BOTDA system's user manual

by

Murad Mohammad

THE UNIVERSITY OF NEW BRUNSWICK

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ABSTRACT

This Manual discusses the hardware design, the control software and the user instructions of the Brillouin Optical Time-Domain Analysis sensing system built at UNB. Chapter one provides an introduction to the BOTDA system, chapter two discusses the hardware design of the system, chapter three discusses the BOTDA control software and chapter four provides instructions for connecting the system, performing a measurement and debugging any possible errors in the system. The data sheets for the used hardware components are included in appendix A.

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Chapter 1

Introduction

This chapter provides brief information about the operation principle of the BOTDA system [1]. Figure 1.1 shows the basic design for a BOTDA sensor.

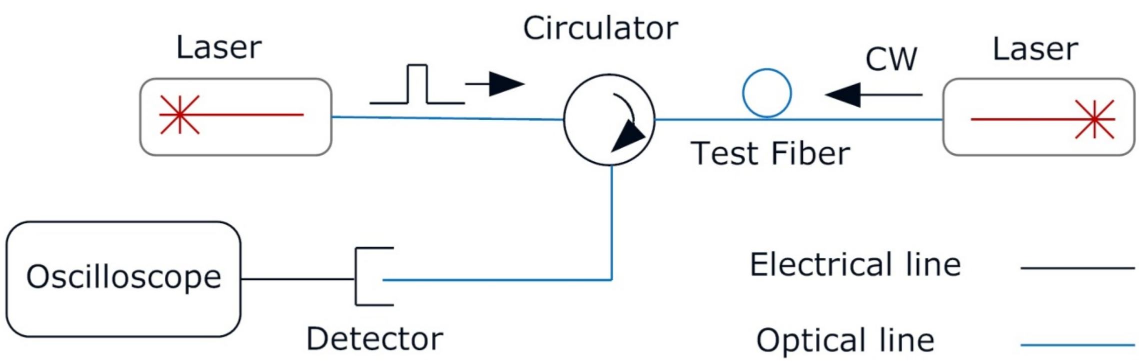

Figure 1.1: Basic block diagram for the BOTDA system.

The BOTDA system takes advantage of the strain and temperature dependency of the Brillouin frequency shift to find the distributed strain and temperature applied to the fiber. The system uses the pump and probe methods, where two lasers, that are separated in frequency by (ν_s) are counter propagating in a sensing fiber. One of the lasers is intensity modulated to form a pulse beam. The frequency separation between the lasers (ν_s) is approximately 11 GHz, which is close to the frequency of the acoustic wave in the fiber (ν_a).

Having this frequency separation between the counter propagating lasers results in Brillouin amplification, in which some energy is transferred from the higher frequency laser (pump) to the lower frequency laser (probe). The maximum energy will be transferred when the frequency separation between the lasers (ν_s) is equal to the Brillouin frequency shift ν_B.

In the BOTDA system, ν_B is found by monitoring the gain or the loss in the energy of the continuous laser beam while sweeping the frequency difference between the lasers over a specific range. This results in a Brillouin gain or loss spectrum for the entire fiber in the frequency-domain.

Furthermore, the BOTDA system records the time of flight of the optical pulses lunched into the sensing fiber to locate the Brillouing frequency shift values $\nu_B(z)$ along the fiber. This results in a three dimensional dataset as Figure 1.2 shows.

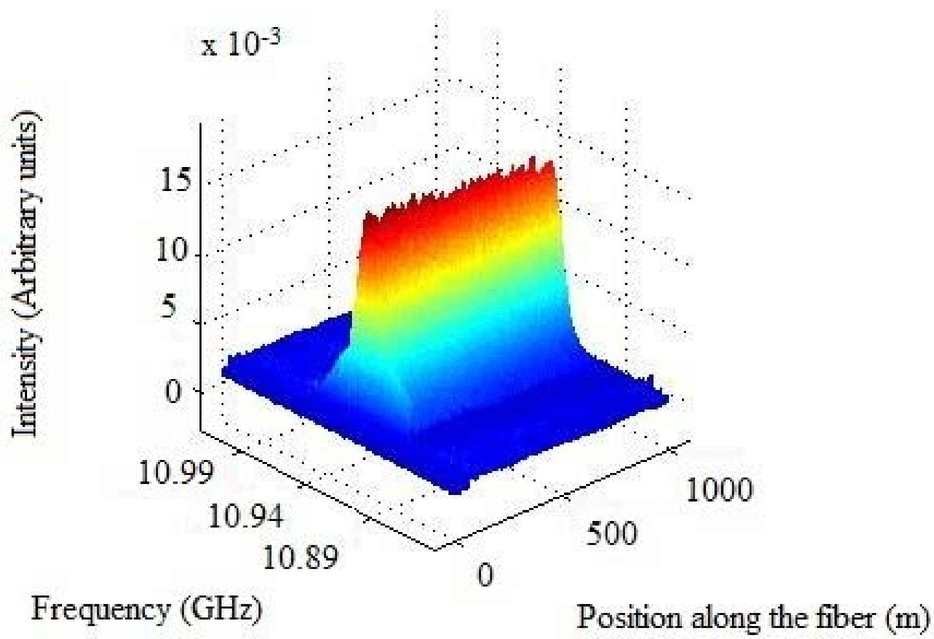

Figure 1.2: Three dimensional plot of Brillouin interaction for 1km fiber.

For each point on the fiber within a specific spatial resolution, a Brillouin gain or loss spectrum can be built using the Brillouin interaction values with respect to the frequency separation between the lasers. The Brillouin interaction values are Lorentzian in shape, where the peak of the curve represents the Brillouin frequency shift. This peak indicates the strain and the temperature applied to the fiber.

Chapter 2

BOTDA system's hardware design

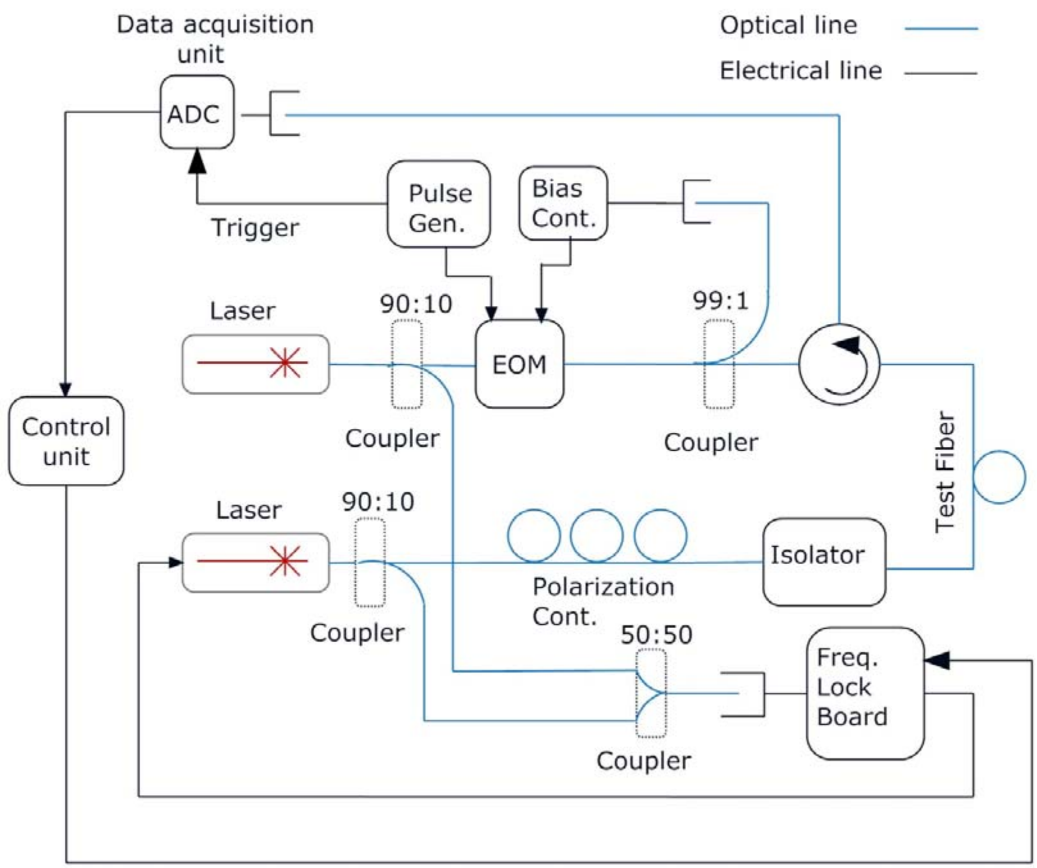

Figure 2.1: Detailed block diagram of the upgraded BOTDA system.

Figure 2.1 shows a detailed block diagram of the hardware design of UNB's BOTDA system. The system uses a two fiber lasers operating in the 1550 nm window as a pump and probe. The frequency difference between the two lasers is controlled using a feedback loop where the monitor output of the lasers (10% of the output power) are fed into a feedback loop, the frequency difference between the two lasers is divided and fed into a Phase Locked Loop along with a signal generated by a frequency synthesizer representing the desired frequency. The error signal is inputted into a high voltage amplifier and fed back to one of the lasers using the Pizo-Electeric port.

The output of one of the lasers is amplitude modulated using an MZ-EOM to create either dark or bright pulses, the bias of the EOM is controlled using a BIAS controller and the user of the system has the option of setting the bias to dark or bright pulses. An RF pulse is inputted to the EOM using an RF pulse generator, where the user adjusts the RF pulse width and amplitude to control the spatial resolution of the measurement.

The laser pulse is inputted in a circulator then into the test fiber, where the test fiber end connected to the pulse laser is considered as the beginning of the fiber.

The second laser is connected to an isolator to protect the laser from the optical pulses inputted from the other end of the fiber. The polarization of the continuous laser is controlled using a polarization switch to provide two perpendicular polarization states. The output of the polarization controller is connected to the end of the test fiber.

The Brillouin signal is detected using a photo-detector connected to the circulator (figure 2.1) in such a way to detect the Brillouin interaction between the pump and probe. The output voltage of the detector is amplified and then connected to an ADC. The ADC is triggered using the trigger output of the pulser; in order to synchronize the data acquisition with the optical pulses lunched into the test fiber.

Chapter 3

BOTDA Control Software

The BOTDA control software is responsible for hardware control, data acquisition, data processing and user interface. BOTDA control contains a user interface to communicate with the user of the system. The following sections explains the main windows of the BOTDA Control [1]:

1. Main window:

The main window enables the user to choose between the main functionalities of the system.

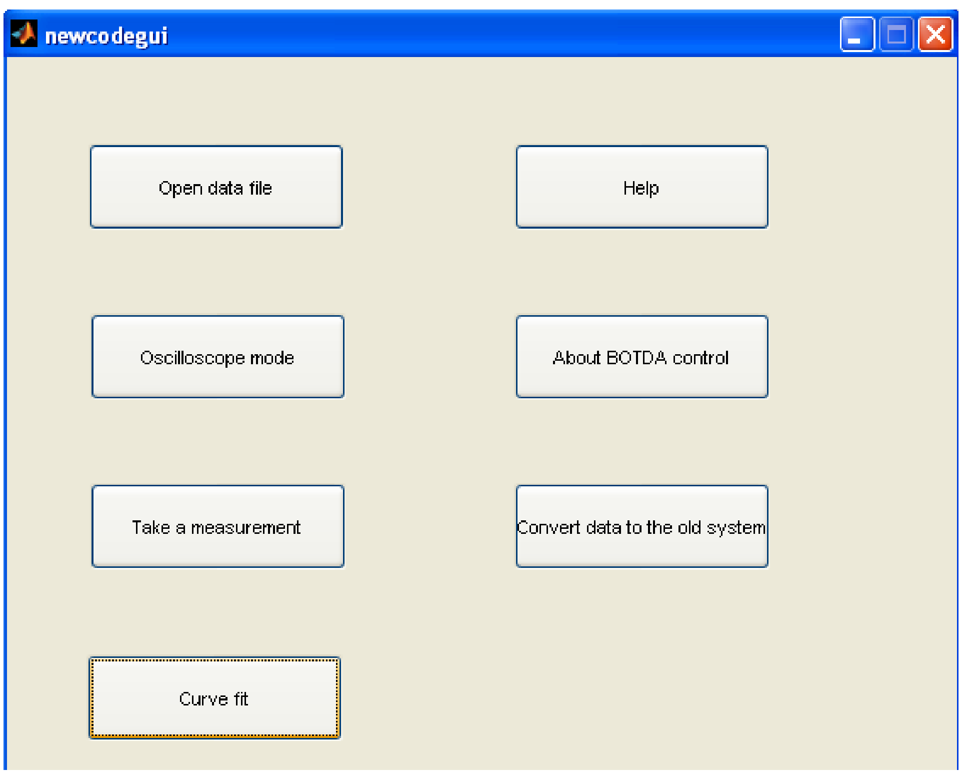

Figure 3.1: BOTDA control software main window

2. Measurement window:

The measurement window allows the user to pass the required parameters to perform a measurement and denoise the results. After the measurement is done, the user is invoked with a message to specify the path to the stored measurement results on hard drive.

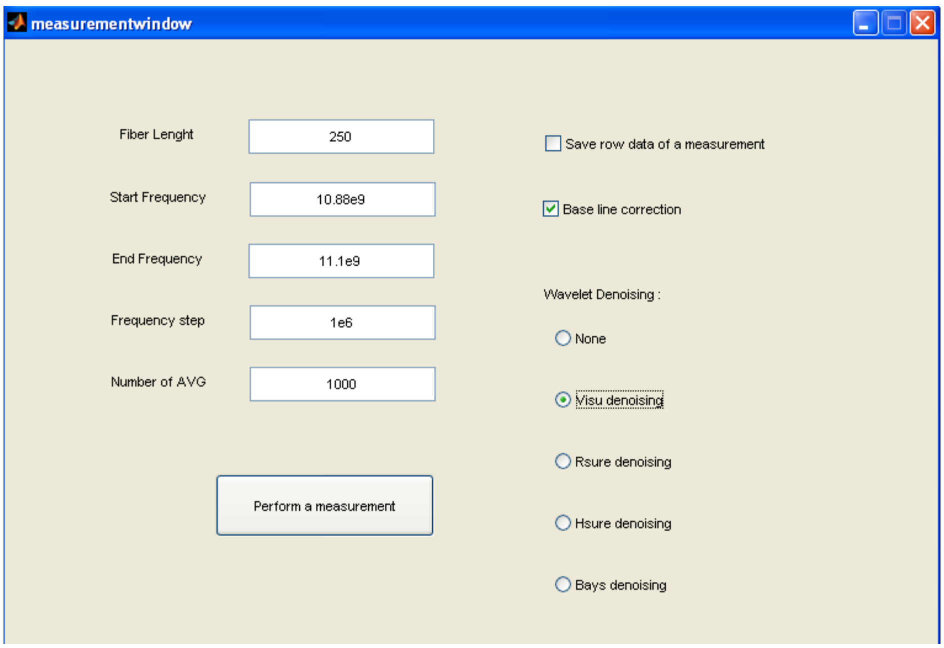

Figure 3.2: Measurement window

3. Real-time window:

The real-time window allows the user to run the system to perform a fast measurement for a single frequency that the user specifies. The window automatically plots the time-domain trace of the Brillouin interaction acquired from the measurement.

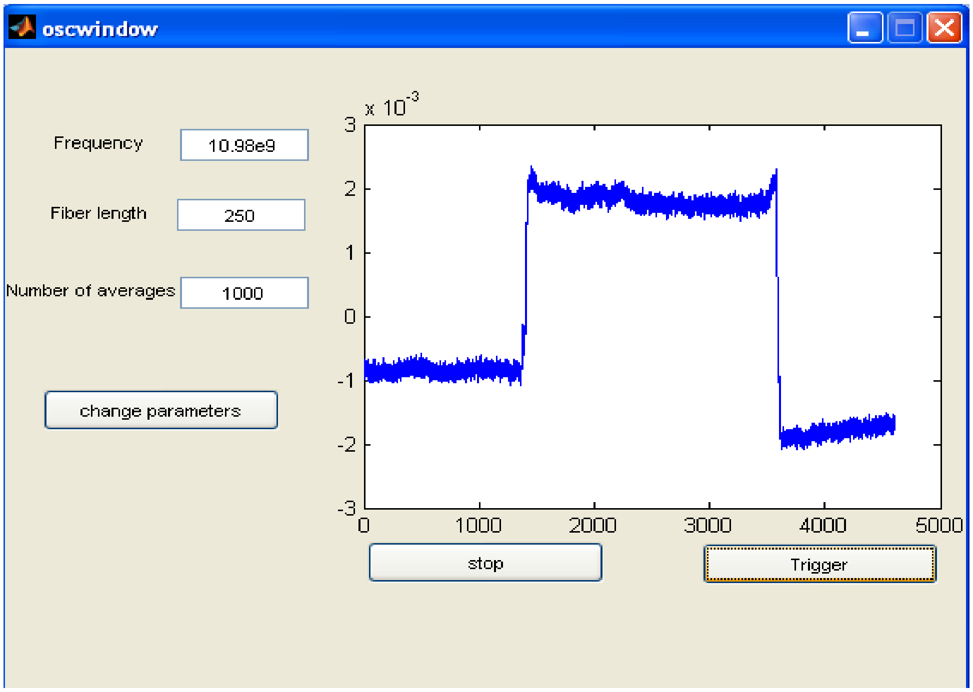

Figure 3.3: Real time measurement window

4. Plot window:

The plot window enables the user to browse and load previously saved measurement results, and then plots the results in three different plots. The first plot is the time-domain trace for a frequency that the user chooses from the same window. The second plot is a frequency-domain plot for a single position along the fiber. The third plot is a three dimensional surface plot for the Brillouin interaction along the fiber for all the frequencies in the scanned range.

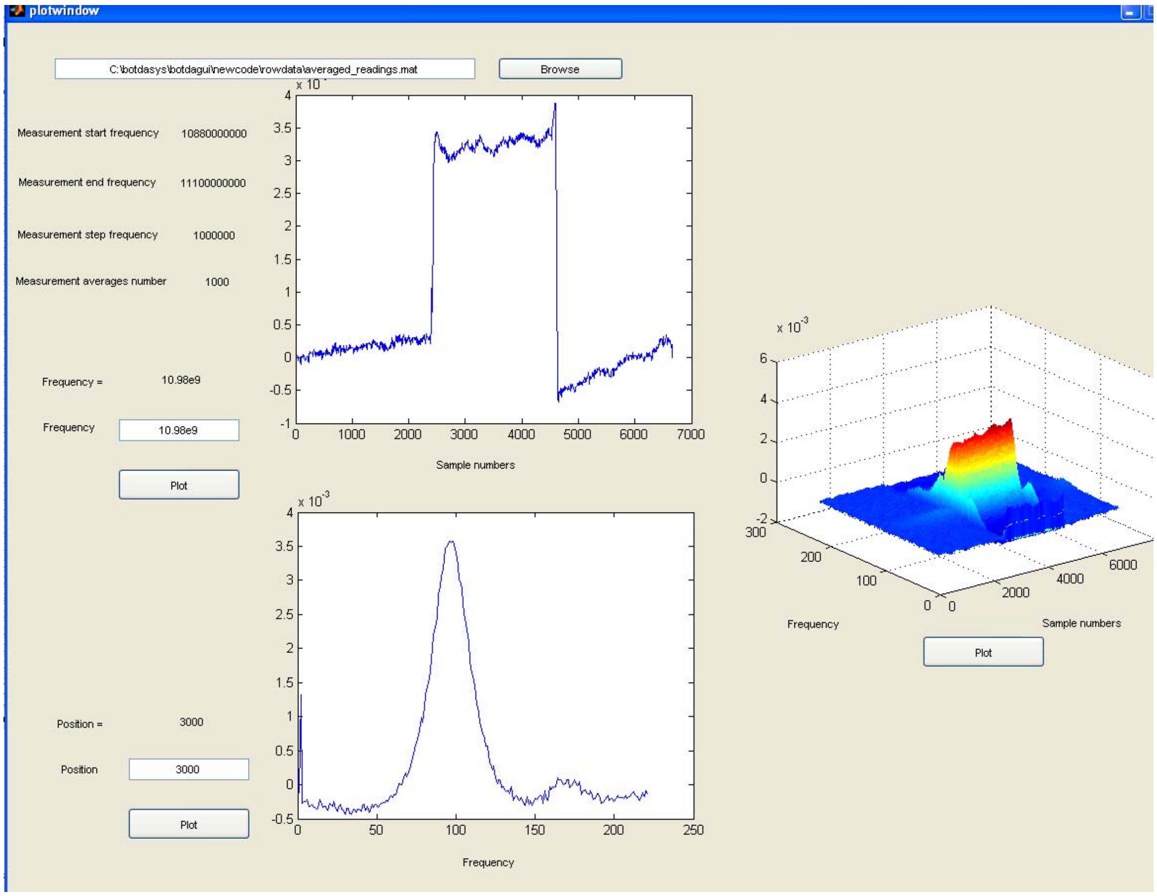

Figure 3.4: BOTDA control system’s plot window

Chapter 4

Using the BOTDA Control system

This chapter provides a step by step guide into connecting the system and performing a measurement. The different operation modes of the system and the post measurement data processing are explained in details in this chapter.

4.1 Hardware units

The BOTDA system consists of the following hardware units:

1. BOTDA system case: the BOTDA system case contains the main optical and electrical components of the system such as the frequency control loop, the bias control loop, polarization control, optical couplers, amplifiers and circulators. The BOTDA system case is provided with different input and output ports such as SMA, Parallel port, angled optical input ports, three wire circular port, and 50 pin ribbon cable connector.
2. Fiber lasers: two fiber laser are used as a pump and probe sources, the lasers are connected to the BOTDA system case using polarization maintaining optical cables. A feedback is connected to the pizo-electric input of the pulse laser from the BOTDA system case.
3. Pulser: the pulse output of the pulse generator is connected to the BOTDA system case using an SMA connector. The trigger output of the pulser is connected to the ADC (GAGE card) to trigger the ADC.

4. Frequency counter: the frequency counter is used to monitor and frequency shifts of the lasers caused by changes in their temperature. Monitoring the frequency counter and adjusting the laser temperature is critical when the system starts for the first time and after each measurement.

5. BOTDA PC: the BOTDA PC contains the ADC responsible for data acquisition. And contains multiple connection ports to be connected to the BOTDA system case as will be shown in detail in the next section.

4.2 Connecting the system

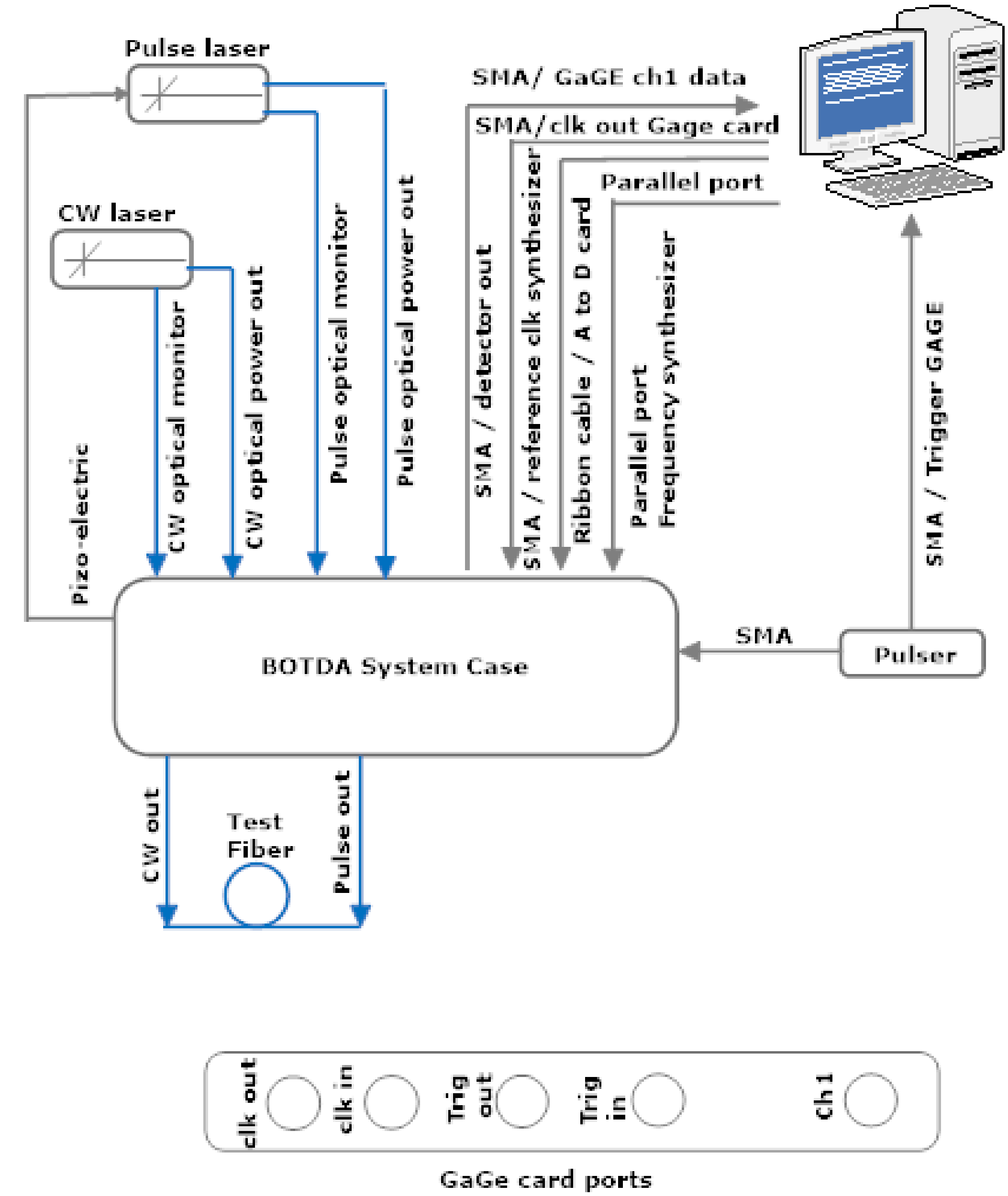

Figure 4.1: BOTDA system's Connections.

In order to enable the BOTDA system to perform correctly the following connections are needed between the hardware units of the system:

1. Connect the Pulse laser's power output to the BOTDA system case's Pulse input port using an angled PM optical cable.

2. Connect the Pulse laser's monitor output to the BOTDA system case's Pulse monitor port using an angled PM optical cable.
3. Connect the CW laser's power output to the BOTDA system case's CW in port using a flat PM optical cable.
4. Connect the CW laser's monitor output to the BOTDA system case's CW monitor port using an angled PM optical cable.
5. Connect the CW out port of the BOTDA system case to the end of the test fiber using an angled optical cable.
6. Connect the pulse out port of the BOTDA system case to the start of the test fiber using an angled optical cable.
7. Connect the monitor port of the BOTDA system case to an optical spectrum analyzer using an angled optical cable (Optional).
8. Connect the Lock port of the BOTDA system case to the frequency counter using an SMA connector.
9. Connect the Lock port of the BOTDA system case to the frequency counter using an SMA connector.
10. Connect the Lock port of the BOTDA system case to the frequency counter using an SMA connector.
11. Connect the pulse out port of the pulser to the RF pulse port of the BOTDA system case using an SMA connector.
12. Connect the trigger out port of the pulse generator to the trigger in port of the ADC using an SMA connector.

13. Connect the digitizer out port of the BOTDA system case to ch1 port of the ADC.
14. Connect the Frequency correction port of the BOTDA system case to the Pizo electric port of the Pulse laser.
15. Connect the PCI DDA card in the BOTDA PC to the Pol.Cont port of the BOTDA system case using a Ribbon cable (use 1-50 pins).
16. Connect the parallel port of the BOTDA PC to the parallel port of the BOTDA system case.

4.3 Performing a measurement

4.3.1 Starting the system

In order to start the system the following steps should be followed:

1. The BOTDA control software should be started from the directory:

C:\botdasys\botdagui\newcode\newcodegui.mat

2. All the hardware units of the system should be powered on.
3. The frequency difference between the pump and probe should be adjusted to be in the range between 10.5GHz- 10.8GHz by adjusting the temperature of the lasers. It is important to note that the frequency difference between the lasers is unstable when the system starts for the first time, so it is important to keep monitoring the frequency difference in this period.

4.3.2 Oscilloscope mode

The oscilloscope mode enables the user of the system to perform a time domain measurement and view it in real time. The oscilloscope mode can be accessed from the BOTDA control software's main window. As it can be seen in Figure 3.3 the user of the system should enter measurement frequency, fiber length and number of averages required. It is advised to use the oscilloscope mode before performing a measurement as it helps the user to spot any uncontrolled SBS, reflections and fiber breaks.

4.3.3 Measurement mode

In order to perform a full measurement, the measurement mode is used. The measurement mode can be accessed using the BOTDA control software's main window. The user needs to specify the following options in order to perform a measurement (Figure 3.2):

1. Measurement's start frequency in Hz.
2. Measurement's end frequency in Hz.
3. Measurement's step frequency in Hz.
4. Test fiber length in meters.
5. Number of averages required.
6. A flag to save the raw data of the measurement.
7. A flag to apply base line correction.
8. A flag to specify the required denoising type applied to the raw data [3].

When the measurement is done the user is alerted with a message, and the measurement data is saved in the following directory:

C:\botdasys\botdagui\newcode\rowdata. The following files are saved after each measurement:

Averaged_readings.mat: contains the averaged and denoised results of the performed measurement. At the beginning of the data set 20 columns of header file is added to the data as shown in the table below:

1	2	3	4	5	6-20	21	…	End
Freq	Start Freq	Step Size	Number AVG	End Freq	Future use	Start of data	…….	End of data
:	:	:	:	:	:	:	:	:
Freq	Start Freq	Step Size	Number AVG	End Freq	Future Use	Start of data	…….	End of data

Table 4.1: averaged_readings.mat data type

Pure_data.mat: contains the data in the previous table without the header file.

Polarization_data.mat: contains the measurement data without applying the polarization averaging.

Baseline_correction_par: contains the parameters used to fit the baseline function for each frequency.

4.3.4 Curve Fitting

The curve fitting function is accessed using the curve fit button in the BOTDA control system's main menu. The only file that can be fit is the averaged_readings.mat file as the curve fitting function needs the header information. The curve fitting results are saved in the following directory: *C:\botdasys\botdagui\newcode\rowdata*, the curve fitting increases the frequency resolution by 0.1*frequency step size. The curve fitting function uses the autocorrelation method [3].

Running the curve fitting will create two files in this directory *C:\botdasys\botdagui\newcode\rowdata :*

CurveFitData: contains the measurement data set after applying the curve fitting.

BrillouinPeaks: contains the frequencies that the Brillouin peaks happened at.

It is important to note that the measurement start frequency will be labeled as 1 and the each step in the previous files will represent 0.1* measurement frequency step size.

4.4 Example of a Calibration measurement

The following is a measurement was performed on a 150m fiber, at approximately 26 ^{o}C, the measurement start frequency was set to be 10.88GHz, measurement end frequency was set to be 11.1GHz, frequency step size was set to 1MHz and number of averages is set to 1000 averages. Measurement's spatial resolution was set to 40 cm using dark pulses. Visio denoising and linear base line correction was applied to the data. The plot shows the Brillouin interaction peaks obtained on each point of the test fiber. The measurement was repeated three times with one hour difference between the measurements which resulted in small room temperature changes. The system proved 1^{o}C temperature resolution as can be seen in figure 4.2.

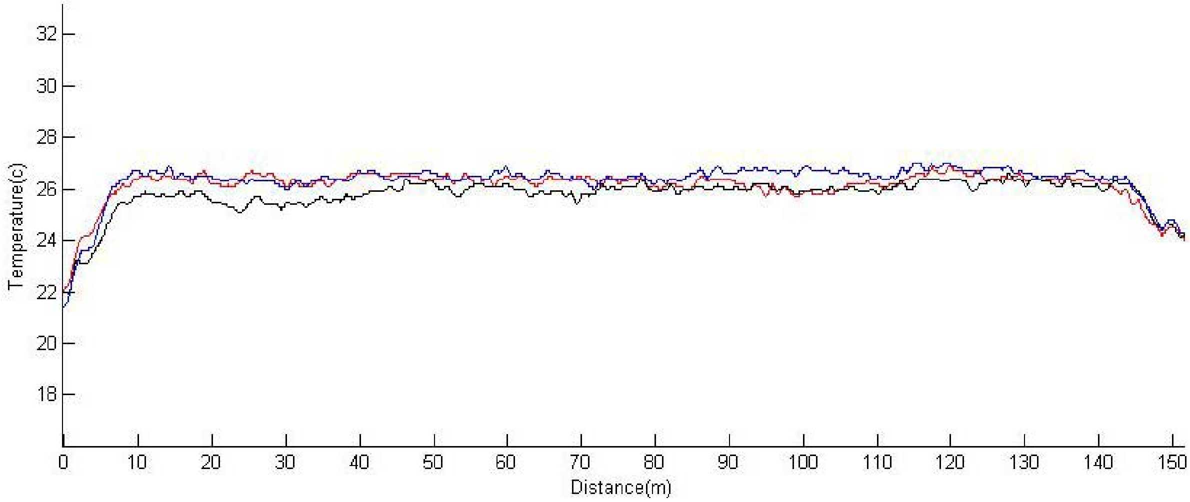

Figure 4.2: Temperature calibration results for 150m fiber

4.5 Installation files on the server

The BOTDA control software, and the used library files can be found on UNB's server on the following directory: *C:\Documents and Settings\b6678\October backup\newcode*. When installing the BOTDA system the gage libraries should be copied to the following directory: C*:\Program Files\Gage*. The BOTDA control software should be copied the following directory: *C:\botdasys\botdagui\newcode.*

An empty folder with the name rawdata should be created at the following directory for measurement data to be saved in: *C:\botdasys\botdagui\newcode\rowdata*.

Appendix A: Datasheets of the individual hardware components.

All the data sheets of the individual hardware components are found on UNB's server at the following directory *C:\Documents and Settings\b6678\October backup:*

1. System's power supply : ZWQ130
2. CW laser: Koheras Adjustik C15
3. Pulse laser: Koheras Adjustik E15
4. Polarization switch: PolaSwitch PSW001-90-pp-nc
5. Isolator: NovaWave PM isolator
6. Circulator (lock circuit): NovaWave PMCIR-55-1
7. Circulator (main): NovaWave PMCIR-55-1
8. Coupler (for bias correction): JDS Uniphase PMFC21077719
9. Coupler(frequency lock): NovaWavePMFC-55
10. ADC: Gage Cobra 8-bit
11. Frequency divider(/8): HMC363
12. PLL:ADF 400 BCP
13. Frequency Synthesizer: ADF4350
14. Detector 1 (frequency lock): DSCR402

15. Detector2(Brillouin signal): DSC405
16. Bias Controller: PSI 0204
17. High voltage amplifier: PAD 135
18. A/D card for polarization control: PCI-DDA 08/16

References

[1] M. Mohammad, “Improvements to the Brillouin Optical Time-Domain Analysis Temperature and Strain Sensing System”, MScE thesis, University of New Brunswick, 2013.

[2] M. A. Farahani, “Performance enhancement of distributed optical fiber sensors”, PhD dissertation, University of New Brunswick, 2012.

[3] M. F. Amiri, M. T. V. Wylie, E. C. Guerra, B. G. Colpitts, “Reduction in the number of averages required in BOTDA sensors using wavelet denoising techniques”, *Journal of Lightwave Technology*, vol. 30, issue 8, pp. 1134-1142, 2012.