated after it goes through the ADC, the type of ADC used in the PXI-5114 is most likely a Sigma-Delta ADC (or a Delta-Sigma ADC). Figure 16 below shows the block diagram for such an ADC [4].

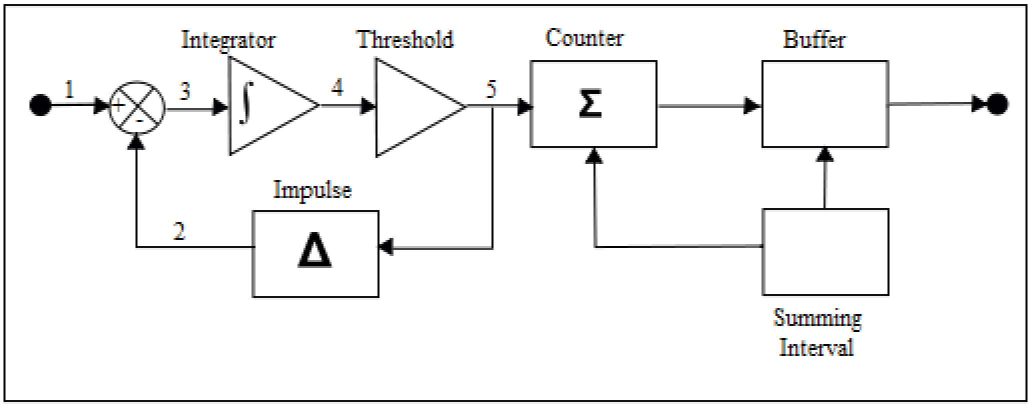

Figure 16. Block Diagram Sigma-Delta ADC

Such an ADC oversamples the desired signal by a large factor and filters the desired signal band. Generally, a smaller number of bits than required are converted using a Flash ADC after the filter. The resulting signal, along with the error generated by the discrete levels of the Flash, is fed back and subtracted from the input to the filter. This negative feedback has the effect of noise shaping the error due to the Flash so that it does not appear in the desired signal frequencies. The decimation process that follows the ADC reduces the sampling rate, filters off unwanted noise signal and increases the resolution of the output.

The PXI-5114 provides two independent digitizer input channel signal conditioning paths. Each path provides a choice of 50 Ω input impedance or 1 MΩ input impedance, as shown in the following Figure 17

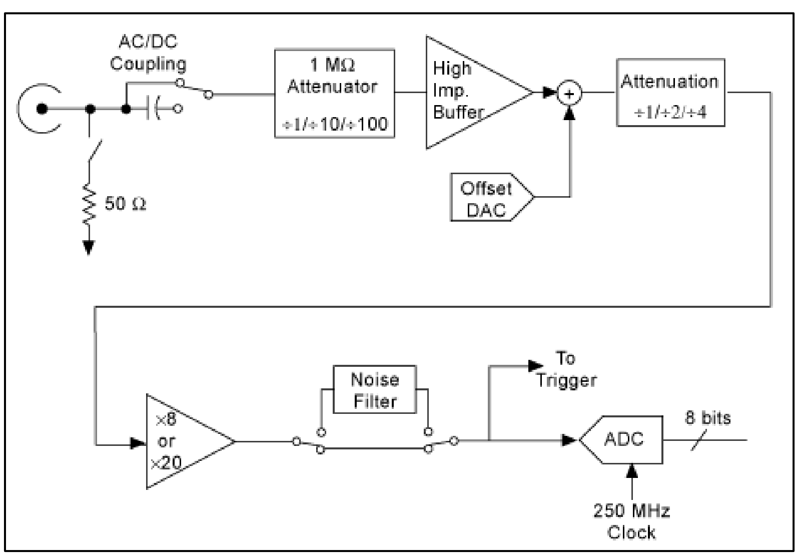

Figure 17. Input Signal Conditioning

The PXI-5114 provides noise filtering on the analog signal before it is sent to the ADC. It has a 20 MHz noise filter that limits the bandwidth of the signal path through both the 1 MΩ and 50 Ω signal paths. This filter is intended to reduce noise when the signal content is 20 MHz or less. Figure 18 shows a typical frequency response of the noise filter [4].

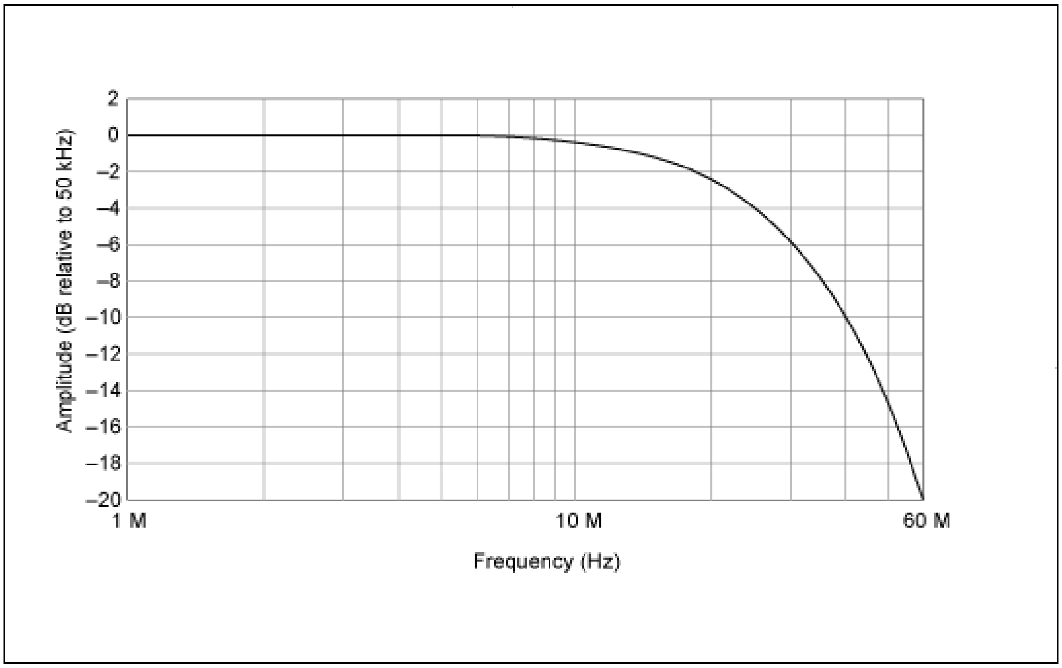

Figure 18. Noise Filter

Having this intermediary noise filter within the overall noise conditioning pathway provides a cleaner signal for the ADC. This cuts out a lot of the noise that would have otherwise unnecessarily showed up in the digitized signal. This doesn't mean that there isn't a need for filters before the signal gets transmitted to the PXI device itself. There are many other sources of interference that have to be dealt with, such as white noise and pink noise. Getting the signal as clean as possible for analysis in LabView® is the main goal of all these filters. Besides acting as the digitizer, the PXI-5114 will also act as an intermediary between the signal generated by the photodetectors and the signal read by the data acquisition device and sent to the computer.

2.1.2.5. Software

The optimal design for the NIRIS involves extensive analysis of the signal from the photodetectors in LabView® software. The user interface will also reside within this program as a standalone VI. Much of the analysis that needs to be done on the signal include filtering, graphing, and recording the vital data.

The programming language of LabView® is called “G”. This language will allow the programmer to visually program a series of instructions, including gathering data from the data acquisition device, filtering it through a Butterworth Filter VI, and outputting it on graphs that make up part of the user interface. The main component involved in gathering data from the PXI-5114 is the DAQ Assistant Express VI [6]. Within this VI, the programmer can select the appropriate input channel from the PXI card, adjust input variables such as the type of input (i.e. voltage or current), and can calibrate the PXI itself. Figure 19 below shows the main DAQ Assistant window in which the programmer adjusts all the necessary settings. Other sampling variables which can be fine-tuned from within the DAQ Assistant manager window include timing settings such as the acquisition mode, the number of samples to read, and the sampling rate. The output of the DAQ Assistant Express VI is a two-dimensional array of type doubles containing the time variable and the signal variable.

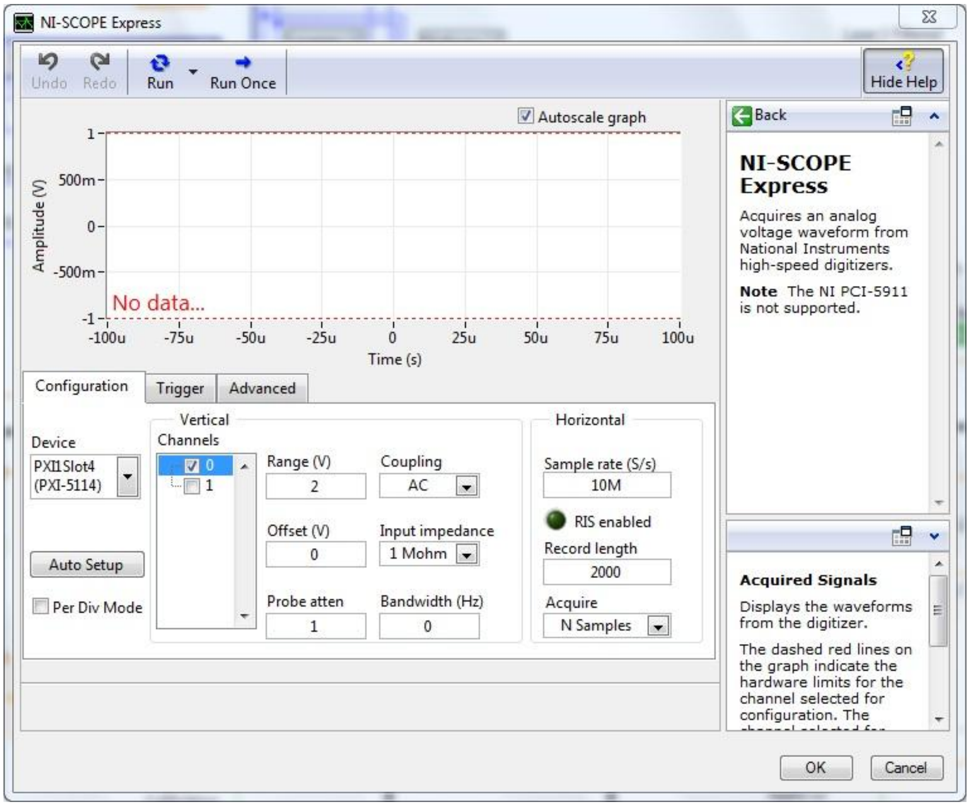

Figure 19. NI-Scope Express VI

The resulting array fetched from the DAQ Assistant Express VI will be fed directly into a graph for the user to visualize the "unfiltered" data. Technically, the data was filtered before it was processed by the DAQ, but without loss of generalization it is possible to label this data as unfiltered. A Waveform Graph will be able to graph the raw signal in real time due to the fact that the whole program will be put into a while loop, stopping only when the user requests it to. The raw signal will also be branched into a Butterworth Filter. Using the Filter Express VI [7], the programmer can select the Butterworth Filter and specify specific cutoffs. Due to the nature of the project, the main type of filter being used will be a bandpass filter. The client requires one or more signals to be detected by the photodetector, sent to the DAQ, and analyzed in LabVIEW. For this reason, a bandpass filter will be used to isolate the specific frequencies at which the signal is being gathered at. Figure 20 below shows how LabVIEW uses point-by-point analysis in its Filter Express VI [8].

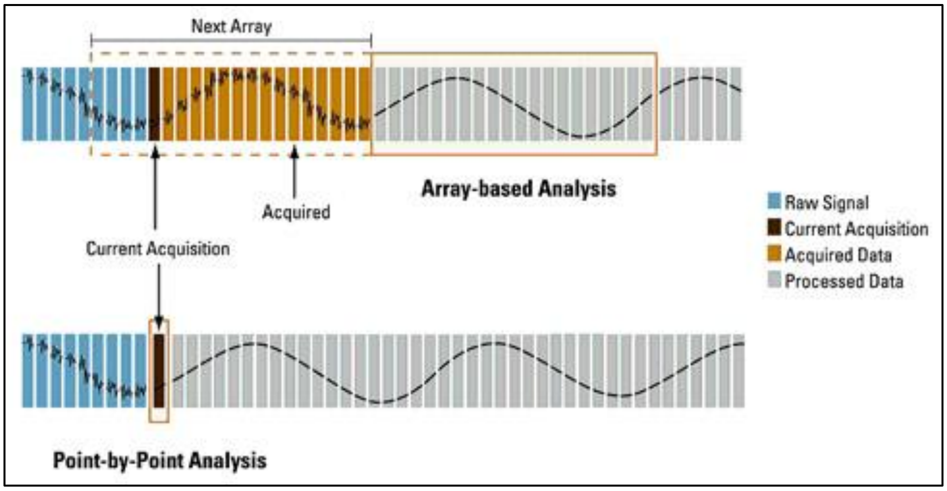

Figure 20. Array-Based Analysis versus Point-by-Point Analysis

Point-by-point analysis is essential when dealing with control processes where high-speed, deterministic, point-by-point data acquisition is present. Any time resources are dedicated to real-time data acquisition, point-by-point analysis becomes a necessity as acquisition rates and control loops are increased by orders of magnitude. The point-by-point approach simplifies the design, implementation, and testing process, because the flow of the application closely matches the natural flow of the real-world processes that the application is monitoring and controlling. Point-by-point analysis is streamlined and stable, because it ties directly into the acquisition and analysis process.

Due to the fact that the range of frequencies is known but not the exact values, a for loop will be used to iterate through the entire range of possible frequencies to find which frequencies are currently being captured by the photodetector. This part of the program exhibits spatial coding properties, in the sense that the LabVIEW program will be able to tell which laser or lasers are turned on, and at which frequencies they are being driven at. Figure 21 below shows an overall flow chart of the processes described in the last two sections.

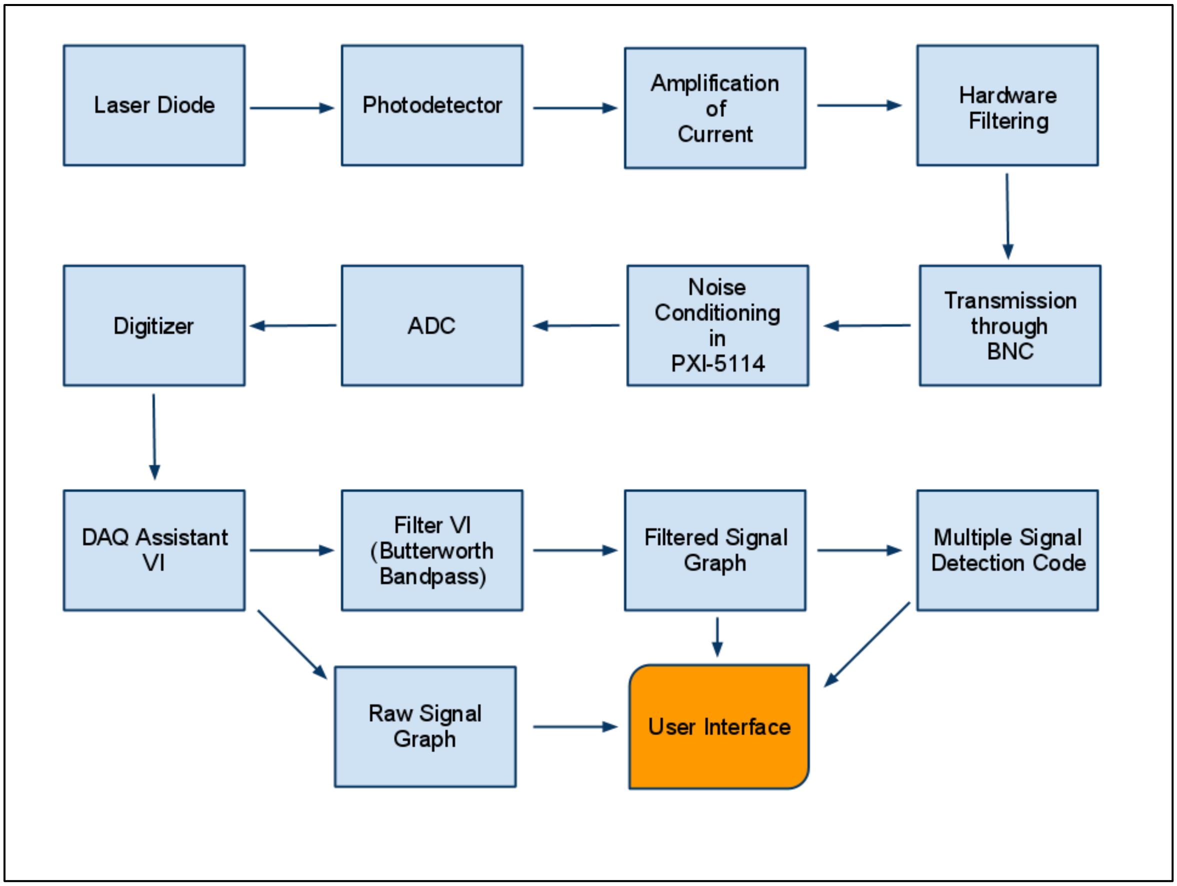

Figure 21. Flow Chart of Signal to User Interface

To maintain proper memory management, a divide-and-conquer algorithm will be used to find and isolate the frequencies of the powered lasers. This will make sure that the overall run time of the program is feasible and can keep up with the live signal feed. This will also make sure the space consumption of the program is well within the limits of LabVIEW's memory allocation manager.

2.2. Prototype

The final prototype consists of a closed box which houses the laser diode and photodetector circuitry. Within the box is also the medium through which the laser diodes will be transmitting. For biological purposes, the medium is a Phantom sample. In order to properly operate the prototype, three pieces of equipment are necessary: two function generators with BNC output, and a Native Instruments DAQ device with a NI PXI-5114 card. The DAQ device is presumably connected to a computer that meets the minimum requirements outlined in Appendix 12.1. Figure 22 shows all the devices used to test the NIRIS prototype.

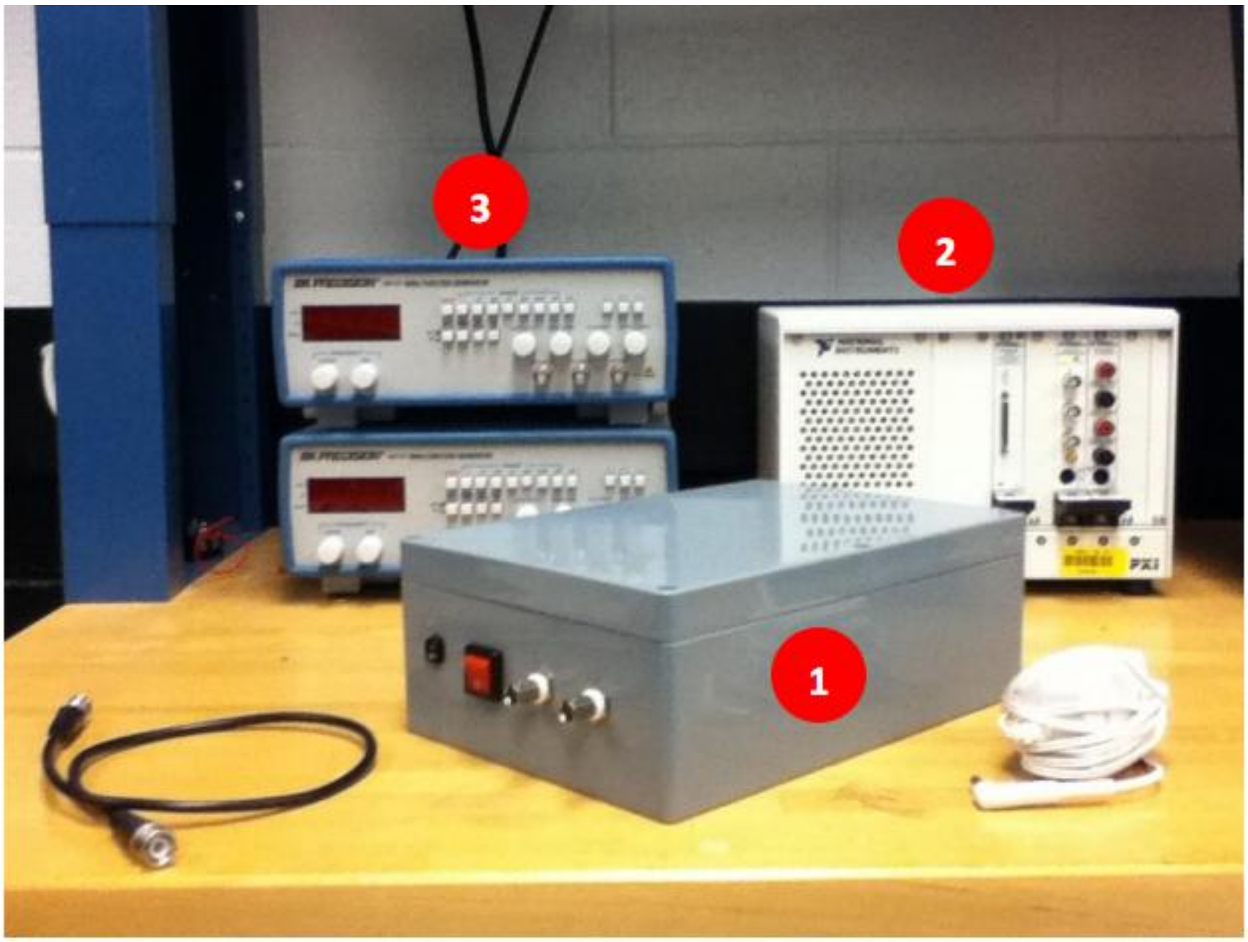

Figure 22. NIRIS Prototype Setup

In the image above, Figure 22.1 shows the NIRIS prototype encased in its housing with its back facing the camera; Figure 22.2 is the Native Instruments DAQ; and Figure 22.3 shows the two function generators stacked on top of each other (note: the function generators do not need to be placed on top of each other; they can be placed side to side).

To start using the prototype, the NIRIS device (Figure 22.1) must be plugged into an outlet using the supplied 9V power adapter. Figure 23 below shows the NIRIS device properly plugged in.

Figure 23. NIRIS Device Plugged In using 9V Power Adapter

In the above image, the blue circle outlines where to plug the power adapter into the device. Once the NIRIS device is successfully plugged into an outlet, it is ready to be attached to the function generators. Figure 24 shows the NIRIS device successfully hooked up to the two function generators using BNC male-to-male cables.

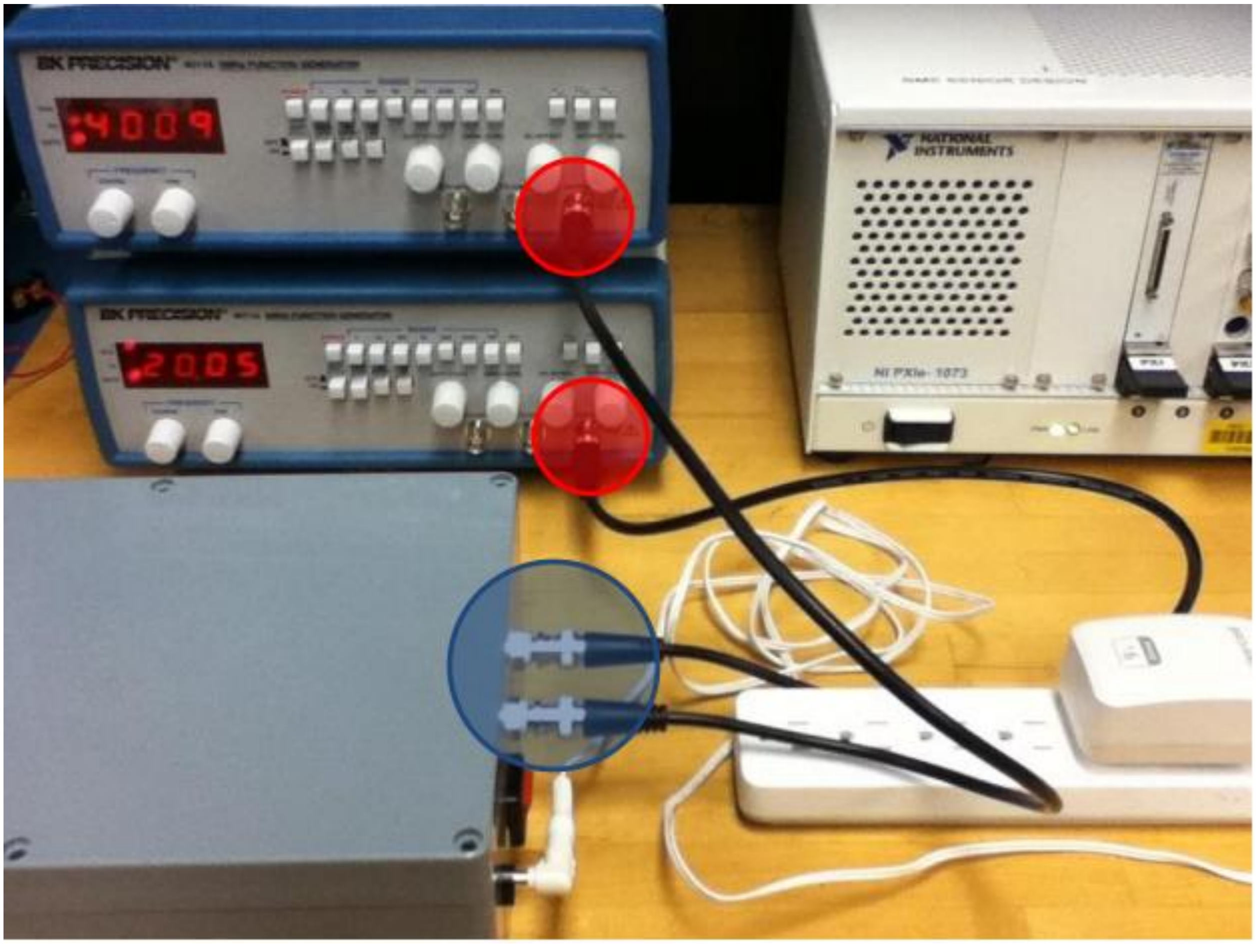

Figure 24. NIRIS Device Connected to Two Function Generators

In the above image, the BNC female inputs on the back of the NIRIS device, circled in blue, are attached to the outputs of the two function generators, circled in red. Not all function generators have the BNC output in the same location as the function generator in Figure 24. The two function generators used for the NIRIS device were BK Precision 4011A 5MHz function generators. When the connections to the function generators are established, the user can turn on each function generator and adjust them to their respective output frequency. To properly use the NIRIS prototype, Input 1 on the back has to be connected to a function generator outputting a sign wave at 40 kHz, and Input 2 to a function generator outputting a sign wave at 20 kHz.

One last connection has to be made before the NIRIS prototype can be turned on. The connection to the Native Instruments DAQ has to be made using one male-to-male BNC cable. Figure 25 below shows the proper setup for this last connection.

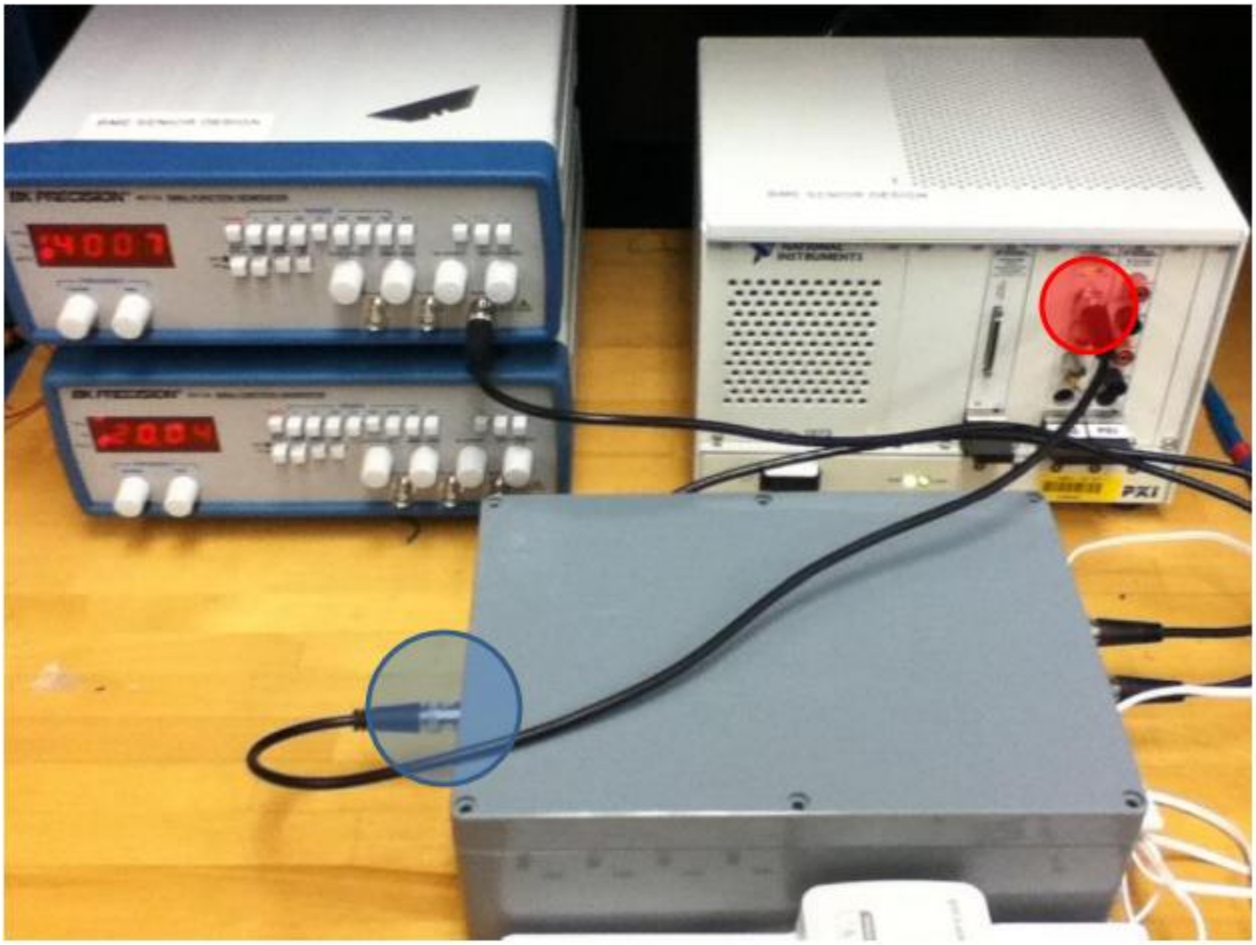

Figure 25. NIRIS Prototype Connected to NI DAQ

In the above image, the BNC female output on the front of the NIRIS prototype is connected to Channel 0 on the NI PXI-5114 card with a BNC male-to-male cable. The red circle shows the connection on the NI DAQ, and the blue circle shows the connection on the NIRIS prototype. If all the connections previously mentioned were successfully made, along with the connection shown in Figure 25 above, then the NIRIS prototype is ready to be turned on. To do so, flip the red switch on the back of the NIRIS prototype from ‘0’ to ‘1’.

When the NIRIS prototype is setup and turned on, the user is now ready to run the LabView® interface. The NIRIS prototype includes an executable LabView® program named “NIRIS.exe” To run this, place the included CD into a compatible computer and double click on the executable.33

For testing purposes, the function generators where turned on one at a time after the LabView® program was opened. Figure 26 below shows the front panel of the user interface after turning on the function generator which outputs 20 kHz to Input 2.

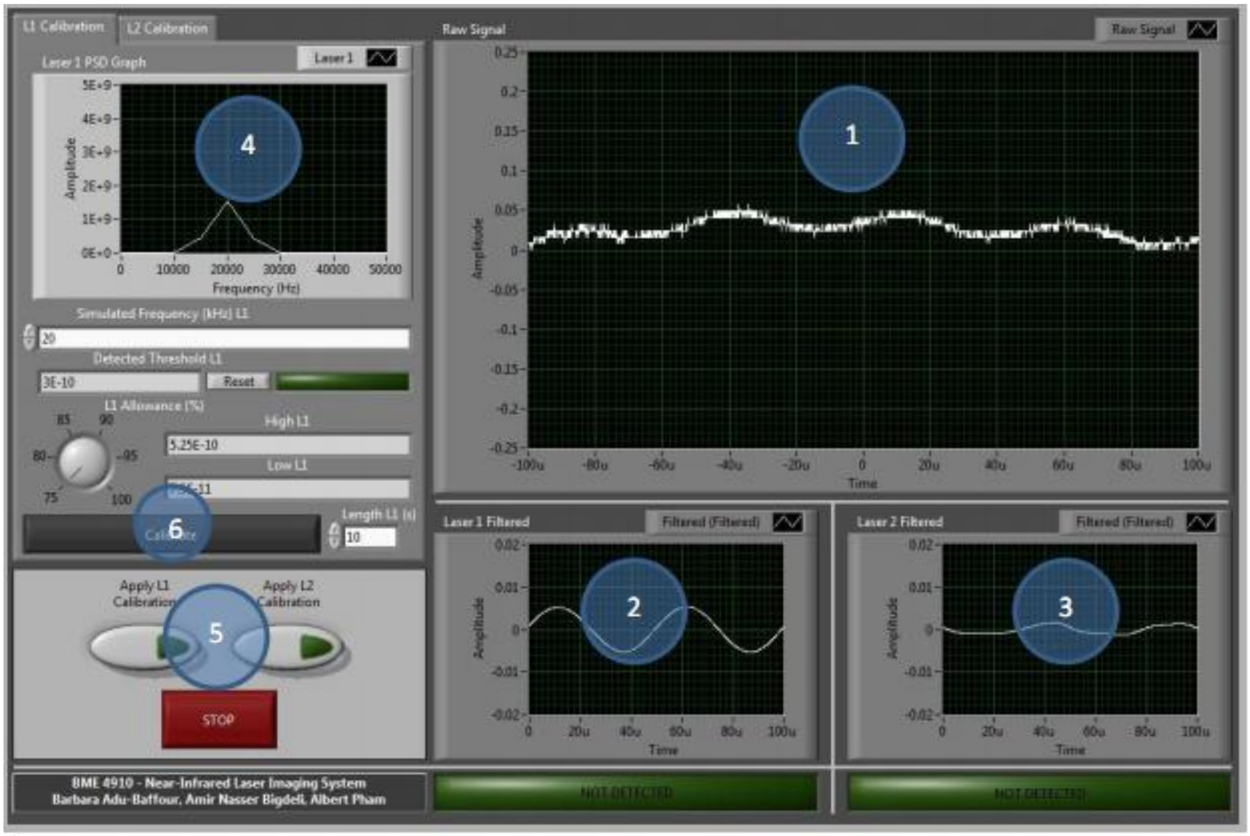

Figure 26. NIRIS User Interface with 20 kHz Attached

In Figure 26, it is possible to see the user interface running with the 20 kHz laser diode data being displayed in the graphs. Figure 26.1 shows the raw data collected straight from Channel 0 on the NI PXI-5114 ADC card. It is possible to see much noise in the wave generated in that graph due to the fact that there are no hardware filters employed in the NIRIS prototype. Figure 26.2 shows the graph designated to filter out a 20 kHz input. A clear and distinct sign wave is being displayed. Figure 26.3 shows the graph designated to filter out a 40 kHz input. Due to the fact that only the 20 kHz input is powered, Figure 26.3 is a relatively flat line. Figure 26.4 shows the power spectrum density of the 20 kHz signal. A clear spike is seen at the 20 kHz frequency, indicating that the photodetector is detecting the 20 kHz signal. Figure 26.5 is the panel where the user can later on apply the calibration settings for the detection of the 20 kHz and 40 kHz signals.

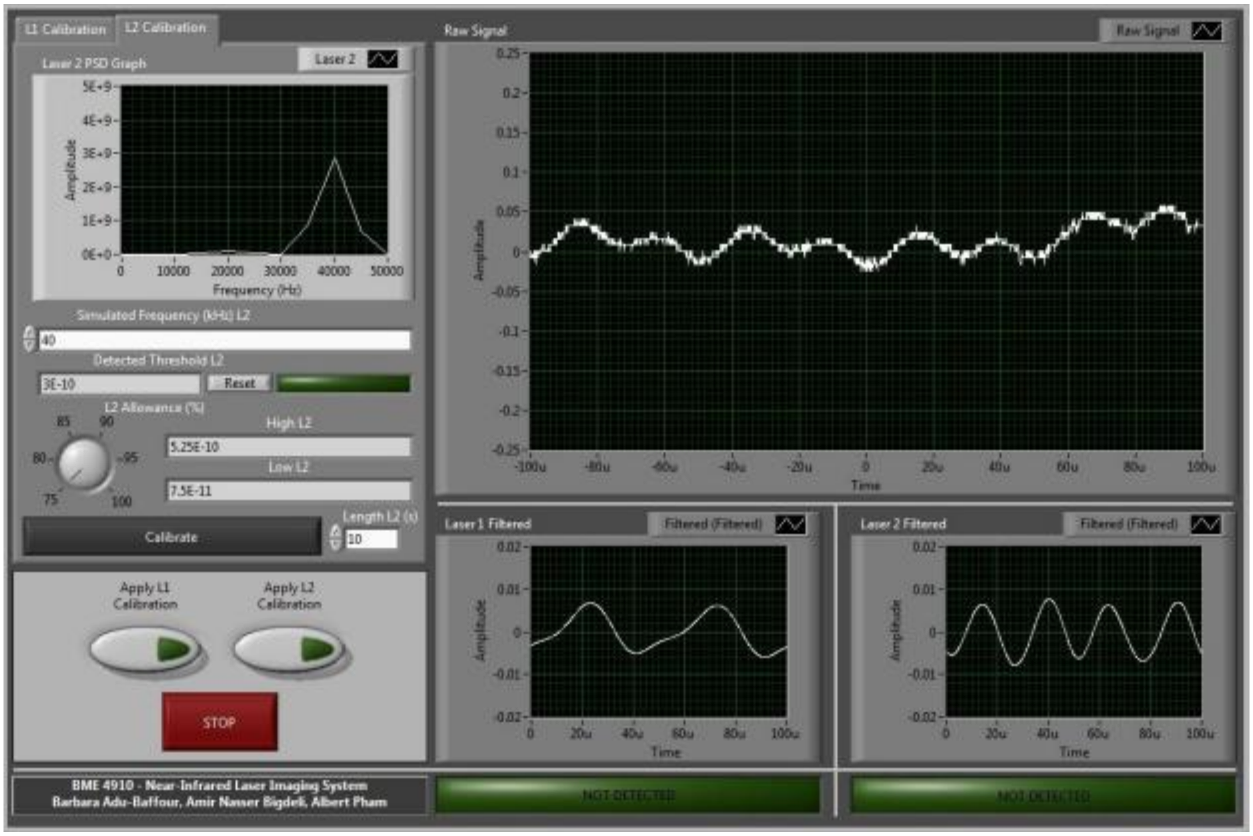

Figure 27. NIRIS User Interface with 20 kHz and 40 kHz Attached

Figure 27 shows the user interface after the 40 kHz frequency laser is turned on in tandem with the 20 kHz frequency laser. Now, the ―Laser 2 Filtered graph, Figure 26.3, also shows a sign wave. Figure 26.4 also shows a spike in the 40 kHz frequency range, assuring the user that the photodetector is capturing light data from the 40 kHz frequency laser, and that the user interface is also recognizing it as well.

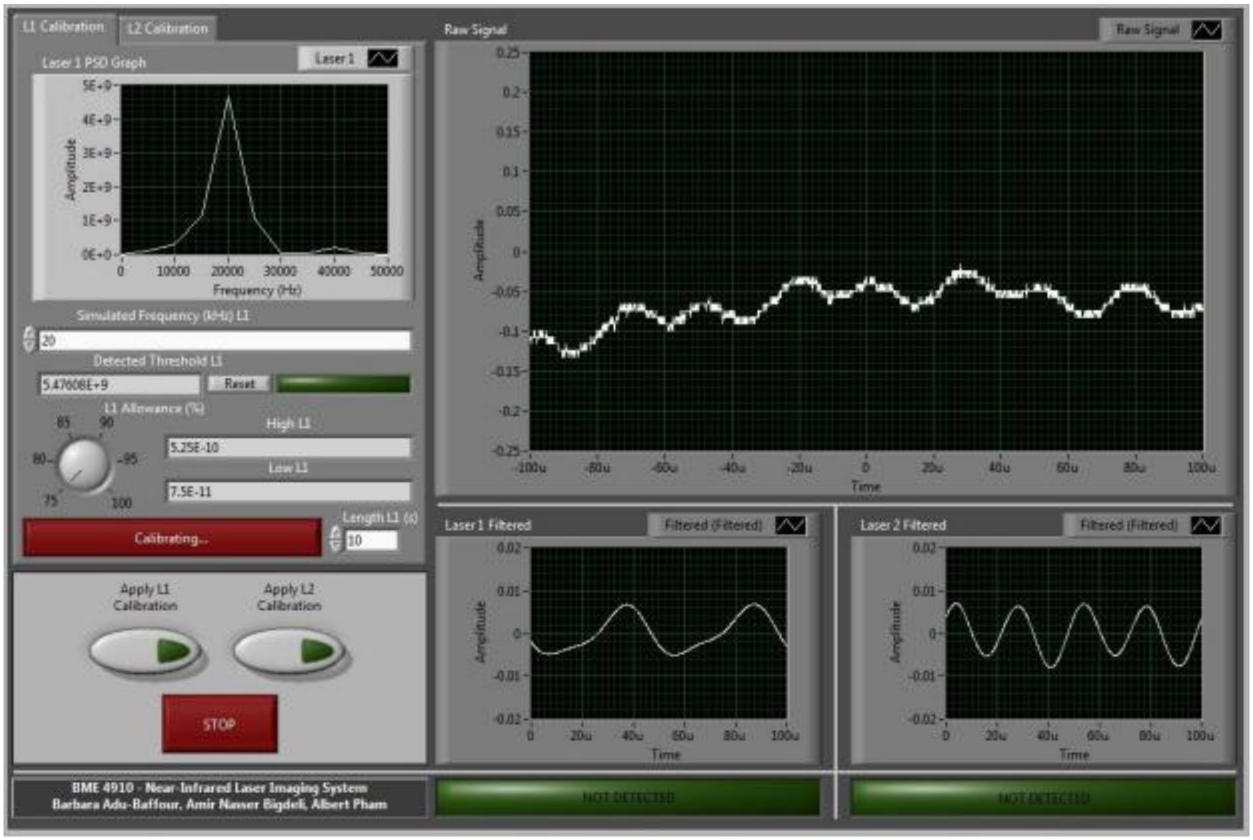

Figure 28. NIRIS User Interface 20 kHz Calibration

Now that both of the lasers are powered and recognized by the LabView® interface, the next step is to calibrate each signal so that the two lasers can be successfully detected. Figure 28 shows what the user interface might look like when calibrating the 20 kHz frequency laser. To start calibration, the Calibrate button, Figure 26.6, must be pressed. When the program is calibrating the signal, the Calibrate button changes from grey to red, as shown in Figure 28. The value in the “Detected Threshold L1” indicator starts to change depending on the peak of the lasers corresponding PSD. Every time a new threshold is detected, the LED next to the “Detected Threshold L1” indicator is lit up. It is important to note that the length of the calibration process is initially set to 10 seconds. This means that the program collects data from the PSD graph of the corresponding laser for 10 seconds to properly find the best threshold for detection. The “High L1” and “Low L1” indicators show the upper and lower ends of the calibrated threshold. To fine tune these values, the user can adjust the fine tune knob to the left of these two indicators, labeled “L1 Allowance”.

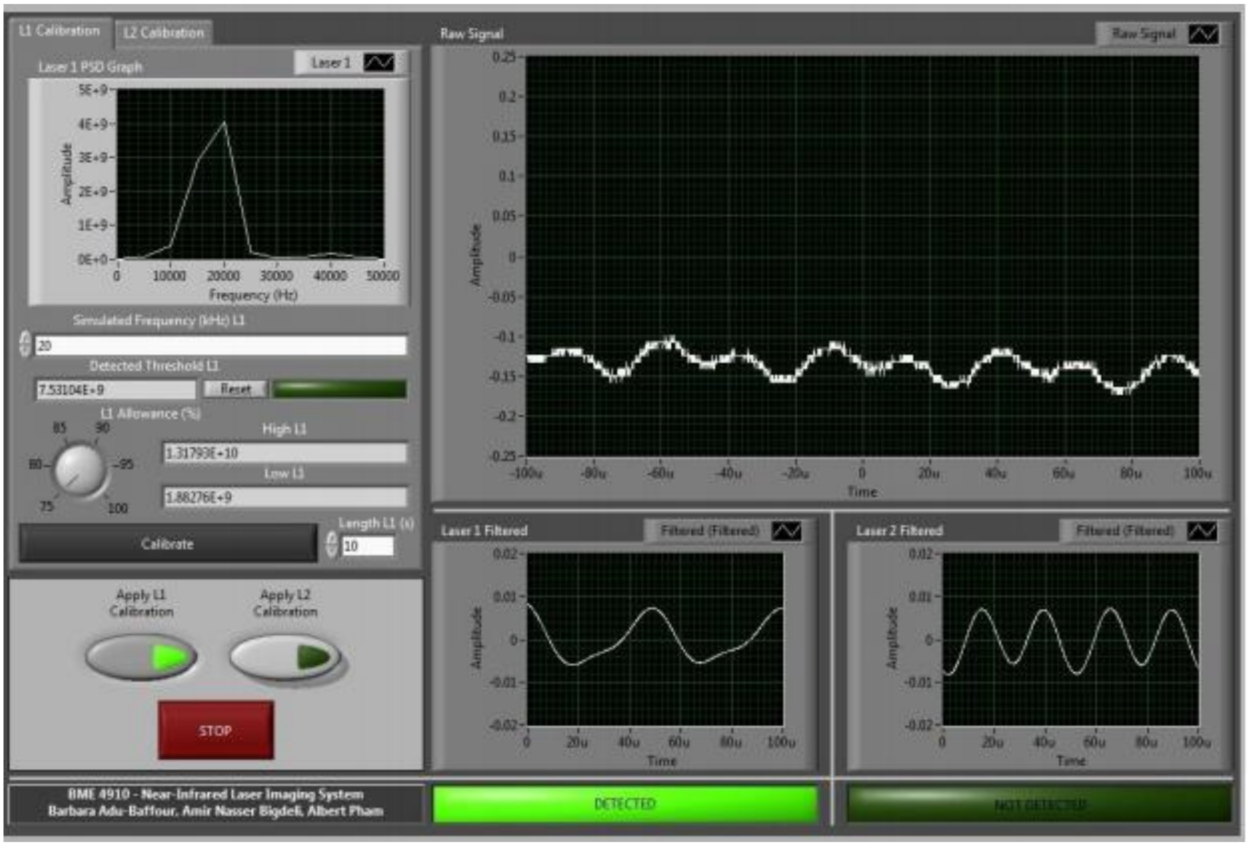

Figure 29. NIRIS Interface 20 kHz Detection

After the calibration is complete, the calibrate button, Figure 26.6, changes back from red to grey. In order to apply the calibration for detection, the user must turn on the —Apply L1 Calibration switch. This is located in Figure 26.5. Figure 29 above shows a the —Apply L1 Calibration button turned on, and the program successfully detecting the 20 kHz frequency laser. Proper detection is indicated by a flashing “DETECTED” below the corresponding lasers filtered graph. In this case, the 20 kHz frequency is associated with Laser 1. The same steps outlined above are also used to calibrate and detect the 40 kHz frequency laser.

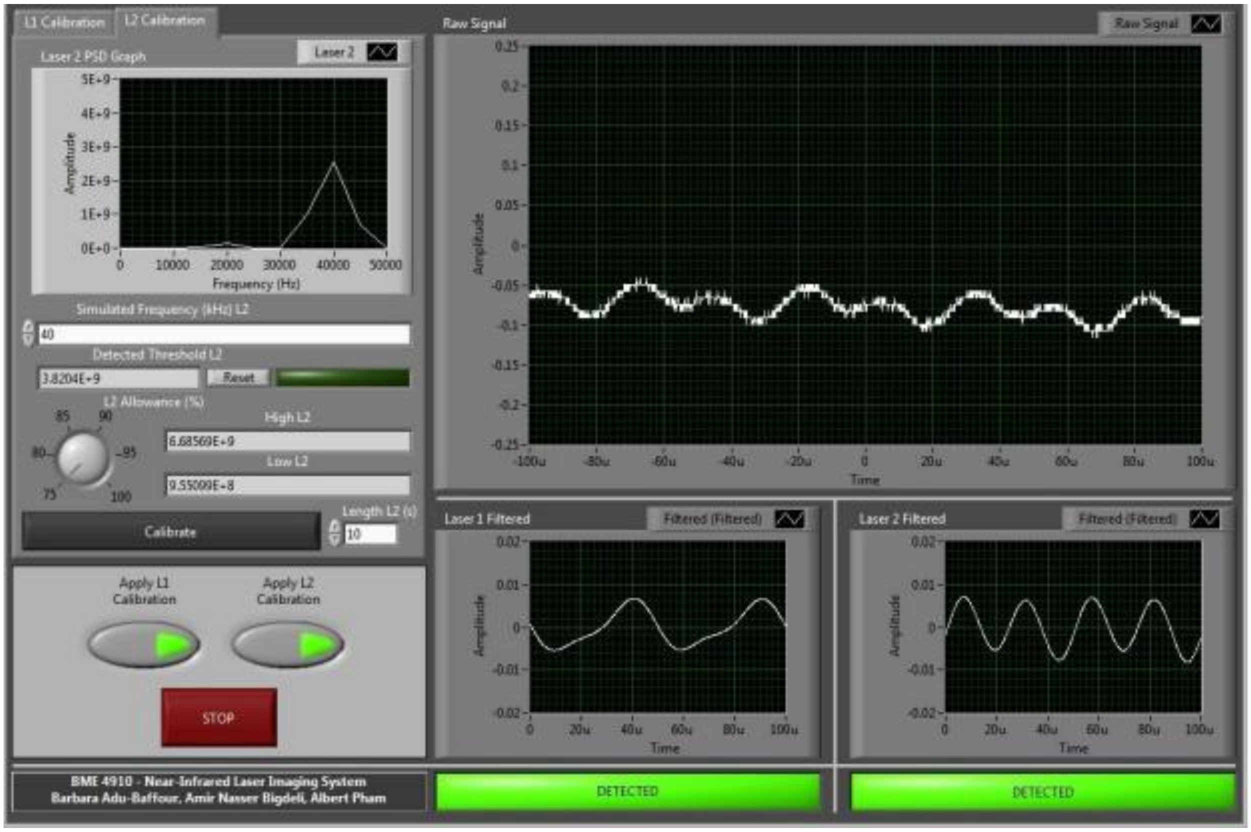

Figure 30. NIRIS User Interface 20 kHz and 40 kHz Detection

The main purpose of this program is detecting multiple signals from one input signal, and this is properly done by a series of software filters that split up the original signal. Figure 30 shows what the user interface might look like after both lasers are calibrated and detected. The DETECTED LED‘s for both lasers, located underneath each lasers filtered graph, are turned on, signifying that both lasers are being properly detected. It is important to note that when running the program, once a laser is detected the DETECTED LED flashes green and yellow. In the case that the detection LED is flickering, the user must adjust the fine tune knobs for the problematic laser. This will increase the high and low range of the threshold, making it easier for the program to detect whether or not a specific frequency laser is powered. This might also result in a false detection if the fine tube knob is turned too close to 100%. To stop the program, the STOP button should be pressed in Figure 26.5

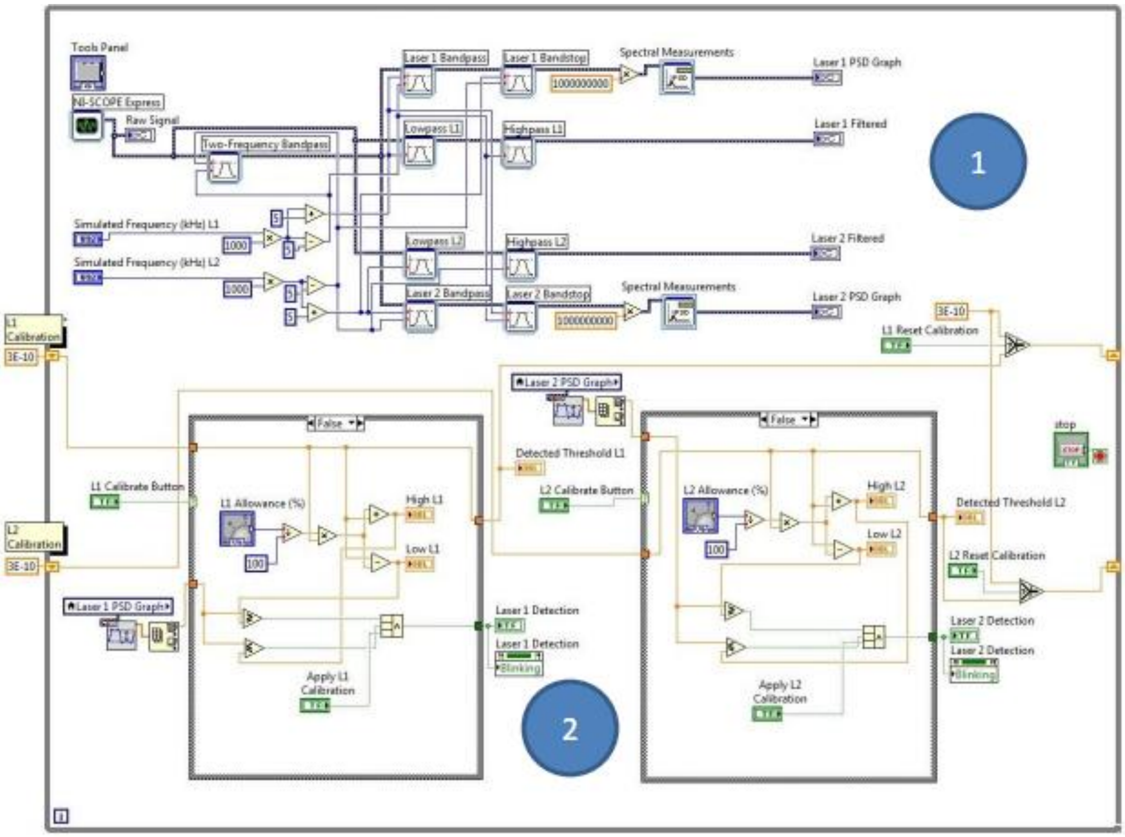

Figure 31. NIRIS User Interface Block Diagram

Figure 31 shows the block diagram for the NIRIS prototype user interface. The code is split into two sections: the signal filtering section and the laser calibration section. Figure 31.1, or the upper portion of the block diagram, is where all the signal filtering takes place. Figure 31.2, or the lower portion of the block diagram, is where the laser calibration occurs.

Testing with Client (Qing Zhu)

Once the NIRIS prototype was complete, Dr. Qing Zhu, the client, came into the lab to test software and hardware. Dr. Zhu brought with her a sample of Phantom to be used as the medium between the laser diodes and the photodetector. After hooking up the prototype to the NI DAQ and function generators, and running the LabView® user interface, Dr. Zhu was very pleased. She commented on the usability of LabView® program and the NIRIS container itself. After testing it herself, she had a couple of her graduate students also use the program, and they all were pleased with the results they obtained.

3. Realistic Constraints

3.1. Engineering Standards

The device will be required to provide multiple inputs from multiple laser diodes and as such it is important to know the states of each diode and what frequency each signal is being modulated at. This allows for special coding of the signals to enable target recognition of cancerous tissues. Also the device will have a filter that will sort out unwanted frequencies due to powerlines and noise from laser diodes. This will enable the desired signals to be interpreted since wrong analysis can be fatal to patient if tumors are not detected properly.

3.2. Economic Constraints

As with any project in the field of science and medicine, there are multiple realistic constraints that will affect the results and overall effectiveness of this project. Economic constraint is the major issue in this project due to the limited budget allocated. In regards to this project, many of the parts that are needed to construct the imaging probe, such as the laser diodes, current drive, and photodetectors considered in this design can be purchased commercially for a relatively low price. Other hardware requirements, such as the National Instruments Data Acquisition (DAQ) device and DC/AC power source, are already provided through the research laboratory. Software requirements such as LabView®, MultiSim® and Filterlab® are also provided. The majority of our economic constraints will depend heavily on the amount of prototypes we render, the amount of hardware instruments that are necessary to completely build the probe and also the cost of shipments of parts.

3.3. Environmental Constraints

Environmentally, there are only a few constraints that we will have to deal with, specifically electronic or e-waste since the project does not have the use of radioisotope materials involved. The disposal of damaged components during the design is the only issue that has environmental issues and as such our completed project should be handled with care and done under environmentally compliant conditions. Sustainability and manufacturability are not going to be a

problem due to the nature of the project. As of now, there are also no ethical constraints involved with laser imaging on biological tissue.

3.4. Operational Constraints

An operational constraint that has to dealt is the fact optical measurements can be easily contaminated by motion artifacts caused by patient or operator as well as relative motion of the probe and soft tissue during contact imaging which is similar to 1D ultrasound probes scanned in 2D to perform 3D imaging. Careful operation procedure and operator training are required to obtain good quality images using hand-held based optical devices over using bulky optical systems employing compression plates or circular geometry.

3.5. Health Issues

Health concerns associated with biological and chemical hazards would not be a problem since the project does not involve the use real human or animal tissue. Instead artificial tissues (phantoms) will be used which have similar characteristics and optical properties as human tissue. Also due to the non-invasiveness of near infrared imaging technology, health hazards due to infections from wounds created from needles. In comparison to other non-invasive imaging techniques such as mammogram, MRIs, PETs, etc., this design does not use radioisotopes and as such health complications related to radiation are avoided from multiple tests.

4. Safety Issues

Safety is the number priority in this design. To protect both user and patient this design will have all if its circuits housed in a plastic box for good thermal and electrical resistance and long-term. Also, no bare wires will be left to prevent electrical shocks to the user. All other electrical components will be protected from any potential interruptions such as physical harm.

The possibility of overheating of the components is also considered which due to the change in current of laser diodes, power-line surges and spikes (transients). This issue will be addressed by using a heat sink in the form of a fan for dissipating heat. This fan together with all parts of the circuits will be put in the plastic housing mentioned above with vents for dissipation

of the heat. This approach also prevents health hazards due to heat damage to the skin and eye and other electrical components of the design.

5. Impact of Engineering Solutions

The design of near infrared imaging system will have a huge impact in the tissue imaging world as it presents a new technique for non-invasive imaging that is cheaper and reduces health risks associated with other forms of imaging mentioned earlier. As the client conducts research in breast cancer, this device will provide a better form of probing into cancerous tissues since near infrared light can probe further centimeters into tissues compared to visible light. Since the design of the device is relatively cheaper, more laboratories and other low funded institutions and facilities to be able afford tissue imaging researches.

On a more social basis, this device when manufactured and used on a large scale will be of great benefit due to its advantage of implementing a more specific and more sensitive imaging technique exceeding that of x-ray mammography. This make near infrared imaging an important development in the means of screening for breast cancer. Screening demands a spatial resolution of a few millimeters or better in order that tumors can be distinguished from surrounding healthy tissue while they are still small in size before metastasis occurs and treatment becomes more difficult which can result in death. The use of this device will encourage more people especially women to see the doctors for early detection of tumors since the development of this design contribute to the better distinguishing between benign and malignant lesions, without a surgical biopsy.

The portability of this device allows easy transport from one place to another compared to available bulky optical imagers. This is a global advantage since a portable device will allow imaging to be done not only in large hospitals and research laboratories but also in remote areas where access to such devices is impossible.

6. Lifelong Learning

Throughout the design process new knowledge has been acquired in many different areas, most of which do not involve direct passing on from teacher to student but through research and time spent on building devices. Valuable knowledge on work ethics has been acquired and most importantly time management. Working as a team from different engineering tracks plays a very important aspect of our ability to work with people from different disciplines in industry and other non-related fields. As a team, the ability to interpret ideas, offer suggestions to improve designs, and delegate work is important to working successfully in the real world. This way knowledge is exchanged and better interaction with people occurs to allow project to be successful.

Understanding the motivation of the design was an important learning experience since device is to serve mainly for research into breast cancer. As design engineers we are responsible for taking the ideas the client is trying to convey and developing a device that meets all of the required needs which is a valuable tool to be used in the future as engineers. Also as design engineers, the knowledge of keeping in touch with the client on regular basis has been improved. This way the team is in a better position, knowing that we are doing exactly what the client requests.

Throughout the process lots of research was done to understand the basics of near infrared imaging and available devices on the market, which helped the team get a better understanding of what was to be done. The major knowledge is gained through the research done on circuit components and how they are to be integrated for a successful project implementation. Building of the circuits for the different components of the device will enable team members acquire and improve skills on implementing theoretical knowledge to practice. Skills in software coding and creating an appealing user interface have also improved since the project required a more complex code compared to previous codes done in class sessions.

Writing skills have improved during the period of senior design as result of the engineering reports to be written. This prepares students to work in industry and engineering research settings as all changes and relevant information are documented to allow relay data for repeating or improving designs. Public speaking skills have also developed and improved from in-class presentations and weekly meetings with project advisors. This also enables professional

communication skills to be acquired and also to retain knowledge obtained from explaining to people.

7. Budget

Merchandise	Price (USD)
Laser Diodes	300
FL-500 current driver	60
Avalanche Photodiodes (x2)	200
Plastic Enclosure	40
Smaller Plastic Enclosure	30
Circuit Components	100
BNC wires	20
PCB Board	80
Shipping Costs	150
TOTAL	960

Figure 22. Budget

8. Conclusion

In conclusion the near-infrared imaging system exhibits the properties of spatial coding and target detection by using laser diodes in conjunction with a LabView® program. The benefits are that there is no training necessary to operate device. The design of the system proved to be cost effective and allowed for the final product cost to fall within the allotted budget. The NIR imaging system has great potential for industrial and medical use. The client, Qing Zhu, was very happy with the end result and is planning to incorporate the system in her labs for use by grad students and undergraduate student assistants.

9. References

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10. Acknowledgements

We would like to thank Dr. Qing Zhu for being a very supportive client, Dr. Enderle for all the help he has given us throughout the year, Marek and Emily for being great teaching assistants, and all of the staff in the School of Engineering Machine Shop.

11. Appendix

11.1. Specifications

<u>Material Specifications</u>

Software: LabView®

User Interfaces: LabView®

Hardware Interfaces: Monitor, 10 cm Laser Diode Probe

Communication Protocals: National Instruments DAQ

Communication Card: NI PXI-5114

Features: Graphical laser detection across a medium (Phantom)

<u>Hardware Specifications</u>

Maximum Input Voltage: 11 V

Minimum Input Voltage: 9 V

Input Current (System): 800 mA

Input Current (Laser): 75 mA

Laser 1 Power (Input 1): 30 mW

Laser 2 Power (Input 2): 5 mW

<u>Computer Requirements</u>

Operating System: Microsoft Windows 7

Processor: 1.5 Ghz Intel Dual-Core Processor

Memory: 4 GB DDR2-SDRAM