

Miniature Elastic Lidar

Research Procedure (RP)

for the Baltimore PM Supersite



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1.0 INTRODUCTION

1.1 Scope

This RP contains information on the use of the Johns Hopkins University (JHU) Lidar system, its system specifications and safety caution. The current version of this RP is an evaluation version and is subject to change. A standard operating procedure (SOP) as a result from the experience with this RP is anticipated. The JHU Lidar system will be deployed in the field during the Baltimore PM Supersite project with the intention to characterize the relative particle concentration in the study area and the dynamics of the mixing layer. Personnel from the Johns Hopkins University, trained to operate the Lidar system, will take measurements with the Lidar system on site.

1.2 Lidar Basics

Lidar is an acronym for Light Detection And Ranging. Lidar systems operate on similar principles as radar (RADio Detection And Ranging), but use a laser beam to scan through the atmosphere over a desired range of directions and elevations. In elastic lidar, light scattered back towards the lidar system from molecules and particles in the atmosphere is collected by a telescope and is measured with a photodetector. The signal is digitized and analyzed by a computer to create an on-site, detailed image of the concentrations within the scanned region.

Using a short (~ 8 ns long) pulse of laser light, the miniature elastic lidar is a small, scanning lidar that uses elastic backscattering to obtain information on the distribution and properties of atmospheric aerosols and the amount of atmospheric attenuation. A Nd:YAG laser operating at 1.064, 0.532 and 0.355 microns is used as the light source. The laser is attached directly to the top of a 26 cm, f/10, Cassegrain telescope. The laser beam is emitted parallel to the telescope after going through a periscope, so that the effective exit aperture is 41 cm from the center of the telescope. The periscope simplifies alignment, and also increases the distance at which the laser beam overlaps the telescope field of view. This separation decreases the chance of near-field detector overloading, and decreases the dynamic range required of the analog-to-digital conversion system. The telescope-laser system is able to turn rapidly through 180 degrees horizontally and 90 degrees vertically using computer-controlled motors incorporated into the telescope mount.

Behind the telescope, the light passes through the interference filter and a lens system that focuses the light on a 3-mm diameter, IR-enhanced silicon avalanche photodiode (APD). The signal is amplified as part of the detector system and fed to a 12 bit digitizer also on the PC data bus. Two detectors mounted in the periscope sample the outgoing laser pulse and produce signals which are used to correct for pulse-to-pulse variations in the laser energy and also serve as a timing marker to start the digitization process. Pulse averaging is used to increase the useful range of the system. A series of pulses are summed to make a single scan. A number of scans are used to build up a two-dimensional map of relative atmospheric aerosol concentrations. The system is capable of operation day and night through the use of a 3-nm wide interference filter, well-blocked in the visible and near infrared, with a peak transmission of 52 percent.

Elastic Lidar Equation. The determination of backscatter and extinction information from elastic lidars is a classic inverse problem in remote sensing. The lidar equation is:

$$P(R) = P_o \frac{A_r}{R^2} \beta(R) \frac{c \tau_L}{2} \exp[-2 \int_0^R \alpha(r) dr] \quad (1)$$

where $P(R)$ is the received signal strength (Watts), R is the range from the lidar (meters), P_o is the outgoing laser energy per pulse (Watts), $\beta(R)$ is the 180 degree backscatter coefficient at the laser wavelength ($\text{cm}^{-1}\text{sr}^{-1}$), c is the velocity of light (m/s), τ_L is the pulse duration (sec), $\alpha(r)$ is the volume extinction coefficient for the laser wavelength (cm^{-1}), and A_r is a system coefficient which takes into account the effective area of the telescope, the transmission efficiency of the optical train, and the detector quantum efficiency. The backscatter and extinction coefficients at each range are not fully quantified by a single wavelength lidar system. Thus, a unique solution to (1) is not available for the general case and some assumptions must be made to reduce the number of independent variables. The most common assumption is the "Klett" assumption that the extinction to backscatter ratio is constant, or alternately, that the relationship is a power law, $\beta = C_2 \alpha^k$, where C_2 is a constant. The value of the attenuation coefficient at the farthest usable range (r_e) must be measured or estimated. Then the value of the attenuation coefficient at each range (r) can be found by working backwards from the reference position using:

$$\alpha(r) = \frac{\exp\left\{\frac{S-S_e}{k}\right\}}{\alpha_e^{-1} + \frac{2}{k} \int_r^{r_e} \exp\left\{\frac{S-S_e}{k}\right\} dr'} \quad (2)$$

where the S_e specifies the logarithmic range-adjusted power at the farthest range ($r = r_e$). [Note that $S(r) = \ln(r^2 P(r))$]. There are several variants on this scheme to improve convergence of the inversion to the "correct" solution. The final result is that the lidar signal indicates variations in attenuation over specified range intervals. Since it is reasonable to assume that atmospheric gas backscatter \ll particle backscatter for many areas, the lidar signal gives particle backscatter information directly. By assuming a relationship between particle backscatter and particle mass or number, the lidar signal can be used in a semi-quantitative manner to monitor and track particle concentrations.

The use of lidar at ground level poses two minor problems. The first is eye safety. The 1.064/0.532/0.355 micron laser is not eye-safe and thus must be aimed appropriately to avoid harming passers-by. This is easily accomplished by programming all scans at angles well above eye level and locating the lidar instrument at elevated positions such as on top of a truck or van. The second problem is returns from infrastructures such as light poles and signs. These materials will give very strong lidar signals which can be used to position overlapping lidar scans, but these reflections make eye safety an important concern. For best results, the lidar is positioned at least 300 meters from the source area. With a maximum range of about 8-10 km, a range resolution of 1.5 meters, and a time resolution of 30 seconds, the lidar is capable of very detailed maps of aerosol concentrations. Furthermore, e.g. the 1.064 μm wavelength will capture returns from particles between roughly 0.4 and 4 μm diameter.

1.3 Important Laser Safety Issues

The miniature elastic lidar employs a Class 4 laser to probe the atmosphere. This class of laser requires the highest degree of laser safety precautions to prevent personal injury because Class 4 laser beams are both safety and fire hazards. The use of a laser under field conditions, where access cannot always be highly controlled as in a laboratory setting presents unique laser

safety issues for the lidar system. The following procedures will ensure safe operation of the lidar laser and must be strictly adhered to by all lidar operators.

1.3.1 Laser description

A Big Sky Laser (Bozeman, MT; 1-800-914-8216 customer service) model CFR-400 Nd-YAG laser (Ser. No. 10000205) operating at 1.064, 0.532 and 0.355 microns is used to generate the lidar outgoing signal. The laser requires continuous water cooling which is provided by the cooler unit and the entire laser system is controlled by the Model 8800-13 “Laser Controller” power supply unit via a menu-driven operating system. The laser operates at a repetition rate of 30 Hz and has a maximum output of 324 mJ (for 1.064 microns). Pulses are of 8 ns duration, the beam diameter is about 0.7 cm, and beam divergence (full angle) is 1.8 mrad.

1.3.2 Location of laser in lidar system

The laser head is mounted directly on top of the lidar telescope using three 8-32 socket-head screws. The laser cooler and power supply units are rack-mounted in a box that sits under the lidar platform box as shown in Fig. 1.



Fig. 1 The LIDAR set up in a typical data collection mode. The major components are labeled.

1.3.3 Laser beam path through lidar instrument

From the laser head, the beam strikes two 1.064/0.532/0.355 micron-reflecting mirrors within the periscope mount before exiting the lidar system. This arrangement (Fig. 2) means that **laser safety goggles must be worn at all times** by personnel working in the vicinity of the operating laser to ensure eye safety. In addition, no objects should be placed in the path of the laser beam either at the exit of the laser head (at entrance to periscope) or at the periscope exit to avoid scattering the laser light. As an additional safety precaution, it is advisable to remove all jewelry when working around the laser.

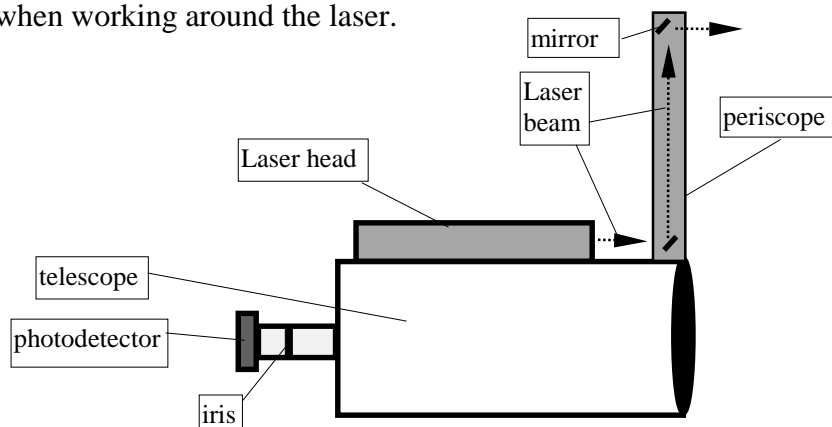


Fig. 2 Laser and Periscope arrangement at top of telescope (not to scale)

1.3.4 Hazard areas

Immediate Vicinity of Lidar. The main hazard areas are immediately surrounding the laser head where the beam enters the periscope (Fig. 2), the interior of the periscope (which is only infrequently accessed by removing 9 screws on coverplate in order to adjust interior mirrors) (Fig. 2), and along the laser beam path from its exit at the top of the periscope (Fig. 2) out to a distance of about 3.5km. Note that due to the relatively high power output of the laser, any objects within a few feet of the laser exit at the top of the periscope will reflect stray laser light into the telescope. Therefore, it is critical to operate the lidar in a location free from any interferences that could reflect the laser beam and cause eye injury.

Distant Locations. At the 3.5km distance, the maximum incident beam irradiance that could reach the unprotected human eye is below the recommended safe threshold value of $5 \times 10^{-7} \text{ Jcm}^{-2}$ (for 0.532 microns). However, reflections from distant objects could still cause eye safety problems up to 1.5km from the lidar! Use the utmost care in controlling lidar scans in locations where specular reflection might be a problem for personnel or the general public (i.e., in urban areas: telephone poles and wires; street signs; buildings)

Electrical. The Laser Controller represents its own hazard and should be protected from the elements (rain) in order to prevent electrical damage and the possibility of fire. Both the laser head and the electronics unit operate at lethal high voltage and current levels. Always unplug and wait at least one minute for capacitors to bleed down prior to working on any part of the laser system.

1.3.5 Laser Use Rules

The following rules always apply to operation of the lidar:

- A. Never permit a person to look directly into the laser source. Always wear safety goggles!!
- B. Never point the laser at an individual's eye or towards a reflective material that could deflect laser light toward eye level.
- C. The beam should be enclosed as much as possible during operation. Only during initial laser alignment should the coverplate be off the periscope.
- D. The laser shutter should only be opened after the laser is positioned to an elevation well above eye level.
- E. Only trained lidar personnel shall operate the laser and two people must be present whenever the laser is operating.
- F. Never point the laser toward aircraft.
- G. Laser safety goggles must be worn by all people coming within 50 feet of the laser.
- H. The laser should only be observed directly with an IR card or IR viewer.
- I. The camera and video monitor should be used to view the beam's location at all times.
- J. The AVOID routine (see LidarDCP software section) should be incorporated into all lidar scans in order to avoid scanning over areas of possible safety concern (i.e., to avoid scanning where there is a reflective background).
- K. In highly populated areas, backstops should be used. The backstops should be diffusely reflecting and fire-resistant target materials and may include natural backstops such as trees.
- L. Laser Warning Signs must be posted on the laser:

For Class 4 lasers, "Danger" must be used with all signs and labels. In addition, the sign must say, "Laser Radiation - Avoid Eye or Skin Exposure to Direct or Scattered Radiation"

For the lidar laser, since the beam is not visible to the human eye, the words, "Invisible beam" should also appear.

- M. Only qualified personnel should perform maintenance on the laser head or remove the laser's protective housing.
- N. Only personnel having satisfied a basic Laser Safety class may be permitted to operate the lidar.

1.3.6 Laser Beam Controls

- A key must be used to start the laser system (Power ON) and begin pumping water (coolant) to the laser head. The key will remain in possession of the senior lidar operator.
- Lasing occurs whenever the **RUN** key is pressed on the Laser Controller panel and the both the beam Q-switching and shutter are **ON**.
- Lasing ceases once the **STOP** key is pressed.
- There is also a remote interlock on the rear of the laser cooler rack that will prevent laser operation.
- Both a coolant flow interlock and a temperature (<150°F) interlock are built into the CFR-400 system to ensure that coolant is flowing through the laser head.
- A switch inside the Laser Controller ensures that the laser will not function with the power supply cover removed.
- When the laser is on, the LED on top of the laser head is lit.

1.3.7 CFR-400 Operating Manual

All lidar personnel must read the attached document, “User’s Manual for model CFR-400 Nd:YAG Laser Systems” (August 2000) prior to use of the system. In particular, the safety information (Chapter 2) must be strictly adhered to (see Appendix C for the Manual).

2.0 LIDAR Equipment Setup

2.1 Laser Power Supply and Cooler Box

As shown above in Fig. 1, the laser power supply and cooler are rack-mounted in a single box that stands about 26” high and 32” square. This forms the base of the scanning lidar system. Note that the rack box has four metal plates on its top surface with depressions to accommodate the four feet on the bottom of the lidar platform box. After removing the ends of the case, remove the high voltage power cord, the two water lines, and the two power cords from the rear of the rack. The trap-door on the rear of the case may be used in inclement weather to protect the electronics while allowing lidar operation.

2.1.1 Lidar Orientation / Geometry Conventions

By default, the lidar is pointing at an azimuth position of 90 degrees when the telescope is in the Home position (where it should be when packed). This corresponds to 90 degrees being “straight ahead” when operator is facing the side of the lidar platform box that has the 4 BNC, the 25 pin computer cable and the high voltage bulkhead connectors. The lidar scanning AZIMUTH range is therefore from 0 degrees (counterclockwise from 90) to 180 degrees (clockwise from 90). For ELEVATION, the Home position is 0 degrees (telescope is flat, points to horizon) and 90 degree limit is when telescope points straight up.

2.2 Scanning lidar platform and telescope mounting

The lidar platform box is approximately 21” long x 15” wide x 9” high. Place the box into the feet on the top of the laser power supply and cooler box *oriented so that the connections side of the lidar platform box is at the rear of the cooler box*. After unpacking the box, the two arms must be attached to the rotary table using the appropriate screws after making the Burndy and BNC connections at the bases of the arms. Next, the telescope is mounted on the arms and attached with four screws. (Mounting the telescope requires two people). Finally, the periscope, laser head and camera are attached to the top of the telescope using the appropriate screws.

2.3 Computer operating station

The lidar computer, the AT6200, the blue high voltage box and the video monitor can be located up to 25 feet away from the lidar platform via the 25pin cable, the high voltage cable and four color-coded BNC cables (see below). Unload the equipment from the footlocker and then use the footlocker as the table for the computer system.

A 6-prong outlet strip is required for powering all the computer station equipment. Make all the appropriate connections and then connect the color-coded BNC cables between the laser box and the computer. Finally, connect the 25pin cable between the laser box and the AT6200.

2.4 Cable Connections

There are four color-coded BNC cables, one 25-pin computer cable and one high-voltage cable (grey with Burndy connectors) that connect between the lidar platform box and other equipment. The four BNC cables have the following functions:

Blue = Camera signal to video monitor

Green = Photodetector (Avalanche Photo Diode, APD) to PDA12 card

Yellow = Output energy detector (high voltage Blue Box and periscope)

Red = Trigger (PDA12 card and periscope)

The 25-pin cable connects to the AT6200; and the high voltage cable connects to the Blue Box. The final connection is the four-pin power cable between the computer and the Blue Box.

2.5 Laser periscope mirror alignment (also see SECTIONS 3.3 and 3.4)

- a. Initialize the telescope and then position the lidar so that the Azimuth position is 90 and the Elevation is close to 90. This means the laser is pointing to the sky and will not present a safety hazard to surrounding infrastructures. In addition, in this position, the two mirror alignment screws at the top of the periscope are readily accessible.
- b. Turn on the laser (push "RUN") and let the flashlamp run for 30sec to 1min before lasing (turning on Q-switching) to allow the lamp to reach equilibrium such that hot spots do not develop on the lenses.
- c. Connect oscilloscope input A to the APD signal BNC (green) using the BNC "tee" and use either the PDA12 board or a 50ohm terminator on the third arm of the "tee". Connect a second BNC cable to the trigger BNC (red) on the lidar box and to the oscilloscope's input B.
- d. Adjust oscilloscope so it triggers on A (the APD signal) at a level of about 2 volts; set full scale to **5V** and use **2 microsecond** scale on time axis.
- e. Turn on APD voltage from the LidarDCP program (see Section 3.3) and then look for the lidar signal on the oscilloscope. You should see a large near-field signal (about 1.5-2.0 V high occurring within 3 μ sec) and then the signal will fall due to the inverse-square signal attenuation with range. Depending on cloud cover and atmospheric conditions, you might see a "bump" in the far-field signal at the time corresponding to the cloud or boundary layer range from the lidar. (For example, a cloud 8km high will produce a bump in the APD signal at about 50 μ sec)

[Rule Of Thumb: 1000m ~ 6.5 μ sec]

- f. Adjust the set screws on the upper mirror in the periscope until you obtain the highest far-field signal possible (this will occur at the expense of the near-field signal). In other words, you want to adjust the mirror until you obtain the highest voltage possible in the tail of the signal. When this is the case, the laser beam is positioned in it's most "parallel" configuration relative to the telescope's field-of-view and you have good laser-telescope alignment. (the main idea is to get the laser to enter the telescope's field-of-view and remain in the telescope's field-of-view forever). Note that when the far-field is

maximized, very slight changes in the adjustment screw will drastically affect the near-field signal without changing the far-field very much. Use an intermediate screw adjustment position so that you have reasonable near-field and far-field signals.

g. See Sections 3.3 and 3.4 for other hardware alignment adjustments.

2.6 Connecting a VCR to the lidar camera

For videotape recording of the images captured by the lidar CCD camera (mounted on top of the periscope), make the following additional connections:

1. Connect one end of the VCR plug connector to the video monitor's "VCR OUT" terminal.
2. Connect the other end of the VCR cable to the VCR's rear connector labeled "VIDEO IN"
3. Press REC and PLAY simultaneously to begin recording.
4. Press STOP to end recording

Note that the lidar's blue BNC cable sends the camera signal to the video monitor via the monitor's connection labeled "VCR IN". This must be connected at the same time the VCR is recording!

For videotape playback,

1. the VCR cable plug on the rear of the VCR must be moved to the VCR OUT position;
2. the VCR cable plug on the rear of the monitor must be moved to VCR IN position (this requires disconnecting the camera signal cable)

2.7 Testing Motors and Limit Switches

A test program is available to check that the motors and limit switches are operating properly before the laser and telescope are mounted. It is a good idea to run the test program after the lidar has been shipped to ensure that no connections have been damaged. The program is self-explanatory and is located at c:\at6400\test.exe. When prompted, choose "AUX1" and the base address for the AT6200 board is "592". Simply accept all of the default values for motion.

3.0 LIDAR OPERATING SOFTWARE "LidarDCP"

3.1 Startup

Type "LidarDCP" from the c:\lidar directory to begin the data collection program (DCP). Accept the license agreement, enter a directory path where data will be saved and input the first sequence number for data files. Then you will be at the Main Menu which contains the following sub-menus:

- File
- Set Digitizer
- Equipment
- Take Data
- Graphics
- Parameter Screen
- Exit

3.2 File Menu

Read Data File

Write Data File

Read Old Format Data

Configure Printer

Shell to DOS

3.3 Set Digitizer Menu

Report Digitizer Status

To display current digitizer values for each parameter below on the text screen.

Sampling Period [10, 17, 30, 50, 100, 133, 200, external]

This tells the digitizer (PDA12) how often to sample the signal from the photodetector. Use **10ns**. This corresponds to 100MHz (two channels on the PDA12). This setting determines the range resolution for the data set (10ns corresponds to 1.5m resolution; see Appendix B.2.d). When using 10ns the range resolution is 1.5 meters and the digitizer operates in interleaved mode (alternating between the two digitizer channels). Be sure that you have loaded the PDA12 calibration tables into directory c:\PDA12 prior to using this option!! (otherwise, you will get some really absurd output).

Set Offset [30, 128, 230, keyboard]

Select **230**: *Unipolar (+) input*. Since our detector has unipolar positive-going output, use this option.

Other choices are 30 = *unipolar (-) input*. For use with detectors having negative outputs.

128 = *bipolar input*. For use with bipolar detectors.

Input offset from keyboard (0 - 255)

Note, from Signatec manual: "The offset is used by the PDA12 board to shift the signal into the ADC into the required range of ± 2.0 volts. The offset voltages have a range of -700 mV to +700mV as the digital offset number is changed from 0 to 255." Thus, "an offset value of 128 gives zero offset voltage... and increasing the offset value shifts the ADC input voltage negatively." The offset that you select contributes to the true baseline value of your signal. Higher offset values decrease the signal baseline. For example, an offset of 254 gives ~5 counts baseline and an offset of 150 gives an offset of ~1850 counts. The relationship is ~ linear.

The reason you need to set the offset value is so the raw signal from the detector doesn't get truncated by the digitizer. Since the digitizer effectively only 'sees' voltages between -2 and +2 volts, you need the offset value to adjust your raw input into this range. You can check the effect the offset has on your signal using Multiscans (50 shots) **without background subtraction** (this is very important – disable BG subtraction in the Graphics menu (Section 3.6).

Set Memory Size [kilobytes]

This value is used to specify total amount of memory space to reserve per scan (single line-of-sight (LOS)). Note that the number of bytes in each element ('element size') in the data array is **4 bytes** (Long integer = signed 32-bit; -2^{31} to $+2^{31}$).

Input Data Array Length (in channels)

This is the total length of the data array along a single LOS (= number of data points * element size). This value determines the total number of sampling points that will be taken along the signal curve for each laser pulse. (the element size is fixed at 4 bytes). Since you want to see the entire signal (i.e., you want to have the far-field signal asymptotically above the X-axis so it is clearly measured by the digitizer), but you also want the signal to return to background levels in the far-field so you can perform

background subtraction, choose the length depending on field conditions. The value you choose depends on the sampling situation (try to cut off at a range where the signal goes to the background level).

DataArrayLength (channels)	Total bytes in each data array	Total Signal Range for ~1.5m range resolution (10ns SamPer) (meters)
2048	8,192	3,000
4096	16,384	6,000
8192	32,768	9,000
16380 **	65,520	18,000

Note that the Total Range of signal in one line-of-sight = Number of Channels * Range Resolution. So, 2048 channels gives the maximum range of the lidar of ~3,000 meters.

*** Remember, there is a 64MB limit in DOS memory transfers and 16kB is reserved space, so this is the maximum MemorySize value allowed.

Set Pretrigger

This option is not available.

Set Input Range [1x, 2x, 3x, 4x, 5x, 10x, 15x, 20x, 25x, 29x]

This setting will determine which gain amplifier setting the DA60 will use. You want the signal size span the maximum number of possible in order to achieve the best signal resolution (for the 12-bit PDA12 digitizer, $2^{12} = 4096$ bins).

Choose the input range (i.e., an amplification factor) depending on the signal you are getting for your location. The input range chosen should correspond to the full scale input voltage setting you want to achieve (i.e., 2V maximum). The input range setting will determine which gain setting the PDA12 digitizer will use. For example, a gain setting of 34dB corresponds to a full-scale input of 100mV peak-to-peak while 0dB gain corresponds to 5V peak-to-peak. What you are doing with this setting is adjusting the fully usable gain ratio between 1 (34dB) to 50 (0 dB).

The easiest way to choose the Input Range value is to LOOK at the RAW signal without background subtraction. A typical signal should look like Fig. 3 (i.e., for clear sky):

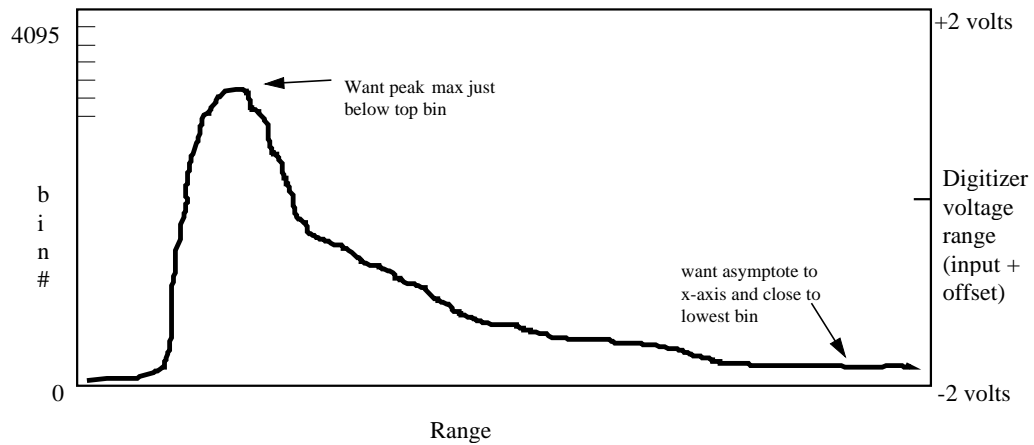


Fig. 3 Raw lidar data signal without background subtraction. Digitizer bin numbers on left correspond to 0-4095 for the 12-bit digitizer. This range spans the -2 to +2 V digitizer input voltage range (right axis). Set the digitizer variables to get the highest dynamic range from your signal while keeping the signal significantly above zero in the far field (where the signal flattens out should be well above zero counts (i.e., ~ 30-50 counts).

Set Trigger Level (volts)

Set to a level that occurs as early as possible on the positive side of the trigger pulse, but not so low that noise is detected. A reasonable value is **3V** and answer [Y] for positive pulse.

Read Parameters File

Used to read-in previously saved values of digitizer parameters from *.PRM file.

Write Parameters File

You must write out the new values to the parameters file (MINIDA60.PRM is the default) in order to save your settings.

3.4 Equipment Menu [many options]

Only two of the numerous options in the equipment menu are currently meaningful with the JHU lidar.

APD Voltage On/Off

Toggles the APD voltage on and off at the voltage setting designated in "...Control".

APD Voltage Control

Used to set the voltage applied to the Avalanche PhotoDiode. This high voltage is transmitted to the detector via the grey cable with Burndy connectors.

Never set this value to below 200 volts!!! Different voltage settings will result in different gain values for the detector. The following rules-of-thumb apply:

200 to 280 V will result in about the same gain.

280 to 330 V will give increasing gain with increasing voltage.

310 to 320 V are normal operating values.

Note that the software is configured to accept information from other instruments in addition to the lidar signal. These instruments include a clinometer (useful for ocean work), Global Positioning System (GPS), among other things. The data for these instruments is stored in the same data file as the lidar data. Bill Eichinger at University of Iowa should be contacted regarding the purchase of such peripheral equipment.

3.5 Take Data Menu

Single Scan

Data is acquired along the current line-of-sight (LOS) for a single laser pulse. Note that the data is NOT automatically saved!!! You must manually save each Single Scan to a filename.DAT.

Multiple Scans

You are prompted for the number of laser pulses that you want to have summed to comprise the data set. Again, you must manually save Multiple Scan files. Multiple Scans are collected immediately from the current lidar position and are displayed on the graphics screen. Multiple Scans are very useful for (a) determining the appropriate X and Y data ranges for subsequent 2D scanning, and (b) visualizing signal to assist in setting digitizer parameter values.

2 Dimensional Scans

Use this menu command to acquire 2D vertical or horizontal scans after the appropriate azimuth and elevation angles and step sizes have been entered in the Parameters Screen.

Horizontal 2D Scan: Elevation is fixed and Azimuth telescope positions vary. For large angles of elevation, the lidar will trace the surface of a cone! Therefore, your graphic of the scan will have arcs for horizontal features such as clouds. This is normal – the graphic is the 2 dimensional projection of the scan and the radius of the arc indicates the altitude of the backscattering object (i.e., cloud). For low elevation angles, close to the horizon, this arcing will not be obvious even over large azimuth ranges. Note that the $x=0$ point on the x-axis is the location of the lidar and $AZ=90$ degrees is straight out from this point. This means the x-axis limits (which are arbitrary units) should be between $-X$ and $+X$ to center a horizontal scan made across 90 degrees.

Vertical 2D Scan: Azimuth is fixed and Elevation telescope positions vary. The resulting image plots range on the x-axis and altitude on the y-axis since the software computes the correct distances based on the return signal time and sine or cosine of the elevation angle.

Note that if the Parameters Screen is not set up correctly the 2D scan will not run and you will get an error (most commonly occurs if starting and ending angles are identical, or if stepsize is zero).

Fast 2D Scan

Not used as much as the 2D scan because, due to motor ramp-up and ramp-down, the step-size may be changing over the course of the scan. Whereas the regular 2D scans query you for the number of points you want along a given LOS, the Fast 2D uses only a single laser pulse per LOS. The other difference is that Fast 2D adjusts the motor speed to give you the requested step size in the shortest amount of time whereas the regular 2D gives precise step intervals, regardless of how long it takes.

Fast scans are not plotted on the graphics screen at the end of every LOS. Instead, to same time and make a faster scan, the data is plotted at the end of the entire scan.

3 Dimensional Scans

Use this menu command to acquire 3D scans after the appropriate azimuth and elevation angles and step sizes have been entered in the Parameters Screen. Note that if the Parameters Screen is not set up correctly the 3D scan will not run and you will get an error (most commonly occurs if telescope endpoints are incorrect). A 3D scan performs a rastering of the sky; changing both azimuth and elevation over the course of the scan.

Note 1. If you enter information in the Parameters Screen for a 3D scan and try to perform a 2D scan, you will get an error.

Note 2. There is no real-time display of 3D scan data.

Correlation Scans

These are for wind measurements.

Fast Time Sequence Scan

Currently this option is identical to the Time Sequence Scan (see below).

Time Sequence Scan

The lidar is positioned along a single LOS and the signal is recorded over time. You indicate the number of pulses per scan and the total number of scans you want (= # of channels). These files can be very big!!! (already 6-8 MB for only 5-10 min of data at low resolution). Files are saved as *.TD (time-distance)

Programmable Sequences

see Section 3.8 of this manual.

*General Note: Time is recorded at the **end** of each line-of-sight for all data files.*

Laser Power Histogram

Plots a histogram based on the outgoing laser power measured by the Thorlabs detector mounted in the periscope (the detector with the 1064nm filter). User inputs the number of laser shots to be histogrammed. A reasonable value is 200.

Network Controlled

Not currently functional. You can control the lidar remotely with this option.

Control Telescope

All manual telescope motion control originates here. A menu will come up on the text screen describing all the options:

I Initialize Do this first!! This will run the telescope through a set routine so that it finds both the elevation and azimuth limit switches and then returns telescope to the 90 Az, 10 El position. Without initialization, the telescope has no idea where it truly is; so you must do this first to enable future correct telescope positioning.

Here is the initialization sequence of events:

- motor moves slightly to left and down
- telescope moves all the way UP (90) and all the way to RIGHT limit (190 deg)
- telescope backs off a little bit down and left
- telescope very slowly approaches UP and RIGHT limits (should hear switches)
- fast return to the 90, 10 position

A Angles Allows you to select specific Azimuth and Elevation angles for a new telescope position.

H Home Takes telescope to 90 azimuth and 0 elevation. This is position for taking lidar apart and putting it back together again. Use “home” at the end of the day.

K or S Kill or Stop Will stop all telescope motion immediately. Try not to use this a lot.

Space Bar or ESC Exits Control Telescope

Arrow moves telescope in 1/10 degree steps in whichever direction arrow points. If you hold down the arrow, when you release it the program will catch up with the total number of “hits” it received.

CTRL + Arrow moves telescope in 0.5 degree steps. If you hold down the arrow, when you release it the program will catch up with the total number of “hits” it received.

ALT + Arrow moves telescope in 2/100 degree steps. If you hold down the arrow, when you release it the program will catch up with the total number of “hits” it received.

Park DO NOT USE!!!!

D Disable soft limits as name implies.

L Set soft limits Use this to prevent pointing laser at a sensitive location.

3.6 Graphics Menu

2D Parameter Screens -- Use to control default setting for graphics screen such as X and Y axis limits, labels etc. when performing a single 2D scan. The **RangeRebinFactor** controls the number of points plotted on the screen. For example, if this value is 10, every tenth data point will be plotted. Note that the plotting screen is only 640 x 480 pixel resolution, so it doesn't make any sense to plot all the data points in real-time. Each LOS must be plotted before the next LOS shot is made, by definition of “real-time display”. Therefore, because data will not be acquired until the previous LOS data has been plotted, setting RangeRebinFactor to a small number will lengthen 2D scan data collection times.

Raw Spectrum – displays the raw backscatter signal as Summed Counts per Bin (y-axis) versus either Range or Channel on X-axis (depending on choice below).

Klett Spectrum – the raw signal is inverted according to the Klett algorithm. User is prompted for Near starting distance, Far ending distance (i.e., integration limits) and reference altitude (where no aerosols). (See the paper by J.D. Klett (1981), Appl. Optics 20, 211-220 for details).

Range-corrected Spectrum -- the raw signal is multiplied by the square of the range for that return.

Display Range or Channels -- this is toggle for X-axis display type. Range is in meters.

Background and Smoothing Controls -- data may be plotted with the background and with 3, 5 or 7 point smoothing. If background subtraction is selected, the program prompts the user for “Input starting channel (2 to MaxLength)” and “Input ending channel (up to MaxLength)”. These channel limits will define the data that is averaged to give the

background signal for subtraction. It is wise to look at your raw data before selecting the channels for background. If you select background subtraction, program will ask you (1) whether you want to select Klett inversion limits (Near starting distance, Far ending distance), and (2) whether you want to smooth the data (3,5,7 point; 1D)

Analyze Digit 1/ Digit 2 For the use of multiple digitizers.

3.7 Parameters Screen Menu

Offset definitions and measurement

Range Offset is a correction factor that allows the program to correct the measured ranges in order to give True range values. The offset is a value that is added to X , the range where a lidar return occurs, to give the true distance to the target.

In order to measure the Range Offset, shoot the lidar at a target that is known to be about 100 meters away and record the range value at which the return from this object appears in a Single or Multiple Scan. The difference between the known and the measured range is the Range Offset. This parameter is entered into the Parameters Screen for accurate multidimensional scan graphical representations.

3.8 Programmable Sequences

Ascii text files can be written to program the lidar to perform a series of pre-determined scans sequentially without operator intervention between scans. The default file is AUTO.IN. Look at this file for the appropriate file format for running the sequences:

```
2D {type of data collection}
Az start, Az end, step, El start, El end, El step # of lines (for TD only)
{Comment line}
x-axis min, max, increment, y-axis min, max, increment Zmin, Zmax {display line}
```

Note 1. Each section MUST have four lines and you cannot have spaces between the segments of code. This means that the STOP segment must have 3 lines after the STOP line even though these lines will not be used.

Note 2. If you put Single Scan or Multiple Scans (*.DAT files) into your programmable sequences these data will not be output on the graphics screen because to exit from these data acquisition modes required manual input at the end of the scans (not something you want for automatic operation!)

3.9 Typical Hardware + Software Start-up Routine

- a. Hook everything up, including oscilloscope to APD signal (green BNC on lidar platform box).
- b. Initialize Telescope (\Take Data\Control Telescope\''I'')
- c. Point telescope skyward (90az, 90el if all clear overhead).
- d. Turn on the laser. Use IR card to check for lasing.
- e. Turn on the APD.
- f. Adjust periscope mirrors to maximize far-field signal.
- g. Adjust iris if necessary to increase or decrease signal intensity.
- h. Take Multiple Scans (\Take Data\Multiple Scan) to see vertical scale for 2D scans.

- i. Set X and Y scales in Graphics Menu. Check both raw and R² corrected scales.

4.0 MAINTENANCE

4.1 Flashlamp replacement

The flashlamp inside the laser head has a finite life and will need to be replaced at intervals determined by lidar use. In general, flashlamps have a useful lifetime of ~ 20 million shots (about 185 hours of continuous lasing). The instructions for replacing the flashlamp are found in the Big Sky Laser Operating Manual (see Appendix C).

4.2 Lubricating rotary table

The rotary table should be lubricated by using a grease gun on the “zirt” connector about twice a year, or more often if the lidar is subjected to highly dusty conditions on a continual basis. Grease it, rotate the table 180 degrees, then grease it again.

4.3 Cleaning periscope mirrors and telescope

It is imperative that all optical surfaces be kept as clean as possible. In particular, the mirrors inside the periscope should be cleaned using “dust-off” with every use of the lidar. Dust on the mirrors and lenses can create hot-spots that distort the outgoing laser beam. Similarly, dust on the telescope lenses can scatter the returning backscatter signal and thus reduce the received signal.

Note: All maintenance procedures must be recorded in the LIDAR field logbook.

5.0 DATA FILES and ARCHIVING

The lidar creates huge amounts of data in very short periods of time!!! Therefore, it is imperative that detailed notes be collected during lidar operation documenting as much information as possible about the data files generated. The following data handling guidelines are recommended.

The general idea of data collection and archiving is as follows:

1. Collect the data and save it on the lidar computer's hard drive.
2. When convenient, or when the hard drive is full, copy data files to JAZ cartridges (1 Gigabyte)
3. When at Hopkins, write the data files from JAZ cartridge to CD-ROM.
4. Use the CD-ROMs for all data analysis.

A database will be created to keep track of all the data files archived on CD-ROMs. It is IMPERATIVE that this database be kept up-to-date!!! And that all CD-ROMs be clearly numbered in sequential order to facilitate data tracking.

5.1 Lidar Computer Subdirectories

All data should be stored in directories other than c:\lidar. This directory is reserved for the lidar operating and data viewing software files only. Please save your data to another directory. You must create this directory **before** starting LidarDCP! One option is to use the

operator's name for subdirectories, another option is to use the date of data collection, or the location of the fieldwork. Remember that storage on the lidar computer's hard drive is TEMPORARY. All data will ultimately end up on CD-ROMs.

5.2 JAZ Cartridges

The external JAZ drive on the lidar computer accepts 1 Gigabyte IOMEGA JAZ cartridges. This SCSI drive can be accessed with the usual DOS commands such as D:; dir and copy. Thus, the easiest way to transfer files is to use the Copy command from your data directory:

```
C:\Markus\ Copy 20May*.* D:\*.*
```

Save the data on JAZ cartridges in the field and transfer from the cartridges to CD-ROM when back at Hopkins.

5.3 Writing CD-ROMs

The CDRomWriter and its software package makes writing the data files to CD-ROM a breeze. Keep in mind that a CD-ROM holds only 680 MB of data and that part of this capacity must be used to label the CD.

6. Data Quality Objectives

This section describes the data quality objectives (DQO's) during the operation of the JHU Lidar at the Baltimore PM Supersite. The JHU Lidar is a research instrument. It is custom made and it has been built with the intention to obtain information about atmospheric parameters such as relative aerosol concentration and the height of the mixing layer. It has already been mentioned (section 1.2) that the use of the JHU Lidar system allows high spatial and temporal resolution as well as an extensive analysis range. However, quantitative measurements are difficult to obtain with one wavelength only due to the inversion problem inherent to the lidar equation (section 1.2). Multi-wavelength lidar systems provide new prospects, but algorithms to extract the sought information on particle size distribution from the multi-wavelength return signal are still under development. The lidar signal (optical backscatter) also depends strongly on the particle composition (refractive index), shape and distribution, but samples of the reflecting particulate matter are not available, which makes a calibration of any lidar system extremely difficult. The precision of the JHU Lidar system in terms of signal to noise ratio is decreasing with increasing range. Therefore, measurements are most accurate immediately beyond the zone of incomplete overlap between laser beam and telescope field of view (~ 500m). A signal to noise ratio that guarantees data of good accuracy even for relatively small aerosol loading of the atmosphere can be assumed for a range up to 3500m. Detection of aerosol particles at far range is limited but clouds and the height of the mixing layer can still be detected due to the strong gradient in aerosol concentration between the free atmosphere and clouds and the free atmosphere and the mixing layer, respectively.

Possible interference during measurements is the presence of an airplane in view anywhere, which will lead to our immediately stopping data acquisition through active control. The process of taking data can be resumed promptly though.

Precision and accuracy of the measurements will be assessed on site by the lidar personnel through visual inspection of the real time display of the data and frequent tests of the raw data at Johns Hopkins.

By taking the known limitations of the system into consideration, our main objectives for the Baltimore PM Supersite are:

- 1) Obtain a dataset of relative particle concentration that covers the intensive measurement periods and the time of routine operation.
- 2) Characterize particle fields of the area under investigation.
- 3) Characterize mixing layer dynamics, such as the mixing layer height.

Furthermore, the data quality objectives for precision, accuracy and completeness are as follows:

- Precision and accuracy: No other data than the LIDAR data is available to contrast the results with and to obtain information on accuracy and precision. Several methods will be used to determine the mixing layer height. A comparison of these methods will provide an estimate of how accurate the results are. The estimates of the mixing height as obtained from LIDAR measurements are expected to be within 20% of mixing height estimates obtained from radiosonde temperature profiles of the atmospheric boundary layer. Digital photographs of clouds and plumes will be used to test visual agreement between relative aerosol concentration as obtained with the LIDAR and the actual aerosol concentration. For a range at least up to 5 km a range resolution along each line of sight of $2.5\text{m} \pm 0.2\text{m}$ is expected. The detection limit for detectable particle size for laser light used in this study (1.06 microns wavelength) ranges from 0.4 to 4 microns. The present standard of LIDAR technology does not allow to provide accuracy and precision of the detectable particle size and of particle concentration.
- Completeness: We aim to obtain a dataset that allows a detailed description of the development and structure of the mixing layer. Data cannot be obtained under the following circumstances: Rain, airplanes passing by and if maintenance or repair of the system is required. It is anticipated to achieve at least 70% data completeness.

The components to achieve these objectives are:

- a. This standard operating procedure (SOP).
- b. Carefully trained personnel operating the LIDAR system.
- c. Daily routine maintenance of the system as outlined in this SOP.
- d. Routine on-site data check.
- e. Review of data at Johns Hopkins every other day.

As was mentioned before, no absolute calibration of the system is possible due to lacking reference data. As for the determination of the mixing layer height and the wind field, a system calibration is not necessary. Relative particle aerosol concentration provides sufficient information to determine those two parameters within the limits described above. The visual comparison of digital photographs of clouds and plumes with images of relative aerosol concentration as obtained from LIDAR data will provide a way to check the reliability of the data.

Appendix A. Wiring Diagram and connections

A.1 Lidar Platform box

There are two important cables that are bundled under the rotary table. The first cable controls the scanning of the lidar both in elevation and azimuth directions by operating the motor drive amplifiers, encoders and microswitches. The first cable is composed of splices to the Burndy 12-wire cable, the encoder 5-wire (black plug), the motor connector 4-wire (red plug). The second cable (smaller) provides power to the CCD camera and high voltage to the photodetector.

25 pin connector to Burndy

<u>Burndy wire</u>	<u>25-pin wire</u>	<u>AT6200 connection</u>	<u>4-wire</u>	<u>Burndy pin labels</u>
blue's black	#21	A+		H white (encoder)
blue	19	Z+		G blue
green's black	20	B+		K brown
green	9***	+5V		J red
brown's black	17 & 18	Gnd	black	F black
brown	14	CW	green	E
yellow's black	15	CCW	red	D
yellow	16	Home	white	C
red's black	to motor amp.	B-		B
red	to motor amp.	A+		A
white's black	to motor amp.	A-		M changed to V
white	to motor amp.	B+		L

4-wire to 25 pin connector

<u>4-wire</u>	<u>25-pin wire</u>	<u>Function</u>
red	10	Az step +
black	11	Az step -
green	12	Az. Direction +
white	13	Az. Direction -
red	22	El step +
black	23	El step -
green	24	El. Direction +
white	25	El. Direction -

Azimuth Motor connector (red plug)

<u>4-wire</u>	<u>Motor connector</u>	<u>To Az. Drive Amplifier</u>
red	red	A+
black	black	A-
green	green	B+
white	white	B-
	(connect brown to orange connect blue to yellow)	

Azimuth Encoder (black plug)

<u>encoder wire</u>	<u>25-pin wire</u>	<u>function</u>
black	5	Gnd
blue	6	Z+
white	8	A+
red	9***	5V
brown	7	B+

4-wire to Az. Microswitches

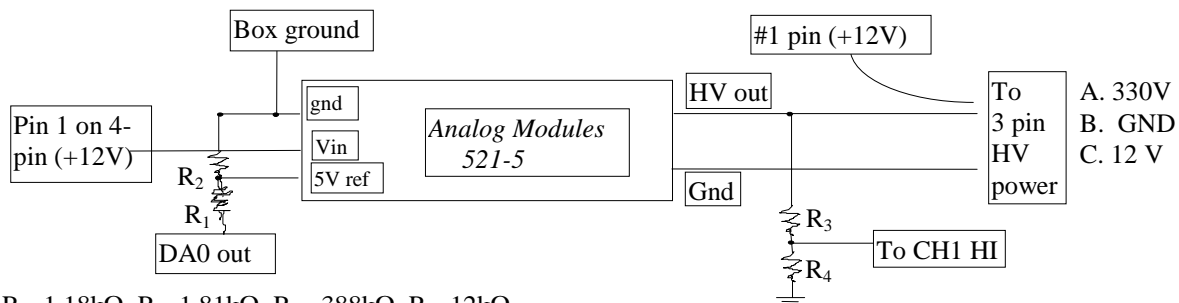
<u>4-wire</u>	<u>25-pin wire</u>	<u>function</u>	<u>microswitch</u>
red	2	CCW	bottom center
black	4	Gnd	
green	1	CW	top center
white	3	Home	top end

A.2 Blue high voltage box

4-pin connector from computer power supply:

- 1 +12 V
- 2 - 12 V
- 3 GND
- 4 +5 V

High voltage power supply (Analog Modules 521-5):



$R_1=1.18k\Omega$, $R_2=1.81k\Omega$, $R_3= 388k\Omega$, $R_4=12k\Omega$.

Sample and Hold (Analog Modules 613)

GND	pins 1, 10, 12, 18	
-12 V	pin 7	User 1
+12 V	pin 13	User 2
signal IN to BNC	pin 4	
OUT to ADC0 HIGH	pin 15	
to ADC0 LOW	pin 18	

A.3 AT6200

		<u>Azimuth</u>			<u>Elevation</u>
		<u>Limits 1</u>		<u>Limits 2</u>	
1		CW		14	CW (POS)
2		CCW		15	CCW (NEG)
3		Home		16	Home
4		Gnd		17	Gnd
				Shield	shield
		<u>Encoder 1</u>		<u>Encoder 2</u>	
5		Gnd		18	Gnd
6		Z+		19	Z+
7		B+		20	B+
8		A+		21	A+
9		5V			
		<u>Drive 1</u>		<u>Drive 2</u>	
10		Step+ (red/1)		22	Step+ (red)
11		Step- (black/14)		23	Step- (black)
12		Dir+ (green/2)		24	Dir+ (green)
13		Dir- (white/15)		25	Dir- (white)

A.4 Elevation Arm cable with Burndy connector

<u>4-wire</u>	<u>25-pin wire</u>	<u>function</u>	<u>Burndy wire/pin</u>
red		A+	red / A
black		A-	white's black / M
green		B+	white / L
white		B-	red's black / B

connect blue to yellow and orange to brown.

A.5 Photodetector: Burndy connector and BNC

There are 3 active connections inside the brass photodetector housing. A = red, B = black and C = red. Wires A and B connect to the upper part of the photodetector board and wire C is attached to the resistor in the lower right on the photodetector board.

The output signal from the detector connects via a blue wire on the board (lower left) to the BNC connector (green dot).

A.6 6-pin Burndy on Lidar Platform Box

This connector carries the HV power for the photodetector as well as ground and +12 V. These wires come into the platform box from the Blue Box Burndy connector.

<u>Burndy Pin</u>	<u>color</u>	<u>3-wire cable</u>	<u>Function</u>
A	blue	clear	
B	black	black	
C	green	red	

Inside the box, a splice is made into a 6-wire cable to the camera power supply (black transformer mounted in box) and the 6-wire cable (with 5 active lines) goes to the arm with the 4 BNC connectors and one Burndy connector.

E	red	to camera power supply wire w/writing
F	yellow	to camera power supply

Appendix B. Other Hardware Information

B.1 Limit Switches Summary Positions

Use the c:\AT6400\TEST.EXE program to observe the switch positions (1 = closed, 0 = open).

Axis 1 is AZIMUTH

Axis 2 is ELEVATION

	AXIS 1	AXIS 2
Telescope Positioned Off both Limits		
HOME	0	0
CCW	1	1
CW	1	1
Telescope at CW limit @ 190 degrees		
HOME	1	0
CCW	1	1
CW	0	0
Telescope at CCW limit @ 0 degrees		
HOME	0	1
CCW	0	0
CW	1	1

B.2 Signal Digitization

B.2.a. Analog-to-Digital Conversion

The Signatec PDA12 board uses dual-slope conversion: the input voltage, V_{in} , is converted to a current which charges a capacitor for a precise amount of time, t_{in} . At the end of t_{in} , a Start signal is given and the capacitor is discharged by a constant current source, I_r , until the capacitor is discharged completely. At this time, the Stop signal is given. The time interval between Start and Stop is proportional to V_{in} . This value is written to one of the memory registers on the board and subsequently mapped to the PC in 16kB blocks. The 16kB represents 8k data samples (16-bit length).

The PDA12 board is a 12-bit digitizer capable of operating at 60MHz when in single-channel mode. This means that the board is capable of distinguishing 2^{12} or 4096 different states or channels and a sample is captured every 1.67×10^{-8} sec (~ 17 nsec) (if operating one sample per clock interval). Note that the way the board is setup it actually has two 60MHz channels, therefore, to get maximum 100MHz sampling rate it alternates between the two channels. The LidarDCP program is used to select the sampling rate (10ns generally) as well as the gain amplification on each channel (range from 1 to 50).

B.2.b. Sample -and- Hold Circuit

Inside the Blue Box are the Analog Modules Sample -and- Hold chip (model 613, square) and the Analog Modules 521-5 amplifier chip. The function of the S&H is to allow very fast analog sampling of the lidar signal. The S&H captures the peak analog input signal and holds it prior to conversion by the digitizer.

B.2.c. Sequence of Events during data collection

1. Command lidar to scan.
2. Sample & Hold is reset.
3. Digitizer is reset.
4. Wait for laser pulse.
5. Both the APD “signal” pulse and the laser “fire” pulse (from Thorlabs detector w/o filter inside the periscope) go to digitizer.
6. Digitizer takes data (50-70 μ sec) and sets a “done” bit.
7. Read the “done” bit (1-2 μ sec), then read Sample & Hold (15 μ sec)
8. Transfer data from digitizer to memory (milliseconds)
9. Do signal averaging.
10. Reset for next pulse.

B.2.d Range Resolution Calculation

For the laser pulses emitted by the lidar, the distance the pulse travels from the lidar (“Range”) is:

$$\text{Range} = \frac{1}{2} (\text{speed of light}) (\text{travel time})$$

Since the laser outgoing pulse (12nsec wide) pulses at a 30 Hz repetition rate (time between laser pulses is $1/30 = 0.033$ sec = 33millisec), the distance the light travels between laser pulses is:

$$3 \times 10^8 \text{ m/sec} * 33 \times 10^{-3} \text{ sec} = 10 \times 10^6 \text{ m} = 10000 \text{ km,}$$

but since the outgoing pulse must return to lidar to be detected, the maximum travel distance between pulses is half of this or 5000 km.

In practice, many pulses are averaged to increase signal/noise at the expense of a longer data acquisition time along a single line-of-sight. For example, 50 laser pulses per line-of-sight would require an averaging time of 1 sec (=50 * 20×10^{-3}).

How does the digitizer sampling period determine the Range Resolution of the lidar?

Since the distance the laser pulse travels between sampling events is determined by the sampling time interval, the lidar range resolution depends on the choice of sampling period.

For example, the 33ns sampling period is how often the photodetector output is sampled by the PDA12 board (this corresponds to a frequency of $3 \times 10^7 \text{ sec}^{-1}$). Using the range equation above,

$$\frac{\text{Range}}{\text{traveltime}} = \frac{3 \times 10^8 \text{ m/s}}{2(10^9 \text{ ns/s})} = 0.15 \text{ m/ns}$$

Therefore, Range Resolution = 0.15 (digitizer sampling period)

<u>Sampling Period</u>	<u>Range Resolution</u>
10 ns	1.5m
17 ns	2.55m
33 ns	4.95m
50 ns	7.5 m

Appendix C. CFR 400 Laser Operating Manual

Not included in this document. Contact Markus Pahlow (mpahlow@jhu.edu or 410.516.4483) for further information about the CFR 400 laser operating manual.

Appendix D. Daily maintenance

To be performed by the personnel on site.

- a) Check the laser shot counter (can be found under the main menu of the laser power supply control panel). The flashlamp needs to be replaced after ~20 million shots!
- b) The tank with the distilled water to cool the laser head must be full at all times during operation.
- c) Check the hard disk space on the lidar computer. Make sure that there is always sufficient disk space before starting to take data. One day of measurements during intensives requires approximately 360MB when using one wavelength.
- d) Control the laser power (main menu of laser power supply). The default value is 18.99 J, which needs to be adjusted depending on the type of measurement that needs to be done.
- e) Check the beam alignment by using the oscilloscope and adjust if necessary.
- f) Clean periscope mirrors and telescope.

All maintenance must be reported in the daily maintenance form. Note any irregularities or unusual events in the field logbook and notify Markus Pahlow. Order replacement parts and items needed for cleaning in a timely fashion.

JHU-LIDAR daily check list

day	date	Shot counter	Distilled water	hd space on lidarcomputer	Laser power	Beam alignment	Periscope mirrors and telescope	signature
mon								
tues								
wed								
thurs								
fri								
sat								
sun								

Appendix E. Contacts

person	institution	phone	Email
Bill Eichinger	Univ of Iowa and IIHR	(319) 335-6034 (office)	\ william-eichinger@uiowa.edu
Britt Holmen	Univ CA at Davis	(530) 752-1213 (office)	\ baholmen@ucdavis.edu
Rich Erickson Roger Gillam (ext. 112)	Big sky laser PO Box 8100 601 Haggerty Lane Bozeman, MT 59715	800 914 8216 - service 800 224 4759 - main Fax: 406 586 2924	\ rerickson@bigskylaser.com \ jgillam@bigskylaser.com \ customerservice@bigskylaser.com
Markus Pahlow	JHU	410-516-4483	\ mpahlow@jhu.edu
Marc Parlange	JHU	410-516-6042	mbparlange@jhu.edu
Jan Kleissl	JHU	410-516-5031	\ jan@kleissl.com

The main contact persons are Marc Parlange and Markus Pahlow.