RAYMETRICS BACKSCATTER LIDAR
MODEL LB10 D-200

User's Manual &

Technical Handbook

DOC 0015

December 2005

PREFACE

This User's Manual contains the technical information needed to properly operate and maintain RAYMETRICS-LB Backscatter/Polar LIDAR system. It provides instructions for set operation, service and preventive maintenance, and a troubleshooting (fault-isolation) guide.

The lidar system consists of four major sub-assemblies: (1) the Lidar telescope (including optical emitter, receiver and detection unit), (2) the Laser source (including the laser head, the power supply and cooler unit), (3) the Transient recorder unit and (4) the portable PC, which includes all the software modules for data acquisition, analysis and visualization.

Caution and warning labels, in accordance with CDRH and CE requirements, are prominently displayed on the Laser Head and power supply of the laser unit, as well as in the front and rear panel of the lidar telescope. For safety, the maximum ratings indicated on the system labels are in excess of the normal operating parameters.

The laser system produces laser radiation, which is hazardous to eyes and skin, can cause burning and fires and can vaporize substances. The laser safety chapter in the CFR Ultra User's Manual contains essential information and user guidance about these hazards.

QualityControl

FINAL TEST DATA SHEET

Test Date: February, 2006

Telescope Alignment:		√
Laser Beam Alignment Procedure:		√
Lidar signals:	532 nm	√
Laser Security Interlocks:		√

Any suggestions to be returned to:

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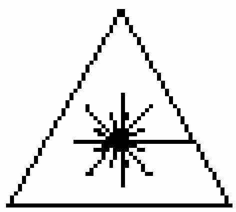
Chapter 1

Laser Safety

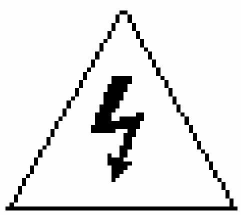
DANGER

VISIBLE AND/OR INVISIBLE LASER RADIATION

The Model LB10-D200 Lidar System carries a Class IV laser. Its output beam is, by definition, a safety and fire hazard. Precautions must be taken to prevent accidental exposure to both direct and reflected beams. Raymetrics S.A. shall not be held responsible for accidents to the user or to third parties caused by non-compliant use of the equipment.
The warning symbols below will be used throughout this document and on equipment to warn the user of important instructions which, if not followed, could lead to potential danger.



WARNING - LASER RADIATION, avoid exposure of eyes or skin to direct or diffused rays. Permanent ocular lesions may occur.



WARNING - HIGH VOLTAGE, electric shocks and burns from capacitor discharge or power circuits could lead to serious injury or even death.

Class 4 laser systems may produce lesions both by the direct beam or its spectacular reflections and by diffuse reflections. These systems must only be implemented by personnel with sufficient experience with their operation; these personnel must be approved by the laser safety officer. The safety rules explained below must be read and followed by everyone who uses the laser.

Always wear protective eyewear

1. Never look at the direct beam from the laser or from a hand piece or one of its reflections.
2. Avoid exposing any part of the body to the beam. Limit access to the work area to the required personnel only. Evacuate all objects with a reflecting or shiny surface from the work area, as well as all inflammable materials.
3. The laser beam emission area must be lit correctly in order that the eye pupils of the people present open as little as possible, which limits the amount of light which penetrates into the eye and reduces the risks of lesions.
4. Only use the laser in supervised areas, which are clearly marked and have supervised access. It is recommended that access ways to work areas be equipped with contactors connected with the external safety loop of the laser. The sign supports must be appropriate and clearly visible.
5. During normal operation, a warning area limited by barriers is necessary to warn all people of the potential risk that lies within the laser area.
6. *Only qualified people may operate the lasers. When not in use, the lidar must be completely inoperable and it must be made impossible for unauthorized people to operate them, for example, by removing the door key or the laser key.*
7. Using laser radiation to aim at individuals, vehicles, aircraft or any other flying object is formally prohibited.
8. Due to the risk of electric shock, the power supplies must be switched off and the power supplies must be disconnected from the flashlamp prior to any maintenance operation. Electric shocks or burns resulting from the power supply of the network or from condenser discharges may cause serious wounds and traumas. They may be fatal.

Precautions for Safe Operation of Class IV Lasers

1. Keep the protective covers on the Laser Head as much as possible. Do not operate the laser with the covers removed for any reason.
2. Avoid looking at the laser output beam.
3. Do not wear reflective jewelry while using the laser, as it might cause inadvertent hazardous reflections.
4. Use protective eyewear at all times

5. Operate the laser at the lowest possible beam intensity, given the requirements of the intended application.
6. Increase the beam diameter wherever possible to reduce beam intensity and thus reduce the hazard.
7. Avoid blocking the laser beam with any part of the body.
8. Establish a controlled access area for laser operation. Limit access to those trained in the principles of laser safety.
9. Maintain a high ambient light level in the laser operation area so the eye pupil remains constricted, thus reducing the possibility of hazardous exposure.
11. Post prominent warning signs near the laser operation area.
12. Provide enclosures for the beam path whenever possible.
13. Set up an energy absorber to capture the laser beam, preventing unnecessary reflections or scattering.

WARNING: Use of controls or adjustments, or performance of procedures other than those specified in this User's Manual may result in hazardous radiation exposure.
Follow the instructions within this manual carefully to ensure the safe operation of your laser. At all times during laser operation, maintenance or servicing, avoid unnecessary exposure to laser or collateral radiation that exceeds the accessible emission limits listed in "Performance Standards for Laser Products," United States Code of Federal Regulations, 21 CFR 1040.10(d).

Chapter 2

Introduction to the lidar technique

The atmospheric laser remote sensing implies the so-called light detection and ranging (lidar) technique, to probe the atmosphere up to altitudes as high as ~120 km. The development of matured pulsed laser sources has enabled the range-resolved measurements of the principal atmospheric gases[1] and atmospheric/meteorological parameters, in a manner somewhat analogous to the radar technique. In this mode of operation a short laser light pulse is emitted to the atmosphere in one or more wavelengths (Fig. 1).

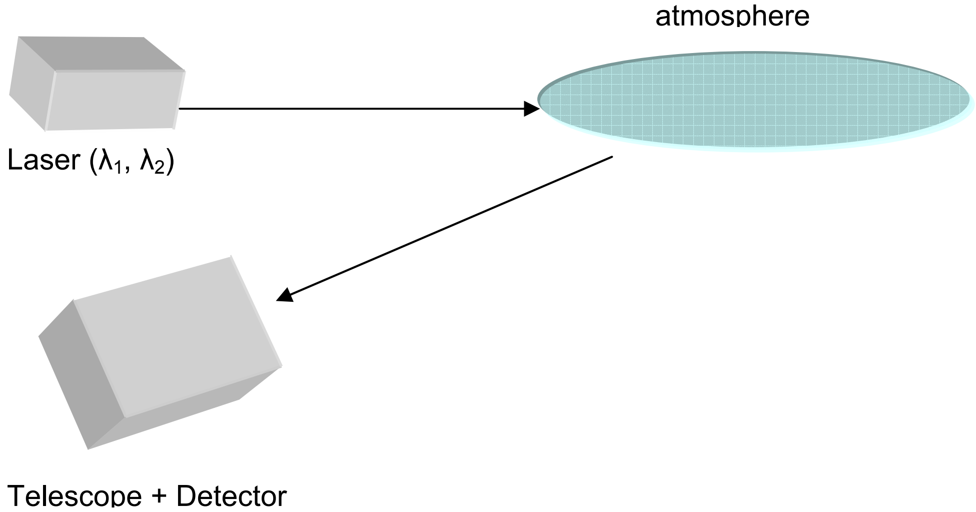


Fig. 1: The principle of operation of the lidar technique.

The time between the transmission of the laser pulse and the arrival of the backscattered return signal is directly related to the range at which the scattering occurred. The most common processes related to laser pulse scattering by the suspended aerosol particles include the *elastic* Mie and Rayleigh scattering and the *inelastic* Raman scattering[2].

The atmospheric volume being probed backscatters the laser radiation and a receiving telescope is used to collect all the backscattered laser light occurring through elastic and inelastic processes. Wavelength-separation units are used to spectrally separate the lidar signals at various wavelengths and to reject the atmospheric background radiation. The lidar signals are then fed to fast detectors (photomultiplier tubes: PMTs). The PMT output signals after amplification and digitization are sent to a central computer machine for further processing and storage.

The lidar observations of suspended aerosol particles can be made remotely with high spatial and temporal resolution using the lidar technique. The lidar systems can be operated from ground or mobile platforms, such as aircrafts, helicopters or satellites.

The basic lidar equation is given below:

$$P(z) = P_o \frac{c\tau}{2} \beta(z) A_{tel} O(z) \frac{1}{z^2} \exp\left[-2\int_0^z a(z^*)dz^*\right] \qquad (1)$$

where, P(z) is the power incident on the receiving optics from distance z, P_o is the laser output power, τ is the duration of the laser pulse, c is the velocity of light, $\beta(z)$ is the volume backscattering coefficient, $a(z)$ is the extinction coefficient of the atmosphere and A_{tel} is the receiving telescope aperture. $O(z)$ is the so-called geometrical form factor (or overlap factor). This factor represents the probability of radiation in the target plane at range z reaching the detector, based on geometrical considerations. The $1/z^2$ dependence leads in many applications to a signal-amplitude dynamic range that extends over several decades. Therefore, two detection modes are used: the analog detection mode and the photon counting operation mode (section 2.3.2).

The detection of the suspended aerosol particles can be performed by an elastic lidar system (single or two-wavelengths) or by an inelastic (Raman) lidar system. The elastic backscattered lidar signals can be inverted using the Klett's inversion algorithm[3], while the inelastically backscattered lidar signals can be inverted using the Raman inversion technique, as presented by Ansmann et al. (1992)[4].

Chapter 3

Lidar sub-systems

3.1. Emitter

The lidar emitter consists of three sub-units: the laser source, the beam expander unit and the reflective mirrors (Fig.2).

Fig. 2: The lidar emitter.

3.1.1. Laser source[1]

The laser source used is a pulsed Nd:YAG laser emitting short pulses at 1064 and 532 (Fig 3a and 3b). The pulse repetition rate is typically 10 Hz to 20 Hz. The pulse duration is of the order of 6-9 ns. The laser source is factory preset for maximum energy output at its second (SHG) frequency (532 nm). Therefore, the user should not change, remove or alter any of the laser parts or sub-units. The laser consists of two major components: the optical head and the power supply. They are connected together by cables, wires and hoses running through an umbilical. A detailed description of the characteristics, specifications and operation mode of the laser source is given in the LASER'S INSTRUCTION MANUAL.

[1] Some of the Laser source characteristics may vary from model to model

Fig. 3a: The laser power supply and controller

Fig. 3b: The laser head

Safety Instructions

- **The user is requested to wear the laser protective eyewear during the laser operation. Do not stare into the laser beam even when using your laser protective eyewear goggles. It may be too dangerous for your eyes!**
- **Do not put any obstruction or reflective object in the emitted laser beam. Primary or secondary reflections may damage your eyes or reflected back to the laser causing damage!**
- Before you turn off the laser, you should leave the water circulation pump in the ON position for at least 10-15 min. to cool down the laser optical head.
- Always respect the instructions of the laser manufacturer regarding the minimum number of laser shots requiring the replacement of the laser head flash lamps (see LASER'S INSTRUCTION MANUAL).
- Always respect the instructions of the laser manufacturer regarding the replacement of the de-ionizing filter/unit of the laser system (see LASER'S INSTRUCTION MANUAL).

3.1.2. Beam Expander Unit (BEXP)

The Beam Expander Unit (BEXP) contains one beam expander and is designed to provide a factory-set expansion of the laser beam at 532 nm. The beam expansion factor is equal to 3 for 532. This beam expansion permits to obtain a magnification factor (MF) of 3 (MF=3) and a reduction of the laser beam divergence by a factor equal to MF. The expanded laser beams are emitted to the atmosphere through specially conceived highly transmission windows placed on the outer cover box of the lidar system.

Attention!

- **Do not stare into the laser beams leaving the BEXP unit, even when using your laser protective eyewear goggles. It may be too dangerous for your eyes!**
- Do not touch the optical components of the lidar system (laser mirrors, laser windows, BEXP lenses, protective windows, etc.). It may lead to a complete destruction of their optical coatings and to a misalignment of the lidar optics.

3.1.3. Reflective mirrors

The reflective mirror (RM) of the lidar system is conceived to provide a high reflection (>98%) at the reflected wavelength (532 nm). The laser mirror is carefully selected for its high quality and long-term durability. Diameter used (phi 200 mm) match the required specifications of the BEXP unit used.

The reflective mirror (RM) is mounted on high quality mirror mount which permits the alignment of the emitted laser beams with accuracy of the order of several micro-radians (μrad).

Attention!

The reflective mirrors are aligned during the on-site installation of the lidar system. However, during operation and due to thermal gradients existing at your site the laser beams may be slightly misaligned. The installation technician of Raymetrics S.A. will give you the correct instructions how to align the laser beams (see alignment instructions on section 4.4).

3.2 Receiving system

The receiving system consists of two sub-units: a receiving telescope (T) (Fig. 4a) and a wavelength separation unit (WSU) (Fig. 4b).

3.2.1. Telescope

The receiving telescope of the lidar system is based on a Cassegrainian design. The primary reflective mirror has a diameter of 200 mm and is coated with a durable high reflective coating suitable for the 350-1100 nm spectral region. The optical material selected shows a very low thermal expansion coefficient.

The secondary reflective mirror has a diameter of 9 mm and is coated similarly to the primary mirror. The received lidar beams are then collected and focused on an Optical Unit (OU) placed on the telescope's focal point. The OU is equipped with a 2 mm diameter diaphragm (field stop). At the exit of the OU the lidar beams are then collimated.

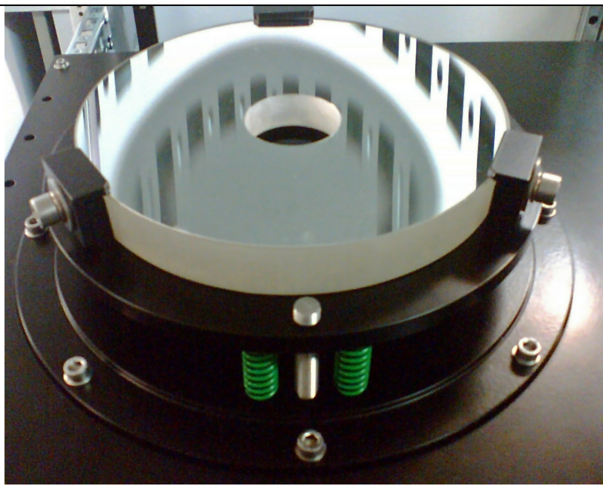


Fig. 4. The primary mirror of the telescope.

3.2.2. Wavelength separation unit

At the entrance of the Wavelength Separation Unit (WSU) of the lidar system the received lidar beams are collimated to one parallel beam having a diameter of 10 mm.

At the specific exit a specially designed interference filter (IF) are used to select the lidar wavelengths and to reject the atmospheric background radiation during daytime and nighttime operation.

Table 1 shows the respective full width at half maximum (FWHM) of the interference filters used at 532 nm.

Wavelength (nm)	FWHM (nm)
532	0.5

Table 1: FWHM values of the interference filter used.

3.3. Signal acquisition unit

The signal acquisition unit (SAU) consists of two sub-units (Fig. 5a and 5b): the lidar signal detector which is a photomultiplier tube, PMT (Fig. 5a) and the detection electronics (Fig. 5b), working in two modes: the analog detection mode and the photon counting detection mode.

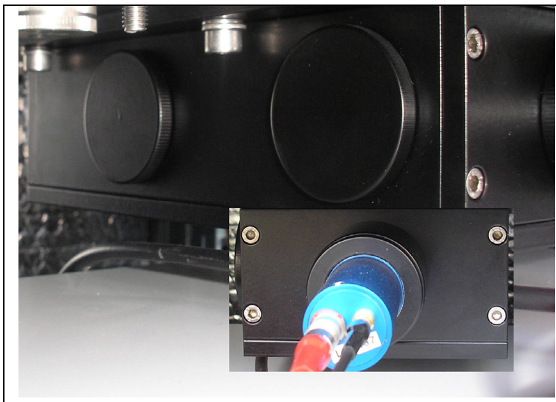


Fig. 5a: Detection box and Wavelength Separation Unit. The signal acquisition unit: photomultiplier tube: PMT.

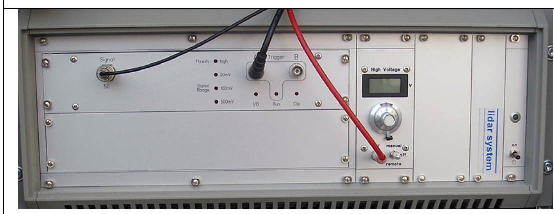


Fig. 5b. The signal acquisition unit: Transient Recorder and High-Voltage power supplier of the PMT. Spare space for system expansion is available

3.3.1. Photomultiplier tubes

The spectrally resolved lidar signals inside the WSU are detected by a photomultiplier tube (PMT) directly mounted at the respective exits of the WSU. The PMT used are selected to be compact and to provide optimum operation in the spectral range close to 532 nm. The PMT works in the pulse mode regime and are characterized by a short rise time constant.

The PMT has been tested prior to shipment. The PMT optimum working voltage (for linear operation) is between 750-850 V, depending on the amplitude of the received signal and the atmospheric conditions (background skylight conditions during daytime or nighttime conditions and/or cloud presence). Usually, during daytime conditions the PMT working voltage is slightly lower than during nighttime operation.

Technical Facts

Part Number	
PM Type	HamamatsuR740
PM High Voltage (V)	0-1000
Supply Voltages (V)	+15
Current Limit (?A)	200
Resistance Anode-GND (Mohm)	1.0
Output Connector	BNC (50 Ohm)

Attention!

- For optimum operation the temperature and humidity conditions should be kept unchanged during field operation.
- Operation at HV higher than 850 V should lead to PMT saturation, thus to a *non linear* operation and/or possibly to PMT permanent failure.

Humidity: Operation in a very damp atmosphere may lead to insulation problems, because of the high voltages (HV) used. Condensation gives rise to leakage currents which in turn increase the PMTs dark current. Therefore, the PMTs should be operated under the environmental conditions given in Appendix 2.

Light conditions: The PMTs are highly sensitive to ambient light conditions, therefore never expose the PMTs to ambient light, even when no HV is applied. If high voltage is applied to the PMTs which are exposed to ambient light, the PMTs are permanently destroyed.

Mechanical stress: Like all electronic devices, PMTs should be protected against mechanical and thermal stress. Vibration or shock transmitted to the PMT dynodes can modulate the PMTs gain.

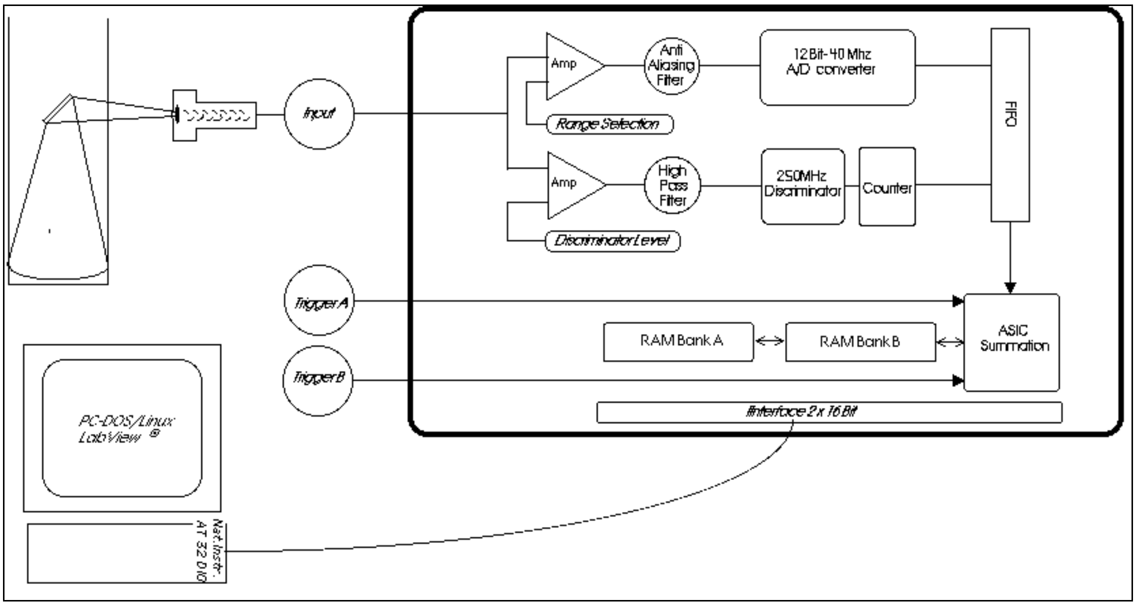
Magnetic fields: Never expose the PMTs to magnetic fields, even as weak as the earth's one. They may affect the PMT's performances. Strong fields may permanently magnetize some parts of the PMTs, thus affecting their performance.

Note: For more details of the PMTs technical specifications (dark current, rise time, gain, etc.) please refer to the PMTs manufacturer Technical Leaflet.

3.3.3. *Detection electronics*

Concept

The Licel transient recorder is a powerful data acquisition system, especially designed for remote sensing applications. To meet the demanding requirements of optical signal detection, a new concept was developed to reach the best dynamic range together with high temporal resolution at fast signal repetition rates.



For the first time analog detection of the photomultiplier current and single photon counting is combined in one acquisition system. The combination of a powerful A/D converter (12 Bit at 20 MHz) with a 250 MHz fast photon counting system increases the dynamic range of the acquired signal substantially compared to conventional systems. Signal averaging is performed by specially designed ASIC's which outperform any CISC- or RISC-processor based solution. A high speed Ethernet data interface to the host computer allows readout of the acquired signal even between two laser shots. The implementation of this concept makes the Licel transient recorder the state of the art solution for all applications where fast and accurate detection of photomultiplier, photodiode or other electrical signals is required at high repetition rates.

Principle of operation

The Licel transient recorder is comprised of a fast transient digitizer with on board signal averaging, a discriminator for single photon detection and a multichannel scaler combined with preamplifiers for both systems. For analog detection the signal is amplified according to the input range selected and digitized by a 12-Bit-20/40 MHz A/D converter. A hardware

adder is used to write the summed signal into a 24-Bit wide RAM. Depending on whether trigger A or B is used, the signal is added to RAM A or B, which allows acquisitions of two repetitive channels if these signals can be measured sequentially.
At the same time the signal part in the high frequency domain is amplified and a 250 MHz fast discriminator detects single photon events above the selected threshold voltage. 64 different discriminator levels and two different settings of the preamplifier can be selected by using the acquisition software supplied. The photon counting signal is written to a 16-Bit wide summation RAM which allows averaging of up to 4094 acquisition cycles.

3.3.3.1. Analog detection

The analog detection mode is used to detect intense lidar signals coming from relatively short distances (typically less than 8-10 km). A transient recorder operating in the analog detection mode is based on an analog-to-digital converter (ADC), which samples and digitizes the lidar signals with a sampling rate of 20-40 MHz (depending on the type of the transient recorder used) with a 12-bit resolution. A memory length up to 8192 or 16000 time bins (Tr-xx-80 or Tr-xx-160) depending on the transient recorder type) can be selected. Each time bin corresponds to a spatial resolution of 3.75 or 7.5 m (depending on the sampling rate of the transient recorder used, Tr-20-yy or Tr-40-yy). For instance the 20 MHz sampling rate corresponds to a 7.5 m spatial resolution.

Typical lidar signals acquired in the analog detection mode is shown in Fig. 6.

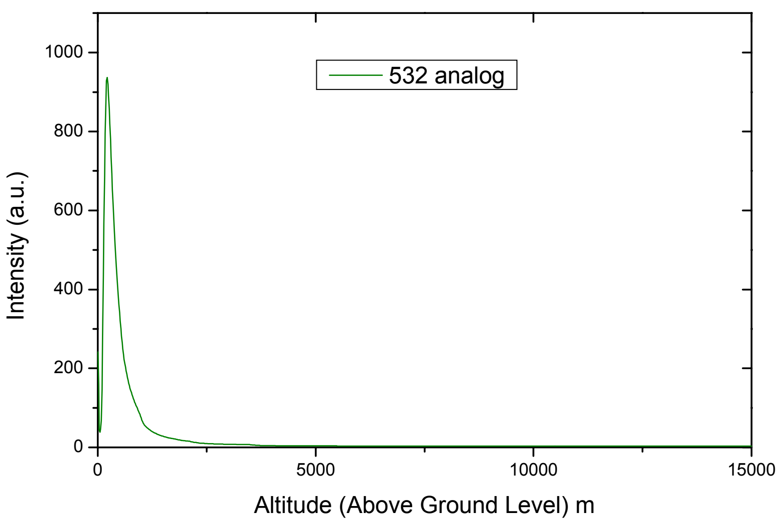


Fig. 6: Typical lidar signal acquired in the analog detection mode.

3.3.3.2. Photon counting detection

The photon counting detection mode is used to detect very low intensity lidar signals coming from relatively large distances (typically higher than 8-10 km). Thus, the PMT is operated under *single electron* conditions. Flux levels as low as a few tens of photons per second can be measured. In the photon counting mode the level of the incident flux is such that the cathode emits only single electrons. The individual anode charges due to single photons are integrated to produce proportional voltage pulses, which are passed by a discriminator to a pulse counter, whose output over a pre-set time period is a measure of the incident flux.

Because of statistical fluctuations in the electron multiplication, the amplitude of the single-electron pulses is distributed according to the Poisson statistics. To obtain a satisfactory signal-to-noise ratio (SNR) of the lidar signal in the photon counting mode, a sufficiently large number of laser shots should be obtained (normally more than 1000). If the received lidar signal is higher than 60-100 MHz the PMT output signal should be corrected to take into account the dead-time effect. If the dead-time of the counter (τ_d) is comparable to the mean interval separating two successive pulses, the counting error may be appreciable. If a dead-time correction has to be applied, then if the N_{obs} is the observed count rate, then the true count rate (N_{true}) corrected for the dead-time effect is given by:

$$N_{true} = \frac{N_{obs}}{1 - N_{obs} \times \tau_d} \qquad (2)$$

Note: The value of τ_d depends on the type of the PMT module used (ie. τ_d = 4 ns).

Specific environmental effects may increase or decrease the count rate. For instance, background radioactivity increases it.

A typical lidar signal acquired in the photon counting detection mode is shown in Fig. 7.

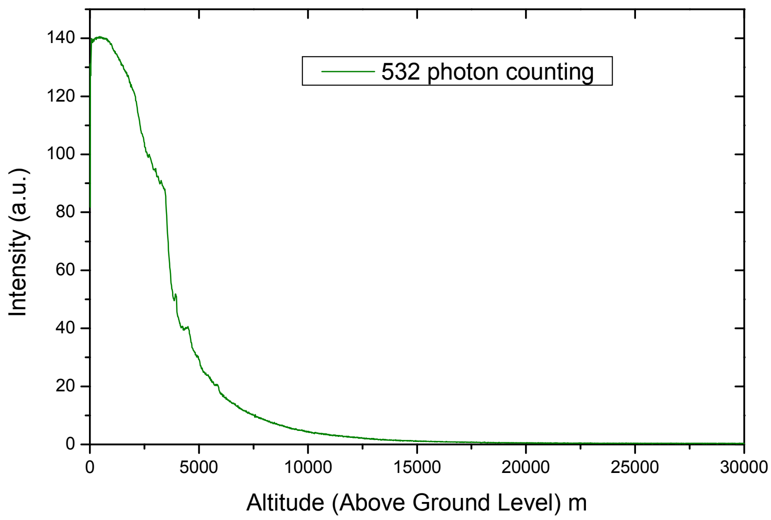


Fig. 7: Typical lidar signal acquired in the photon counting detection mode.

Note: For more details and technical specifications of the detection electronics unit, please refer to the detection electronics manufacturer Instructions Manual.

3.4. Signal processing

The lidar data processing is fulfilled in two steps: (i) *lidar data pre-processing* and (ii) *lidar inversion algorithm,* which are explained hereafter.

Step I- Lidar data pre-processing

The lidar data pre-processing is performed on the raw lidar signals. Each lidar data file (containing the average of a certain number of backscattered lidar signals S(z) coming from a distance z) is corrected for the background noise contribution (BG) due to atmospheric skylight and electronic noise of the instrumentation used. A distance square-law correction (z^2) is applied to each data point (time bin) to compensate for range-related attenuation from the atmosphere. Then, the natural logarithm of the resulting quantity is calculated. On the resulting *log range-corrected* signal SLOG where $\mathrm{SLOG} = \ln\left[(\mathrm{S}(z) - \mathrm{BG})z^2\right]$, a running low-pass derivative digital filter, with variable path is applied. The smoothing method is a running least-square fit of the dataset to the second-order polynomial, which represents a good fit for the vertically decreasing atmospheric scale height (Ancellet al., 1989)[1]. The spatial resolution of the measurement is related to the number 2n+1 of data points fitted to the second-order polynomial.

Step II- Lidar inversion algorithm

To retrieve the vertical profile of the aerosol backscatter coefficient (b_{aer}) at 532 nm the improved Klett inversion technique is used. This technique is based on a far-end backward iterative technique, taking into account also the atmospheric molecular contribution as described by Klett (1985)[3]. The uncertainties associated with this technique have been discussed in detail by Chazette et al.(1995)[5] and by Boesenberg et al. (1997)[6], while the limitations of this technique arise from an ill-posed mathematical problem (one set of signals measured with two sets of parameters to be retrieved: the aerosol extinction and backscatter coefficients) in conjunction with the a priori assumptions made for the lidar inversion, such as the fixing of the 'reference height' (where the atmosphere is purely molecular), and of the so called aerosol '*lidar ratio'LR where* $LR(sr) = \frac{a_{aer}\left(km^{-1}\right)}{\beta_{aer}\left(km^{-1}sr^{-1}\right)}$.

At 355 nm the inelastically backscattered lidar signals can be inverted using the Raman inversion technique, as presented by Ansmann et al. (1992)[4]. This technique is applicable mostly under low light conditions (during early evening and nighttime) since the Raman lidar signal is sensitive to the presence of daytime background skylight.

Chapter 4

Unpacking and Installation

4.1. Unpacking the lidar system

The lidar system has been carefully packaged in a wooden case to assure its secure delivery to the customer.

- *Inspection after shipment*

Check carefully the crates for damage before uncrating the lidar system. Take notes of all visible external damage. To unpack the lidar system start to uncrate the upper parts first, leaving the heavier metallic pieces as the last ones to unpack. Check every component you unpack for external damage (scratches etc.). In any case, all optical material should be left in their boxes of origin since they should be unpacked only by the authorized personnel of Raymetrics S.A. during the lidar installation on site.

Note: It is strongly recommended that the unpacking of the lidar and laser systems to be performed only by the authorized personnel of Raymetrics S.A. during the lidar installation on site.

4.2 Installation of the lidar system

Site:

For proper operation of the lidar system the ambient temperature should range between 5 and 40^{o}C.

It is preferable that the lidar system is positioned and secured on a solid horizontal surface. When choosing a place for your lidar system other than an open field, assure an opening (window) over it, with an area 15-20% larger than the total area of the emitting/receiving windows of the lidar system.

Keep always in mind:

- access should be available from all sides of the lidar system, especially to those where the alignment is performed,
- Choose a location for the laser and power supply and cooling unit, cabinet (PCC), such that each side of the cabinet is not less than 50 cm away from a wall or obstacle. Front and rear panels of the instrument should be placed at least 100 cm away from a wall or other obstacle, to allow efficient cooling of the instrument.

- Power and water services:

Power is to be 220 V or 110 V (50/60 Hz) with available average current up to 5 A or 10 A, respectively. This information is clearly indicated on the rear panel of the PCC unit. The cooling unit is a water/air heat exchanger and does not require any tap-water facility.

The on-site installation and lidar system alignment will be totally assured by the Raymetrics S.A. personnel.

Attention !

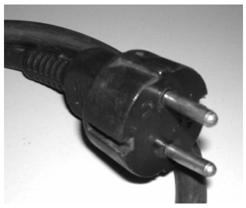
No attempt should be made by the user to install the lidar system. Damage occurring due to the non-respect of the previously mentioned instructions will not be covered under our warranty.

4.3 Connection and Start-UP

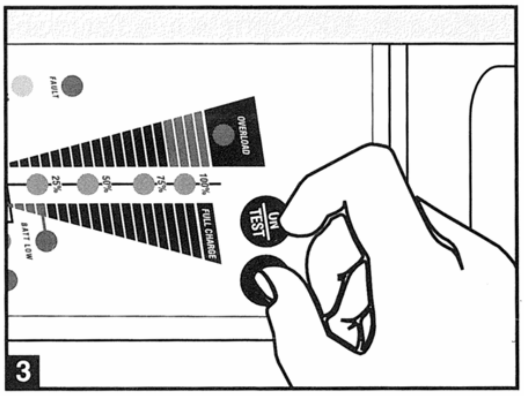
1. Plug your Lidar's line cord female blue colored socket into the blue appliance inlet at the right side of your instrument

2. Plug your Lidar's line cord into an electrical outlet

3. Turn on the Main Switch at Power box *(see Electrical wiring figure)*



Once your UPS (model depended) is power properly, the fan and all Indicator Lights will turn ON. The "Line" and "Load active meter" LEDs will illuminate and the UPS will emit a beep to indicate normal operation



4. (model depended) Turn your UPS ON:
   - Press the "ON/TEST Switch
   - Hold it for several seconds until you hear a beep
   - Release it

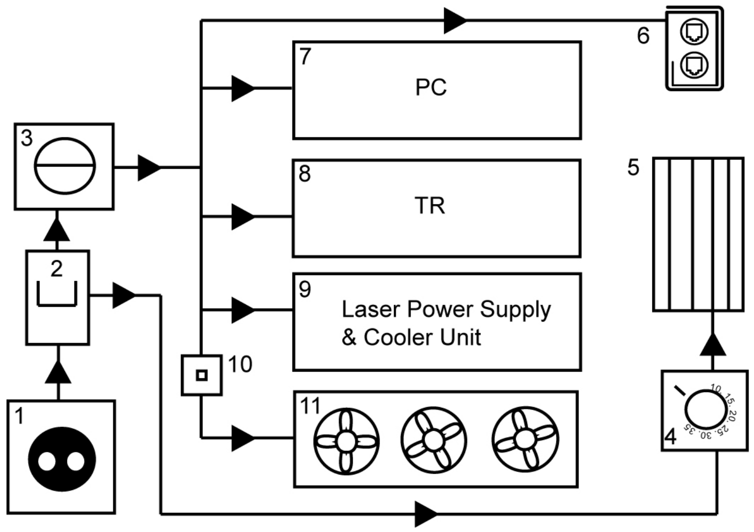
Your UPS will begin providing AC power to its outlet. The "ON LINE" LED will illuminate.

5. First Power UP Laser power supply unit

6. Power UP the rest of instruments

CAUTION: It is important to power up laser first.

Electrical Wiring Figure



1. General Power Input (outdoor)
2. Main Fuse
3. Main Switch (outdoor)
4. Heater Controller
5. Heater
6. Ethernet Switch
7. Panel PC (PPC103)
8. Transient Recorder
9. Laser Power Supply & Cooling Unit
10. Front door interlock
11. Fans

Optional Connections

Your lidar instrument will function properly without this connection:

Your instrument may come with a sealed panel mounting shielded RJ45 socket, which meets IP67 rating when mated with the suitable plug.

If you do not use woodhead IP67 sealed male connector humidity and water drops may damage your instrument.

If you do not use the socket, you MUST USE the accompanied dust cap which gives an IP65 rating.

4.4 Storage and Services

<u>Storage</u>

- Turn all the electrical units OFF.
- Turn the UPS off: press the “OFF” switch to turn power off at the UPS outlets.
- Disconnect the power cord from the lidar system.
- If you plan to store your lidar for an extended period of time, protect it against intense rain and humidity. Place it indoors or cover it up with a waterproof material.

WARNING: If you plan to store your lidar outside and there is even a minor possibility that the ambient temperature will drop below 5 ^{o}C, make sure that the power cord is NOT disconnected. That ensures that the heater will be automatically switched on in order to prevent freezing of the water in the laser cavity and permanent damage to the laser head.

WARNING: Follow the instruction for every unit on your instrument

<u>Service</u>

If returning your lidar to Raymetrics, please carefully pack the lidar using the original packing material that came with the unit.

CAUTION: If you are planning ship your lidar by air or install it in a cold environment, your laser system must be completely drained before transporting, since the coolant could freeze. Follow very carefully the instruction at laser manuals.

4.5 Software installation

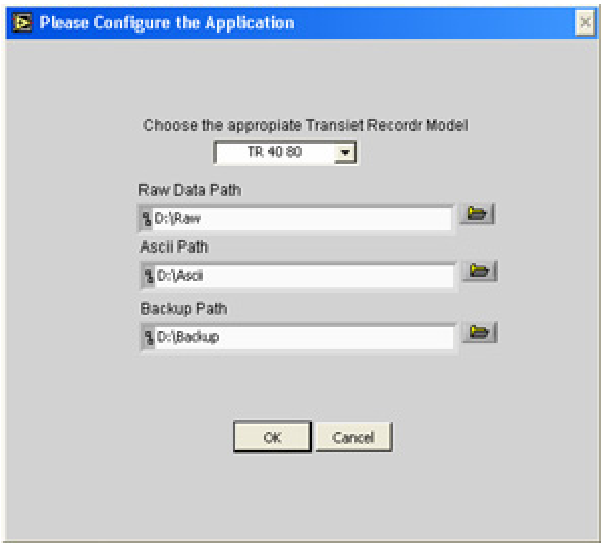
"This section of the manual may not be updated please call Raymetrics for an updated version"

Raymetric's Lidar systems are supplied with a computer system which has already installed all the necessary software for apparatus alignment, data acquisition and data preview. The following instructions are given in case that a reinstallation of the software is needed.

When insert the supplied CD from Raymetrics s.a. a setup program starts.

Install Lidar Acquisition Software.

Before setup ends, a configuration dialog appears.



Select type of Transient Recorder Tr-xx-yy (Tr-20-80)

xx: Sample rate

20 MHz (7.5 range resolution)

40 MHz (3.75 range resolution)

yy: FIFO memory Lenth

160 (16384 databins)

80 (8192 databins)

Select default location (folder) for saving raw data during data acquisition

Press Ok to confirm.

<u>Safety instructions</u>

All personnel within the lidar room must wear eye protective laser goggles, while the system is in operation. Even, low energy levels (of a few mJ) from the pulsed laser can cause irreparable eye damage.

Goggles should be at least :

Optical density (O.D.) >4 at 1064 nm
(O.D.) >4 at 532 nm

Note: It is strongly recommended that you keep a detailed Logbook on all operational details of your lidar/laser systems, and that you respect all instructions given by the lidar and laser manufacturers.

Chapter 5

Data Acquisition, Analysis and Visualization

5.1. Alignment Procedures

5.1.1 General

The lidar alignment is achieved in two steps. During the first step (coarse alignment), the far-range signal is monitored and the optical axes are fixed in a position where that signal is maximum. During the second step (fine alignment), the range-corrected lidar signal (RCS) $P_{cor} = P(z) \times z^2$ is compared to the range corrected exponentially attenuated Rayleigh backscattered coefficient $\beta_{cor} = \beta_{Ray} \times z^2 \times \exp(-\int a_{Ray} dz)$, at a range interval, which is considered free of any aerosol loading (pure molecular atmosphere). The molecular backscatter and extinction coefficients (β_{Ray} and a_{Ray}, respectively) can be calculated either from a Standard Atmosphere (U.S.S.A 1976)[7] or more accurately from available local radiosonde data. The advantages of this method are that it does not require any extra equipment; it can be performed on line during daytime or night-time measurements and is very accurate.

Fig. 8 shows a typical lidar signal correctly aligned 'matching' the pure molecular atmosphere (*fine alignment*).

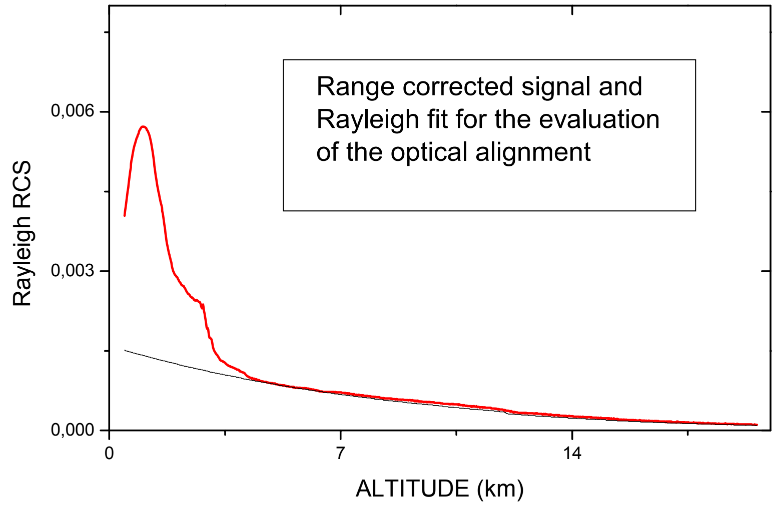


Fig. 8. Lidar signal aligned ‘matching’ the pure molecular atmosphere.

Once the fine alignment procedure has been terminated the lidar system is ready to acquire elastic and inelastic lidar data.

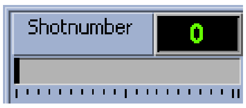
5.1.2 Using the Software

To use coarse or fine alignment click on the corresponding icon at panel desktop

Caution: *Before call the interface is suggested to have already start triggering the system, and all cable connection have been done.*

5.1.3 Description of Coarse Alignment Interface

If all cable connections have been done and the system is triggered successfully when open coarse alignment interface is running automatically and the shotnumber indicator increasing for every trigger pulse transient recorder receives (or a laser pulse if the recorder is triggered from the laser source).



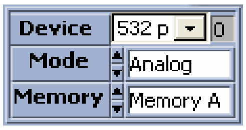
Shotnumber indicator

Set the desired value for #update indicator.

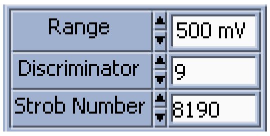
When shotnumber is equal to update value the data are read from the recorder, are displayed at the graph and the procedure starts over until click exit button.

The dataset which is displayed to the graph depends on the selections you made.

Select devise, mode and memory bank

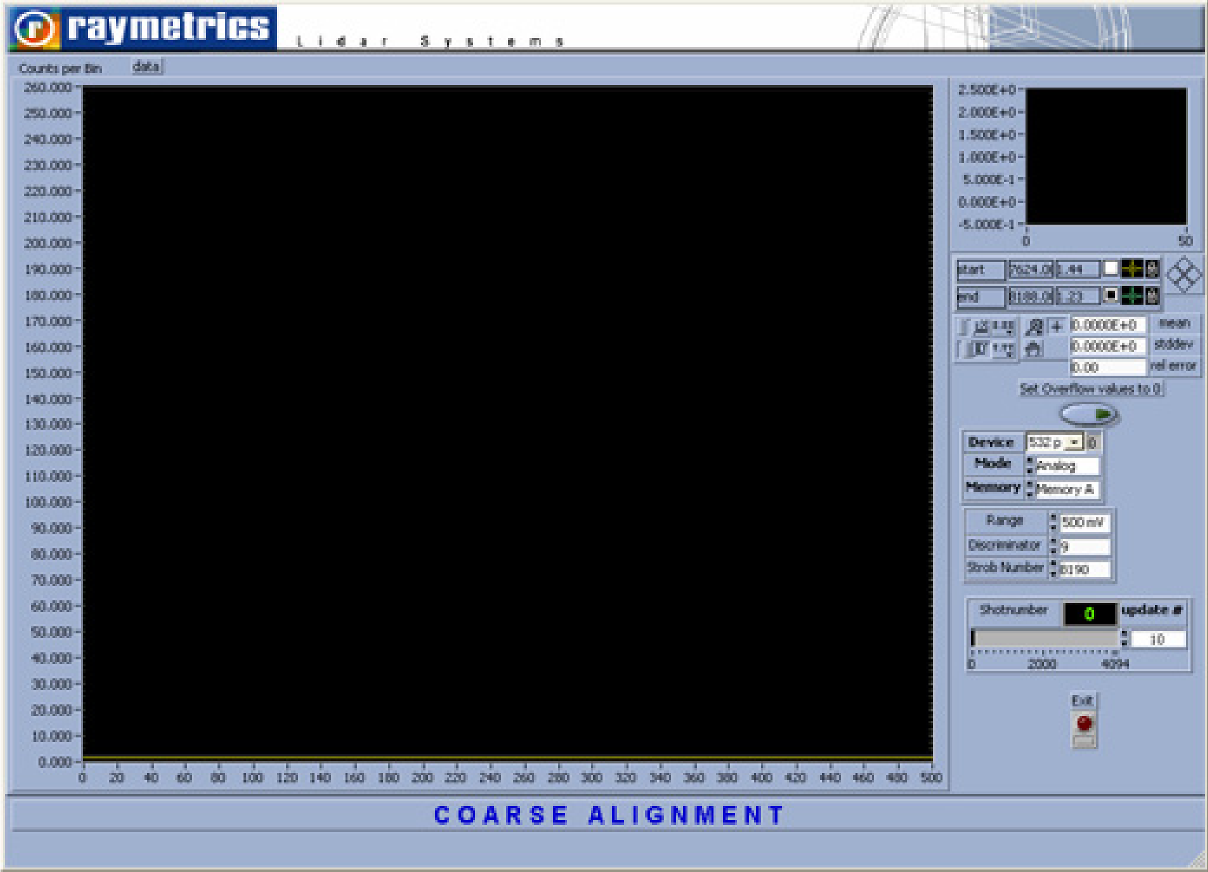


Set discriminator level, the number of bins to be transfered from the transient recorder and to be displayed (strob number) and the analog input range of the preamplifier. The signal starts at 0 and extends to -20, -100, or -500mV.



Turned on the overflow swith, to display all bins with overflow as 0.
The small graph at the right corner of the interface shows the average of the region of interest on the waveform graph that is selected by using the cursors.The cursors at the right of the waveform graph allow for the selection of a region to average over. The average of the region selected is displayed in small graph at the right upper corner. The x and y controls at the left allow the user to allow for autoscaling of the x or y axis. Default is autoscaling for the y axis and fixed values for the x axis. These can be changed by sliding the controls. The x.xx and y.yy controls allow for the specification of the format precision and mapping modes of the x and y axis.

For further information refer to electronic form of this manual and to Licel's documentation.
For more information about wave-graph refer to Labview manual.



WARNING:

NEVER BLOCK THE EMITTED LASER BEAM, WHILE THE PHOTOMULTIPLIERS AND THE APD IS SWITCHED ON. THE REFLECTIONS FROM THE BLOCKING OBJECT WILL DAMAGE THE PMTs AND THE APD. IF YOU WANT TO BLOCK THE LASER BEAM (e.g. for screening purposes during alignment) ALWAYS SWITCH OFF THE POWER SUPPLY OF THE PMT's AND APD AND COVER THE TELESCOPE (with a piece of soft black cloth) IN ORDER TO PREVENT THE ENTRANCE OF REFLECTIONS INSIDE THE TELESCOPE.

5.1.4 Description of Fine Alignment Interface

The interface and the operation of the fine alignment interface is quit similar with coarse alignment interface.

Below deference's are outlined.

Select height range for which the background calculation will be done be setting the first channel (1BC) and the length (2BC number of channels).

Height = 1BC* range resolution + altitude + range resolution/2)

Example: 1800*7.5 + 200 + 7.5/2 = 13.7 Km

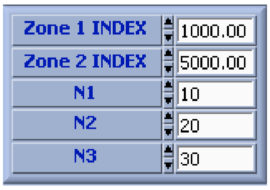
Attention: *Make sure that 1BC + 2 BC < ShotNumber*

Set ground temperature and pressure of the measurement sites (in Celsius an mha respectively)

Set the height range interval, which is considered free of any aerosol loading (pure molecular atmosphere), by entering values to Min R and Max R parameters (in Kilometers)

Attention: *Make sure that Max R < shotnumber*range resolution + altitude + range resolotution/2*

Smooth acquired range corrected signal.



Smooth is done by setting three height zones

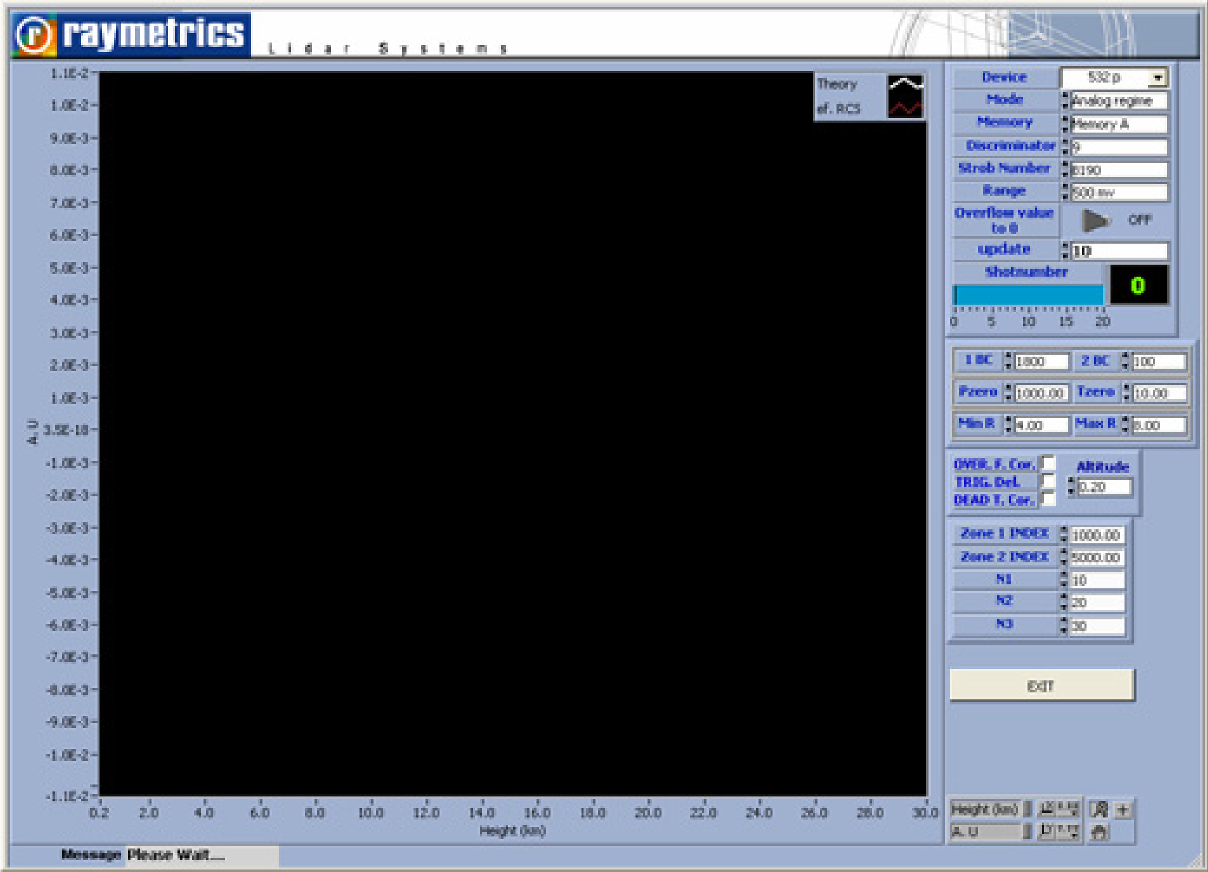
First zone start from channel 0 and finish at Zone 1 Channel Index

Second zone start at Zone 1 Channel Index and stops at Zone 2 Channel Index

Third zone starts at Zone 2 Channel index and stops at channel equal to strob number

Attention: make sure that Zone 2 Channel index + N3 < strob number

In each zone a glidding filter is applied the corresponding N (N1, N2, N3)



5.2. Data Acquisition

5.2.1 Data Acquisition Interface

After exiting alignment procedures click on Data Acquisition button to call the corresponding interface.

- Use this interface for single data acquisition or for multiple measurements.
- When program starts asks for a user name and password. This information is inserted into the Main Database for every successfully saved measurement a user complied.
- Before start a measurement all parameters have to be configured (see below).
- After configuration press start button to start a single measurement.
- The transient recorders, in which you have activated data sets, should now acquire data if a sufficient trigger signal is connected to the input. If the acquisition has been started successfully, the number of shots done in the multiple acquisitions group should start increasing.
- Press stop button to stop data acquisition. The waveform graph will be refreshed and will display the dataset that the user has specified.
- Press save button to save acquired data to a unique file for further analysis. A new record into the database will be added with the same values into the start and stop time fields.

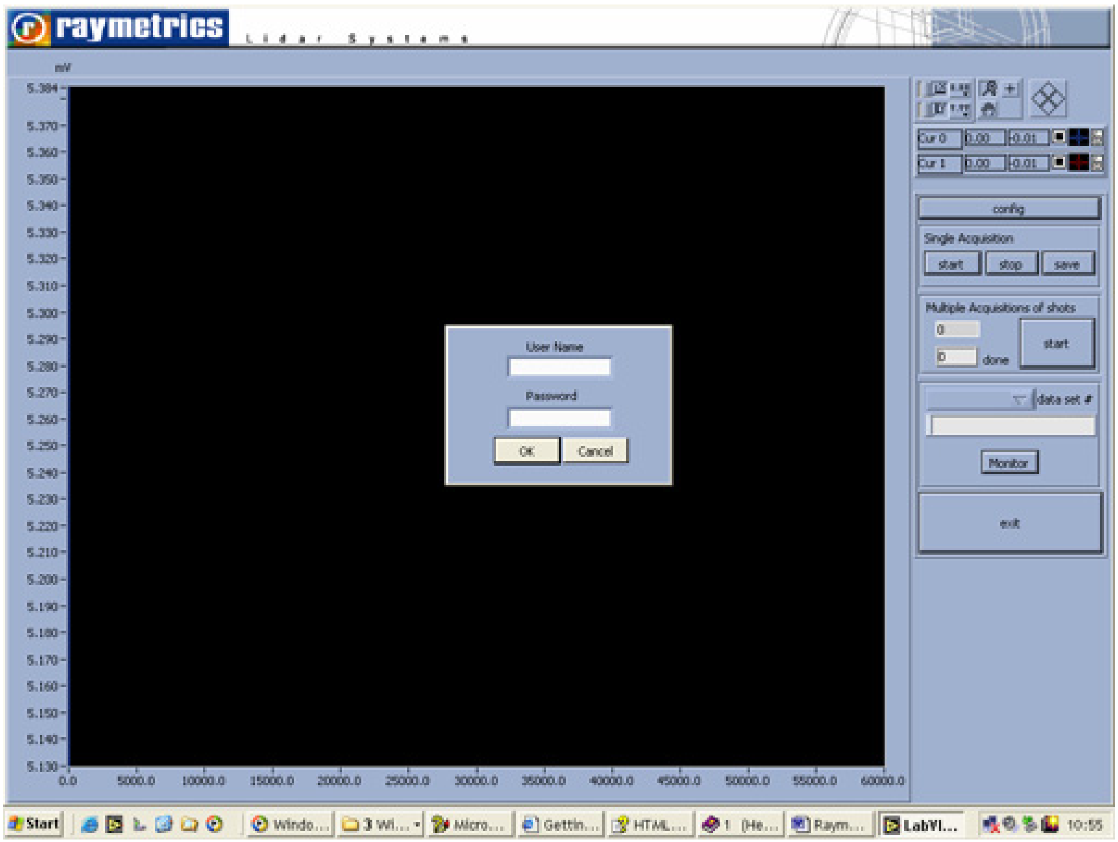
For multiple data acquisition press start button. After starting the acquisition, the text of the button changes to stop, which indicates that the series of multiple acquisitions, can be stopped by pressing this button again.

By starting multiple acquisition, the software automatically accumulates the specified (in the global configuration section) number of shots data. When “Done” indicator reach the value of shotnumber the program automatically writes data to a file with a unique identifier whose naming convention is explained in the Ascii Conversion Topic and starts a new measurement. The waveform graph is refreshed with the newly saved data. Select the desired dataset from the drop down list to be displayed.

The shotnumber is the number of averaged acquisition cycles (number of laser pulses) and is increased by one for every trigger pulse that is received (max value is 4095 due to ram limitation).

Every successful set of multiple measurement is corresponding to a new record into the main database with start time field shows the time of the first saved file and stop time field the time of the last saved file.
During multiple acquisition, click on monitor button, to view a surface graph of the currently acquired data files. To refresh the monitor graph press once again the button.

Caution: *Exiting program without previously stop a running multiple acquisition, may cause unpredictable entries into the main database.*

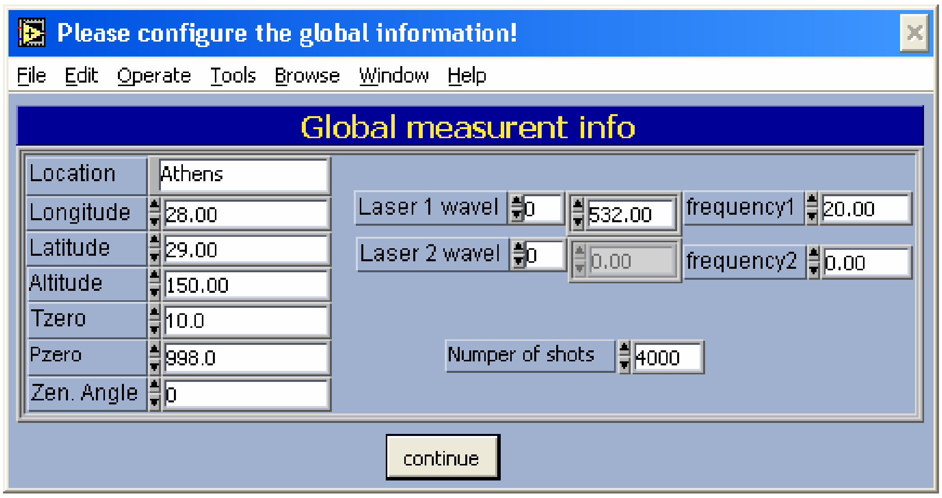


5.2.2 Configure Measurements

Before starting acquisitions, configure the default global information so that this information can be included properly in the header of the data files. After that, set up the Transient Information which is specific to your dataset.

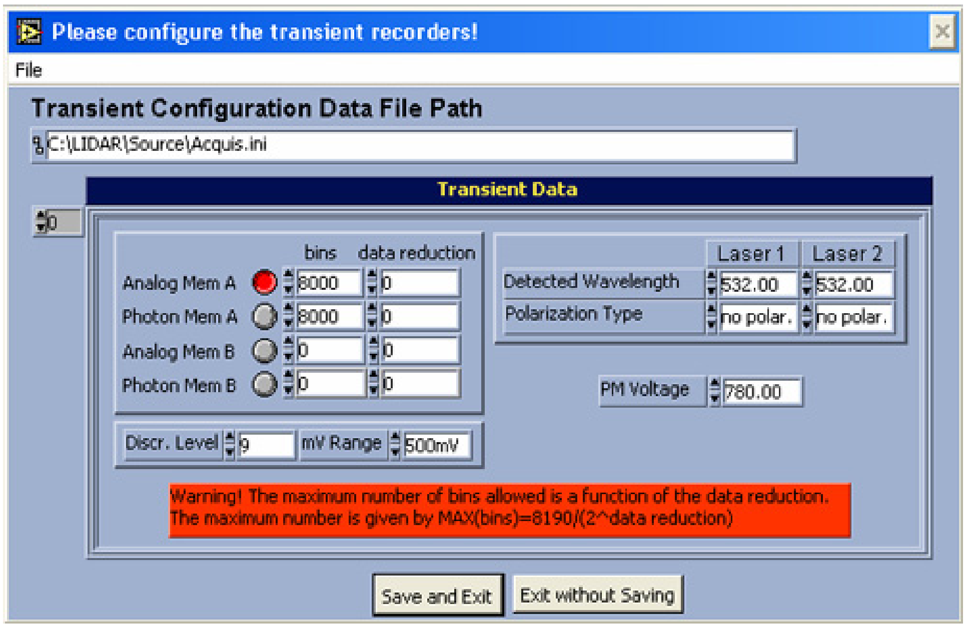
Configure Global Parameters

- Set global information like Location of the measurement site (8 characters length), longitude, latitude and altitude (in meters), ground temperature (in Celsius) and ground pressure (in mhA).
- Set emitted wavelengths and frequency from laser sources (1 and 2).
- Finally set the shotnumber for the multiple data acquisition. The number of shots should be set high enough so that data files are not written more quickly than every ten seconds (i.e. 100 shots at 10Hz, 200 shots at 20 Hz, etc...). This is due to a limitation of the naming convention. The maximum allowable value is 4094 due to transient recorder ram limitations.



Configure Transient Recorder

After selecting to configure datasets, the default transient information found in the file Acquis.ini is preloaded and the user is given the possibility of configuring the transient recorder information using the interface shown below



Configure each transient recorder unit by change the index number.

Activate the desired memory bank (A, B and Analog, photon).

Set the number of bins (strob number) to read out from the memory bank. The maximum number of bins is given by 16384/(2^data reduction) (or 8192 depending on the type of transient recorder).

Set the data reduction which allows for binning. A data reduction level of 0, 1 and 2 corresponds to a height resolution of 7.5m, 15m, and 30m respectively. Each increasing in value reduces the height resolution by 1/2 and doubles the number of bins that are combined together to make a superbin. Thus the levels 0,1,2 correspond to 1 , 2, and 4 bins per data point respectively.

Set the discriminator level for the transient recorder. There are 64 discriminator levels (values 0-63) which correspond to either a range of 0-24mV without gain reduction or 0-96mV with gain reduction.

Set the range values of the transient recorder. Valid values are 0-20mV, 0-100mV and 0-500mV.

Set parameters which indicate the type of equipment that is used in channel. This information is stored as a header in the data files, so that the user (or whoever has to evaluate the data) can see what parameters were used to take the data. The fields are used for the Channel A and B descriptions, the detected laser wavelengths and the corresponding polarization, the filter number of central wavelength, the photomultiplier voltage. The information entered in these fields has no effect whatsoever upon the data acquisition. It is used purely to store information about the experimental setup in the data files.

The menu item file contains four sub-items that the user can choose from.

If you would like to edit an existing file, choose "Load transient information" and select a file. After doing this, the information including the file path as shown in point 8 will be updated to the new data that has been read from the file. After you have edited the data and are satisfied with the configuration, you can save the information by choosing "Save transient information as..." and either choose the same file name, which overwrites the old file, or give it a new name. If you have edited the data and have made a mistake, you can reload the original information by pressing Reset Information.

After finishing configuration of the transient recorder units, you can exit the configuration program by either pressing the Save and Exit button, if you would like to save the information to the actual file path as shown, or, alternatively, you can press Exit without Saving or choose File->Exit in the pull down menu, if you would like to exit without saving your changes. Please note that when you exit the program without saving, any unsaved data is lost! Thus if you have configured the data and wish to keep it, you need to either choose Save and Exit or choose File->Save transient information as... from the pull down menu before you exit the program. If you want the current transient recorder configuration to be used as the default transient recorder information, you must save this data as Acquis.ini in the installation path.

5.3. Data Preview and Analysis

5.3.1 General

- Open Data Preview and Analysis program group raymetrics.
- Use this program to preview old or new acquired data, to plot or to analyse (calculation of Lidar parameters) them.
- The window consists of a toolbar and the Main DB interface.

A brief description of the main actions following:

- Use worksheet interface to insert data from external files or database into a worksheet.
- Plot directly database data or from external files using Plot interface.
- Create surface graphs from acquired data using Surface Graph Interface
- Convert automatically database files to an ascii format to use them with other programs.

For more information about worksheet and plots refer to electronic form of Raymetrics user manuals.

5.3.2 Main Database Interface

Main Database Interface is consisted of:

A Main Table, whose every record represent a set of measurements.

Each record has the following fields:

- UserName: is the username that is entered when someone call data acquisition interface.
- Location: Is the Location which is entered during global information configuration procedure.
- Start, Stop Time and Date
- Look picture below for fields information.

Whenever a single measurement is saved, a new record is added to the main table with same start and stop date and time fields.

For multiple measurement start date and time fields shows the data and time information from the first filename of a set of measurements and stop date and time fields from the last saved file.

The owner of a record (a set of measurements) might delete it (all files contained to the selected record, will be also deleted) or edit it, by doubleclicking on a record.

A Filelistbox whose contents are the filenames which belong to the selected record of the Main Table
An Info Block which contain information of all the datasets for a selected filename from the Filelistbox.
Upper left block contains trigger's information.
Upper right block contains general information (which are set by configuring global information during measurement acquisition) of the set of measurements such as altitude, longitude etc.
Several rows below describe every dataset of the selected file. Select a raw to view corresponding plot.
Every raw consist of eleven shells.

Tr.: Transient recorder device
Wave L.: Detected wavelength
Polarization Type: p-parallel, s – cross, o – no polarization
Type: AN-analog, PC – photon counting
Scat. Type: scattering type, elastic (emitted wavelength equal to detected wavelength) anelastic (emitted wavelength not equal to detected wavelength)
Chan: Number of channels recorded
Res: resolution = 2 ^ (reduction number) * resolution (7.5 for Tr 40 or 3.75 for Tr20) in meters

Distance: maximum distance in meters
H. Volts: High voltage (V)
Shots: Number of shots
R/D: For analog: input range (mV), for photon counting discriminator level.

5.3.3 Data Analysis

Previewing and analyzing data can be accomplished from several places depending on user desired. Data can be inserted into a worksheet or a surface plot and be further analysed. Alternatively, lidar parameters can be plotted directly using 2D plot interface. When users ask for data to insert them to a worksheet or to plot them directly from 2D plot interface, has two options:

a) to use data from an external file

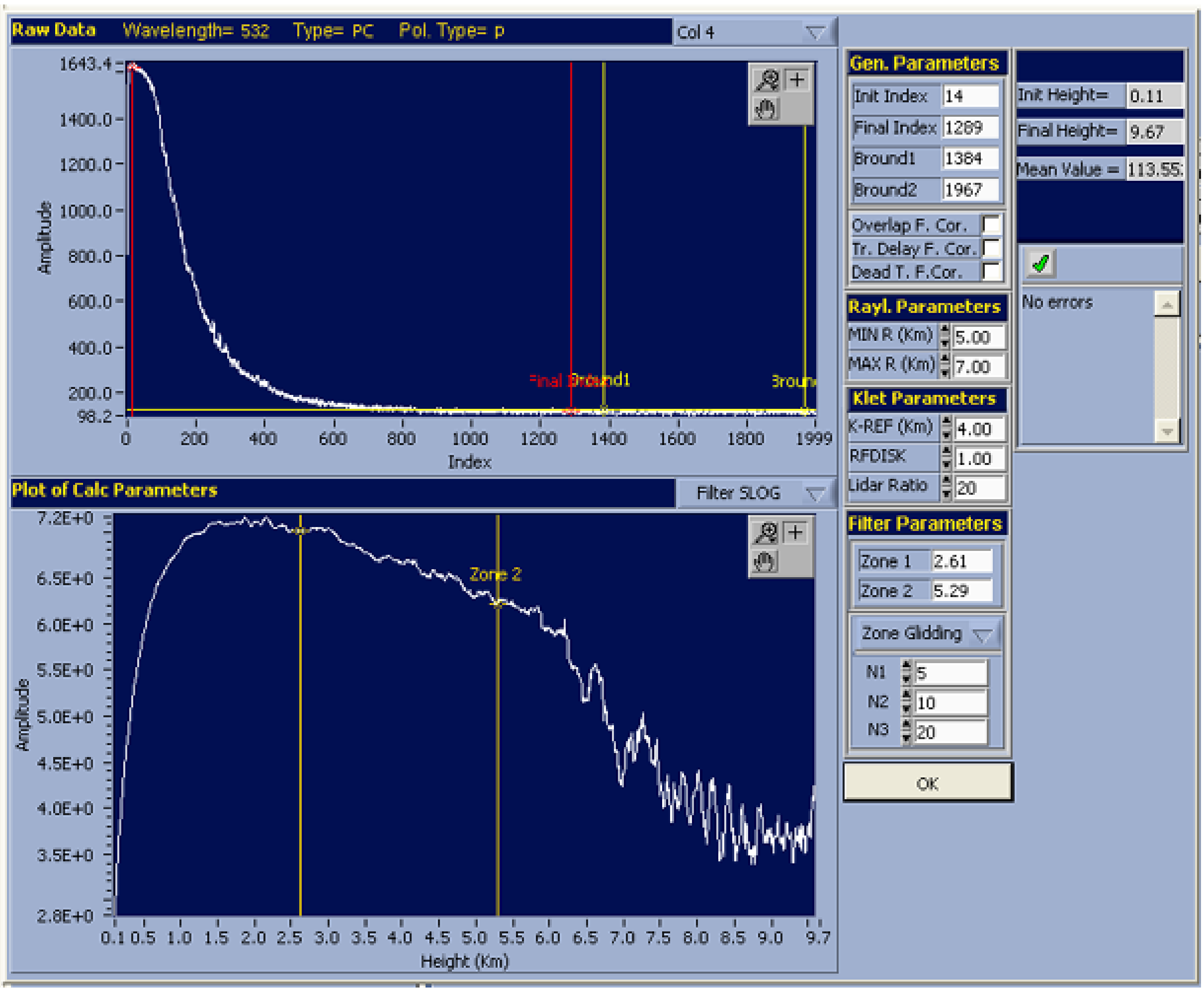
b) or to select data from a database interface.

5.3.3.1 Database view interface

- When a user asks for data that have been acquired using raymetrics software database view interface is appeared.
- In this interface users can preview data or/and select them for further analysis.
- The interface is similar to Main Database Interface (see above).
- To select file or files for further analysis select a record from the main table, click on a file name from the filename listbox and press “start” button (to select a single file only press again “stop” button), click on a different filename, which is below from the first into the list, and press stop button.
- Depending on the location from which a user asks for data, deferent sub-interfaces appear.

5.3.3.2 Lidar Parameters Calculation Interface

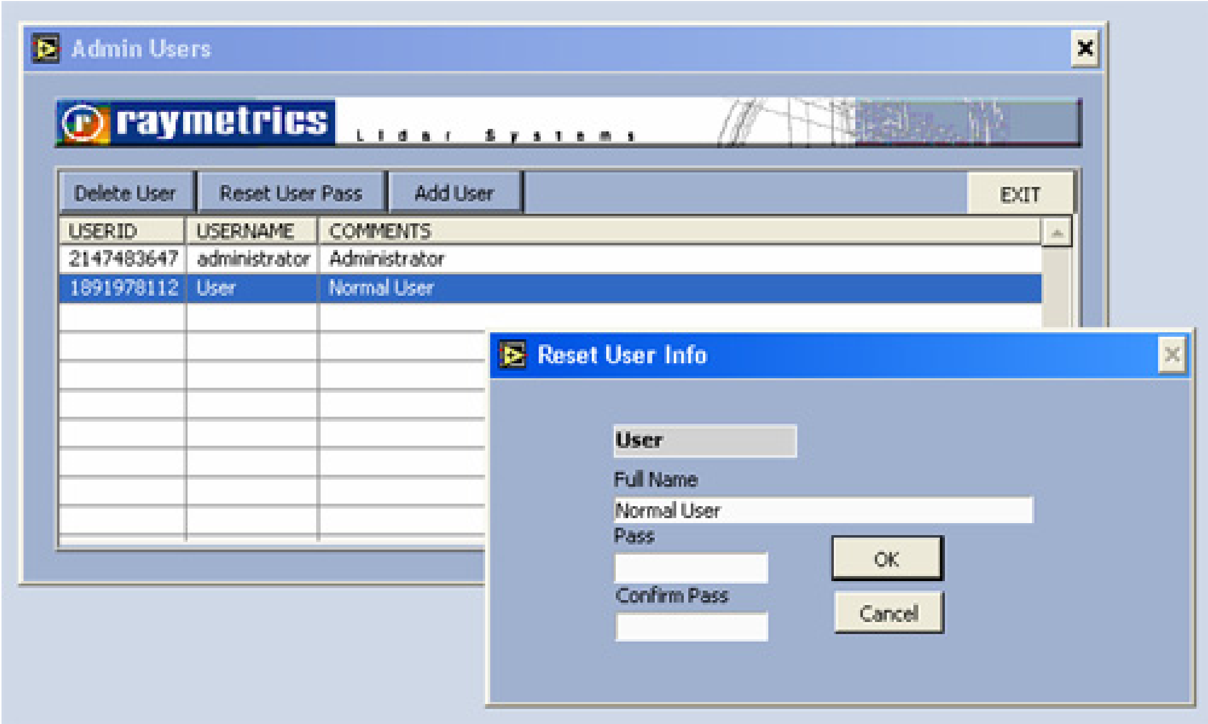
- After calling the interface a set of parameters have to be initialized.
- First select a dataset if more than one files have been used.
- Set initial and final height of interest by moving the appropriate cursors (red Init Index, red Final Index) at the “Raw Data Graph”
- Set first and last channels for background calculation by moving the appropriate cursors (yellow Bround1 and yellow Bround2 respectively)
- Set the values to General Parameters Block
- Set the values to Rayleight Parameters Block
- Set the values to Filter Parameter Block
- Set the values to Klet Parameter Block to calculate A and B parameters



When you press "Lidar Calc" button at the worksheet interface the Lidar Calculation interface is slightly different as in that case wavelength, resolution, temperature and pressure parameters need to be initialised (the initialisation is done automatically when database interface is used, as this information already exists into the database).

5.4. Administrative Tasks

Administrating users



The software is shipped with a default administrator password (**100l_pu()**)

Chapter 6

Lidar system technical specifications

Note: All specifications of the lidar system or sub-systems are subject to change without notice.

Emitter	
Pulsed laser source (Class IV laser)	Nd:YAG (Quantel CFR Series)
Wavelength	532 nm
Energy / pulse	20 mJ @ 532 nm
Pulse duration	8 ns
Repetition rate	10-20Hz
Laser beam diameter (expanded)	10 mm
Laser beam divergence	<0.1 mrad
Receiver	
Telescope diameter	200 mm
Field of view	0.5-2 mrad
Interf. filter bandwidth	0.5nm @ 532nm
Detection Unit	
Transient Recorder	LICEL
Detection Channels	1 channels for elastic backscattering
Detectors	1 PMT
Detection mode	Analog and photon counting
Data Output	2-D time-height cross sections, 3-D temporal evolution of any parameter, ASCII files.

Chapter 7

Lidar system maintenance

7.1. Laser system

The laser system requires minimal maintenance, if it is operated in a standard laboratory environment with specified power line and ambient temperature conditions (see Chapter 3). Please, refer to the LASER's INSTRUCTION MANUAL for a detailed description of the laser's maintenance procedure (alignment verification, flash lamps replacement, cooling group unit, etc.).

7.2. Reflective Mirrors

Although the closed lidar structure provides a dust-free operation for optical components, the lidar should never be operated without the protective housing. In case the reflecting mirrors of the lidar system at 532 nm (phi 25 mm) become dusty, they should be cleaned with *absolute ethanol* using flint-free optical paper. If this is done by non-specialized personnel, serious damage may occur on the optical components and the warranty will not be further valid. Therefore, it is strongly recommended that you sign an after sales Servicing Contract with Raymetrics S.A. for a trouble-free maintenance of your lidar system.

7.3. Telescope

Although the lidar structure provides a dust-free operation for optical components, it is preferable that in open air the lidar system should be operated with the protective housing on. In case the telescope becomes dusty, it should be cleaned with *absolute ethanol* using flint-free optical paper. If this is done by non-specialized personnel, serious damage may occur on the optical components and the warranty will not be further valid.

7.4 Cleaning of optical components

All optical elements are delicate and should be handled as carefully as possible. The glass and antireflective (AR) coated surfaces will be damaged by any contact, especially if abrasive particles have come into contact with the surface. In most cases, it is best to leave minor debris on the surface.

Use of oil-free dry air or nitrogen under moderate pressure is the best tool for removing excessive debris from an optical surface. In the case that the contamination is not dislodged by the flow of gas, please use the following protocol for cleaning the part:

1. Clean the part using an absorbent towel such as Kimwipes™, not lens paper. Use enough toweling so that solvents do not dissolve oils from your hands which can make their way through the toweling onto the coated surface.
2. Wet the towel with an anhydrous reagent grade ethanol.
3. The use of powder-free gloves will help to keep fingerprints off the part while cleaning.
4. Drag the trailing edge of the ethanol soaked Kimwipe across the surface of the component, moving in a single direction. A minimal amount of pressure can be applied while wiping. However, too much pressure will damage the component.
5. If the surface requires additional cleaning, always switch to a new Kimwipe before repeating the process.

The purpose of the solvent is only to dissolve any adhesive contamination that is holding the debris on the surface. The towel needs to absorb both the excessive solvent and entrap the debris so that it can be removed from the surface. Surface coatings on interference filters and dichroics are typically less hard than the substrate. It is reasonable to expect that any cleaning will degrade the surface at an atomic level. Consideration should be given as to whether the contamination in question is more significant to the application than the damage that may result from cleaning the surface.
In many cases, the AR coatings that are provided to give maximum light transmission amplify the appearance of contamination on the surface.

Chapter 8

Limited Guarantee

NOTICE

Raymetrics SA reserves the right to make improvements of the products described in this Manual at any time and without notice. Thus, all specifications of this lidar system or sub-systems are subject to change at any time and without notice.
Raymetrics SA shall not be liable for errors contained in this Manual or for incidental or consequential damages in connection with the furnishing, performance or use of this material.

WARRANTIES

Raymetrics SA, as well as the lidar-components providers (laser source, acquisition electronics, photo-multiplier tube (PMT), personal computer, Digital acquisition PC-card and cables) warrant the products or sub-systems of this lidar system to be free from defects in materials and faulty workmanship under normal use for a period of 12 months after the date of the original purchase and following the delivery to the FOB site (for details see the Instruction Manuals of the lidar sub-systems providers and comments therein). Laser flash lamps are guaranteed for 20 millions shots or 1 year whichever comes first.

This warranty does not cover:

- equipments or components where the original indentification markings have been altered or removed or if any parts have been replaced by other components
- equipment or components that have become defective due to mishandling, erroneous use, accidental alteration, improper operation, or any other cause, without the prior written agreement of Raymetrics SA.

The cost and terms of non-warranty service are fixed by Raymetrics SA and the lidar sub-systems providers and are subject to change.

Chapter 9

Returns, Adjustments and Servicing

If warranty, service or general repair of a Raymetrics SA lidar system is requested by the customer, which leads to the product's return to Raymetrics SA, the terms of such return include the following:

a) freight and insurance (CIF) charges are pre-paid by the customer, who also takes all the risks of loss, damage or delay in shipment,
b) the lidar system must be packed in the original containers provided by Raymetrics SA. All water must have been drained from the laser head according to the laser manufacturer rules, prior to packing.
c) Prior to sending the product back to Raymetrics SA the customer must obtain a written authorization for the product return for service.
d) After the product receipt Raymetrics SA reserves the right to fully inspect the lidar system and determine the cause of failure and warranty status. The same is valid for the laser provider. If the product has been suffered a damage during the shipment Raymetrics SA has no duty to perform a warranty repair.
e) If the warranty of the product has expired the customer will be advised of the cost of such repair and a written purchase order for the repair and service work will be required before the performance of the work.
f) If the product is still under warranty status it will be repaired or replaced free of charge in accordance with the terms of the Raymetrics SA and lidar components providers. Finally, the warranty period for a replaced or repaired component will be only the period remaining on the original product, thus no extra warranty is provided by such repair.

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Appendix 1: Troubleshooting

This Appendix addresses some of the problems you might encounter while running your lidar system and indicates ways how to solve these problems.

- *Laser system*

Please refer to the LASER'S INSTRUCTION MANUAL for a relevant troubleshooting list for any problems you may encounter when using your solid state Nd:YAG laser.

- *Detection electronics*

Please refer to the detection electronics subsystem INSTRUCTION MANUAL for a relevant troubleshooting list for any problems you may encounter when using your detection electronics unit (digitization and detection of lidar signals).

- *Misaligned lidar signals*

When due to external factors (intense thermal gradients) the lidar signals become misaligned in one or more wavelengths, please follow carefully the alignment procedure described in Chapter 3.

Appendix 2: Environmental specifications

- *Temperature*

Operating: +5 to 40^{o}C

Storage: +5 to 50^{o}C

- *Humidity*

Operating: 10 to 75% non condensing (+5 to 28^{o}C)

Storage: 10 to 85% non condensing (+5 to 28^{o}C)

Lidar location Warnings

Your lidar instrument can be installed outdoor or indoor, away from excess heat and conductive contaminants.

For outdoor use avoid direct sunlight at the back side of your lidar instrument.

In case of very low temperatures (< 0 ^{o}C) place the lidar indoor, protect it from excess freeze or set the heating device ON (systems with heating devices) in order to avoid freezing of laser system.

Lidar mounting Warning

Do not tilt your lidar instrument more the 15 degrees. Misalignments may occur and other damages may happen.