

# Diagnostic Data Acquisition for the Laser Beam at FNPL

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*Abstract-* The A $\phi$  department at the Fermi \*NICADD photoinjector laboratory (FNPL) is a research and development facility. The facility is open to research from individually proposed projects in the area of Accelerator Science [5]. Research done at this facility depends on the beam line produced at the A $\phi$  laser room. In order to guarantee that the beam that reaches the user experimental area carries with it stable properties, part of the beam is sent to a diagnostics table to be analyzed. Two instruments are set up to characterize the beam's pulse width and bandwidth in the time and frequency domain.

Previously, the beam had been analyzed using LabVIEW programs set up on Macintosh computers. The LabVIEW Visual Instrument Programs were connected directly to the instruments in order to analyze the laser beam signals and catalogue the information. As Fermilab no longer supported the Macintosh computers and switched its computer usage to PC's these programs needed to be transferred to the new PC's, upgraded, and a new one created to guarantee that the right kind of data was being obtained from the instruments. This paper explains how the laboratory continued its renovation phase by way of modifying, upgrading and creating new programs in order to acquire, store and analyze diagnostic data via remote control.

## I. INTRODUCTION

FNPL is a research and development facility, conducting studies in collaboration with other institutions in Accelerator Science. Accelerator science is composed of the study and understanding of accelerators, photoinjectors, the characterization of beam lines, and the interactions between these mechanisms. Previously, the A $\phi$  Photoinjector (A $\phi$ PI) of the FNPL had been built stemming from the collaboration it had with Germany's TeV Electron Super-conducting Linear Accelerator (TESLA) project. However, A $\phi$ PI's present and

future objectives have changed. Presently, A $\phi$ PI conducts Accelerator Science research in fields which include: plasma wake-field acceleration, channeling radiation, and beam physics. The Photoinjector's objective for the future, in the high energy physics community, is to become the prototype injector for an International Linear Collider (ILC). It is hoped that this future international particle collider will be a pathway for the further understanding of the most intriguing questions facing the physics community today—questions regarding; dark matter, dark energy, extra dimensions and the fundamental nature of matter, energy, space and time.

The accelerator uses short photon bunch pulses to shave electrons off of the photocathode by way of the photoelectric effect and send an electron beam down the beam line towards the experimental area and finally a dump. This source photon beam is created at the A $\phi$  laser room. In order to make sure that the beam that goes into the amplification phases in the laser room and later to the projects in the Accelerator phase with nondestructive properties that may damage the instruments in its path, it is diagnosed shortly after coming out of the seed laser. There are two instruments in the diagnostics table of the beam's path. These instruments are known as the Continuous-Wave Autocorrelator (CWAC) and the Optical Spectrum Analyzer (OSA).

In order to talk and retrieve data to and from these diagnostic instruments and, more precisely, specify the kind of data obtained from them, five years ago Jamie Santucci created Macintosh Visual Instruments programs with the use of LabVIEW. These programs were connected directly to the instruments and would acquire, characterize and diagnose the signals. As Fermilab no longer supported Macintosh computers and as the whole laser system was rebuilt, the programs that had been created to analyze signals from the laser laboratory's instruments had to be transferred into PC's.

As an intern I was assigned to the A $\phi$ PI Laboratory to modify, transfer, upgrade and create LabVIEW programs that would enable us to acquire, catalogue and analyze diagnostic data

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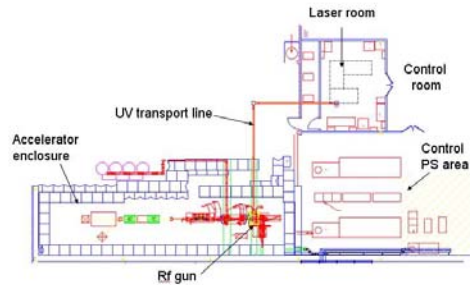
\*NICADD is an abbreviation for Northern Illinois Center for Accelerator and Detector Development

from the pulse beam in a more efficient and practical manner. Due to my unfamiliarity with LabVIEW programming, however, for the beginning of the summer much time was devoted to becoming proficient in the language and in learning how to apply it correctly to fit the researchers' needs.

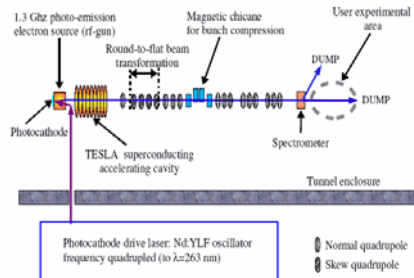
## II. BACKGROUND

### i. AØPI Laboratory

The AØPI Laboratory is composed of two sections: the laser room and the accelerator [See **Figure 1**]. The laser room produces an amplified, Ultra Violet, stable and uniform laser beam of photons which is delivered to the photocathode of an Electron Gun in the accelerator.



**Figure 1.** AutoCad drawing of the AØ Laser Room and Accelerator Enclosure composing the AØPI.

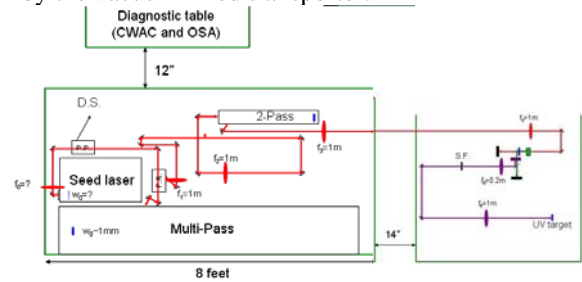


**Figure 2.** Diagram of the beam's pathway once in the accelerator.

The photons hitting the photocathode release the cathode's surface electrons, and thus a beam of photoelectrons (electrons) is produced. The Electrons Gun's RF cavity accelerates the electron beam up to 4MeV [See **Figure 2**]. The beam of electrons then passes through a superconducting nine-cell accelerating RF cavity which then adds 12MeV to the momentum of the electrons. The high-quality electron beam bunches come out of the nine-cell cavity with 16MeV. The laser travels enclosed in vacuum

through the UV transport line to the photocathode.

The seed laser oscillator is responsible for creating the stable infrared beam which generates a power 450mW/pulse and which eventually goes into the accelerator's RF gun to produce the electron beam [2]. After coming out of the seed machine the 1nJ seed laser then goes through a pulse picker which picks one pulse every second to continue the path set up in the laser room. The infrared beam passes through the faraday refractor which acts like a one way gate allowing it to pass in the direction to the Multi-Pass. The beam does six rounds in the Multi-Pass in order to be amplified 2000 times. The beam is sent back to the faraday refractor and then it is angled into the two pass to be further amplified twenty times to 1054 nm wavelength pulses. At the second phase of the beam's pathway, there are two doubling crystals which change the beam from info red light (1053nm) to green (532nm) to Ultraviolet light (266nm). The Ultraviolet then is protected from particles in the air by the vacuum filled transporter.



**Figure 3.** The AØ laser room.

One out of every 81.25 million laser pulses is chosen by the pulse picker to travel down the beam's pathway, the rest are dumped to Diagnostic Table to be analyzed [1]. This diagnostics section is essential because it is important to make sure that the beam coming out of the seed beam will not harm the instruments it will eventually pass through. The necessary parameters to measure are: the temperature of the laser room, the laser intensity, and the profile of the laser beam—consisting of time and space parameters. The laser beam's time and space parameters are monitored by data acquisition instruments such as the Continuous Wave Auto-Correlator (CWAC) and the Optical Spectrum Analyzer (OSA). These two machines are able to receive and analyze signals and measure these signals in the frequency and time domain.

### III. PROJECT DESCRIPTION

#### i. Previous Work

Problems arise when more specific type of data is needed to be obtained, as opposed to that which the instrument is programmed to give. In order to talk to these diagnostic instruments and specify the kind of data received, five years ago Jamie Santucci created Macintosh Visual Instruments with the use of LabVIEW. As Fermilab no longer supported Macintosh computers and as the whole laser system was rebuilt, the programs that had been created to analyze signals from the laser laboratory's instruments had to be transferred into PC's and were unavailable for some time during those five years. During this process some of the programs needed to be adjusted or, for example in order to get data from the Continuous Wave Auto-Correlator a new program had to be created.

#### ii. Motivation

Meanwhile, in order to catalogue information such as the FWHM, the amplitude, frequency and time of the laser pulses an impractical system of taking photos of the systems screens, hand writing data, and analyzing waveform print-outs of the oscilloscope signals' had to be resorted. It is important to note that these machines can be programmed to save their respective FWHM data onto floppy discs; however, the data which can be obtained is still restricted. These temporary methods of acquiring data limited the researcher's control over the precision of the data, and the methods were sometimes impractical and unprofessional [See Figure 4 & 5.]

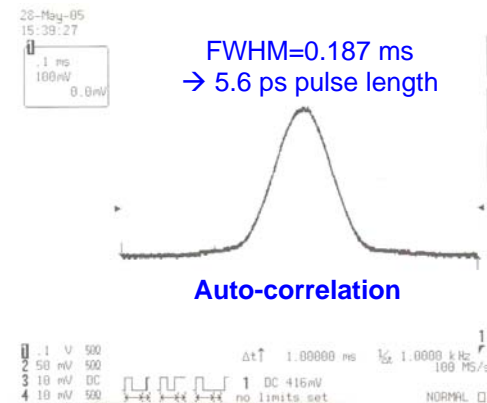


Figure 4. Print-out obtained from the CWAC.

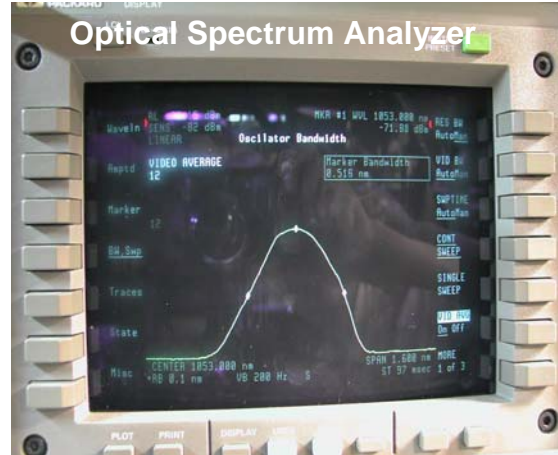


Figure 5. Photographed waveform from OSA

The CWAC print-out is an example of the kind of information that used to be obtained and catalogued. This print-out allows us to get an FWHM reading, but it makes cataloguing this information difficult—as it can not be immediately available by a click of a mouse. Also, from the photographed waveform of the OSA's screen, it is obvious that this kind of data is just as difficult to analyze and catalogue. Again, some of the problems faced are that there exists great inaccuracy in the measurements that can be done by hand on these pictures and the inconvenience that there is due to not being able to obtain data by remote control. Digitizing these waveforms and programming a computer to analyze the data for the researcher appeared a more practical and advantageous method of data logging.

### IV. INSTRUMENTS

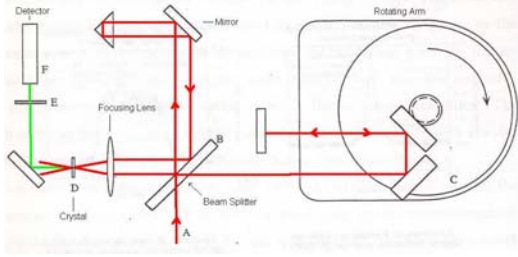
#### i. Continuous Wave Auto-Correlator

The Continuous Wave Auto-Correlator measures the pulse width of the beam in the time domain. It is important to measure these pulse durations, because their consistency over time tells us about laser stability and power efficiency. If the pulse length is too long, for example, then in the process of converting the light from infrared to green, to ultraviolet there could be less and less energy efficiency.

#### ii. Beam's pathway inside the CWAC

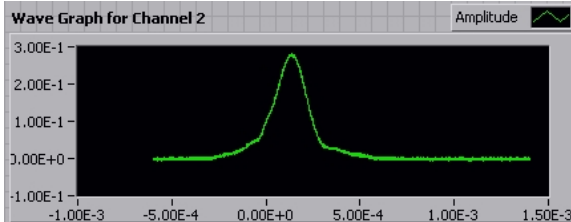
The beam that goes into the CWAC goes through its beam splitter [See Figure 7]. The

beam splitter allows 50% of the light to pass through and the other 50% is deviated on a 90 degree angle in the direction of the CWAC's rotating arm. The portion of the beam which



**Figure 6.** The Continuous Wave Auto-correlator measures the pulse length in the time domain.

goes directly through hits a mirror followed by a prism which acts like a mirror; this device makes sure that the beam goes back towards the beam splitter. Then, this part of the beam is focused by the lens onto the doubling crystal. The crystal doubles the frequency of the infrared beam to a green beam. The other beam which comes back from the rotating arm is focused on the crystal too. The product or correlation of these two beams results in a green light. This use of a rotating arm and a fixed arm are so that there is a changing delay between the two infrared beams. This changing delay is what results in our Gaussian-shaped waveform [See Figure 7].



**Figure 7.** LabVIEW remotely obtained graph of the CWAC

In sum, the beam which passes through the fixed arm is basically constant in time whereas the one which goes through the rotating arm has pulses separated by a longer amount of time. This ratio of successive peak separation to full width at half-maximum (FWHM), called the finesse, is smaller for the rotating arm than for the fixed arm [7]. The rotation of the arm delays the time between the pulses—making them increasingly longer and then increasingly shorter until the amplitude and time signal obtains Gaussian shape.

It is important to analyze standard data points of the waveform of the green signal

detected by the CWAC such as the FWHM. Since the FWHM obtained from the green signal can be correlated to the FWHM of the infrared beam, from the data of the green signal we can, by some calculation, obtain the corresponding information of the original infrared beam. In Figure 7 we have graphed the resulting green's light waveform. The x-axis is the pulse length and the y-axis is the amplitude. The spacing between pulses is around 12.8nm and the length of the actual pulses is in the order of picoseconds [4].

### iii. Mathematical Understanding of Continuous-Wave Autocorrelator

Since the output of the CWAC correlator is data specific to the green beam, and what we are concerned with is to find the FWHM information of the infrared's beam, hence, we now proceed with a more mathematical understanding of the CWAC. The physical cross-correlation of the two infrared beams onto the crystal is responsible for this machine's name—a correlation. If these two beams each represent a function such as  $f(x)$  and  $g(x)$ , respectively, then their cross correlation can be mathematically described as

$$F(x) = f(x) \otimes g(x) \\ = \int_{-\infty}^{\infty} f(t) \cdot g(x-t) dt$$

Knowing that the two colliding infrared beams are the same frequency, or  $f(x) \equiv g(x)$ , the

resulting green beam,  $F(x)$ , is given by

$$F(x) = g(x) \otimes g(x) \\ = \int_{-\infty}^{\infty} g(t)g(x-t)dt$$

This means that the function represents the convolution of beams with similar properties. This process is known as the autocorrelation of the two beams.

Also, previously we explained that the waveform achieved by the CW AC could be fitted with a Gaussian waveform. This means

that the resulting  $F(x)$  equation looks like

$$F(x) = e^{-\left(\frac{x}{w}\right)^2} \quad \text{meaning that we may therefore}$$

assume  $F(x) = \int_{-\infty}^{\infty} e^{-\left(\frac{t}{w}\right)^2} \cdot e^{-\left(\frac{x-t}{w}\right)^2} dt$  and, hence, also assume that the two original infrared beams are also Gaussian-like in form.

In conclusion we may say that  $F(I_{Green}) = F(I_{IR_1}) \cdot F(I_{IR_2})$  where  $F(I)$  represents the Fourier transform of the beam. Hence

$$I_{Green}(t) = I_{IR_1} \otimes I_{IR_2}$$

$$= \int_{-\infty}^{\infty} e^{-\left(\frac{t}{w}\right)^2} \cdot e^{-\left(\frac{x-t}{w}\right)^2} dt = e^{-\left(\frac{x}{W_G}\right)^2}$$

And in order to obtain the pulse duration's FWHM if we make function equal to .5, then  $X$  represents the Full Width at Half Maximum. Given the previous statement then we know everything except the  $W_G$ , but Assuming the Gaussian relationship holds then we may say that

between the  $FWHM_{CWAC} = FWHM_{IR} \times \sqrt{2}$  and so  $W_g = \sqrt{2} \cdot W$ , where  $W_g$  represents the illuminated width in the detector [7].

### C. Optical Spectrum Analyzer

The Optical Spectrum Analyzer (OSA) [See Figure 8] monitors the spectrum of the oscillator in terms of resolution, or more precisely, the bandwidth in the frequency domain. After light comes out of the seed laser beam and gets directed into this diagnostic instrument, it is collimated by an optical element. A plane grating is responsible for diffracting the collimated light. The wavelengths are then angularly separated—this separation is given in radians as:

$$\frac{d\beta}{d\lambda} = \frac{kn}{\cos \beta} \cdot 10^{-6}$$

Where  $\lambda$  is the wavelength of the light in nm,  $\beta$  is the angle of diffraction in degrees,  $k$  is the diffraction order (an integer), and  $n$  is the grating density in lines/mm [6]. Due to the position of

the diffraction grating the desired center wavelength passes through the aperture. The aperture allows only a small range of wavelength region to be scanned.

The better resolution the spectrometer has, the better it can differentiate between wavelengths and due to the OSA's four course pathway [See Figure 8]—this analyzer obtains very high resolution with a low range of spectral coverage. The ability of an instrument to separate adjacent spectral lines, or its resolving

power is given by  $R = \frac{\lambda}{d\lambda}$  where  $d\lambda$  is the

wavelength difference between two spectral lines having the same intensity. The resolution for our spectrometer is 1250nm to 1600nm. And the resolution selections {FWHM} are .08nm and .1nm-10nm in a 1,2,5 sequence [5].

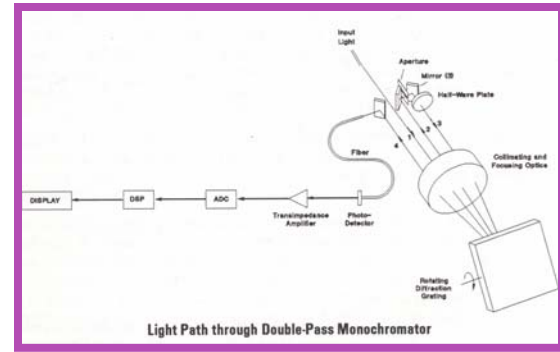


Figure 8. The Optical Spectrum Analyzer

The width of the aperture determines the bandwidth of waves allowed to pass to the OSA's detector. The photo-detector converts the optical power to an electrical current. This electrical current is then converted into a data signal which is what is seen in the Virtual Instrument graph measuring the bandwidth in the wavelength domain.

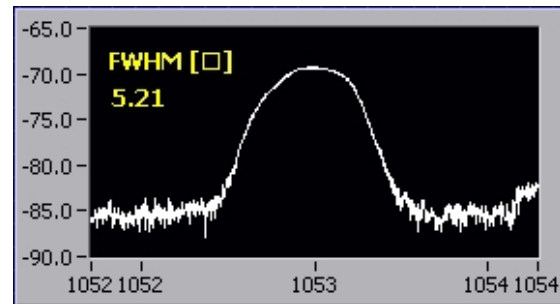


Figure 9. LabView obtained graph for the OSA.

The FWHM of the wavelength bandwidth helps us to monitor the stability of the seed laser. In the above graph we have managed to obtain the waveform and have graphed the x – axis as the wavelength, and the y-axis as the amplitude. The actual OSA is able to print out the OSA’s calculated FWHM, further work in this project may involve comparing the LabVIEW’s calculated FWHM to the OSA generated FWHM.

## V. REMOTE CONTROLLED DATA ACQUISITION

### i. *Communication Set-up*

As an intern, having no previous experience with LabVIEW programming, I was first set up to communicate, through GPIB connection, with an oscilloscope placed in my office. Upon becoming proficient with the language, I obtained data from this instrument. The oscilloscope was then moved into the laser room where it was connected to a National Instrument ENET/100 box. This box was then connected to the internet. Communication via internet from the laser room to my office took some time due to some problems. After many phone calls and help from my supervisor, I was able to obtain data from the CWAC and analyze it. The OSA was immediately connected to the ENET/100 box and with the use of the modified and upgraded LabVIEW program, I was able to obtain and analyze data from the OSA as well.

The created and modified CWAC and the OSA programs are each shown in the Appendix. They both consist of Front Panels and Block Diagrams. The Front Panels act as a user interface by allowing the controller to specify parameters such as the Time/Div, the Trigger Mode or the Time/Div—screen parameters. The Block Diagrams contain subVI’s—smaller and more elementary programs important for the program’s function. A brief description of the programs’ functions follow.

### ii. *Continuous Waveform Autocorrelator Program*

The program was created by going to the National Instruments website and obtaining drivers for the oscilloscope which was connected to the CWAC. These drivers contained an example program which would display the waveform. This program was extensively modified to obtain the data researchers wanted.

Figures 10 through 14 contain the main LabVIEW parts making up the program which talked to oscilloscope.

Figure 10 contains the Front Panel on which the user can control the GPIB address specific to the oscilloscope. Among other things, the front panel is where the screens parameters are specified, and a button that allows us to choose whether we want to save data of the waveform or simply view it is available. Figure 11 shows the first sequence structure which initializes the program. Figure 12 shows the language which sets up the oscilloscope’s parameters for the next structure. Figure 13 contains a the parts of the program responsible to data taking and a small program which helps output a time domain column next to our amplitude array on a spreadsheet. Figure 14 contains the section which releases the remote control usage and takes it back to local.

### iii. *Optical Spectrum Analyzer*

Figure 15 displays the Front Panel of the modified OSA program. In this interface, the user is able to choose the number of the GPIB address the instrument is utilizing. In this case our OSA machine was connected to GPIB address number 12. In order to make this program work an ENET/100 system needed to be connected in the laser room. This instrument allowed the OSA as well as the CWAC to be connected to the internet and as a result of this connection the LabVIEW programs were able to interact with these instruments by seeing their online connections on the NI 488.2 interface.

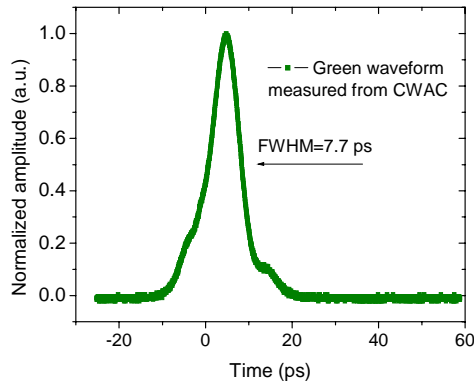
Figure 16 initializes the OSA program. Figure 17 shows the part of the program which converts the amplitude given in dBm to mW. Figure 18 shows the section of the program which was most modified. Basically the data saving technique used for the CWAC was implemented for the OSA. An attempt was made to release the Remote Controlled setting for this program just as in the CWAC program, however, the different programming style may not support this feature.

## VI. RESULTS & DISCUSSION

### i. *Continuous-Wave Autocorrelator*

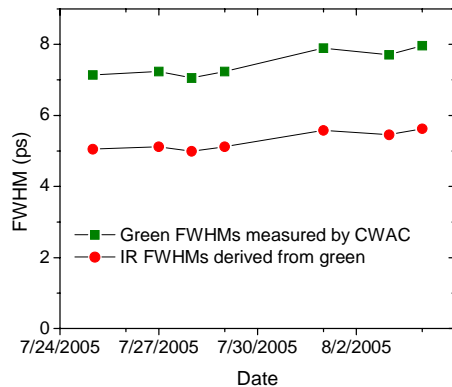
We were able to calculate the bandwidth of the infrared wave by knowing bandwidth of the green’s wave.





**Figure 19.** Waveform of CWAC

It is evident from this graph that the waveform's shape is not a perfect representation of a Gaussian waveform. The inconsistencies are due to the fact that the assumptions are based on mathematical ideologies. It was assumed that the infrared beam coming into the autocorrelator is Gaussian in shape and that the resulting waveforms will also be Gaussian in shape. However, the Mathematics used to estimate this waveform does not follow reality strictly because in actual physical environment we need to consider interferences such as background noise.

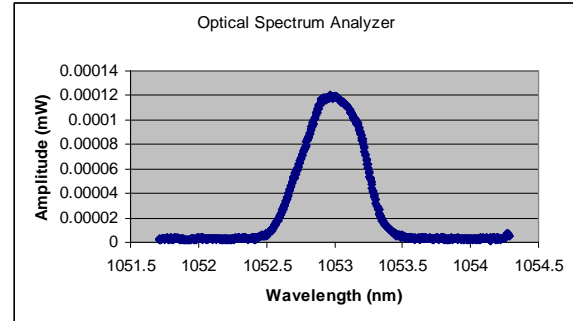


**Figure 20.** Laser beam's stability over a week's period.

Above, the infrared FWHM data for the green and the derived data for the infrared beam over the course of one week is graphed. The results we obtained are strictly dependent of Gaussian assumptions. We were able to tell that our beam was healthy in the time domain because the standard deviation of our points were within the allowed range of inconsistency.

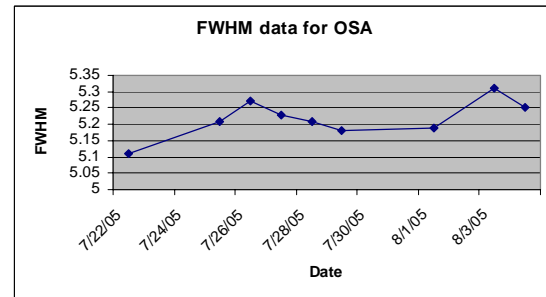
## ii. Optical Spectrum Analyzer

We obtained the waveform of the OSA. This is a standard point of measurement because when plotted over days it tells the researcher about the stability of the laser beam in the frequency (or wavelength) domain.



**Figure 21.** Excel obtained graph for the OSA's FWHM.

The following FWHM graph of data taken over several days was analyzed to make sure there was consistency. The consistency was measured by calculating the standard deviation divided by the mean value. If this error value is more than



**Figure 22.** Excel obtained FWHM data for the OSA.

10% then the analysis could tell us that our beam may have problems. However, for this data our percentage error came out to be 0.9486% which allows us to infer that the beam is highly resourceful and stable.

## VII. CONCLUSION

LabView's capabilities allow us to get precise measurements and control the type and kind of data acquired. My project involved setting up the computer to talk to instruments inside the laser room via remote control, and acquiring, cataloguing and analyzing these data. In order to obtain data from the CWAC a program was created by finding online the drivers of the machine and modifying these

according to the researcher's specifications. The program previously written for the OSA was modified.

#### VIII. ACKNOWLEDGEMENTS

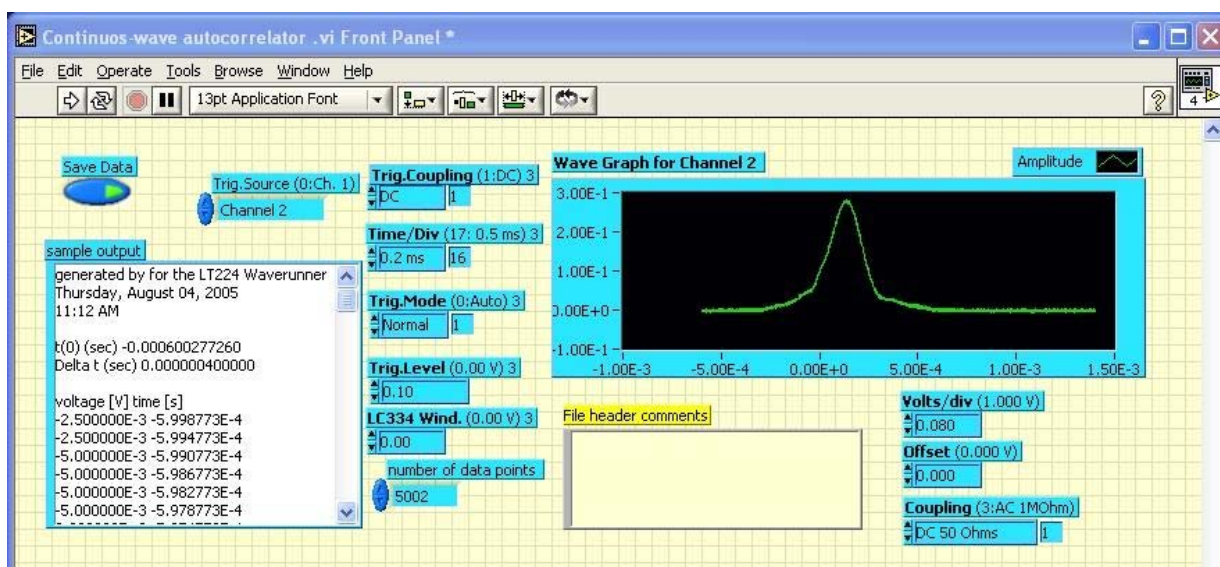
I would like to thank my supervisor Jamie Santucci for answering my ever reoccurring questions. Great gratitude goes to Jianliang Li for his support and patience. My deep gratitude goes to Elliott McCrory, Dianne Engram, Dr. Davenport and the SIST committee members for the opportunity to learn and work at this great laboratory. My sincere thanks go to Eugene Lorman and Bob Flora for their technical support and guidance. And special thanks go out to everyone at AØ Laboratory for their kindness and welcoming.

#### IX. REFERENCES

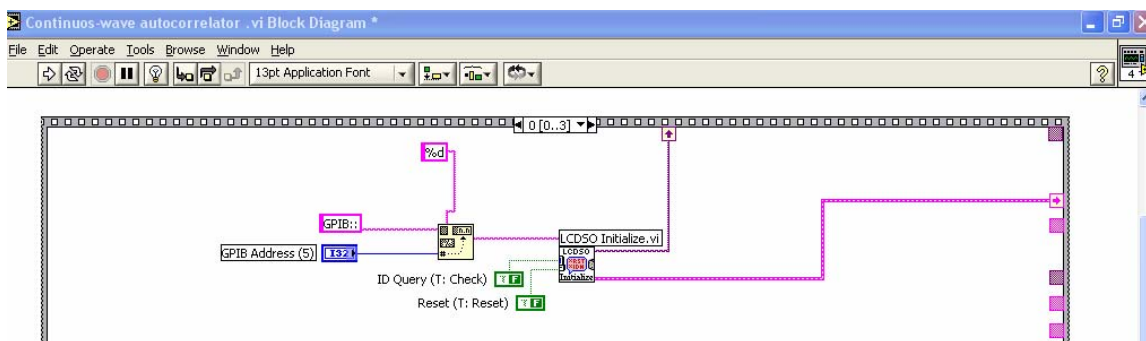
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Edition, Prentice Hall, 2002
- [6] <http://nicadd.niu.edu/fnpl/>
- [7] <http://www.mellesgriot.com>



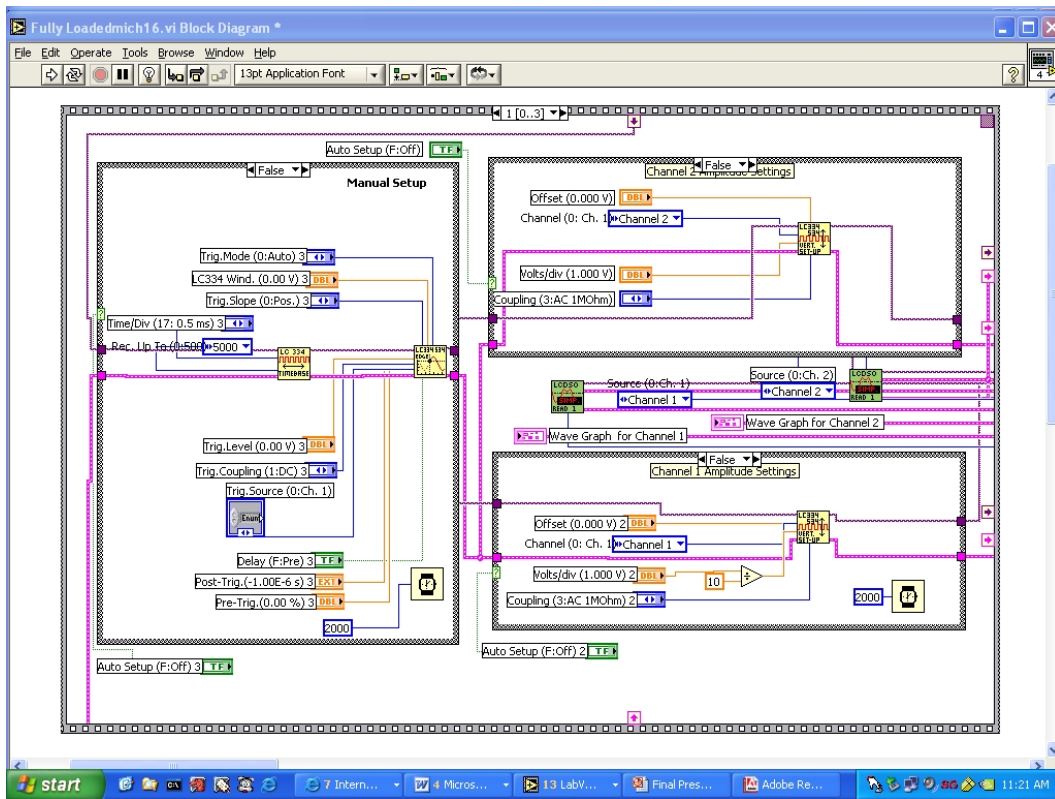
## X. APPENDIX



**Figure 10.** This is the Front Panel to the CWAC program.



**Figure 11.** This is the first Sequence Structure which initializes the Program.



**Figure 12.** This second Structure sets up the oscilloscope parameters.

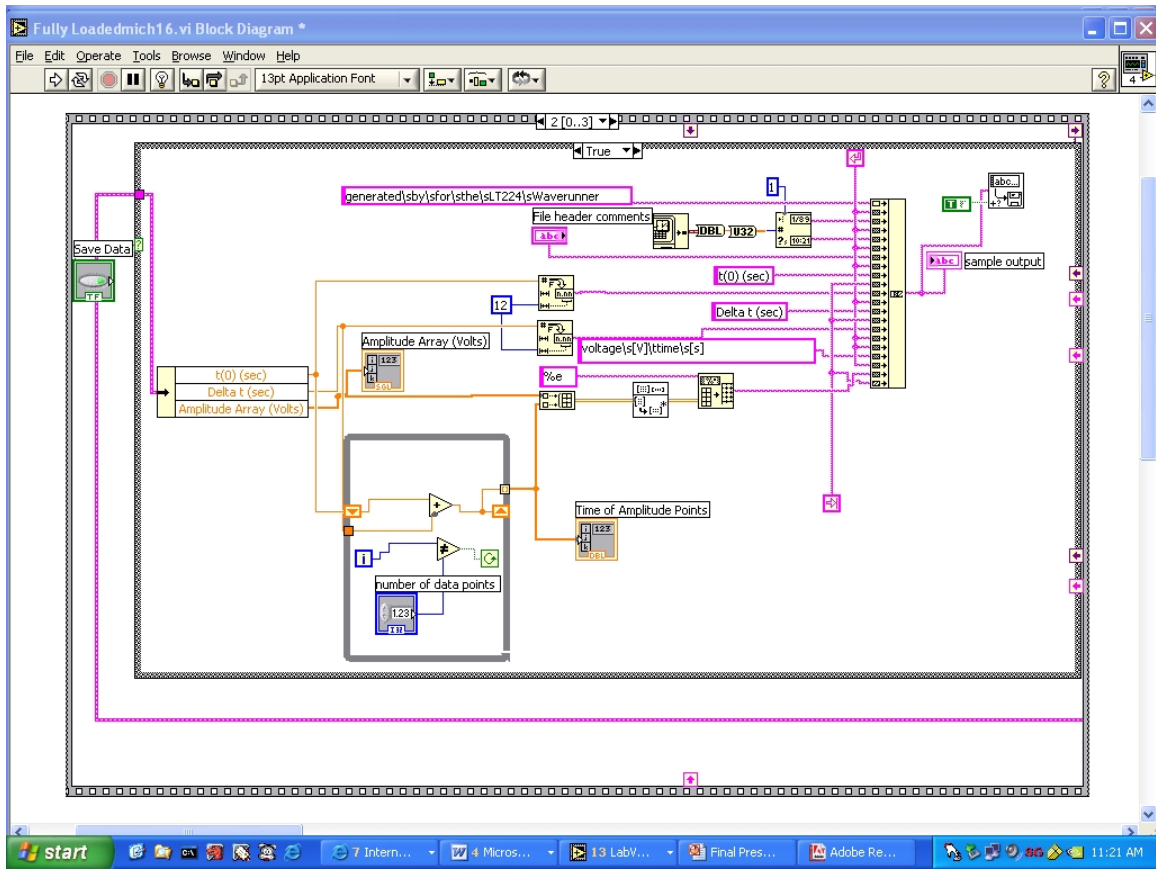


Figure 13. This third Structure calculates a second column and saves data.

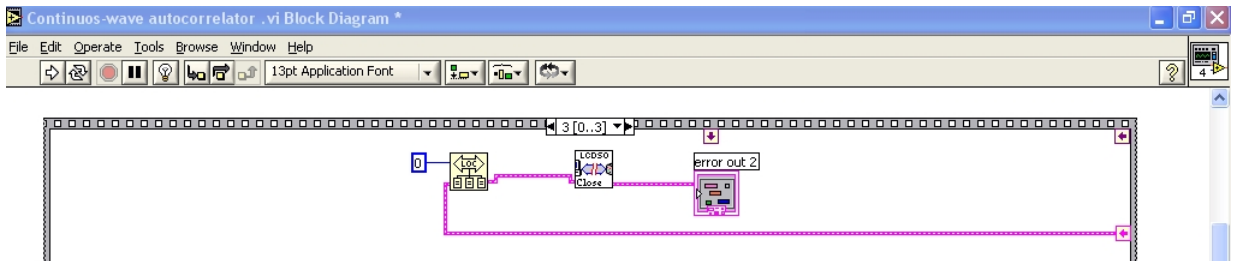
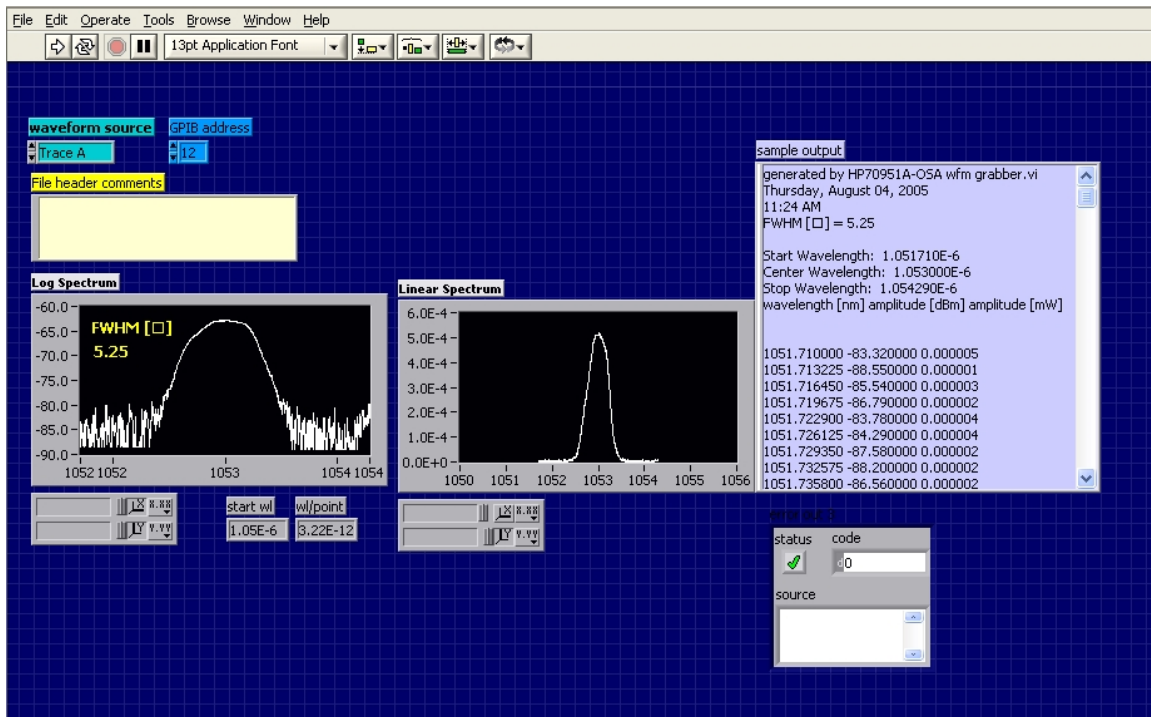
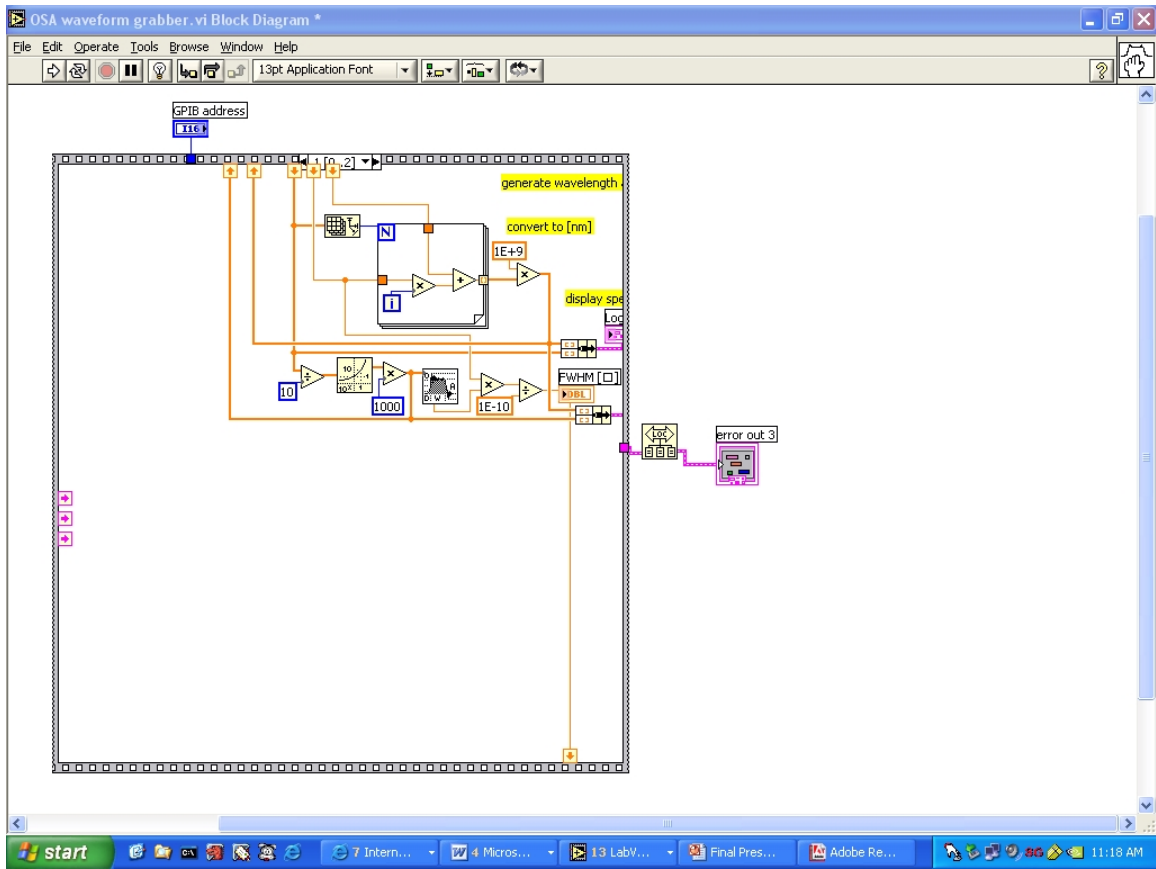


Figure 14. This last Sequence Structure to the program changes the physical control setting to local and closes the program.



**Figure 15.** This is the Front Panel to the program controlling the OSA.





**Figure 17.** This is the second Structures; it converts power information from dBm's to mW's.



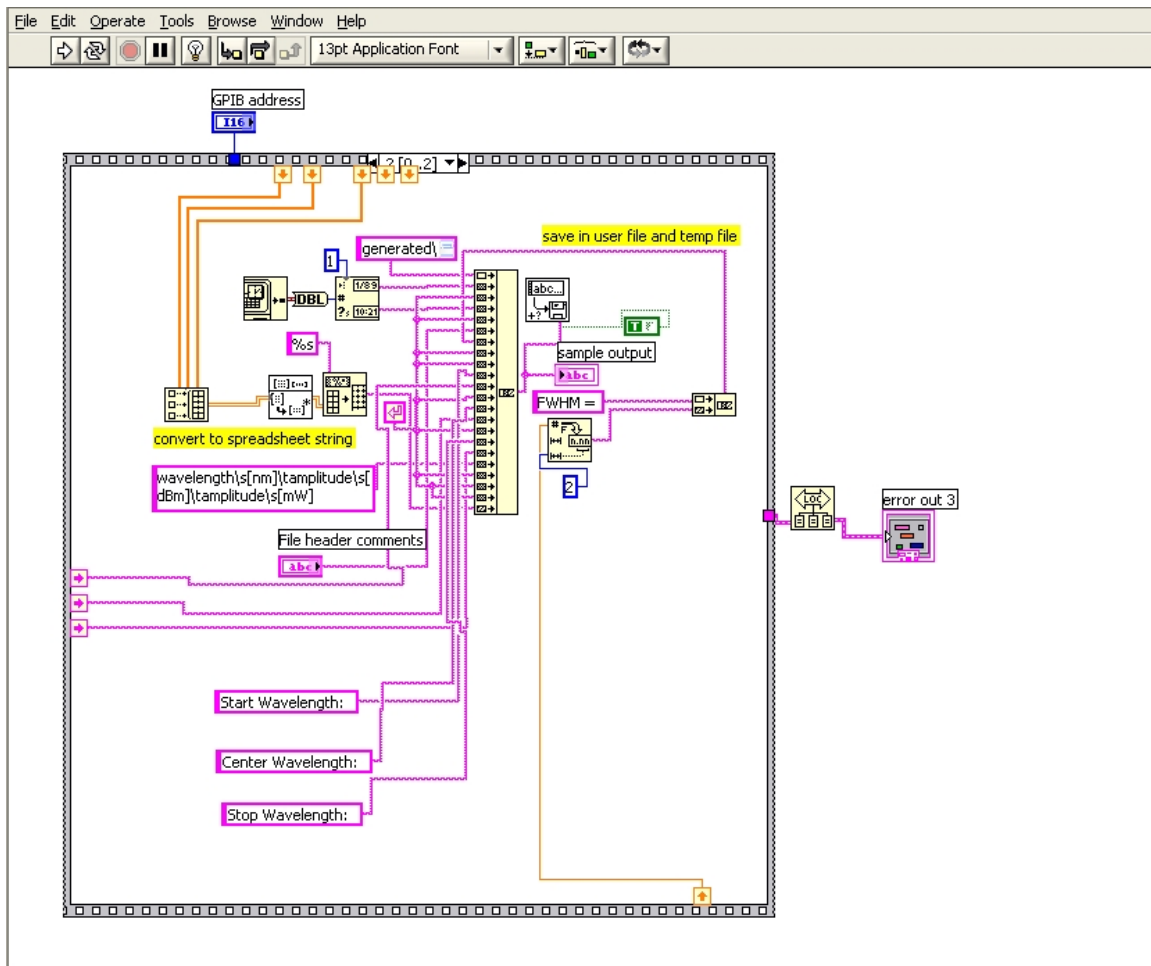


Figure 18. This last Sequence Structure saves data.