raymetrics

USER MANUAL

LR111-ESS-D200

Raman Depolarization LIDAR

DOC 0601

December 2015

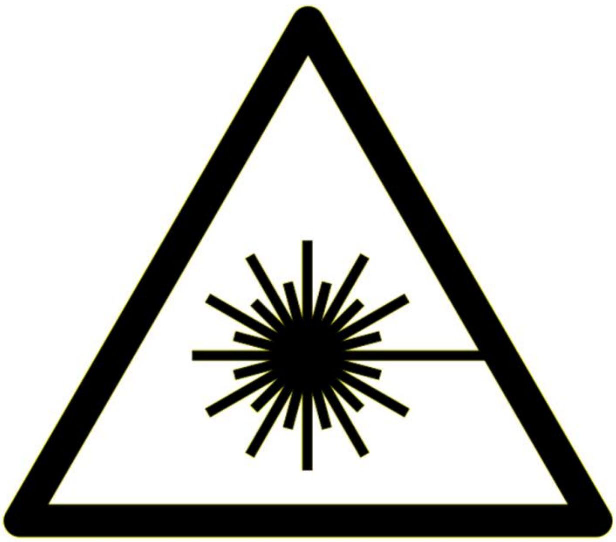
PREFACE

This User Manual contains the technical information needed to properly operate and maintain RAYMETRICS' Raman Depolarization LIDAR system. It comprises a set of instructions for operation, servicing and preventive maintenance, as well as 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 laserhead, power supply and cooler unit), (3) the Transient Recorder unit and (4) the PC, which includes software modules for data acquisition, analysis and visualization.

Caution and warning labels, in accordance with CDRH and CE requirements, are prominently displayed on the Laserhead and power supply of the laser unit, as well as in the front and rear panels 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 User Manual contains essential information and user guidance about these hazards.



QUALITY CONTROL

FINAL TEST DATA SHEET

Model: LR111-ESS-D200

S/N: 200-04-15

Last Revision: 30/07/2018

Test Date: 03/10/2014

Telescope Calibration:		✓
Laser Beam Calibration:		✓
Lidar alignement :		✓
Lidar signals	355 nm P:	✓
	355 nm S:	✓
	387 nm:	✓
Polarization Calibration:		✓
Laser Safety Interlocks:		✓
Laser Energy Measurement:		✓
Electrical Connections :		✓
Internal –External connections:		✓

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TABLE OF ABBREVIATIONS

ABREVIATION	EXPLANATION
A/D ADC	Analogue to Digital Conversion
AN	Analogue
APD	Avalanche PhotoDiode
AR	Anti Reflection
ASCII	American Standard Code for Information Interchange
BG	Background
CGU	Coolant Group Unit
CNC	Computer Numerical Control
DAQ	Data Acquisition System
DB	Database
EXT	External
FOV	Field Of View
GL	Glued
HR	High Reflecting
HT	High Transmitting
HV	High Voltage
HVAC	Heating Ventilation and Air Cooling
IFF	Interference Filter
INT	Internal
IP	Internet Protocol
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LIDAR	Light Detection and Ranging
LR	Lidar Ratio
LSB	Least Significant Bit
ND	Neutral Density
OU	Optical Unit
PBC	Polarizing Beamsplitter Cube
PC	Photon Counting

PCC	Power Supply Cooling Unit Cabinet
PMT	Photo Multiplier Tube
PSU	Power Supply Unit
QS	Q-Switch
RAM	Random Access Memory
RCS	Range Corrected Signal
RDP	Remote Desktop
SAU	Signal Acquisition Unit
SHG	Second Harmonic Generator
SNR	Signal To Noise Ratio
TCP	Transmission Control Protocol
THG	Third Harmonic Generator
TR	Transient Recorder
TTL	Transistor–Transistor Logic
WOL	Wake On LAN
WSU	Wavelength Separation Unit

Contents

1. LIDAR SAFETY

DANGER

VISIBLE AND/OR INVISIBLE LASER RADIATION

The Model LR111-ESS-D200 Lidar System contains 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. Safety information provided in this manual, the laser manual and on training courses must be adhered to at all times. Raymetrics S.A. shall not be held responsible for accidents to the user or to third parties caused by improper use of the equipment.

The warning symbols below are used throughout this document and on the Lidar equipment itself in order to highlight potential hazards.

DANGER	Imminent hazards which, if not avoided, will result in serious injury or death.
WARNING	Potential hazards which, if not avoided, could result in serious injury or death.
CAUTION	Potential hazards which, if not avoided, could result in minor or moderate injury.
CAUTION	Potential hazards which, if not avoided, could result in product damage.
NOTE	Points of particular interest for more efficient or convenient equipment operation; additional information or explanation.
WARNING LASER RADIATION	Avoid exposure of eyes or skin to direct or diffused laser radiation. Permanent eye damage or blindness may occur.
WARNING HIGH VOLTAGE	Electric shocks and burns from capacitor discharge or power circuits could lead to serious injury or even death.

Class IV laser systems may produce lesions from the direct beam, its spectacular reflections and its diffuse reflections. The laser must only be accessed within the enclosure by personnel with sufficient experience with their operation; these personnel must be qualified and approved by the Laser Safety Officer. The safety rules explained below must be read and followed by everyone who accesses or attends the laser. Access to the laser should be limited to required personnel only.

1. Never look at the direct or scattered beam of the laser.
2. Avoid exposing any part of the body to the beam.
3. Remove all objects with a reflecting or shiny surface from the work area prior to work commencing, as well as all inflammable materials. Do not wear reflective jewelry while using the laser, as it might cause inadvertent hazardous reflections.
4. Ensure that the laser beam emission area is well lit, in order to limit the amount of light which enters the eyes of workers.
5. When not in use, it must be made impossible for unauthorized people to operate them, for example, by removing the door key or the laser key.
6. Using laser radiation to aim at individuals, vehicles, aircraft or any other flying object is formally prohibited.
7. Laser radiation must never be aimed at individuals, vehicles, aircraft or any other flying object.
8. Due to the risk of electric shock, the laser power supply must be switched off and 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 and may even be fatal.

Precautions for Safe Operation of Class IV Lasers

9. Do not operate the laser with the covers removed for any reason.
10. Use protective eyewear at all times
11. Operate the laser at the lowest possible beam intensity, given the requirements of the intended application.
12. Increase the beam diameter wherever possible to reduce beam intensity and thus reduce the hazard.
13. Avoid blocking the laser beam with any part of the body.
14. Establish a controlled access area for laser operation. Limit access to those trained in the principles of laser safety.

15. Post prominent warning signs near the laser operation area.
16. Drain the laser power supply and cover the Lidar if you intend not to use for more than a month.
17. Operate the laser power supply every day for at least 30 minutes in order to circulate the coolant fluid.
18. In low ambient temperatures (below zero Celsius) it is preferable to leave the laser power supply on.
19. After continuous operation for more than an hour, leave the laser power supply on for at least 10 minutes to cool down the head.

Precautions for Safe Operation of LIDAR

1. Always leave the HVAC on to control temperature and humidity inside the cabin.
2. Do not cover the inlet and outlet of the air-conditioning unit.
3. Check frequently the number of flashlamp shots and replace after 50million shots.
4. Never allow direct sunlight to reach the telescope's FOV.
5. Do not direct the laser beam inside the telescope.
6. Do not place any additional force on the telescope.
7. Do not alter the height of the primary and secondary mirrors of the telescope.
8. Always wear clean surgical gloves when handling optical parts.
9. Keep the protective windows clean.
10. Avoid any action which may scratch the protective windows.

WARNING: Only operations or procedures which have been described in this User Manual should be undertaken. Any procedures undertaken which have not been described in this manual may result in hazardous radiation exposure.

2. INTRODUCTION TO THE LIDAR TECHNIQUE

Atmospheric laser remote sensing employs 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. For the Lidar technique a short laser light pulse is emitted into the atmosphere in one or more wavelengths (Fig. 2.1).

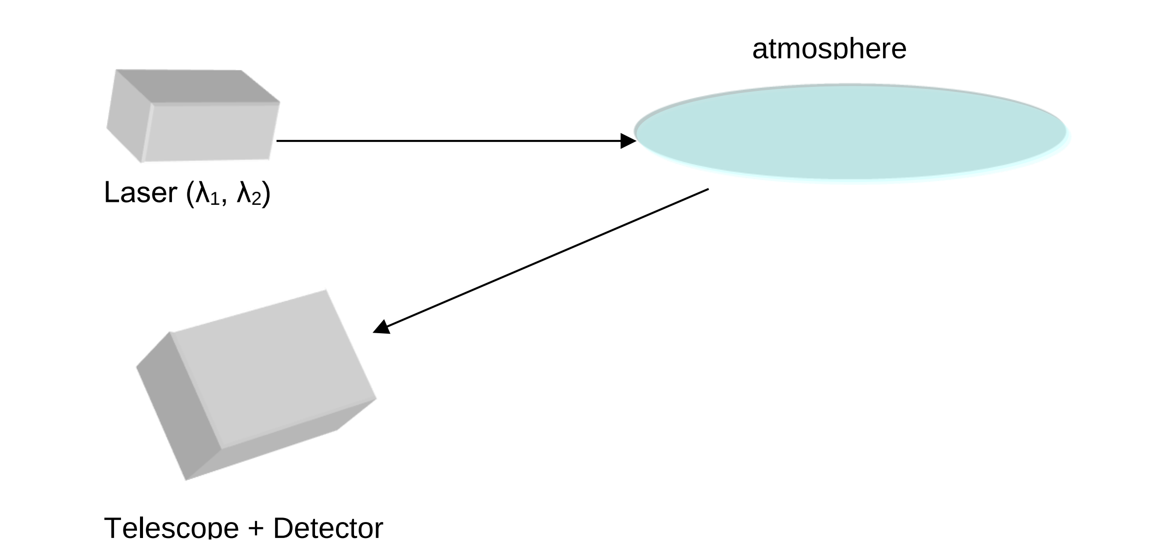


Fig. 2.1: The principle of operation of the Lidar technique.

The atmospheric volume being probed 'backscatters' the laser radiation. A receiving telescope is used to collect the backscattered laser light which occurs through elastic and inelastic processes. A Wavelength Separation Unit (WSU) is 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 or PMTs). After amplification and digitization the PMT output signals are sent to a central computer for further processing and storage.

The time between the emission of the laser pulse and the arrival of the returned backscattered 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].

Observations of suspended aerosol particles can be made remotely, with high spatial and temporal resolution using the Lidar technique. Lidar systems can be operated from ground or mobile platforms, such as planes, 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 tens of kilometers. Therefore, two detection modes are used: the analogue detection mode and the photon counting operation mode (section *3.3.2. Detection Electronics*).

The detection of the suspended aerosol particles can be performed by an elastic Lidar system (one to three 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].

3. LIDAR SYSTEM HARDWARE COMPONENTS

A typical LIDAR contains an emitter, a receiver, a Data Acquisition System (DAQ) as well as a computer that controls the transmitter and receiver and also stores the acquired data. A power distribution unit is used to protect and power the various systems. The unit that contains the transmitter and receiver is called Lidarhead. The Lidarhead is enclosed in a climate controlled enclosure and mounted on a positioner that can turn the head in any direction of a hemisphere. The computer along with the DAQ and the Laser's power supply form the control unit which is also enclosed and climate controlled.

The image below shows a typical Lidar with its main components illustrated.

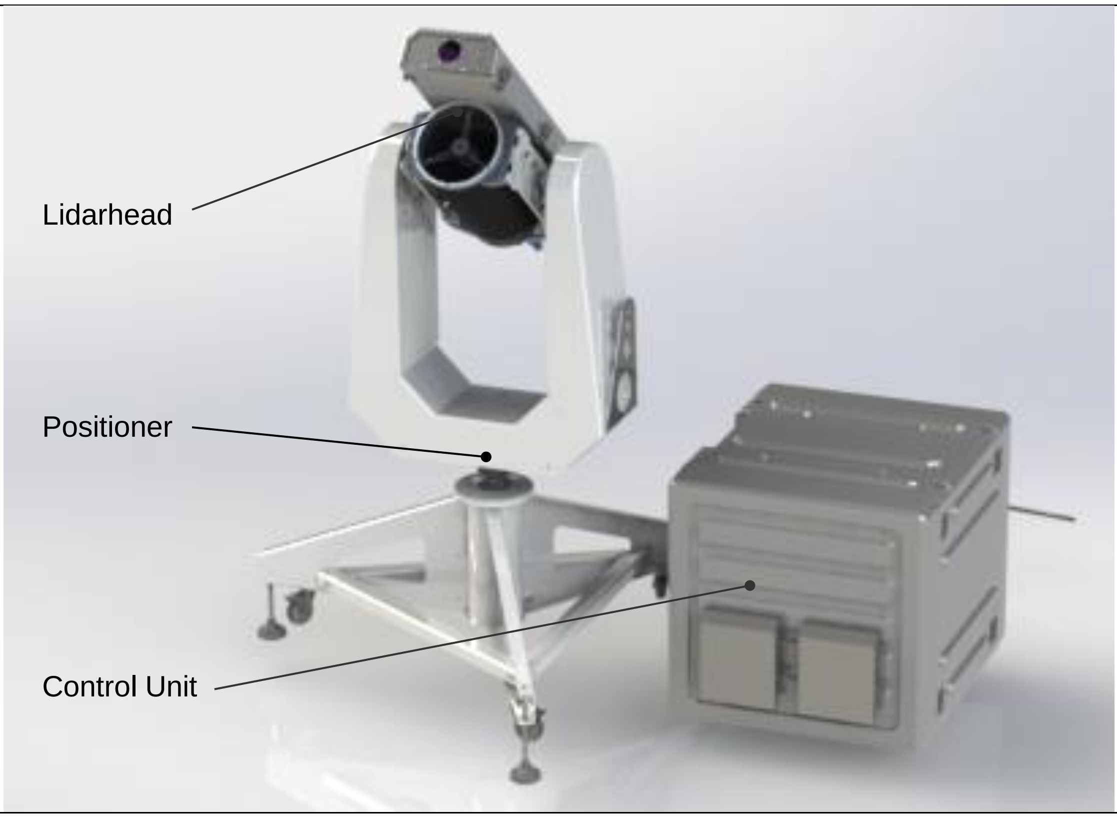


Fig. 3. 1: Typical Scanning Lidar

All these components are described in detail below.

3.1. EMITTER

The Lidar emitter consists of four sub-units: a laser, a High Reflective mirror, a Beam Expander, and a motorized High Reflective mirror.

The emitter and the light path are enclosed in a case that protects the user from direct contract with the laser beam and also prevents light to enter the receiver.

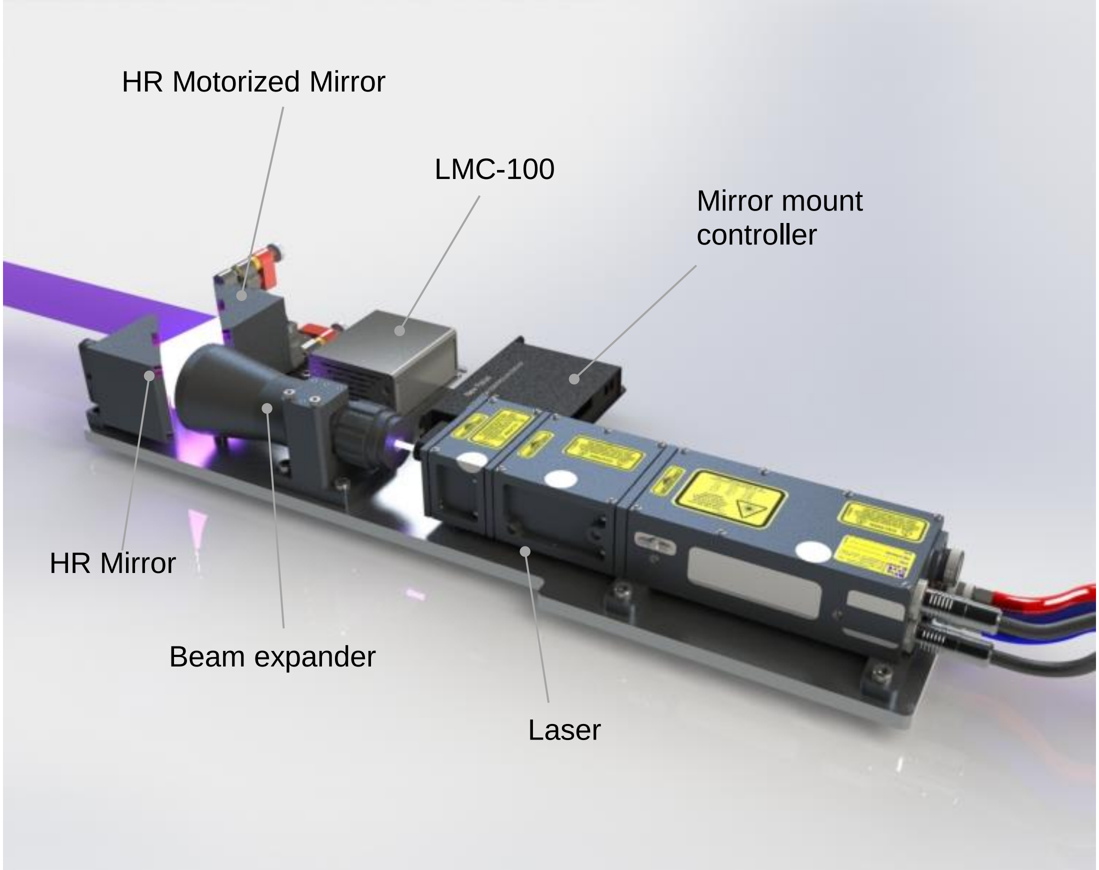


Fig. 3. 2: Lidar Emitter Layout

3.1.1. Laser

The laser source is a water cooled pulsed Nd:YAG laser emitting short pulses at 1064nm. The pulse repetition rate is 20Hz. The pulse duration is of the order of 6-9 ns. Through the Second Harmonic Generation (SHG) the 532nm wavelength is produced and through the Third Harmonic Generation (THG) the 355nm wavelength is produced. This specific laser is optimized for maximum energy at 355nm. Note: the user should not change, remove or alter any of the laser components or sub-units. The laser consists of two major sub-components: the laserhead and the power supply unit (PSU). They are connected together by power and signal cables and water hoses for cooling the head. The laser model is a ULTRA100 manufactured by Quantel, including the PSU model ICE450 standard version.

A detailed description of the characteristics, specifications and operation mode of the laser source is given in the laser's instruction manual DOC00040.pdf.

Safety Instructions

- The user is requested to wear the laser protective eyewear during the laser operation whenever close to the Lidar. Even when using laser protective eyewear goggles, the beam must not be stared at directly.
- Do not place any obstruction or reflective object in the emitted laser beam. Primary or secondary reflections may damage eyes or be reflected back into the laser causing damage.
- Before you turn off the laser the water circulation pump (ICE450) should be left in the ON position for at least 10-15 minutes to cool down the laserhead.
- Always adhere to the instructions of the laser manufacturer regarding the maximum number of laser shots before replacement of the flashlamp is undertaken. (See laser instruction manual DOC00040.pdf).
- Always adhere to the instructions of the laser manufacturer regarding the replacement of the de-ionizing filter unit of the laser system (see laser instruction manual DOC00040.pdf).

Fig. 3. 3: The laserhead

Attention!

- Do not touch the optical components of the Lidar system (laser mirrors, laser windows, protective windows, etc.). This may lead to a complete destruction of their optical coatings and/or to a misalignment of the Lidar optics.
- Before undertaking any laser maintenance, consult the laser manual and follow all instructions exactly. Failure to comply with instructions may result in total destruction

of the laserhead, requiring complete laser replacement which would not be covered under warranty.

3.1.3. Beam Expander

The beam's diameter is expanded by 10 times. The beam expander serves two main purposes; it reduces the energy concentration and adjusts the light’s divergence. This means that it adjusts the beam angle and eventually it improves the maximum range and the precision of the system.

Fig. 3. 4: Beam expander

3.1.4. Motorized HR Mirror

A crucial component for remotely operated systems is the motorized High Reflecting mirror. The High Reflective mirrors (HR mirrors) in Raymetrics Lidars provide a high reflection >98% at 355nm wavelength and high transmission at 532nm and 1064nm due to the special coating on the front side which is designed for high laser energy. On the reverse side there is a special anti-reflection coating to ensure that no back reflections will be emitted. The beam has to be aligned to the telescope in order to achieve the best possible data. A piezoelectric motorized mirror mount manufactured by New focus is used for this purpose. The main advantage of a motorized mirror mount in comparison to a manual mirror mount is that the user can align the LIDAR remotely. In addition there is no need to remove any covers or use any tools which makes the process safe and easy.

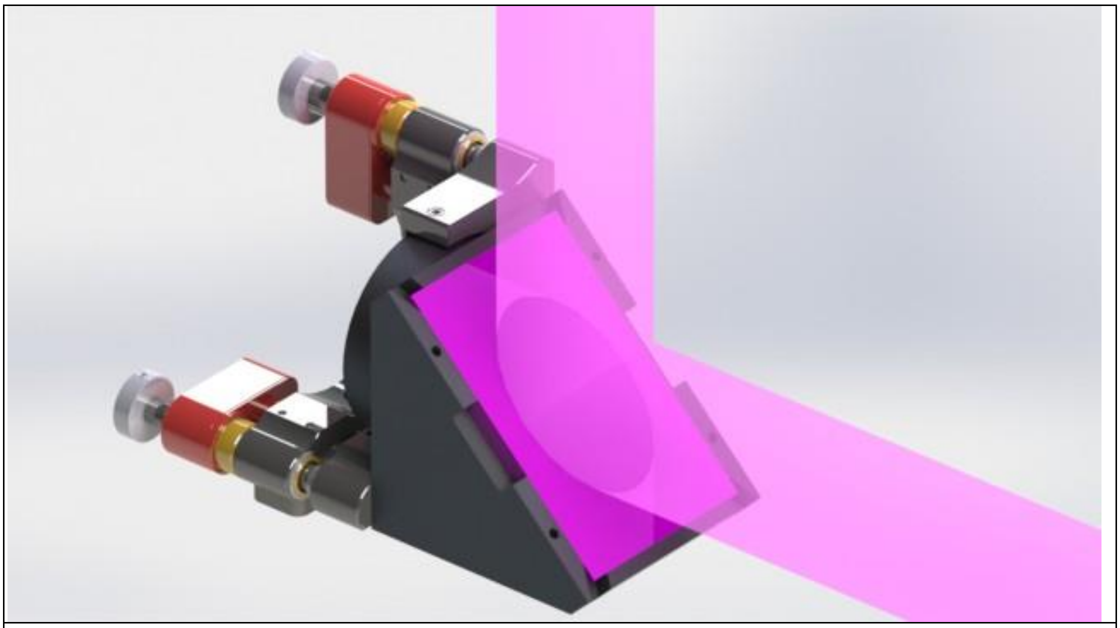


Fig. 3. 5: Motorized HR Mirror

3.1.5. Photo Diode

The user can monitor laser power using a photo diode installed inside the emitter. The photo diode is located close to the laserhead and receives light from the reflection of the first HR mirror. The photo diode is factory calibrated to match its return signal to the laser's power.

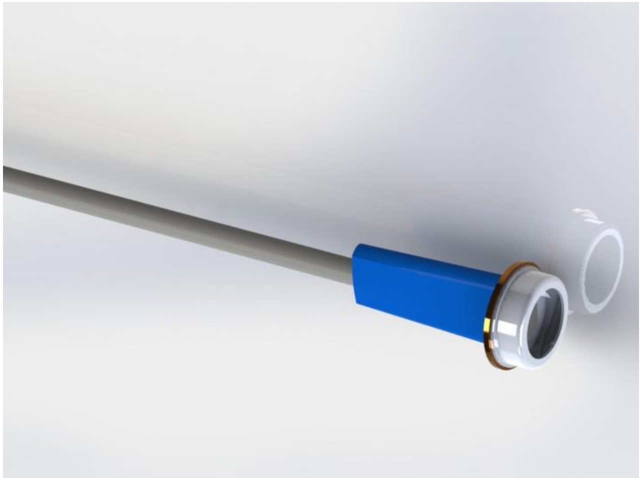


Fig. 3. 6: Photo diode

3.2. RECEIVING SYSTEM

The receiving system consists of two sub-units: a receiving telescope and a Wavelength Separation Unit (WSU) (Fig. 3.6).

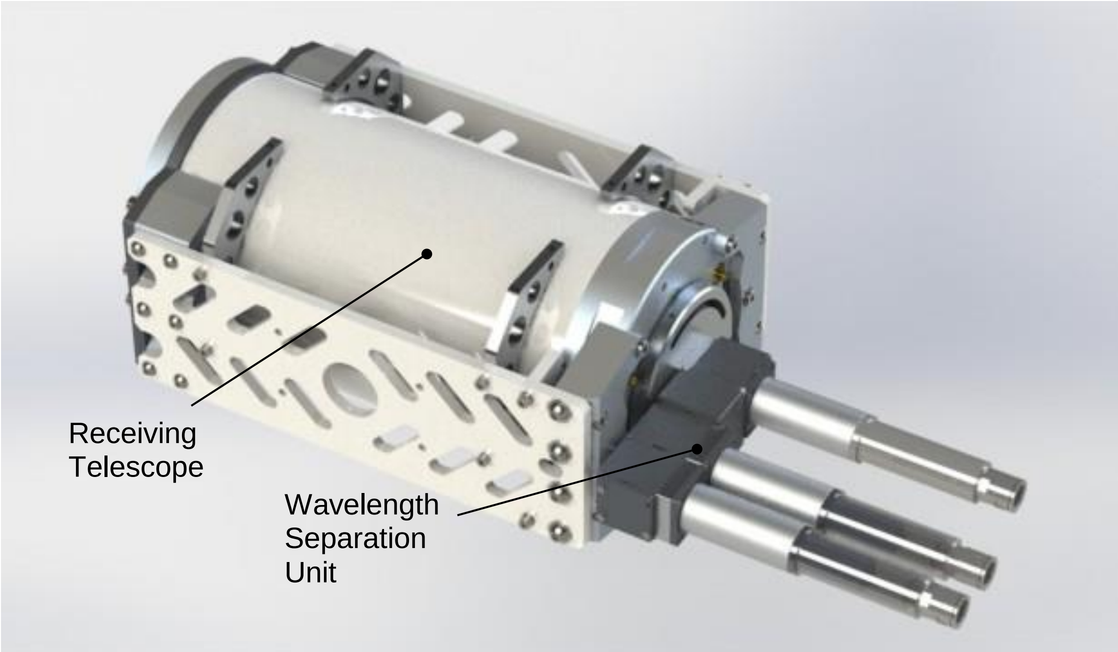


Fig. 3. 7: Receiver Components

3.2.1. Telescope

The backscattered light is relatively weak. It is therefore essential to collect as much light as possible with the telescope. In this Lidar a powerful 200mm diameter Cassegrain telescope is used. The primary reflective mirror has a diameter of 200mm and is coated with a durable High Reflective coating designed for the 350-1100 nm spectral region. The optical material selected displays a very low thermal expansion coefficient, similar to that of *Zerodur*® optical properties. The secondary reflective mirror has a diameter of 48mm and is coated similarly to the primary mirror.

The received Lidar beams are collected and focused on an Optical Unit (OU) placed at the telescope's focal point. At the exit of the OU the Lidar beams are then collimated using an achromat technique.

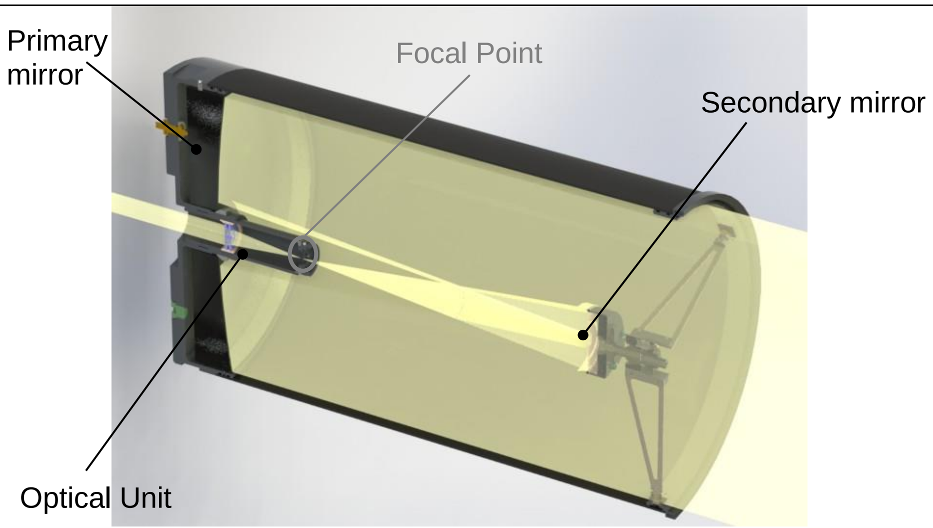
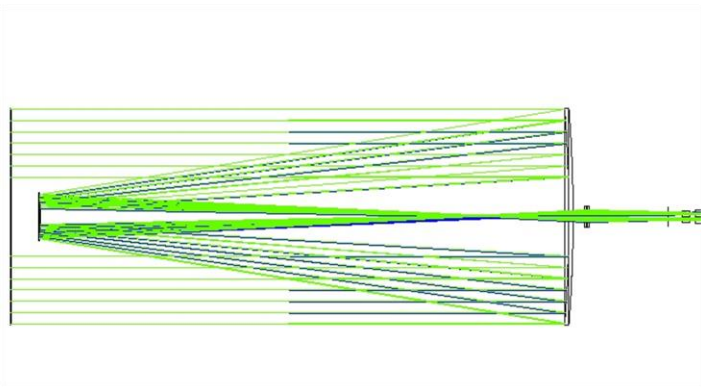


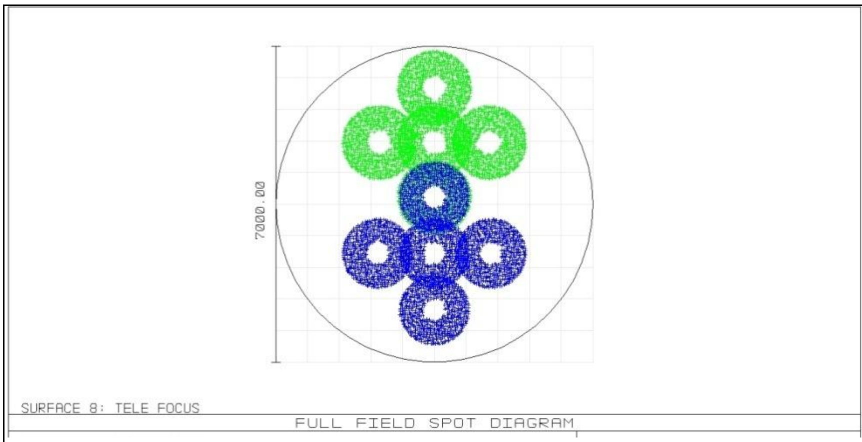
Fig. 3. 8 Telescope Main Components

Each telescope designed and built by Raymetrics has been designed using advanced raytracing techniques in Zemax software. As with all optical instruments, each distance is critical. Even a fractional error can alter the focus of the telescope, resulting in drastically inferior performance.



- Telescope
  - Type: Cassegrain
  - F4
  - Focal Length: 800mm
- **Primary**
  - Diam.: 200mm
- **Secondary:**
  - Diam.: 48mm

Fig. 3. 9: Telescope Characteristics



- Green : Far Field (25 Km),
- Blue : Near Field (0.5 Km)

Fig. 3. 10: Typical Light simulation from far and near field at the field stop

3.2.2. Wavelength Separation Unit

At the entrance of the Wavelength Separation Unit (WSU), the received light is collimated into one parallel beam. A series of factory preset custom-made dichroic reflective mirrors and one polarization cube perform the wavelength separation at the various wavelengths and polarizations [355P, 355S, and 387 nm].

At each wavelength exit specially designed interference filters (IFF) are used to select the required wavelengths and to reject the atmospheric background radiation.

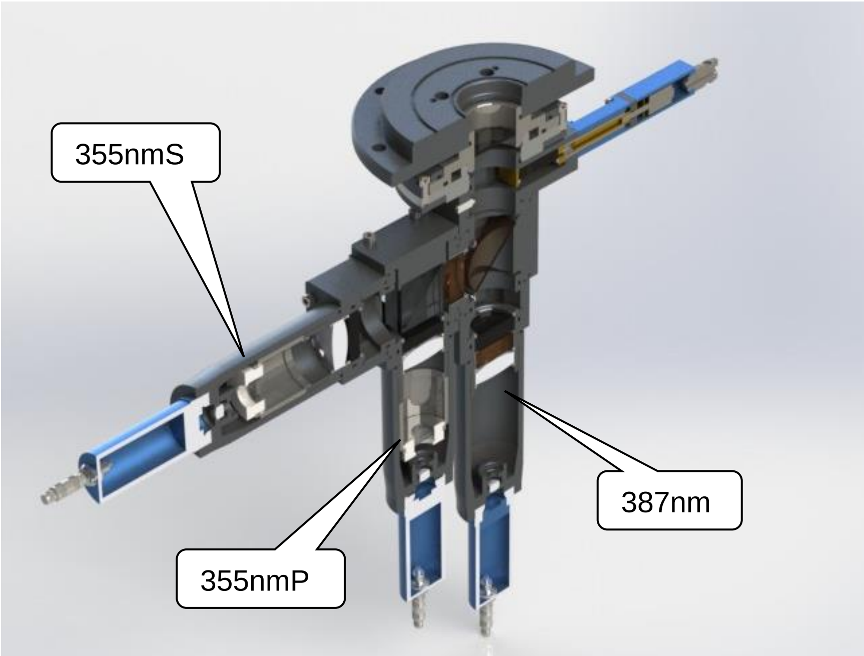


Fig. 3. 11: WSU

3.2.3. Depolarization Technique

The laser emits a narrow, fully polarized beam of light in which light waves all oscillate in the same plane. The receiver measures the polarization of light scattered in the backward direction. For a cloud of spherical water droplets, the backscattered light is fully polarized in the same direction as the emitted beam; i.e. it has only a 'co-polarized' or parallel component. However, for a cloud composed of non-spherical ice crystals, the backscattered light can be partially depolarized; i.e., it can have a 'cross-polarized' component which vibrates perpendicularly to the emitted polarization.

This system has the ability to measure simultaneously both the parallel (P) and the cross-polarized (S) component of the backscatter wavelength which is at 355nm. This is achieved by separating the parallel and the cross-polarized components, with a depolarization cube. Each component is then measured using a PMT. From the combination of these two signals the user can extract the depolarization ratio. The depolarization ratio can therefore reveal the presence of non-spherical particles.

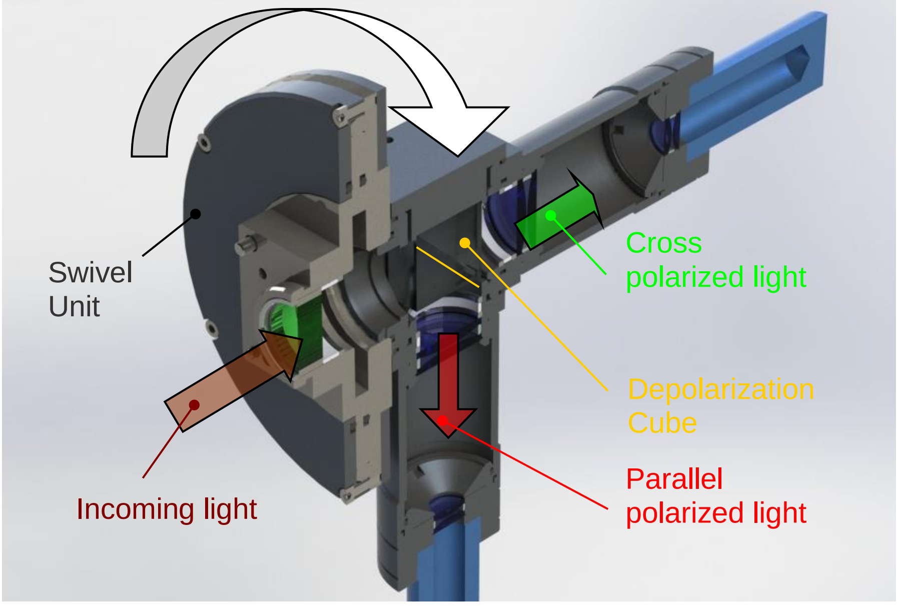


Fig. 3. 12: Depolarization Module

In order to reduce the contamination of the different polarized light, additional linear polarizers are placed between the two collimating lenses of each eyepiece. These are calibrated during the WSU assembly to reject any unwanted polarization. Therefore the eyepiece must be mounted correctly relatively to the polarizer; if for example the eyepiece is turned 90 degrees the resulting signal will be very weak because the useful polarized light is rejected.

In order to calculate the depolarization ratio the user has to calculate the depolarization calibration constant. This constant depends on various things such as the atmosphere the temperature and the specifications of the system itself; thus it is impossible to calculate this analytically. This is calculated by comparing measurements taken with the depolarization module turned at ±45° degrees from the normal position. When the depolarization module is turned the parallel signal is decreased and the cross-polar signal is increased. It is important during the ±45° Degree Test to keep all parameters regarding the electronics the same. Using the same high voltage for the cross polarized PMT will increase the range and insert an error to the calibration constant. To avoid this, an extra neutral density filter is inserted in front of the cross polarized eyepiece.

The swivel unit is machined in CNC mills from a single block so that the best precision is achieved even when it is turned. Moreover the sophisticated design makes this procedure as easy as possible. The procedure can be outlined in three steps.

1. Pull the plungers illustrated below.
2. Turn the depolarization module slightly, release the pins and turn at 45 degrees until a clicking sound is heard from the pin.

3. Now you the measurement can be started.

If the rotation is not easy, the screws located on the reverse of the swivel unit may require loosening.

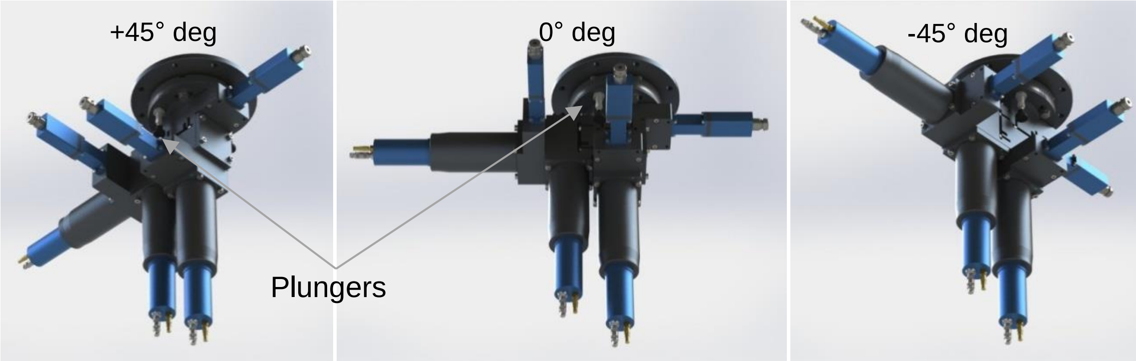


Fig. 3. 13: WSU ±45° polarization calibration procedure

3.2.4. Light Detectors

Light is detected by the photomultiplier tubes (PMT) and converted into a signal that is passed to the detection electronics. The electronics are synchronized with the laser control and the signal is recorded in relation to the time. The electronics communicate via Ethernet with the PC where the data is saved. The detection electronics are discussed in section 3.3.2. The detectors along with the electronics are called Signal Acquisition Unit (SAU).

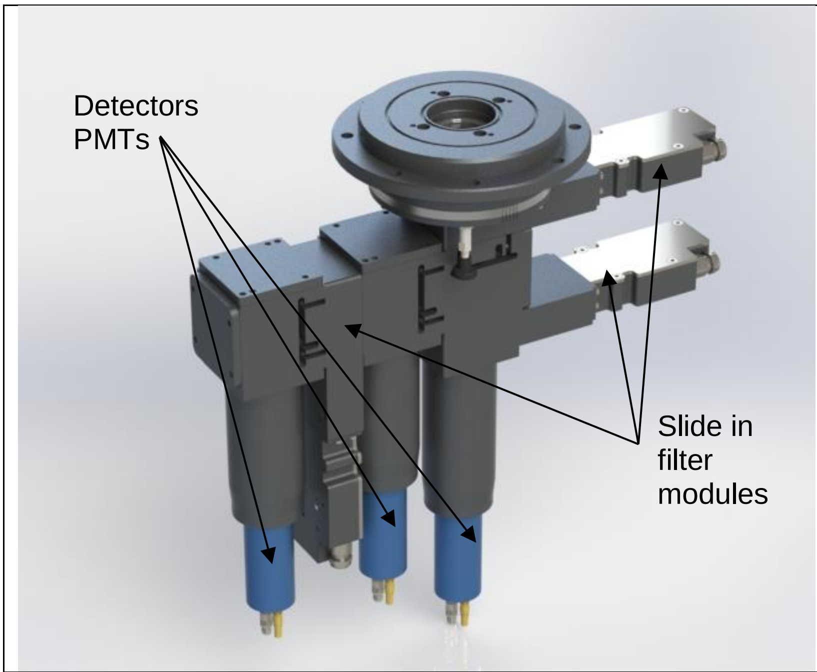


Fig. 3. 14: WSU and PhotoMultiplier Tubes (PMT).

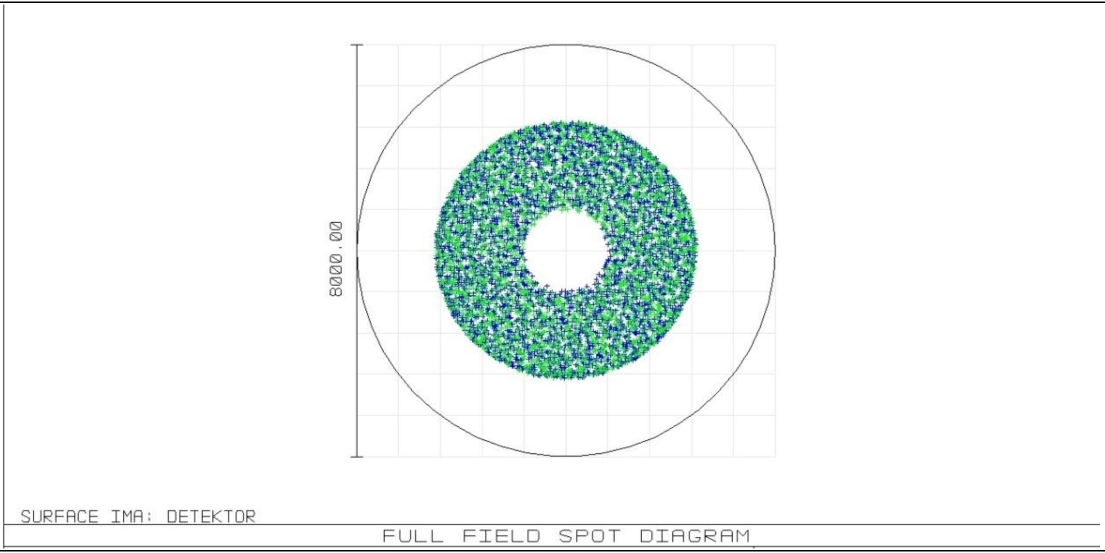


Fig. 3. 15: Image of the Cathode for 355 nm

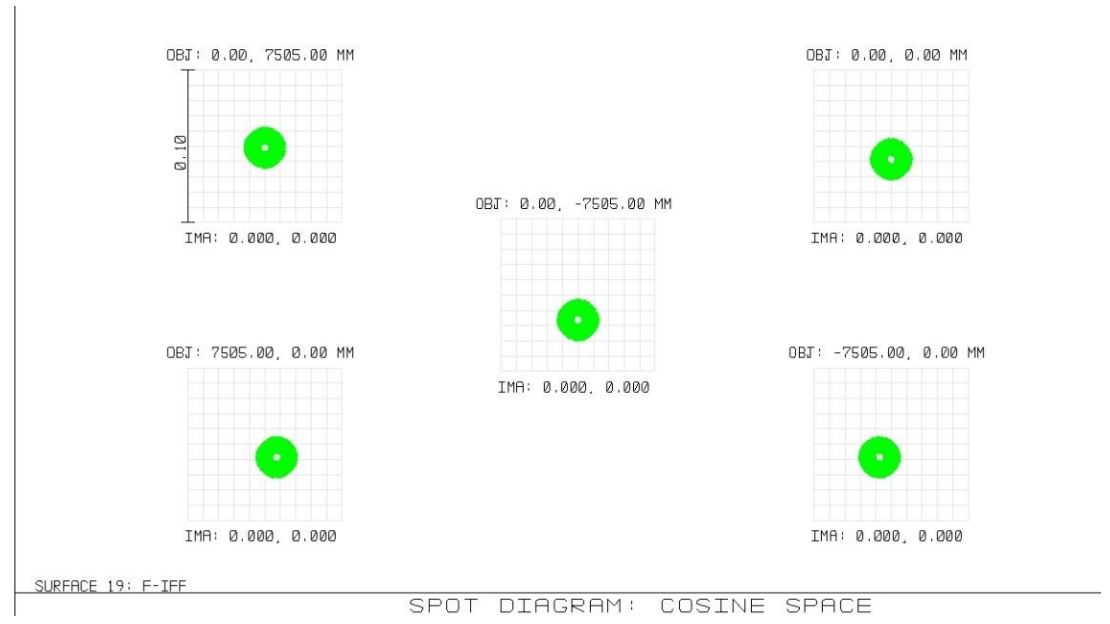


Fig. 3. 16: Max Angle for IFF 355 : typ 1.54 degrees

The spectrally resolved Lidar signals inside the WSU are detected by photomultiplier tubes (PMTs) directly mounted at the respective exits of the WSU. The PMTs used are selected to be compact and to provide optimum operation in the spectral range 355-532 nm. The PMTs work in the pulse mode regime and are characterized by a short rise time constant.

The PMTs have been tested prior to shipment. The PMTs optimum working voltage (for linear operation) is between 750-900V, depending on the amplitude of the received signal and the atmospheric conditions (background skylight conditions during daytime or nighttime conditions and/or cloud presence). During daytime conditions the PMT working voltage should be slightly lower than during nighttime operation.

Technical Specs

Part Number	R9880U-110
PM Type	Hamamatsu
PM High Voltage (V)	0-1000
Supply Voltages (V)	+15
Current Limit (mA)	200
Resistance Anode-GND (Mohm)	1.0
Output Connector	BNC (50 Ohm)

Detailed technical specifications for the PMTs are included in Licel's printed manual.

Attention!

- For optimum operation the temperature and humidity conditions should remain unchanged during field operation.
- Operation at HV higher than 900 V may lead to PMT saturation, thus to a *non linear* operation and/or possibly to PMT permanent failure.
- Environmental conditions of the PMTs have been provided below (noting that they are included in a climate controlled enclosure).

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 only under the environmental conditions given in Licel's user manual.

Light conditions: The PMTs are highly sensitive to ambient light conditions. They must never be exposed 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 will be permanently destroyed.

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

Magnetic fields: Never expose the PMTs to magnetic fields. Even magnetic fields as weak as the Earth's may affect the PMT performance. Strong fields may permanently magnetize some parts, thus damaging the PMT.

3.2.5. Slide-in Filters

For some measurements, the user is required to cover the telescope or add an extra filter. To simplify the process, slide-in filter modules have been supplied within the WSU by using the same modular design. As seen below in Fig. 3.17 there are an actuator and a filter case that slides in and out the light path. Instead a filter it can be used a thick rubber gasket to block the light.

Fig. 3.17: Slide in filter modules

These are typically used for three purposes:

a. As a shutter to block all incoming light for a dark current measurement.

b. As a shutter to block the light at the Raman channels during daytime to increase its lifetime.

c. As a filter for the cross-polarization channel during the depolarization constant calculation procedure.

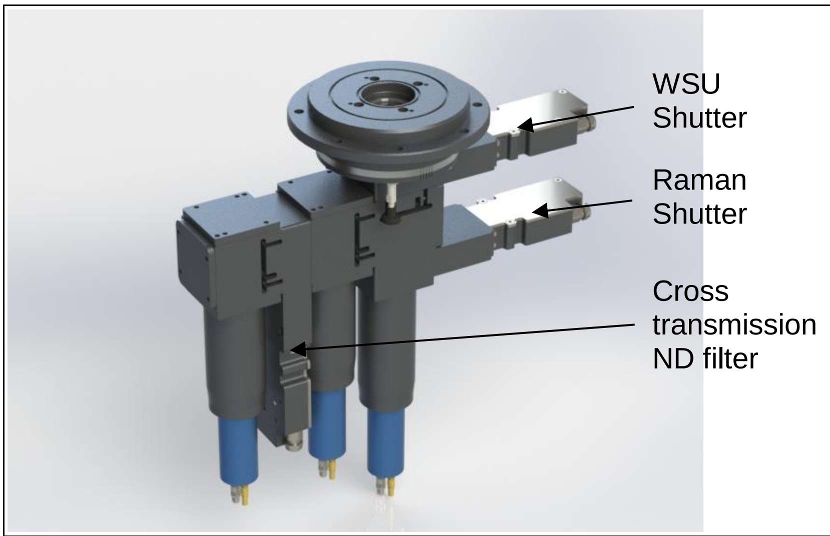


Fig. 3. 18: Slide in filter modules

3.3. CONTROL UNIT

The control unit consists of four main components; the laser control and power supply (ICE450 standard version), the Transient Recorders and PMT power supply, the PC and the electrical cabinet.

3.3.1. Laser Control and Power Supply

This device controls all of the functions of the laser and supplies the laserhead with power and deionised water as a coolant.

Fig. 3.19: Laser power supply and controller

3.3.1.1. Control

The user can operate the laser and check its status through the laser Control Box. The main operation performed this way is the flashlamp/Q-switch start and stop and the Q-switch delay (that reduces the laser beam energy). The user can also obtain various information about the status of the laserhead, such as the counted number of shots, the temperature, the flow of the pump etc. All interlocks appear on the control with a short explanation.

The device has two interfaces; one remote control box and a RS232 that is connected to the PC. This means that the laser can be controlled either from the Lidar itself via the PC or through the Control Box.

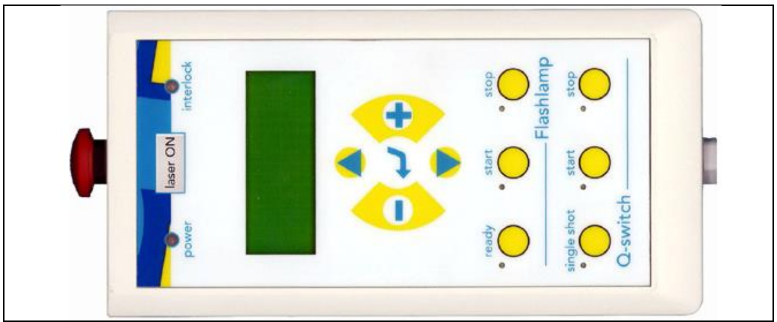


Fig. 3.20: Control Box

NOTE: in order to control the laser from the PC the user has to switch manually from the Control Box the serial link. This can be done by navigating using the buttons to select 'System Info' and confirm with the button. Serial link can be selected and changed from 'off' to 'on' with the ✚ button. Every time a button on the Control Box is pressed, the serial link automatically turns to 'off'.

3.3.1.2. Power and Water Supply

The laser requires a water supply since the head is water cooled. This is achieved via an individual sub-unit inside the ICE450 called the Coolant Group Unit (CGU). The CGU cools the flashlamp(s) and the laser rod with a closed loop of de-ionized coolant. This temperature regulated coolant also provides thermal stabilization of the oscillator's structure.

A thermostatic electronic circuit, which regulates the fan's speed and airflow rate through the exchanger, provides thermal stabilization of the coolant. The temperature stabilization is within ± 1 °C. The ambient air temperature within the enclosure can range from 15 °C to 28 °C with no effect on laser operation.

The CGU includes a de-ionizing system that, with proper maintenance, can maintain the conductivity of the coolant at less than 1.0 μS · cm-1 (resistivity ≥ 1.0 MΩ · cm). The CGU has coolant level, flow, and heat-sensing switches to interlock with the Power Supply Unit to prevent damage to the laserhead in the event of a cooling system failure.

The CGU requires approximately 1.5 liters (0.4 US gal.) of coolant for standard systems incorporating three-meter coolant lines. **Use only distilled water with 1MΩ-cm to 5MΩ-cm resistivity.** The water is transferred to the laserhead though two hoses. In one of the hoses a deionizing cartridge is interfered that deionizes the water. Even though the CGU contain a powerful pump, if the umbilical cord is bend too much then an interlock will appear and the laser will not operate. For further information refer to the laser manual.

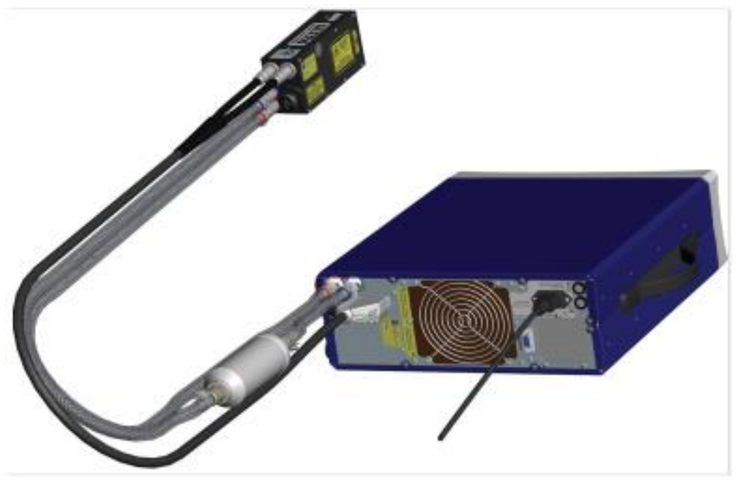


Fig. 3. 21: Control Unit With coolant hoses, power and signals cables.

3.3.2. Detection Electronics

The detection electronics receive an analogue signal from the PMTs and transform it into a Lidar signal. This device is designed to work in two modes: analog detection mode and photon counting detection mode.

3.3.2.1. 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.

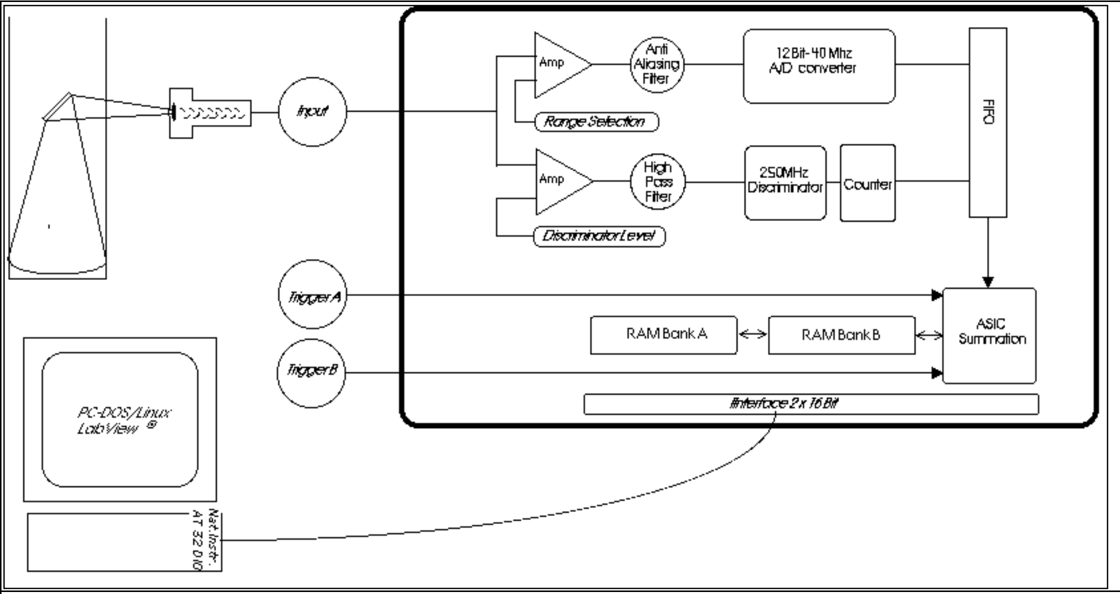


Fig. 3.22**:** Electronics concept

Analogue detection of the photomultiplier current and single photon counting are combined in one acquisition system. The combination of a powerful A/D converter (12 Bit at 40 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 data interface to the host computer allows readout of the acquired signal even between two laser shots. Fig. 3.22 shows the connectivity of the Transient Recorder. The implementation of this concept makes the Licel Transient Recorder a 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.

3.3.2.2. 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 analogue 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.

3.3.2.3. Analogue Detection

The analogue 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 analogue detection mode is based on an analogue-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.

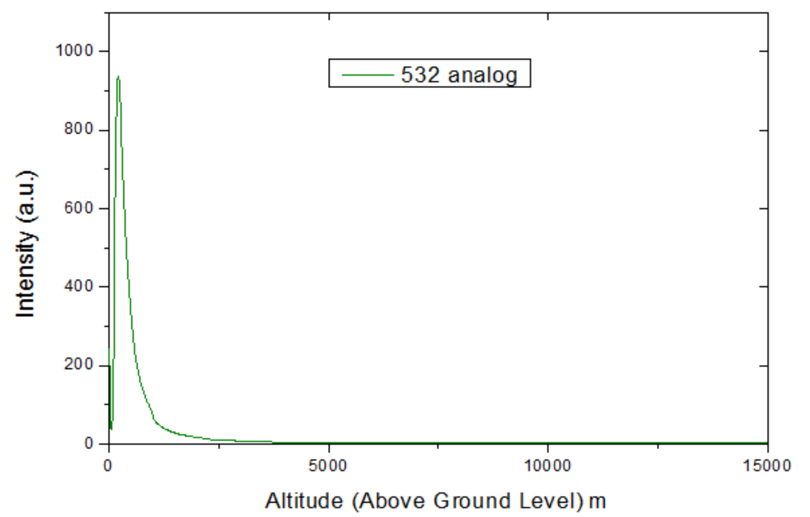


Fig. 3. 23: Typical Lidar signal acquired in the analogue mode.

3.3.2.4. 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 transmits 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 (i.e. τ_d = 4 ns).

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

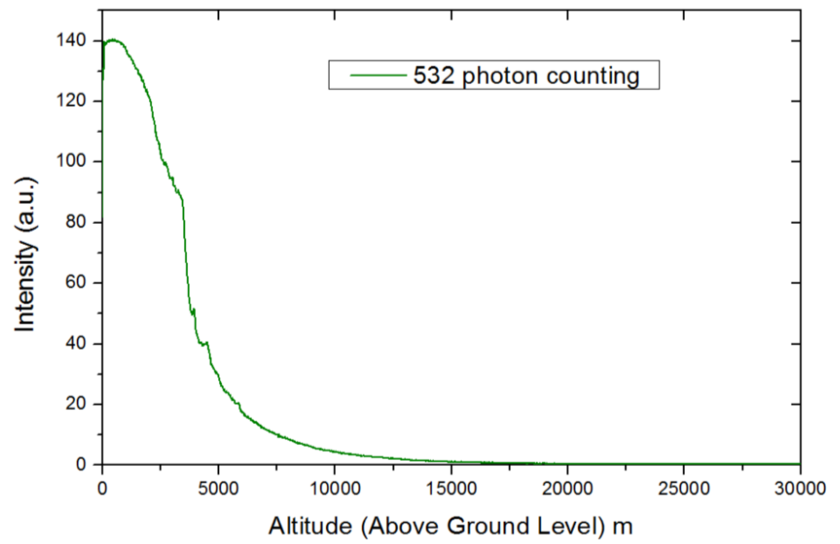


Fig. 3. 24: Typical Lidar signal acquired in the photon counting mode.

3.3.2.5. 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 $\mathrm{SLOG} = \ln\left[(S(z) - BG)z^2\right]$, 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 355 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* $LR(sr) = \dfrac{a_{aer}\left(km^{-1}\right)}{\beta_{aer}\left(km^{-1}sr^{-1}\right)}$.

At 387 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.

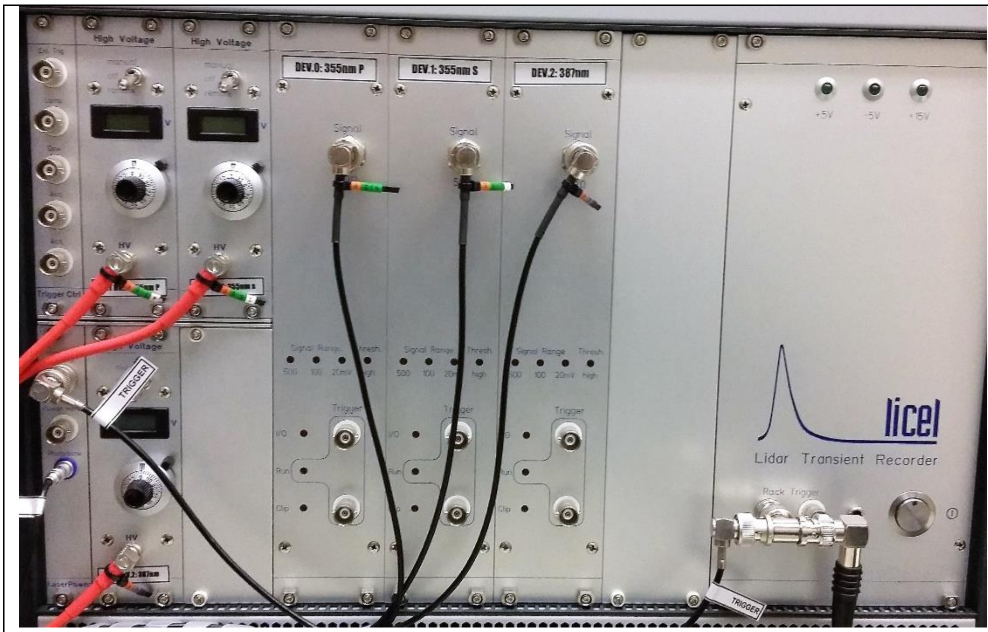


Fig. 3. 25: Rack 6 with
3 x Transient Recorder Devices (TRs)
3 x High Voltage Power supply for PMTs
1 x Laser Power Monitor
1 x Trigger Generator

3.3.3. Industrial Computer

The LIDAR system uses an embedded industrial computer as a Controlling Unit, which features industrial grade robust mechanical design and reliability. All LIDAR subcomponents (LASER, DAQ, mirror mount and LMC) can be controlled from this Unit. The Controlling Unit also acts as a storage unit and as a communication interface.

Features

The ARK3360L Embedded Box Industrial Computers are state-of-the-art Human Machine Interfaces with Intel Atom processors 500 Series with Intel 82801HM I/O Controllers and the following key features:

- **Fanless**

By using a low-power processor, the system does not have to rely on fans, which often are unreliable and cause dust to circulate inside the equipment.

- **Windows CE Support**

In addition to the OS support of Windows XP, Advantech offers platform support for WES7 and Windows XP embedded.

- **Energy Star Certified**

Fig. 3. 26: Advantech Industrial Computer

3.3.5. Lidar Measurement controller

The Lidar Measurement Controller (LMC) module is responsible for selecting the best Lidar configuration of each measurement for optimal results. Optical filters and apertures are used to alter the Lidar measurement parameters to ensure the optimum performance of the device. The LMC-100 is the small version of the LMC and can control shutters and filters that slide in and out of the light path in the WSU.

Fig. 3. 27: LMC-100

The LMC firmware is dedicated to receiving commands through the serial port (COM20 by default) from the Lidar PC and to moving the appropriate optical components. Three channels can incorporate up to 14 linear actuators (using an add-on module), with the ability to have all three channels active simultaneously.

Upon starting the LMC has to establish communication with the PC via the serial port. Next it identifies the connected actuators in each channel and moves them to the 'home' position. The add-on module is auto-discoverable and if not connected the LMC will only scan for 1 actuator per channel. After initialization of the LMC and its actuators, the module awaits for a command from the PC.

The receiving commands have a format of up to 4 ASCII characters followed by a comma (,) and then up to 28 digits. The supported commands are:

1. Get Firmware Version: Responds with the firmware version of the LMC.
2. Get Status: Responds with the Status of the actuators of the LMC. It is a sequence of a set of 3 zeros or ones for the unconnected or connected actuators respectively, a comma (,) and another set of 3 zeros or ones for the state of the actuators (one is for the home position). If the add-on module is connected each set is 14 digits long.
3. Set Actuator to Position: Moves the actuator to the selected position. Various no – motion controls ensure the validity of the command.
4. Set All Actuators to Position: Moves all connected actuators to a selected position. Various no – motion controls ensure the validity of the command.
5. Initialization: Move each actuator to the 'home' position.
6. Force Set Actuator to Position: Moves the selected actuator to a set position overriding any no – motion controls.
7. Set Thresholds: Changes the internal parameter for the movement of the actuators.
8. Get Thresholds: Responds with the internal parameters for the movement of the actuators.

The acquisition software is responsible for handling the state of each module according to the type of measurement. For example when acquiring a dark current file the software sends a command to the LMC to close the WSU shutter

#	Connector Description	Type	Pins	Description
1	Shutter Actuator	RJ-45	8	Can control only one main shutter of the WSU used for dark current.
3	RAMAN Actuator	RJ-45	8	Can control up to 8 shutters used for Raman channel's PMT lifetime increase.
2	CTND Actuator	RJ-45	8	Can control up to 2 sliding neutral density filters for the cross receiving channel.

NOTE: For more accurate and updated info for LMC100 please read the dedicated User Manual.

3.3.6. Electrical Cabinet

The electrical cabinet provides protection for the electronics. It contains the laser power supply unit, the Licel electronics and the industrial computer.

Having two front doors and sliding trays, enables easy access to every component. The cabinet is made from aluminum alloy sheet steel which is robust and lightweight.

Fig. 3. 28: Control Cabinet

3.3.6.1. Features

- Weather protection
- Internal heater
- Fans for air circulation
- Easy access to all components
- Castors and handles for easy transportation
- Door locks
- Robust and lightweight
- Connectors and plugs for quick connection
- Energy box with circuit breakers for every part
- Embedded industrial Ethernet switch

3.3.6.2. Connections

The Licel Transient Recorder communicates with the PC via an Ethernet network with the PC and to an external host. By default the network IP is set as shown in the figure below. The user can easily connect to the Lidar and remotely control the instrument simply by using Windows remote desktop. As illustrated below the internal computer has two Ethernet ports. One is used by the Lidar Local Network whilst the other is connected to the external Ethernet socket. This gives the option to connect to a Local Area Network (LAN) or directly to another computer with a cross link cable. If the local network allows access to this computer through the firewall, then it can be reached and the lidar can be operated from anywhere in the world.

The image below shows the connections between all components.

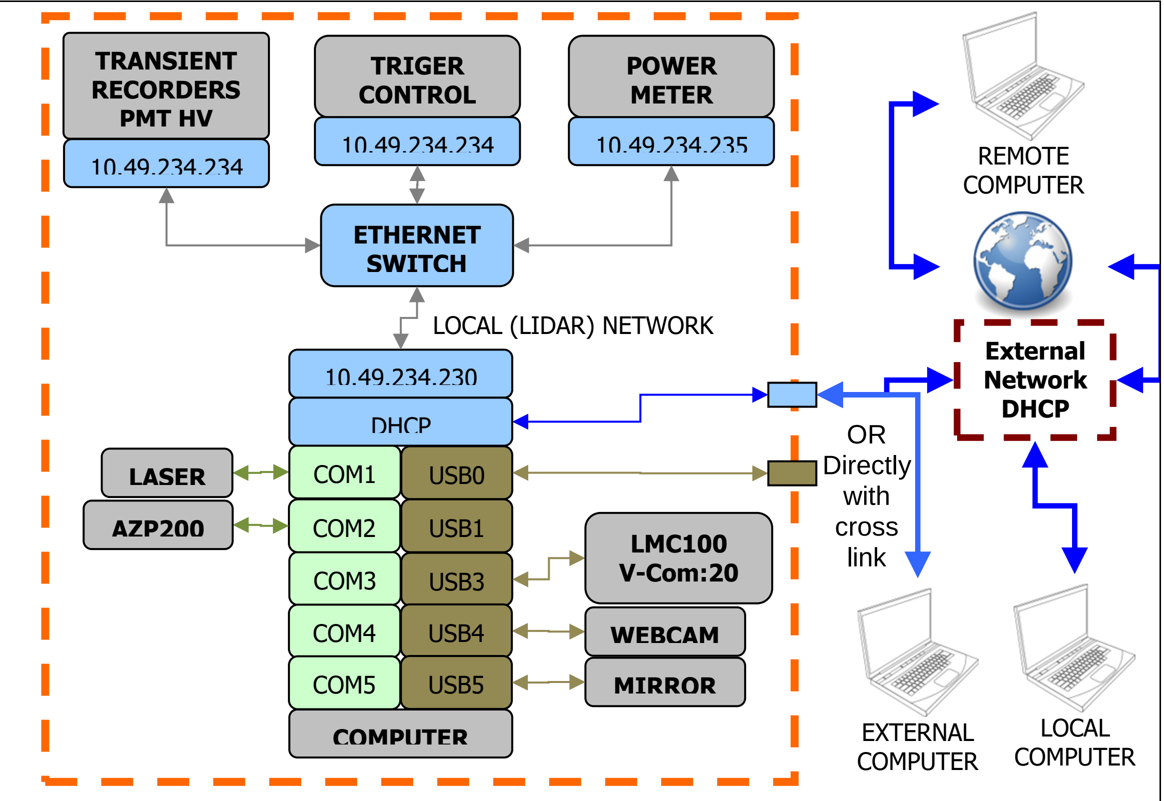


Fig. 3. 29: LIDAR Local Network

The Transient Recorders are externally triggered from the ICE450 through a BNC cable. The laser creates a TTL pulse to trigger the flashlamp for every shot. . The Q-switch is factory pre-set to create a short delay to produce optimum energy. The user can increase the delay to reduce the energy. For this reason another TTL pulse is produced to trigger the Q-Switch with the required delay. The Transient Recorders are triggered by the Q-Switch TTL pulse, so that the laser emission is synchronized with the acquisition start time.

As shown in the image below default connection is at memory A on the Transient Recorder and at 'QS OUT' on the laser.

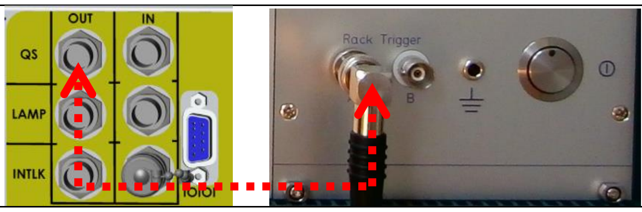


Fig. 3. 30: Trigger Connection

There are also two trigger inputs for the Transient Recorder and there are several outputs and inputs for the laser. These are for triggering externally or for using the flashlamp TTL pulse to trigger an auxiliary device. How to use these features is explained in appendix section A1 HOW TO CONTROL THE LASER.

3.3.6.3. Electrical Drawing

The electrical cabinet has a power distribution unit which contains the switches for the components of the control unit.

1. 'Main' Switch. This gives power to the rest of the components.
2. Circuit protection breaker 30mA. In case of a short circuit this automatically shuts down the mains power.
3. 'PC/MM/LMC'. Switches on the air condition unit.
4. 'TR' Switch for the Licel Electronics
5. 'AZP200' Switch for the positioner.
6. 'FANS/HEATER' Switches on/off the heating or cooling depending on the thermostat
7. 'LASER' Switch for the laser.
8. 'SOCKET' Free socket for powering external devices.
9. 12V power supply which powers the LMC, the controller of the mirror mount, the computer and the industrial Ethernet switch.
10. Thermostat for controlling heating device (You have to uncover for reveal it)

Fig. 3. 31: Energy box

WARNING – HIGH VOLTAGE: Do not operate the Lidar without the protective cover. Keep away from liquids. Electric shocks could lead to serious injury or even death.

The figure below shows a simplified electrical drawing of the power distribution unit. Note that this is for reference only. Changes must not be applied without first consulting Raymetrics.

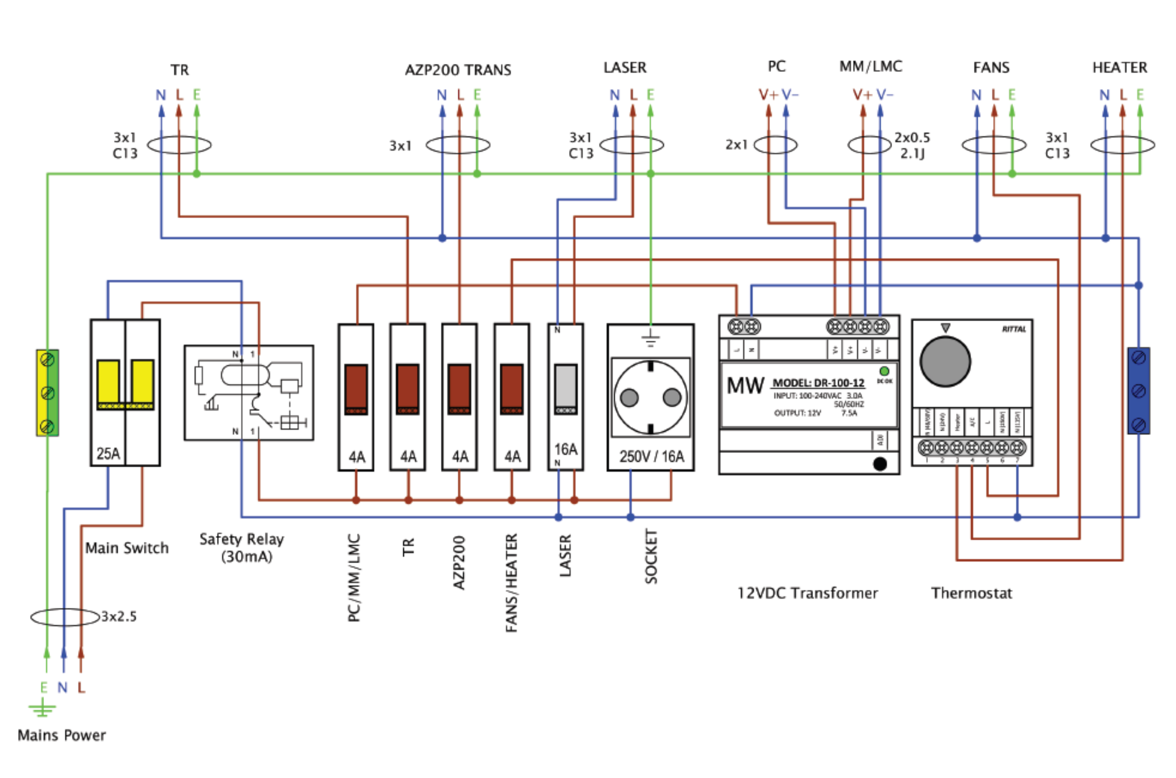


Fig. 3. 32: Wiring Diagram

4. LIDAR SYSTEM SOFTWARE

The Lidar comes with a suite of software. Programs can be grouped into three main categories; System Operation, Post Processing, Tools. Operational software programs are used to acquire the Lidar raw data. Post processing software is used to analyze the raw data. Tools are used for maintaining the Lidar at peak performance, for customization and for system diagnostics.

Below is a diagram showing some of the basic software modules.

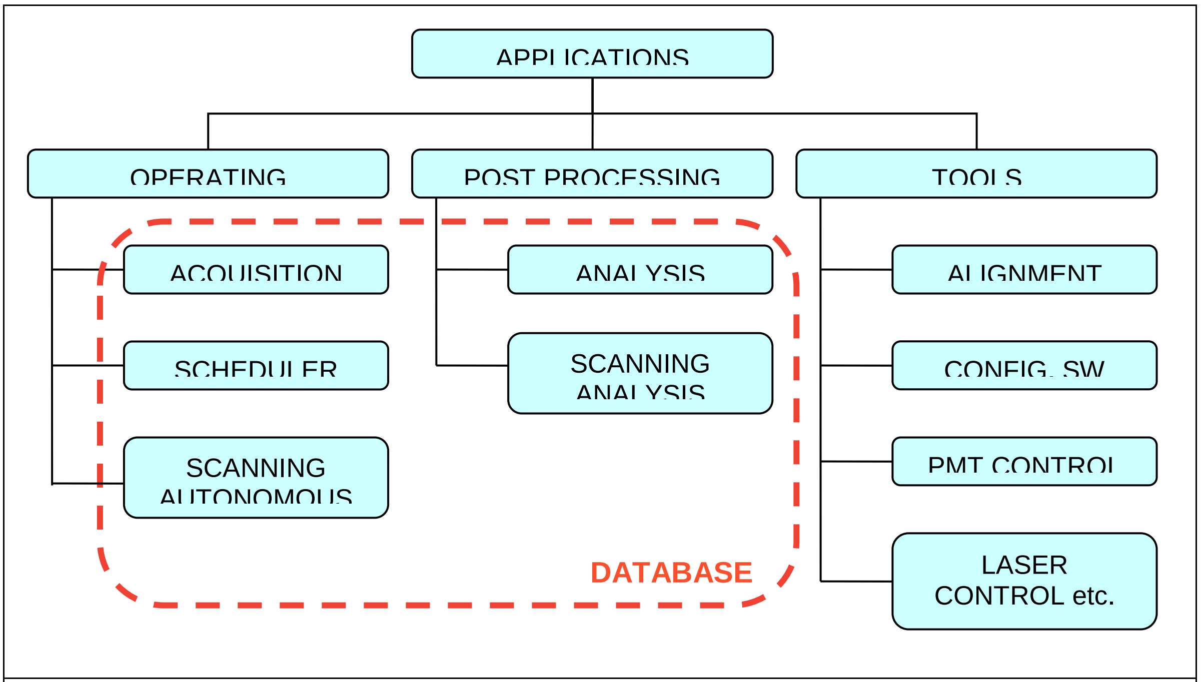


Fig. 4.1: Software Modules

Data from the measurements (raw data) is saved in a database. This database is shared with the analysis software which can also edit it. It is important to understand how this database works so that the measurements are registered normally. Users can create more that one database but it should be kept in mind that the raw data can be bulky and not easy to handle. All raw data in each database is saved in a single folder with a unique datalog file which contains all information for the records (measurements).

The following sections present the main software modules as a reference guide only. Some features may not be available in every system. Refer to chapters 6. LIDAR OPERATION and 7. LIDAR DATA PROCESSING for further information on how to use the software.

4.1. SYSTEM OPERATION SOFTWARE

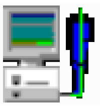
As previously noted, operation software is used to acquire the Lidar data. In other words this program will start, stop and save a measurement. This means that the software controls the devices that are used for the measurement and data logs the output of the measurement. Raymetrics has combined all different software from each device in a single program to make the process of measurement as easy as possible.

The acquisition software simultaneously does the following:

- Transient Recorders control
- PMTs control
- Laser control
- Data logging

While the scheduler gives the user the ability to schedule a series of measurements.

4.1.1. Acquisition



The acquisition program is the most important program for the Lidar. Knowing how to acquire good Lidar data is effectively more important than analyzing the data, as good post-processing can only be done if there is good data to begin with. Below is the interface of 'Lidar Acquisition.exe'.

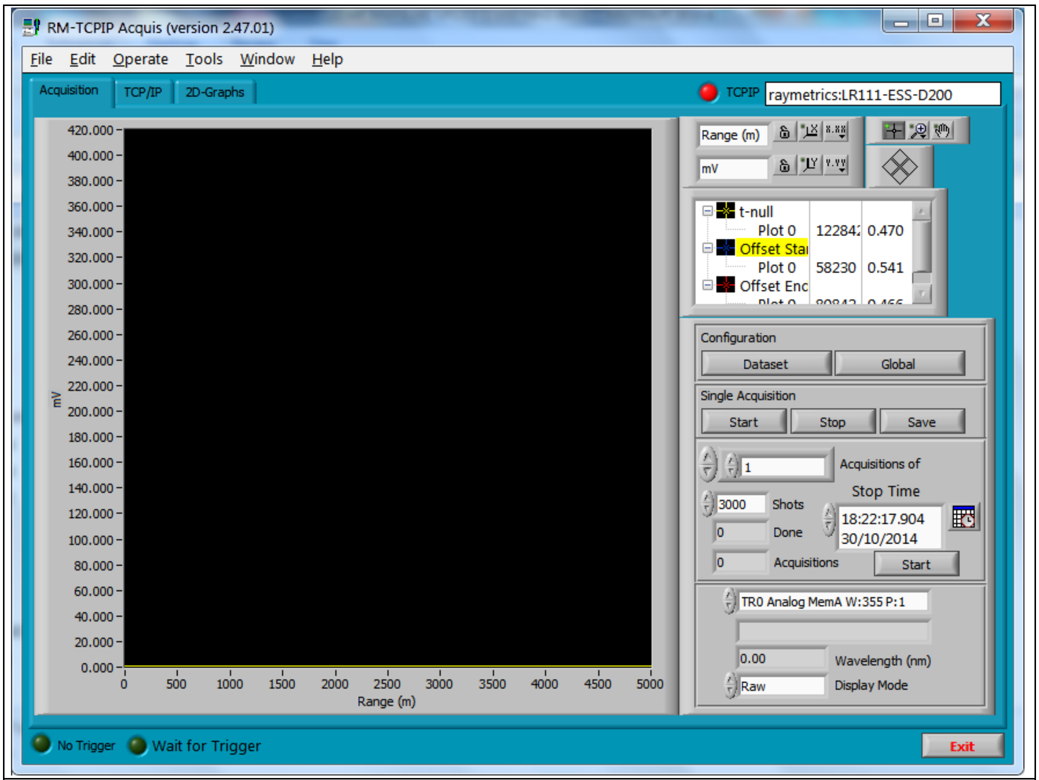


Fig. 4.2: Lidar Acquisition.exe

The GUI contains three main tabs. The Acquisition tab, the TCP/IP tab and the 2D Tab. Here only the Acquisition tab is presented since this is the most important. The TPC/IP is used only for the configuration of the connection with the Transient Recorder whilst the 2D tab shows a 2D graph of the time evolution of the acquired measurements.

The main features in the Acquisition tab are:

- a graph that displays the acquired profiles in real time
- various controls for the graph display features
- two configuration buttons 'Dataset' and 'Global'
- a Start/Stop button

The 'Dataset' button opens a new window which allows the user to set the parameters for each channel. The interface and the main parameters have been shown below.

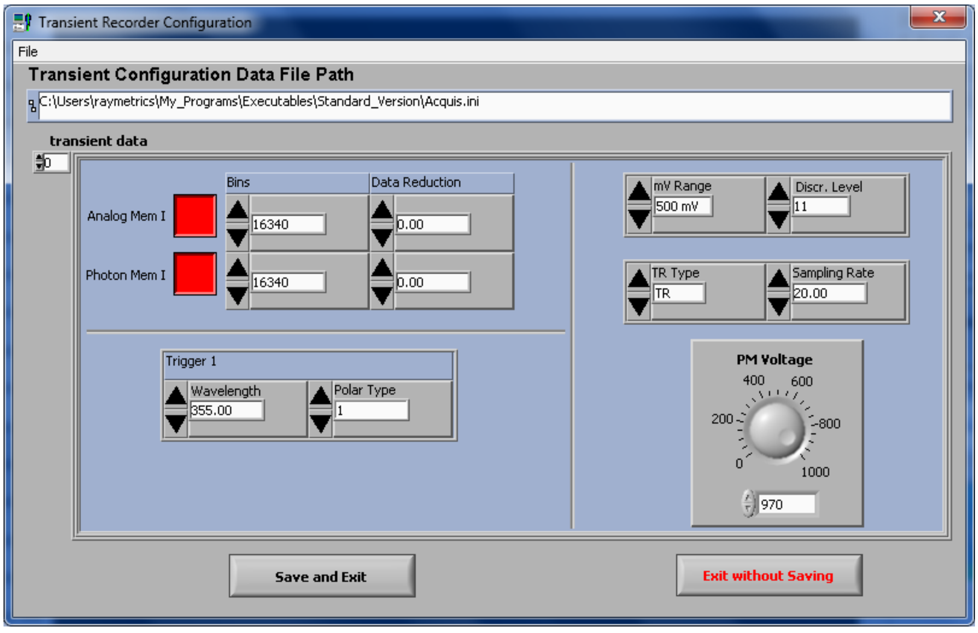


Fig. 4.3: Dataset window

On the menu under 'File' is the option to load and save a configuration file. The selected file is shown at the text box under 'Transient Recorder Data File Path'. Next to the Transient Data frame there is a numeric control that indicates the selected device

The parameters and settings here are:

- Memory selection button and measurement size for Analogue and Photon counting separately.
- TR parameters such as mV range, TR type and sampling rate.
- PMT high voltage setting. This not only sets the header file but also sets the desired voltage to be used for the specific PMT throughout the measurement.

The 'Global' button opens a dialogue to set general settings regarding the measurement. As shown below the user can set:

- the location parameters (Name, Altitude, Longitude and Latitude)
- The ambient temperature and pressure
- The laser's information (wavelengths and frequency)
- And (most importantly) the number of shots for each profile.

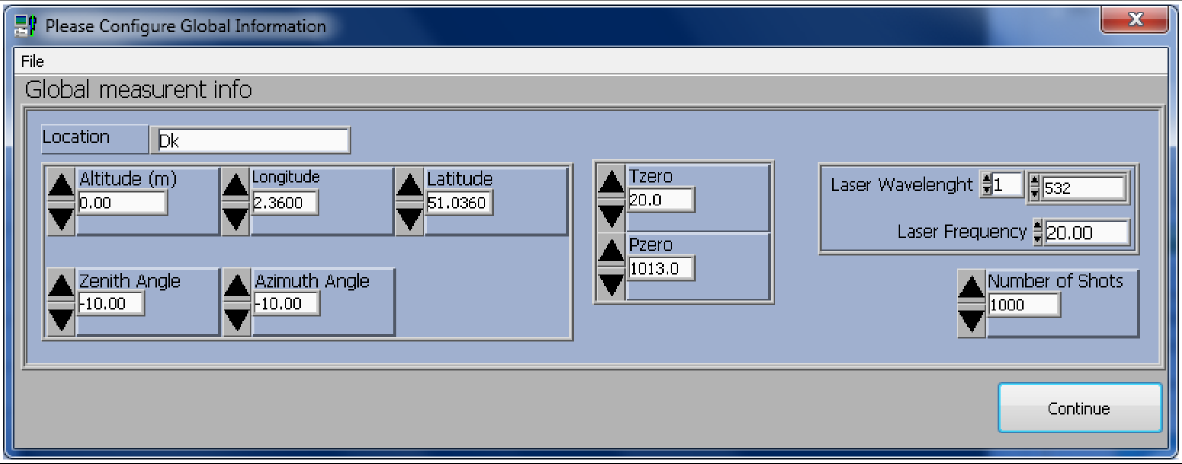
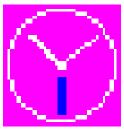


Fig. 4.4: Global settings dialog

4.1.2. Scheduler



The 'Time scheduler' program allows the user to program the Lidar to perform scheduled measurements. This is extremely useful when the instrument is in a remote location without a fast internet connection. The user is able to set a daily plan of measurements and may select which days of the week will use this plan.

The concept of this software is to use the Lidar in a fully automated mode. There is no need for an operator since the Lidar will start and stop and save data automatically. Furthermore if a mobile phone is installed the software can produce text messages which will prompt the user in case of an emergency or a failure. All these features combined make for a fully remotely controlled Lidar.

Only the main interface of the program is shown here. For more information please refer to 6.4. MEASUREMENT SCHEDULING.

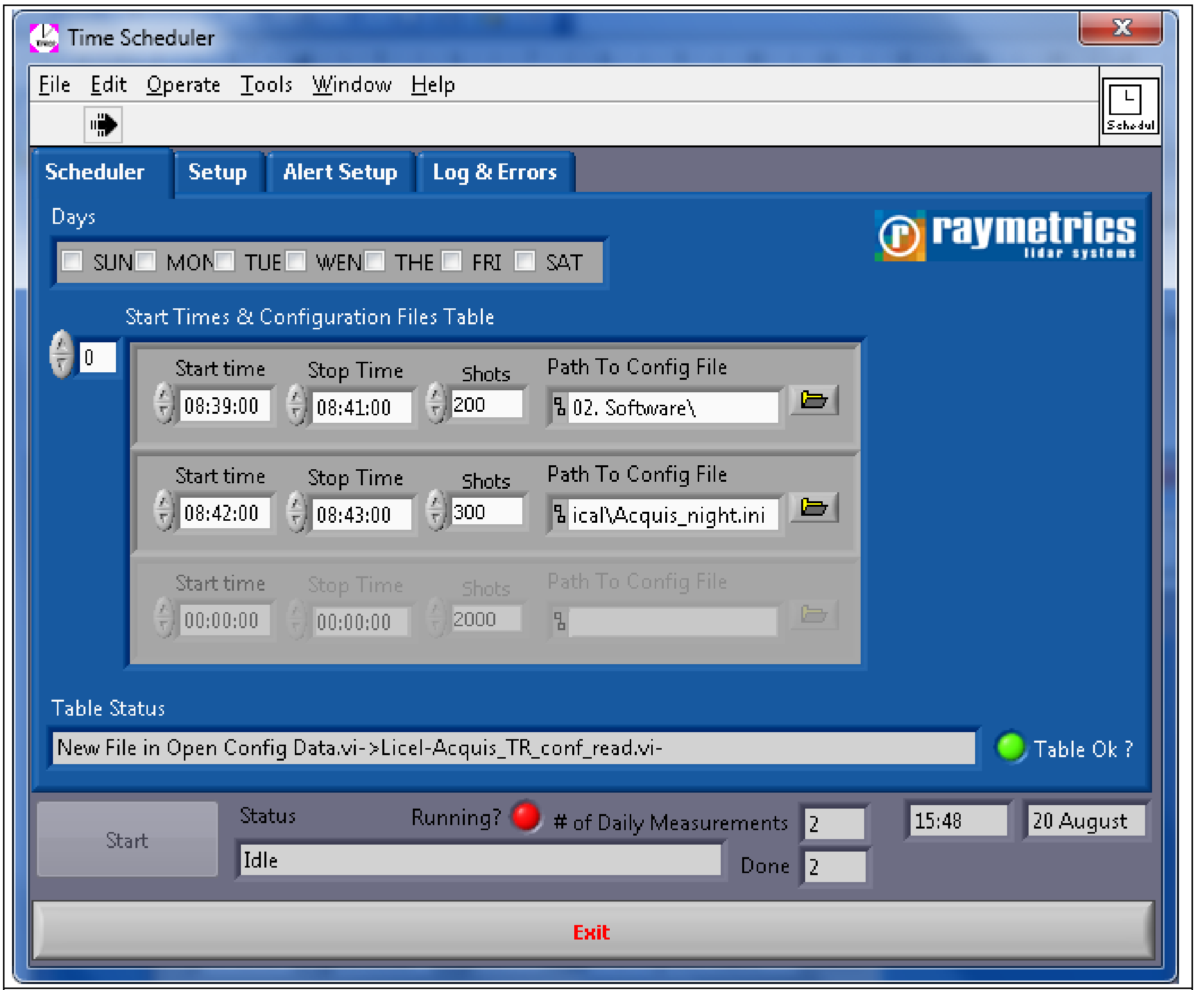


Fig. 4.5: Time scheduler main interface

4.1.3 Scanning autonomous and Time scheduler

For a scanning lidar there is the ability to scan an area or even schedule to scan multiple areas. There are two main programs available; scanning autonomous and Time Scheduler Scanning. Both programs use configuration files as the fixed point time scheduler but these files contain geometrical information regarding the scan. To create such a file there is an extra tool called acquisition configurator. This set of programs make a full scanning lidar operation software pack which gives the user all the possible options one could ask. To make this software complete there the equivalent data processing program for scanning measurements. This is totally necessary while the volume of data when scanning is vast.

Below are only presented the main interfaces of the configurator and the scanning autonomous. The Time Scheduler Scanning differs very little from the one presented above and thus is skipped. You can find more information for these programs in paragraph **Error! Reference source not found.**.

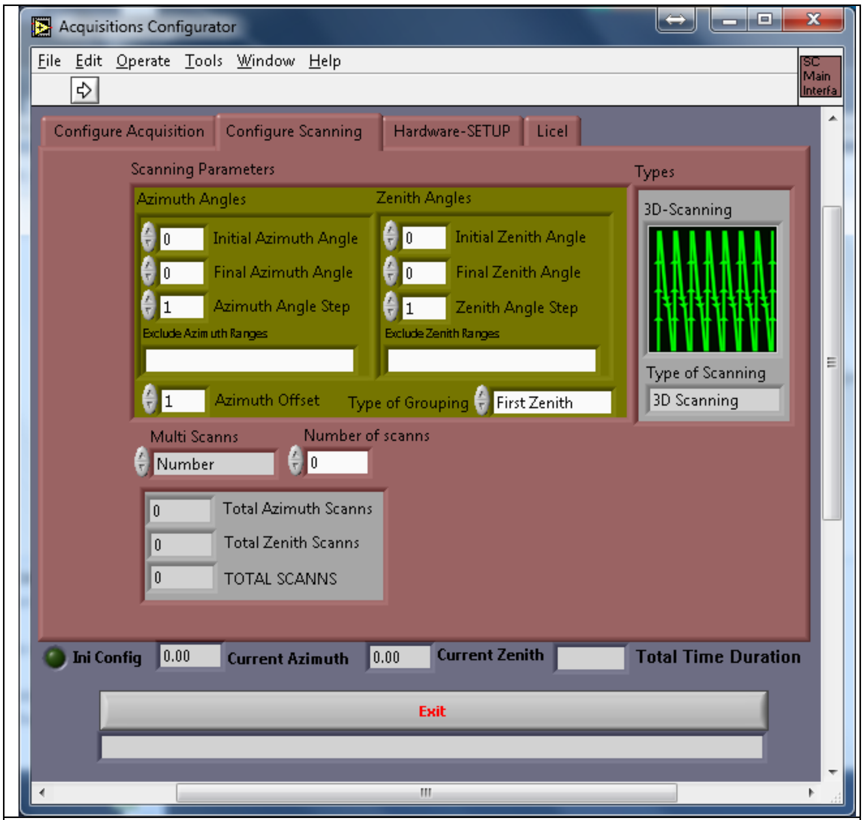


Fig. 4.6: Scanning Configurator main interface

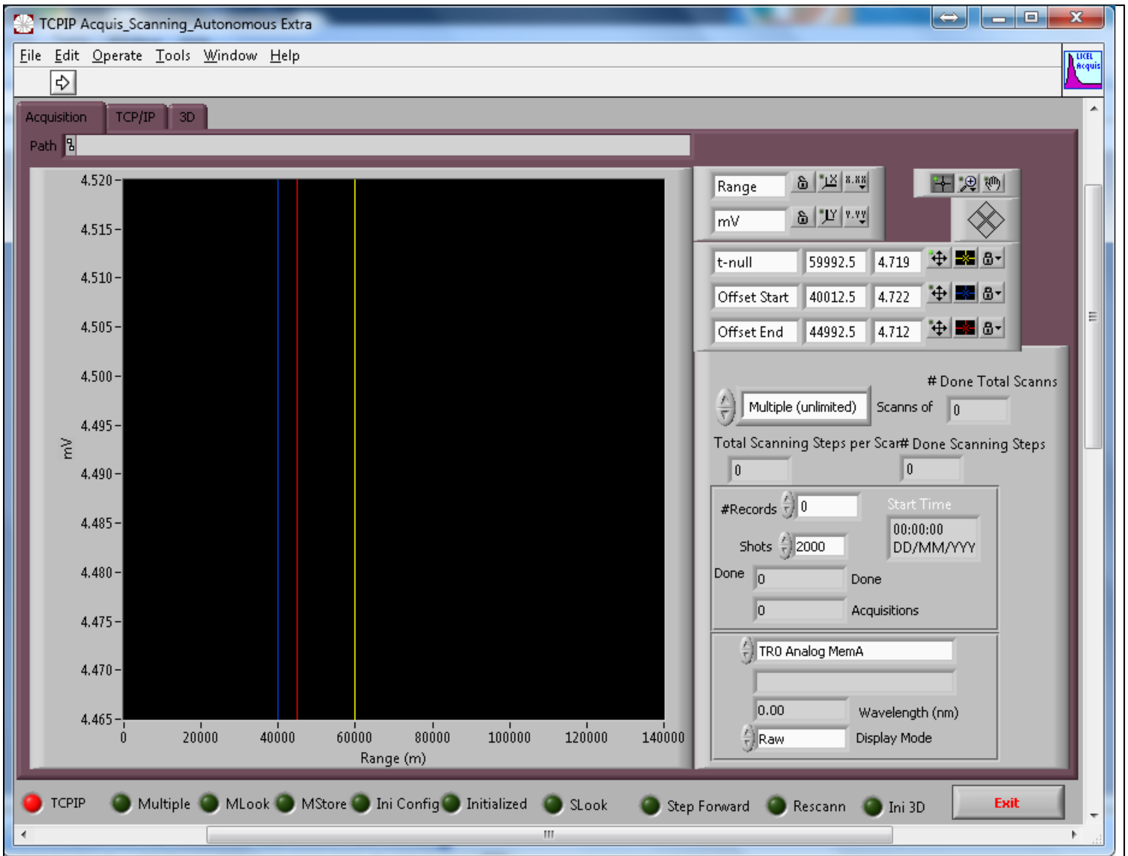


Fig. 4.7: Scanning Autonomous main interface

4.1.4. Database and Working Directory

Each measurement produces a series of binary files which contain the raw data. The volume of data is normally large, which makes it necessary to use a program which can arrange the data in databases.

As previously explained all raw data files are saved in one working directory (one single folder) which forms along with the datalog file one unique database. At first glance this appears unwieldy since one folder can contain thousands of data files. However these files are not relevant for the user since they are in a binary form. There is no actual need to ever use this folder directly. Files are instead organized automatically in the database. It is important not to alter the folder and keep a regular backup of your data.

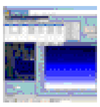
A new database can be created by changing the working directory. Users may make as many databases as desired, but should be kept in mind that it will not be possible to have an overview of the measurements with multiple databases.

4.2. POST PROCESSING SOFTWARE

There is an obvious need to use a program which can organize the database and at the same time process and plot the data. The Lidar computer has a powerful program preinstalled, named 'Data Preview and Analysis' for post processing raw data. Many users prefer to use another computer for the data analysis. Raymetrics software is currently fully open source* and can be easily installed on any other computer. The software was compiled in Labview and thus the user needs to install the Labview runtime engine which is supplied free of charge from the National Instruments website.

Some users prefer to use their own software to post process the data. In this case we provide a software tool which translates the data from binary to ASCII format, as well as the encoding method to use the binary files.

* All software may not always remain open source.



The **'Data Preview and Analysis'** program was created based on the needs of Lidar users. This software has been developed over the past 12 years so that today the user can find many features embedded. However in this section the program is only briefly presented. Please refer to section 7.2. DATA PREVIEW for more information on using the database and for data analysis. With the 'Data Analysis and Preview' program the user can:

- Preview and edit a database

- Analyze the raw data and extract various information such as the Range Corrected Signal the backscatter coefficient the beta molecular, the telecover and many other parameters.
- Use a worksheet to perform additional calculations which may not be included in the main analysis.
- Use advanced Lidar techniques such as data Gluing
- Present the data in 2D, surface (time evolution) and 3D plots.
- Use this software as a health diagnostic tool for the system i.e. Lidar Alignment state.
- Convert data to ASCII from binary files
- The program also supports radiosonde data import, or background noise files

Raymetrics also provides the methods used by the software for the analysis, so that the user can be aware of the theory which underpins the result.

The software contains an extra module for the data analysis. Each time the user attempts to create a plot or to a process raw data, a series of widows appear which allow the user to select the dataset to be used; followed by a window where the output of the analysis can be selected. Only after this the main analysis window appears. In this window there are many user-selected or automatically-selected parameters, which provide a more precise analysis.

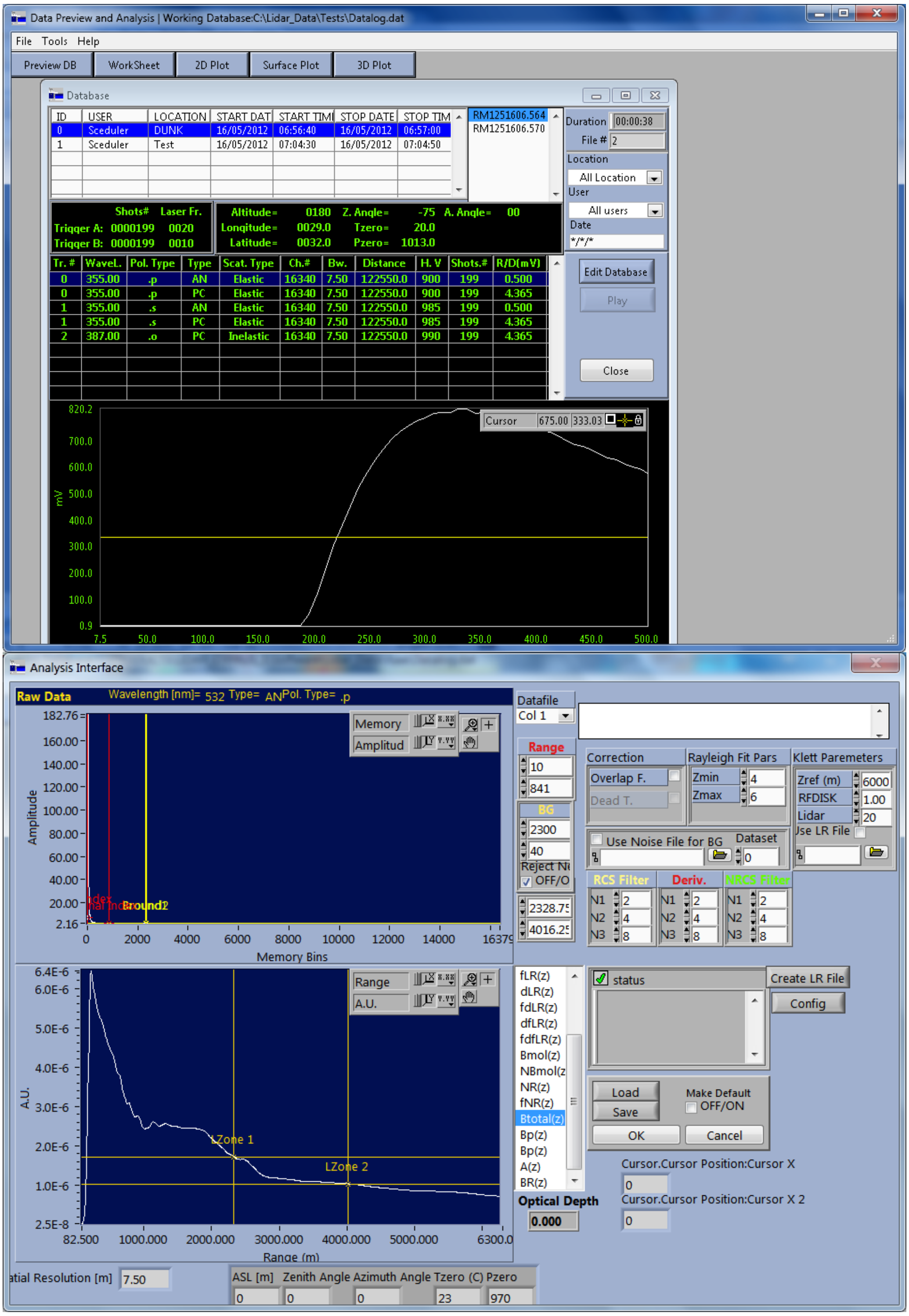


Fig. 4.8: Data Preview and Analysis Interface

Another useful tool is the Advanced Viewer Extra which is specially designed to handle scanning data. With this program the user can group scanning data analyse plot save and many more. This software also cooperates with Google SketchUp to create 3D representations of scanning data in Google Earth. You can read more in paragraph **Error! Reference source not found.**.

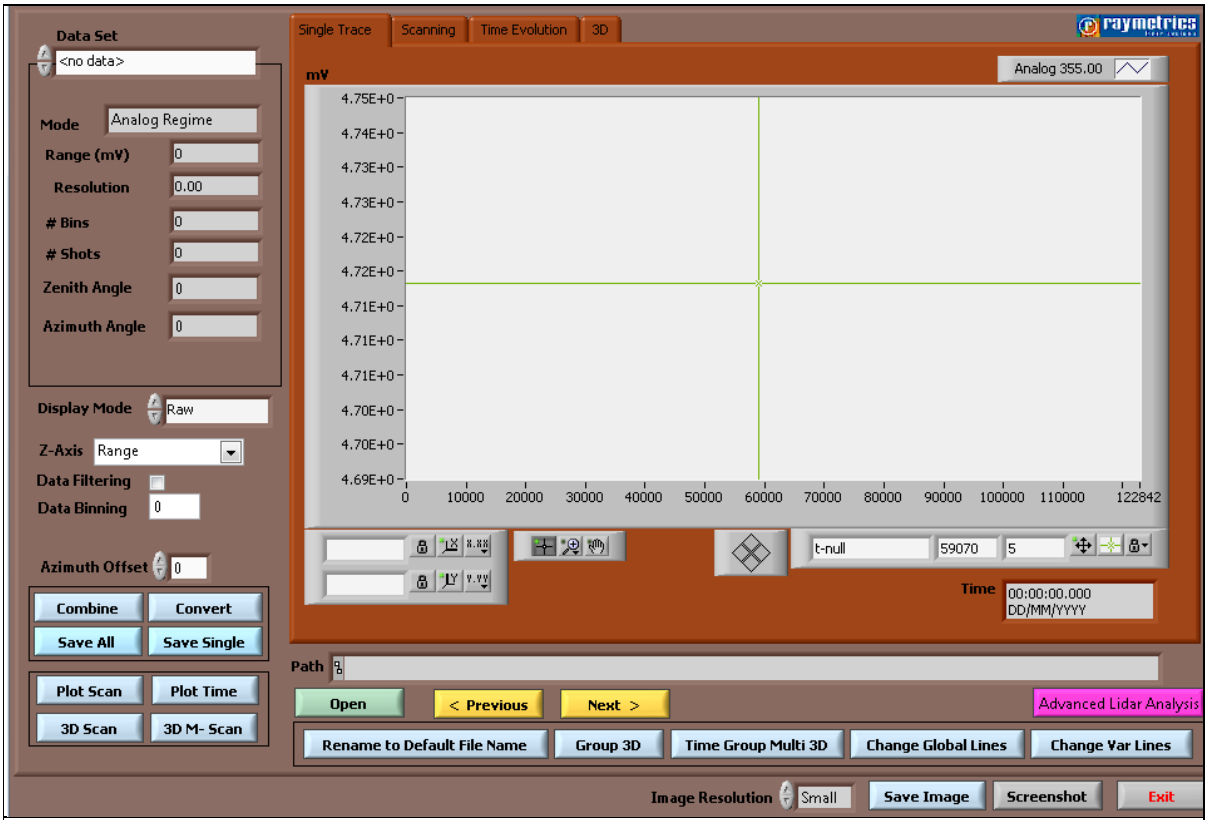


Fig. 4.9: Advanced Viewer Extra

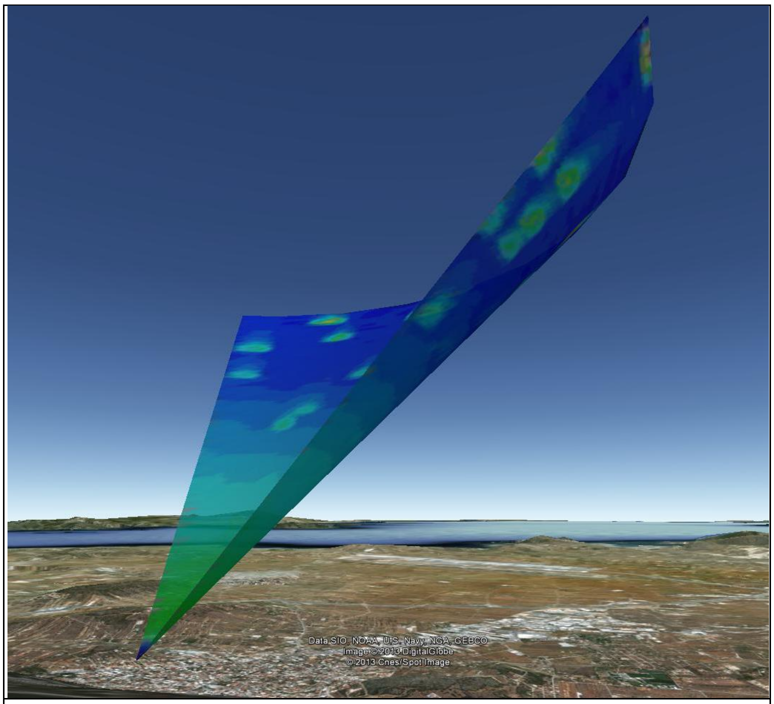


Fig. 4.10: Advanced Viewer Extra

4.3. SOFTWARE TOOLS

There are some software tools which is will become very useful to the Lidar operator. To begin with a very useful tool is the 'Lidar Alignment' program, which is used to align the Lidar. In addition a series of software modules have been provided to control different devices individually. Finally there is software used for diagnostics and for the configuration of the Lidar’s components.

4.3.1. Lidar Alignment Program

This program is real-time acquisition software which does not save any raw data files but is only for viewing the signal. Furthermore the user can control the motorized mirror mount to steer the laser beam where it should be. It is suggested to check the signal regularly to make sure that the data acquired is optimal. Further information concerning the alignment has been included in section 6.2. LIDAR ALIGNMENT.

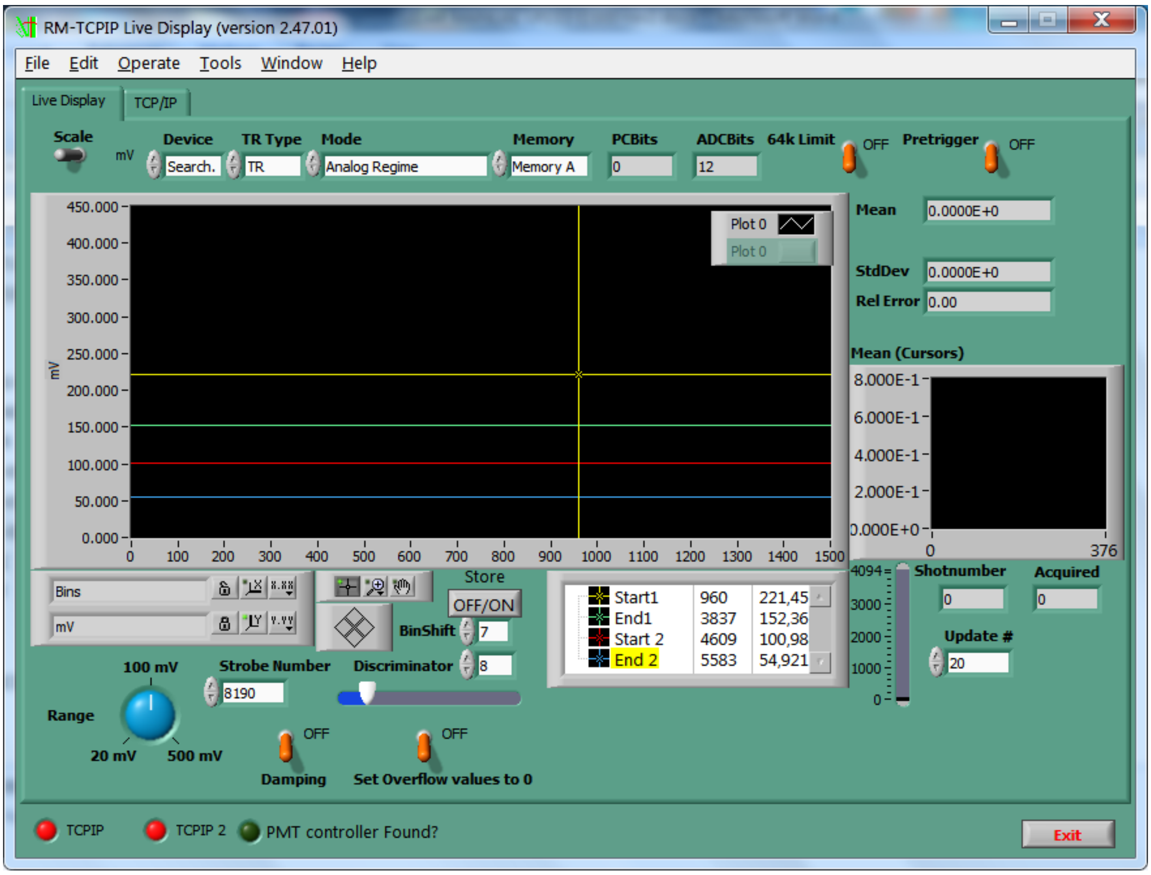


Fig. 4.11: Lidar Data alignment Interface

The interface appears similar to the 'Lidar Acquisition' program. However there are some important differences which make this alignment tool unique. Starting with the common features there is a graph which includes the control buttons for the axes and four cursors used as markers. There are also the same numeric inputs all together in the same interface. These are the shot number, the memory bins, the discriminator, the range, TR Type, the mode and the device. The interface has also a tab which allows the user to set the control the PMT High Voltage. Another addition is a small graph on the right side of the window with a series of numeric outputs above. These are used to verify the process of the alignment. Finally this interface is equipped with an extremely useful tool which allows for control of the motorized mirror mount.

4.3.2. Configure Other Hardware

Another configuration tool is the 'Configure Other Hardware' program. With this program the user can select which devices will be controlled automatically from the acquisition software as well as changing the communication port for the device.

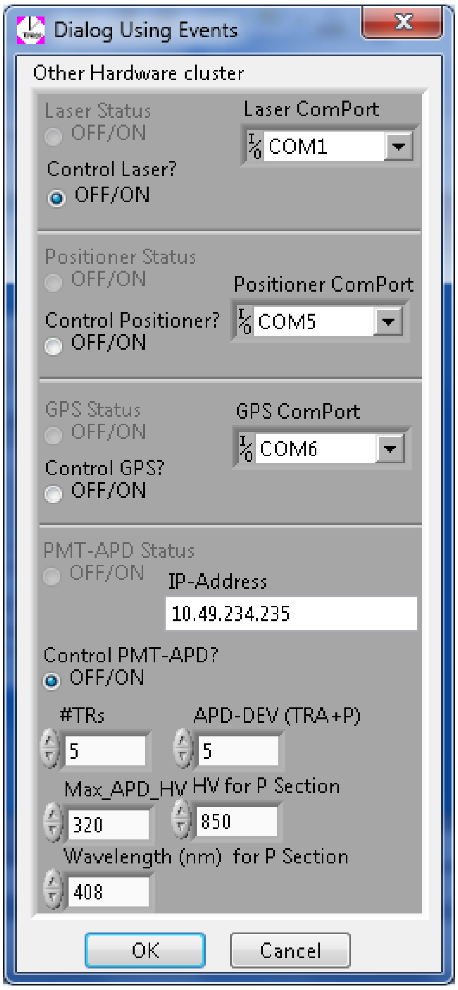


Fig. 4.12: Configure Other hardware

For example in Fig. 4.12 the laser has been selected to communicate via COM1 and the PMT-HV device through the IP address 10.49.234.235.

4.3.3. Laser Control Interface

This software module is provided in case the user may need to control the only laser. Furthermore it provides information about the laser state (flashlamp shots, water level and flow etc).

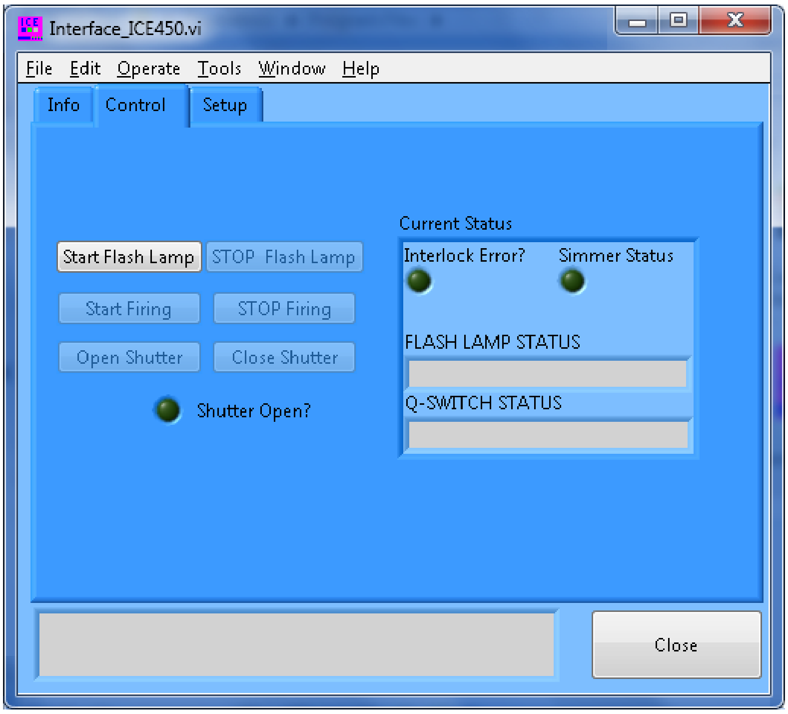


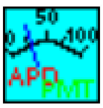
Fig. 4.13: Laser Control Interface

4.3.4. Licel Software

As well as Raymetrics' software, Licel's software has also been installed. This can be used as an alternative means of controlling the Transient Recorder the PMT HV device and also some additional devices such as the trigger generator. It also provides diagnostic tools such as the 'Track' or 'search controllers' programs.

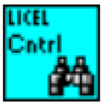
With this set of programs an experienced Lidar user has the ability to separately control the devices and can also perform advanced Lidar measurements. Since these programs have their own documentation, only the most commonly used are presented here.

4.3.4.1. Control PMT APD program



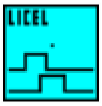
In order to run a non-automated but remote measurement the user also needs to control the PMTs High Voltage. Licel provides, among other programs, software to control the PMTs. The interface is similar to the device's front panel. The user has to set is the number of the PMT's and APD's and the IP address of the device.

4.3.4.2. Search Controllers program



This tool is useful when the user has a communication issue and wants to debug. If for some reason the computer is not communicating with the Transient Recorder or the PMT's HV device, then when the user runs the Acquisition or the Alignment software, an error message will appear and the TCP/IP LED will turn red. This may be caused by a faulty cable or by an Ethernet card overflow. The 'Search Controllers' program searches for Licel devices in the same network and provides information about their status and their IP address.

4.3.4.3. Control Timing program



The Lidar is equipped with a trigger generator which is used to trigger the laser and the electronics individually. This option is useful when a special study needs to be performed where there must be a time delay in between the laser pulse and the recorder. When using this option the acquisition becomes a non-automated procedure and the user has to use all control programs separately.

4.3.4.4. TCPIP Set Fixed IP Address program

Users with advanced network knowledge may at some stage need to change the IP addresses of the Licel devices. In this case the 'TCPIP Set Fixed IP Address' program may be used to set a new fixed IP address for each device. Note here that the external trigger is a different device and has a unique IP address.

5. UNPACKING AND INSTALLATION

5.1. UNPACKING THE LIDAR SYSTEM

The Lidar system has been carefully packaged to ensure its secure delivery to the customer.

Inspection after shipment

Inspect carefully the crate for damage before uncrating the Lidar system. Take notes and photographs if any external damage is visible. **If you notice any damage caused during the transportation please advise Raymetrics before signing the delivery note.**

Unpacking

DANGER: Serious injury or even death may be caused during unpacking. The Lidar system should be unpacked only by the authorized personnel of Raymetrics S.A. during the Lidar installation on site. Raymetrics S.A. will not be held responsible for any damage caused to the Lidar or for any injuries sustained by personnel who improperly handle or attempt to open the crate. Any attempt to unpack and install the Lidar without prior written authorization from Raymetrics or without an authorized member of Raymetrics staff present may result in damage which is not covered by the warranty. . At all times the Lidar must be kept safe from falling due to tilting. At all times the Lidar must be protected from impacts and sudden movements.

NOTE: The following instructions must only be applied if Raymetrics has granted the user permission in writing to unpack the Lidar system.

1. First the external film must be removed.
2. Then the crate may be opened crate by removing all screws (being careful to ensure the lid or sides of the crate do not fall once they have been unscrewed).
3. The straps holding the lidar in place can then be removed.
4. The Lidar head can be removed out of the crate taking care of the umbilical.
5. Next the electrical enclosure must be taken out of the box.
6. Remove the screw holding the positioner in place.
7. Assembly the tripod as described below
8. Mount the positioner on the tripod

9. Lift the lidar head and place it on the positioner.
10. Using a number 13 wrench secure the lidar head with the supplied screws.
11. Once the Lidar is assembled and onto solid ground, it can be moved into place using its wheels and finally lower the leveling feet to hold it steadily in position.

5.2. INSTALLATION OF THE LIDAR SYSTEM

Site:

For proper operation of the Lidar system the ambient temperature should range between 18 and 28˚C, unless otherwise specified in 10. LIDAR SYSTEM TECHNICAL SPECIFICATIONS.

It is preferable that the Lidar system is positioned and secured on a solid horizontal surface. When choosing an indoor location for your Lidar system, make sure that the housing has an opening (hatch) over the Lidar with an area 15-20% larger than the total area of the emitting/receiving windows of the Lidar system. The housing/room must have an air conditioning and heating unit.

If the lidar is intended for outdoor use it should be placed on solid ground and be leveled by the feet. The maximum allowable tilting angle is 5 degrees. You may also secure the feet using the holes. If the location suffers from intense wind gusts it is better to place the lidar on a concrete platform and replace the feet with metal expansion anchors with an M12 bolt.

Keep always in mind:

- Access should be available from all sides of the Lidar system, especially in the front where the control unit is located,
- Each side of the cabinet should be at least 25-30 cm away from a wall or obstacle. Front and rear panels of the instrument should be at least 50 cm away from a wall or other obstacle, to allow for efficient cooling of the instrument.

- Power:

Power is to be 220 to 240V or 110 V (50/60 Hz) with available average current up to 10A or **!Undefined Bookmark, LIDAR_POW**A, respectively. The power must be stable with no large motors on the same line. If for any reason the power has large peaks the laser will not function. If there are often power failures it is strongly suggested to install an external on-line UPS for safe shut down of the instrument. The on-line UPS also stabilizes the power. **For the installation the user must ensure the availability of a socket rated for at least**

25A and must supply an appropriate plug to fit this socket and the power cable (Fig. 5.2). The power cable type is 3x2,5mm^2.

- *Water Coolant:*

The laser cooling unit is a water/air heat exchanger which does not require any external water supply. However the user must make sure that there is distilled water with 1MΩ-cm to 5MΩ-cm resistivity always available at any time and especially during the installation.

The on-site installation and Lidar system alignment will be undertaken by Raymetrics S.A. personnel.

CAUTION: No attempt should be made by the user to install the Lidar system. Any damage which may occur due to the non-respect of the previously mentioned instructions will not be covered under the warranty.

5.2.1. Assembly

The main assembly to be done is for the tripod which is packed in pieces to reduce space. At the image below it is displayed the tripod assembly procedure,

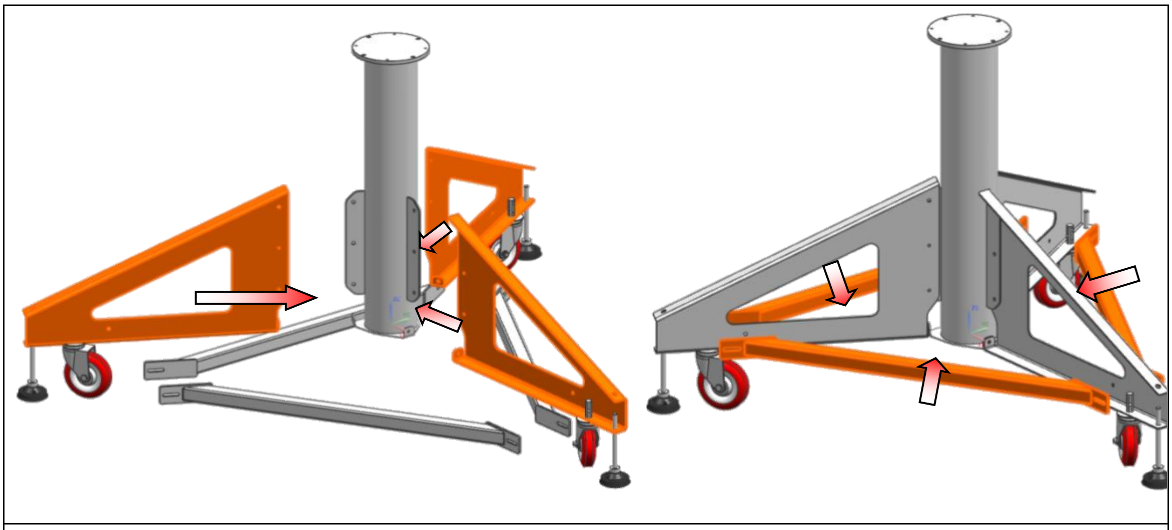


Fig. 5.1: Tripod Assembly

Once the tripod is ready the positioner can be mounted on top and the lidar head in between the positioner. Finally the power cable has a free end which needs a suitable plug which will fit the socket on site.

NOTE: The polarity is not critical for the lidar operation, however due to the laser's capacitor discharge sometimes there may be a residual current which may escape through the neutral wire causing the buildings protection breaker to switch off. Therefore it is always better to keep the polarity as suggested below.

The cable colours are explained below:

Brown cable goes to 'L' (Live)

Blue cable goes to 'N' (Neutral)

Yellow-Green cable goes to '⏚' or 'G' or 'E' (Ground or Earth)

A plug which fits the socket at the installation site can be attached to the power cable (Fig. 5.2) The plug and socket must meet the requirements of the Lidar's power consumption. The power cable is a 3 x 2,5mm^2 10 meters long.

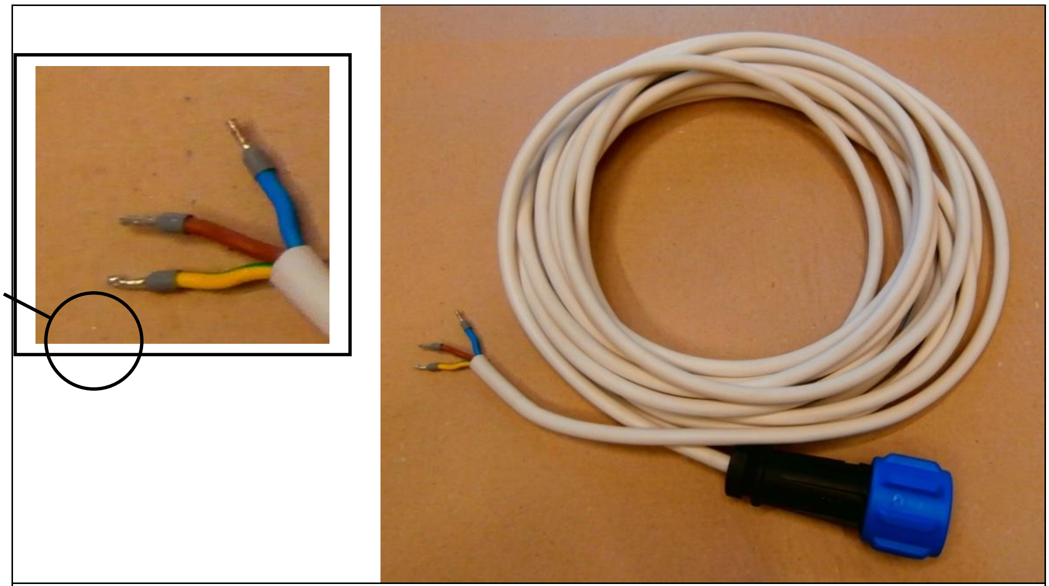


Fig. 5.2: Plug Assembly

5.2.2. External Connections

Additional connectors are located on the enclosure. The Ethernet port maybe used to connect the Lidar with a network. The USB port maybe used to connect a USB device. Also there is an external communication port with RS-232 protocol and a VGA port to connect a monitor to the embedded computer.

Fig. 5.3: External Connections

The lidar is equipped with three interlock inputs. These all connected in series and must keep the circuit closed. In case of an interlock the circuit opens and the laser stops the emission. The first from the left 'Emerg Intlk' as indicated in **Fig. 5.3** is permanently connected to the emergency push button box. The middle one 'Aux Intlk' is used as auxiliary and the furthest right 'Radar Intlk' is used to connect a radar. Both are short-circuited. The user can connect any normally closed switch to the auxiliary input simply by removing the pin and replacing it with the supplied connector.

5.2.3. Water Filling

In order to ship the Lidar from the factory, the coolant has been drained from the laser's reservoir. Before use, the customer must fill the coolant reservoir with approximately **1 litre of distilled water with 1MΩ-cm to 5MΩ-cm resistivity**. The instructions below should be followed to prepare for water filling. After this, the laser manual supplied by Quantel should be followed. The laser manual is located on the USB stick supplied by Quantel, in the Raymetrics binder, or on the Lidar computer in the following folder

'C:\Users\user\My LIDAR\Software\LASER\DOC00040.pdf'

1. Turn on the red main switch which can be found on the rear side of the cabinet.

Fig. 5.4: Main Switch

2. Open the front door of the cabinet.
3. Switch on all of the switches on the front of the energy box.

Fig. 5.5: Energy Box Switches

4. Press the first button on the left of the UPS. The UPS should go to bypass mode. The UPS display will read 'BASS'.

Fig. 5.6: Energy Box Switches

Note: Not applicable to all models

5. Wait until the UPS goes into online mode. UPS display will read 'LINE'.
6. After this has been completed, the instructions on how to fill the laser on page 11 of Quantel User's Manual DOC00040.pdf should be followed. (Quantel's USB stick is in Raymetrics' binder)

CAUTION: Each time the Lidar is transported by plane the coolant **must** be drained from the reservoir and especially from the Laserhead to avoid freezing which will destroy the Laser and will not be covered under warranty.

5.2.4. Software Installation

Raymetric's Lidar systems are supplied with a computer system which has all the necessary software for apparatus alignment, data acquisition and data preview and analysis pre-installed.

For post analysis software which can be freely installed to any computer it is not nessecary to install any file.

The executable files which come with the instrument may be installed at any time on any number of computers.

5.3. STORAGE AND SERVICE

Storage

- Turn all the electrical units OFF.
- Disconnect the power cord from the Lidar system.
- Even if the Lidar is not used, the laser's ICE450 should be turned on every month for 30minutes.
- If the Lidar is to be stored for an extended period of time, it must be protected against intense rain and humidity. It should be brought indoors or covered up with a waterproof material.

Service

If the Lidar is to be returned to Raymetrics, it must be carefully packed in the original package material that came with the unit.

NOTE: The packing material must therefore be retained.

WARNING: The instructions in the manuals must be followed for every instrument. Any actions undertaken which have not been fully described in this manual or in a component's manual may result in serious injury or system damage which is not covered by the warranty.

6. LIDAR OPERATION

6.1. START-UP

There are two ways to use the Lidar; manually and automatically through the software. The user can choose which is more convenient to use. Both methods have been described here. The next steps will guide you through the operation safely. The first steps are common for either manual or automated operation.

1. Plug in the power cord (**Fig. 5.3**) and follow the first 5 steps of the procedure described in section *5.2.3. Water Filling*.
2. Turn the '**Power Key Switch**' on the front panel of the PCC to the ON ('I') position. The 'power' and the 'interlock' indicators on the Remote Box will illuminate. If this does not happen, check for interlock fault messages on the Remote Control Box LCD Display (**Fig. 6.1**).

Fig. 6.1: Laser Power Up

3. Wait approximately 10-15 minutes, depending on the environmental conditions and amount of coolant in the system (coolant line length), until the coolant temperature reaches the preset value for flashlamp operation.
4. Power up the Licel electronics (TR, PMT).

Fig. 6.2: Electronics Power Up

5. Select the desired control mode for all PMTs High Voltage. Lift the switch first to turn it up or down. Set to manual for manual operation or remote for automated operation.

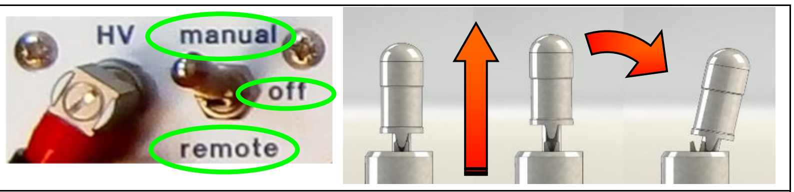


Fig. 6.3: Control Mode Selection

6.1.1. Manual Operation

6. Set the switch on each PMT HV to manual. Adjust the applied High Voltage to the PMTs. Check that signal, HV and trigger cables are at the correct position. Turn on the HV by switching the HV switch to the manual position for each HV power supply to be used. (For remote operation through software, switch to the remote position). Turn the HV potentiometer counter clockwise up to the desired value. (High Voltage values should be 750-900V for linear range of operation)

Fig. 6.4: PMT High Voltage Adjustment

7. Press the '**Flashlamp Ready**' button on the Remote Control Box. The corresponding 'ready' LED and 'LASER ON' indicators should illuminate. Wait for a couple of seconds and if no interlock appears press the '**Flashlamp Start**' button on the Remote Box. The corresponding flashlamp 'start' LED will blink and (in internal mode) the flashlamp will begin flashing.
8. The PCC requires a safety delay of up to 8 seconds after the flashlamp starts before it enables Q-Switch operation. This is the same for both Internal and External Q-Switch operation modes.

WARNING: The following steps result in laser light emission from the output aperture of the laserhead. Do NOT look directly the laser beam. Before pressing the Q-Switch it should be ensured that nothing is blocking the light path.

9. Press the 'Q-Switch Start' button to activate the Q-Switch. Verify that the corresponding Q-Switch 'start' LED blinks and the 'Laser ON' sign illuminates.

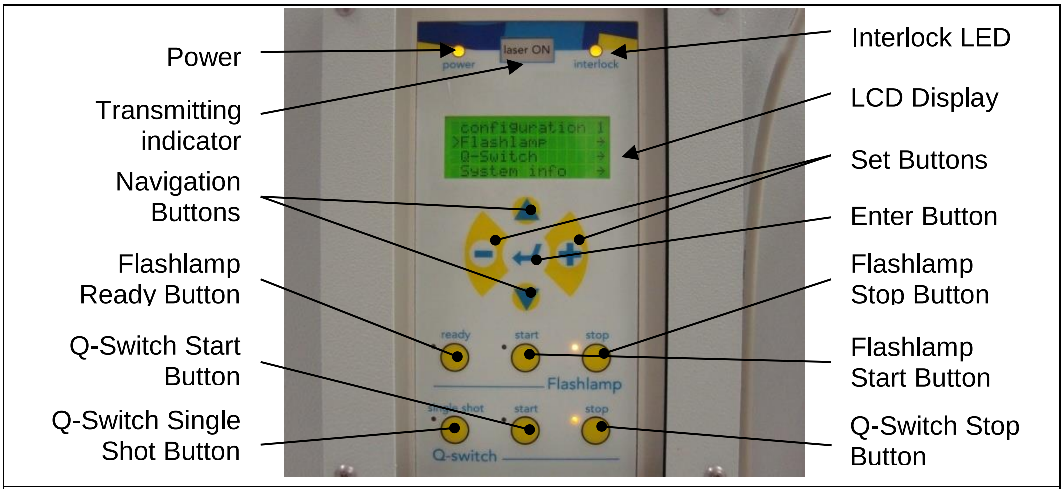


Fig. 6.5: Remote Control Box Indications

10. Run the 'Lidar Alignment' program
11. Watch the signal and fine align if necessary (see section 6.2. LIDAR ALIGNMENT)
12. Run the 'Lidar Acquisition' program
13. To stop laser emission, press the 'Q-Switch Stop' button. Verify that the Q-Switch 'start' LED turns off. To stop the flashlamp, press the 'Flashlamp Stop' button. Verify that the flashlamp 'start' and 'ready' LEDs turn off.

6.1.2. Automated Operation

7. Set the switch on each PMT HV to remote.
8. **Whenever the user presses any button on the remote control of the laser the serial communication with the computer is lost**. To set the serial communication navigate through the menu using the buttons, choose 'System Info' and validate with the button. Go to serial link and with the button change the status from 'off' to 'on'.

WARNING: The following steps result in laser light emission from the output aperture of the laserhead. Do NOT look directly the laser beam. Before pressing the Q-Switch it should be ensured that nothing is blocking the light path.

9. Run the 'Lidar Alignment' program to check the signals and align if necessary, or directly run the 'Acquisition' program to perform a single measurement or the 'Scheduler' program to set a series of daily measurements. To stop the measurement press the 'stop' button to stop the laser and PMTs.

6.2. LIDAR ALIGNMENT

In order to acquire the best possible Lidar signal the user has to align the laser beam to the telescopes field of view. Measurements acquired with a misaligned Lidar can lead to fault results. Normally the Lidar is aligned as illustrated in **Fig. 6.6**. The signal starts to increase when the light of the laser beam enters into the telescope's Field Of View (FOV) (point A) and reaches its peak value when the entire beam is inside the field of view (point B). After this point the signal starts to decrease as the light is attenuated.

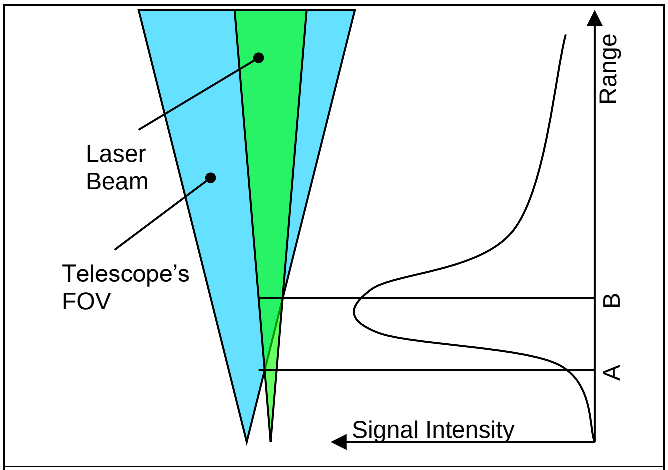


Fig. 6.6: Aligned Lidar

There are two ways that the Lidar can become misaligned. Both are shown in **Fig. 6.7**. In the first case the laser beam is tilted away from the telescope resulting in no Lidar signal. However there is still some noise from the electronics and the background. In the second case the laser beam enters the telescope's FOV (point A-B) but exits after a certain point (point C-D). The second case is more difficult to identify as the signal looks like a normal Lidar signal. However there are techniques to perfectly align the Lidar such as the Telecover test.

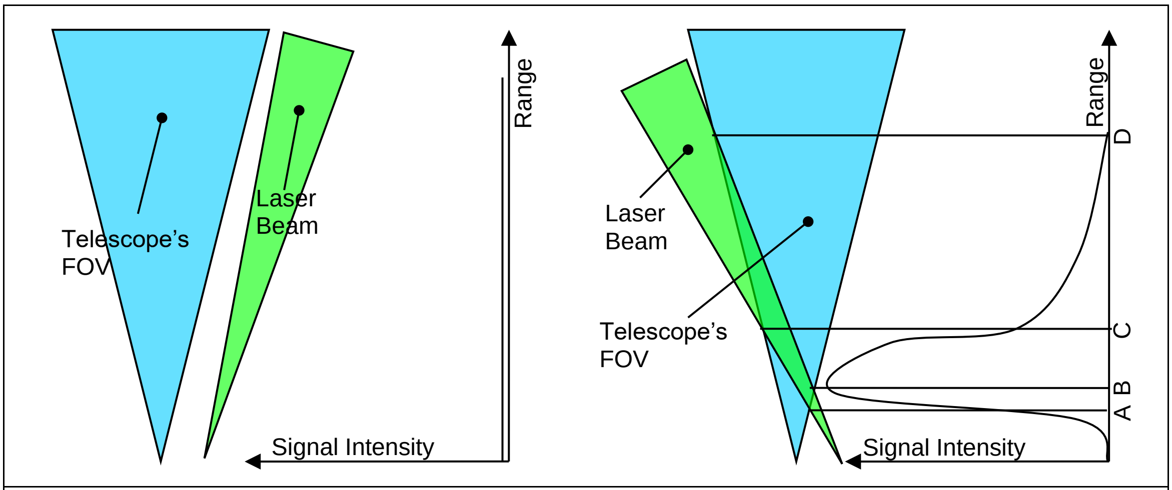


Fig. 6.7: Misaligned Lidar

The next figure shows real Lidar signals for these cases. The black curve corresponds to a properly aligned Lidar, while the Red and Green curves (same alignment but reduced signal intensity) correspond to cases similar to Fig. 6.7b.

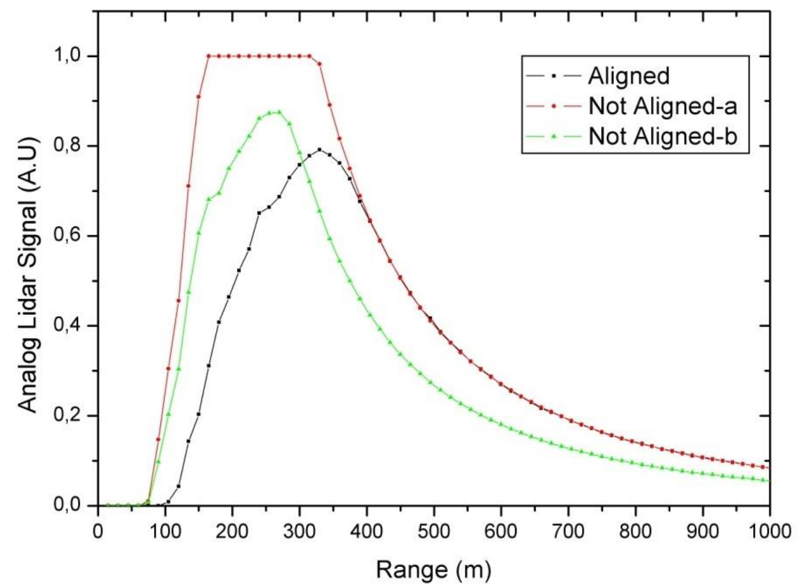


Fig. 6.8: Alignment Example Real Signals

In many cases an inexperienced user may consider the red curve as a very good alignment since this signal is very strong (it even has saturation between 150 and 350 meters). However when the signal intensity is reduced (see *6.2.4 Signal Intensity Reduction*) in order to get rid the saturation, the signal matches the green curve, with half the far field value of the properly aligned black curve.

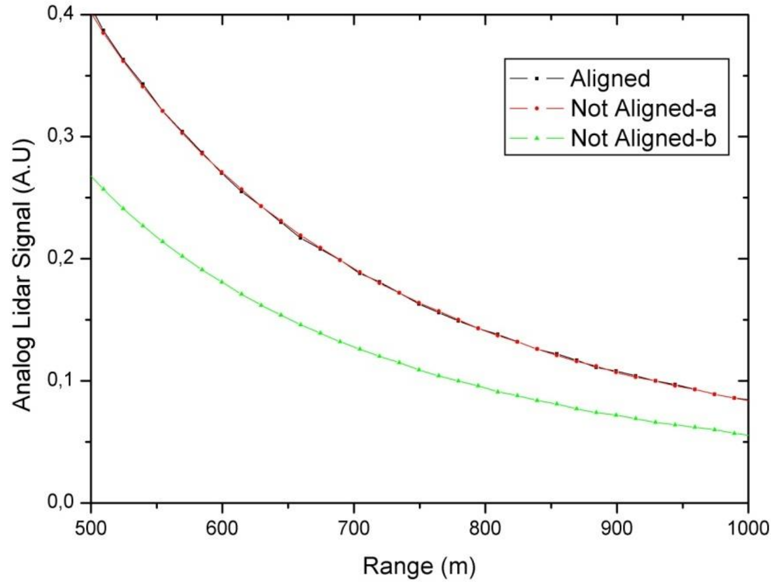


Fig. 6.9: Alignment Example Real Signals far filed

6.2.1. Laser Beam Kinematic

The Lidar alignment is achieved using a motorized mirror mount. By moving the mirror mount's actuators the laser beam is maneuverable to meet the axis of the telescope's FOV. To choose which actuator to move is not always immediately apparent so the effect of each actuator is described here. The mirror mount has two actuators A, B.

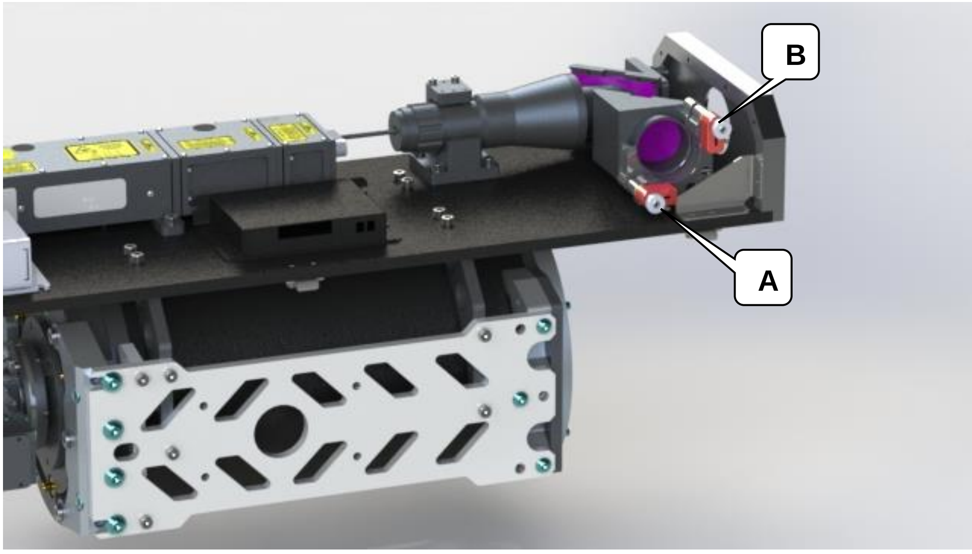


Fig. 6.10: Mirror Mount and Actuators

Because of the small allowable angle the actuators have a very small resolution so that the movement is also small and the Lidar signal is not very sensitive to the actuator movement. This give the user the ability to micro align the Lidar.

The next figures show the effect of actuator A and B on the laser beam direction.

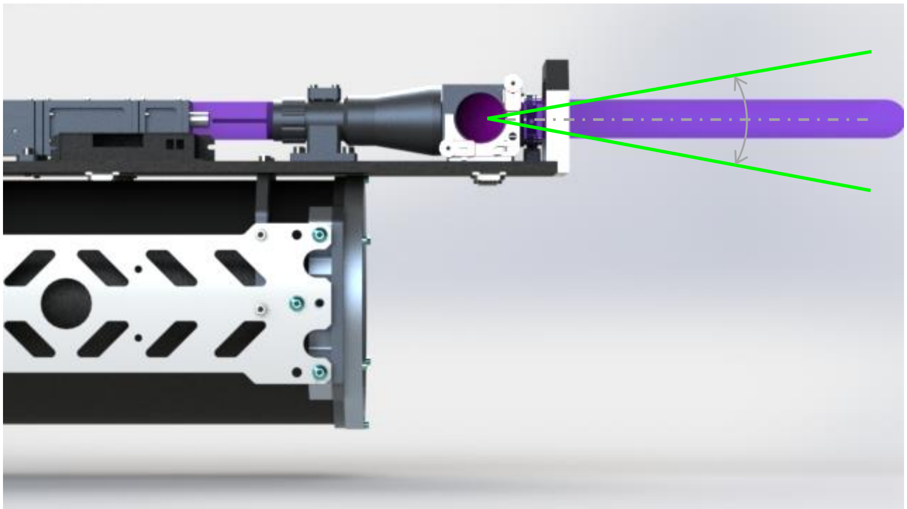


Fig. 6.11: Actuator A Effect

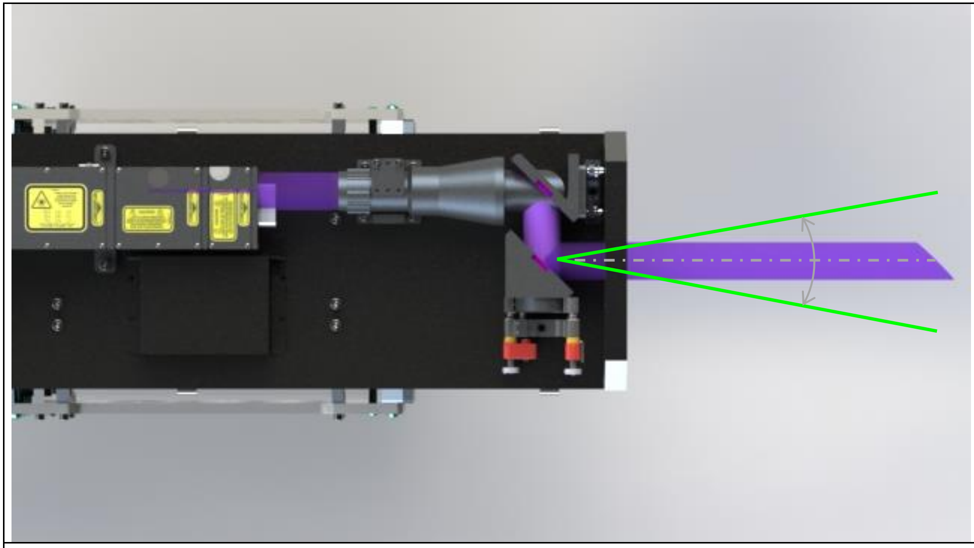


Fig. 6.12: Actuator B Effect

Below is a schematic representation of the laser beam movement caused by each actuator in relation to the telescope. In summary, actuator B moves the beam in a 'vertical' direction and actuator A moves the beam in a 'horizontal' direction.

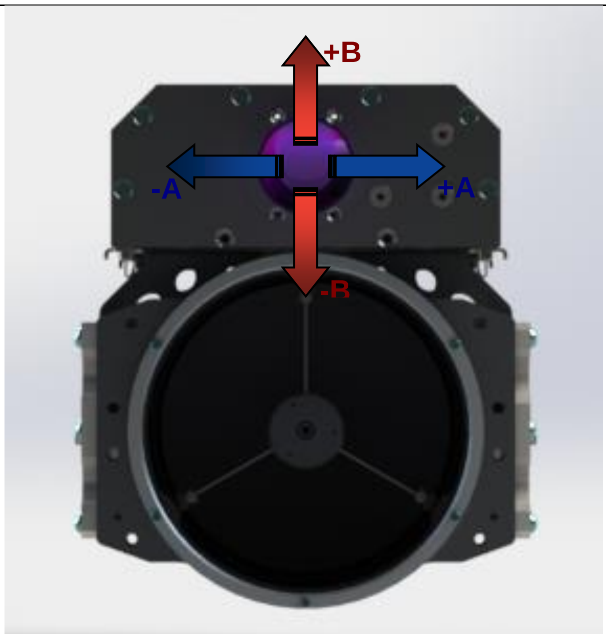


Fig. 6.13: Laser Beam Kinematics

6.2.2. Lidar Alignment Procedure

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. The second step (fine alignment) can be done in two different ways. One is by increasing the intensity of the signal in the far range and the other is by performing a fast Telecover test. To verify also the alignment the user can perform a comparison with a pure molecular atmosphere model in the analysis software. For more information see section *7.3.4 How to Check Lidar Alignment*.

6.2.2.1. Intensity Maximization at Far Range

When the intensity of the signal increases, in general it means that more light is entering the FOV of the telescope. It is very easy to increase the signal in the near range but it is also easy to misalign the Lidar as shown in case II in Fig. 6.7. When the intensity of the signal is maximized in the far range then it means that as far the telescope can see there is a laser beam.

The alignment procedure is quite simple; the user selects an area on the slope as far as possible and tries to maximize the mean value of this area by using the actuators. Once the mean value reaches its peak, another area further than the initial area is selected and the process is repeated with a smaller actuator step. When the value does not change for the selected step size it means that the Lidar is aligned. The procedure is described in detail in more following steps:

1. Run the 'Lidar Alignment' program. On start up the program establishes a connection with the Licel controllers, the laser, the motorized rotation stage, the LMC100 and the motorized mirror mount. At the bottom of the program window there are three red LEDs. If all controllers are found these should turn green. If not there is a communication problem.

NOTE: Since this program uses all of the hardware no interface should be opened otherwise it will not establish the connection.

2. On the last tab (see **Fig. 6.14**) the user can control the laser. The user can check the flashlamp shots (denoted in millions) and can alter the laser energy by turning the knob of the Q-switch delay (the bigger the number the smaller the energy is. By pressing the start button the laser starts, unless if there is an interlock. In this case refer to paragraph **Error! Reference source not found.**. Once the user presses the start button there is a small delay to start the Q-switch where the program remains idle.

CAUTION: BY PRESSING THE START BUTTON THE LASER IS EMITTING, FOLLOW THE SAFETY INSTRUCTIONS CAREFULLY.

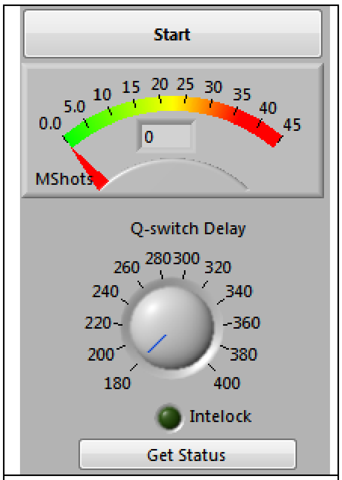


Fig. 6.14: Laser control

3. Next set the desired value for the first PMT (Channel 355P) and turn the PMT On. It is recommended to use initially a low voltage such as 400Volts to avoid signal saturation. The user can change the value and activate any PMT at any time (see **Fig. 6.15**).

Fig. 6.15: PMT High Voltage Control

4. Go to the 'Live Display' tab. The signal should now be visible. If there is no signal, see chapter 9. TROUBLESHOOTING to run a series of diagnostic tests.
5. On the right are the controls for the cursors. Click  and select 'Bring to Center'. Click again and select 'Lock to Plot' if not selected.
6. Place the yellow cursor (start) on the graph, roughly in the middle of the falling edge of the signal.
7. Next do the same with the green cursor (end) and place it somewhere before the signal is flat.
8. Zoom into the area using the axes scale controls . The scale is either automatically adjusted to the maximum value or it can be fixed in a specific range. Click on the  switch to toggle between these two states. When the axes are fixed set the lowest and highest values close to where the selected area is.

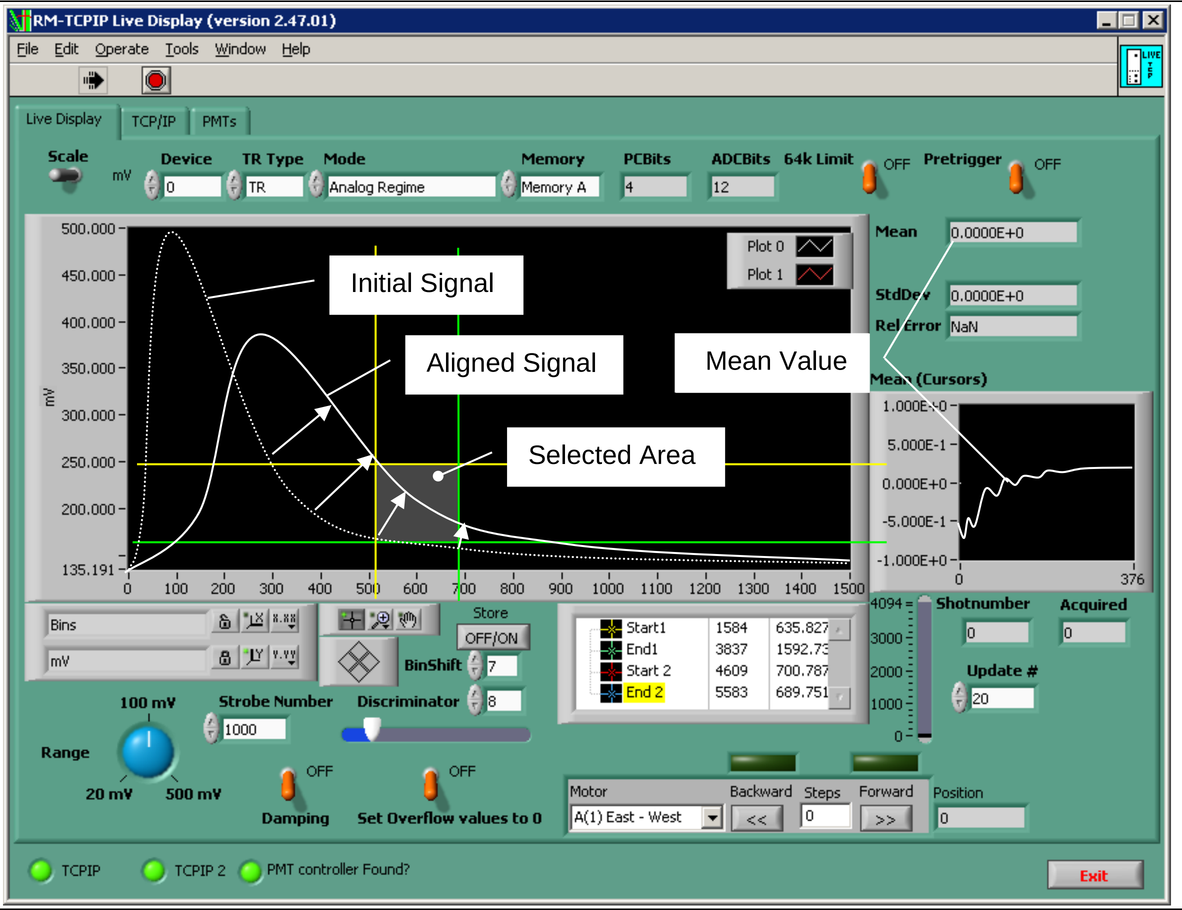
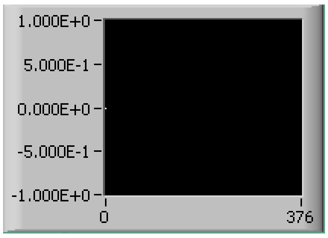


Fig. 6.16: Intensity Maximization Alignment Method

9. The number of shots for each profile can be set using the 'Update Every' input on the right. Set the number so that the image is good and is refreshed in less than 5 seconds.

10. Once everything is set click on the small graph on the right and select clear graph. This will empty all previous values. Remember to do this each time you change the selected area. Wait for a couple of profiles to be taken so that you will have a starting view.



11. Towards the bottom of the window are the controls for the motorized mirror mount. Select the actuator to be moved in the field 'Motor' (A or B) and set the step size. This is a trial and error procedure, so it does not matter which one you select. For the step size select a rather big step to begin with. For reference a small step size is 20 steps and a big one 200 steps.

12. Press the left << or right >> arrows to move the actuator forwards and backwards. A short, high pitched noise indicates that the motor is working. A change in the signal

should be also noticed. The user should then wait for the signal to stabilize for one or two profiles and should notice the change in the small graph. If the mean value is getting higher, then the user should continue to move this actuator at the same direction. If the mean value is reduced the actuator should be moved in the opposite direction and the user should check if the value improves.

13. After repeating this process the mean value will reach a point where moving the actuator in either direction results in reduced the same mean value. At this point the user should change the selected actuator to the other one.
14. The same procedure as described above should then be used for the other actuator.
15. The user may have to alternate between the actuators until reaching a point where there is no improvement in the mean value. At this point an area even further than the current area should be selected, the graph should be cleared, the step size reduced, and the procedure repeated.

6.2.2.2 Telecover Test

The Telecover test involves isolating different parts of the telescope and checking the signal for each area. The telescope is divided into four quarters. Each quarter is named after the cardinal compass points for simplicity and standardization reasons. The north is always towards the laser beam. A properly aligned Lidar should have identical signals in the west and the east quarter, whilst the south area signal gives the full overlap.

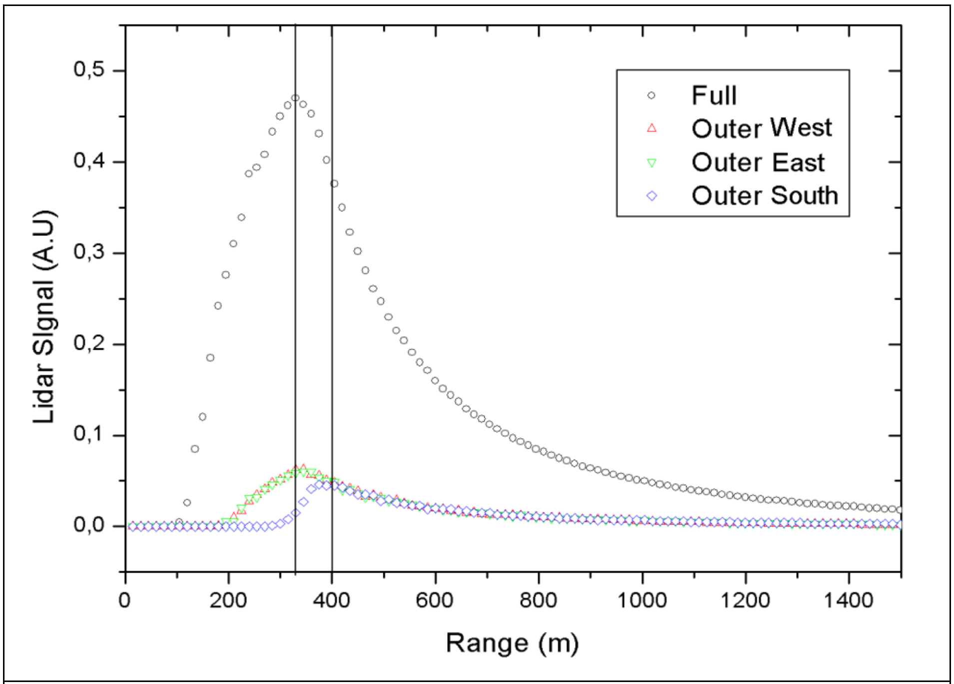


Fig. 6.17: Telecover Signals

Fig. 6.17 shows an example of a Telecover test from a D400 Lidar. Although the peak signal for the full telescope appears around 320 meters the real overall is around 400 meters, as can be seen from the Outer South part test. In addition it can be seen that the OW and OE signals are in theory identical. In reality however the east and west parts can never be exactly identical because of the inhomogeneity of the optics and the PMT cathode. This means that the signal intensity cannot be used as a criterion for the comparison. The overlap on the other hand is absolute.

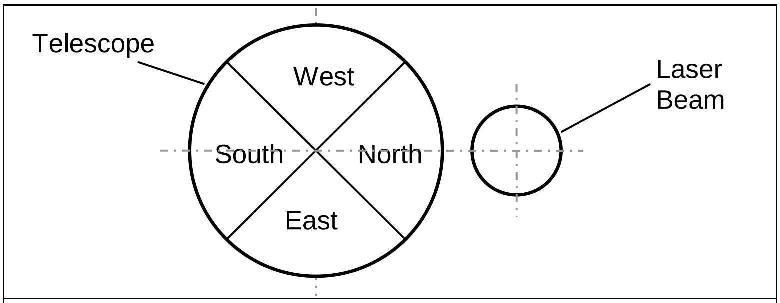


Fig. 6.18: Telescope Division

It should be noted that the image at the cathode is reversed. The light focuses at the field stop and then defocuses, resulting to an upside down and mirrored image. This explains why moving the laser beam towards the obvious desired direction has the opposite effect on the signal.

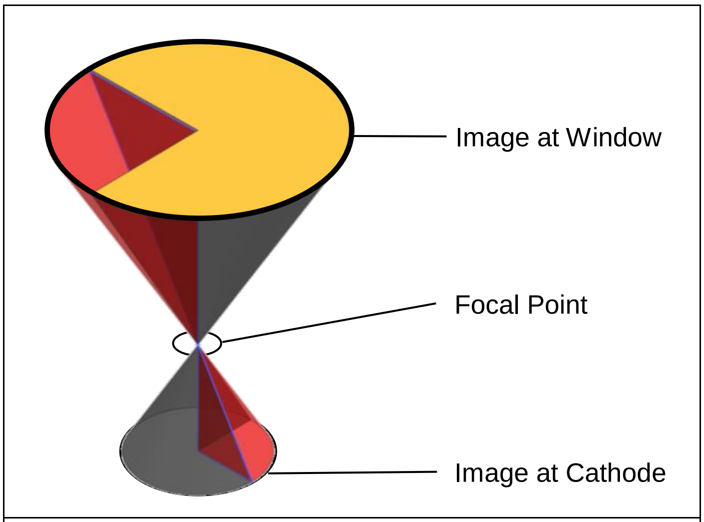


Fig. 6.19: Image Inversion

To make this telecover even more precise each quarter can be divided into two equal areas; inner and outer. This needs to take into account the blind spot of the telescope created by obscuration from the secondary mirror. The telescope is therefore labeled with two letters: the first letter is either O for outer and I for inner, while the second letter is W, E, S or N, standing for West, East, South and North respectively. Now imagine an axis from the center of the telescope to the center of the laser beam. This axis is not always horizontal or vertical. So when placing the telecover you have to align the center of the clear area with the imaginary axis.

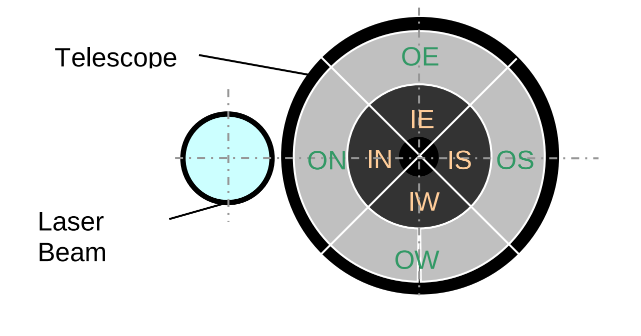


Fig. 6.20: Detailed Telescope Division

The fine alignment procedure using this method is described below.

1. Run the 'Lidar Alignment' program and follow the steps 2 - 4 described in paragraph **Error! Reference source not found.** to set the high voltage to the PMTs and to start the laser.

CAUTION: THE LASER IS NOW EMITTING, FOLLOW THE SAFETY INSTRUCTIONS CAREFULLY.

2. Place the cover on the telescope's window so that light enters only from the south side.
3. Using actuator B shift the peak of the curve on the live display until the desired full overlap is reached. This systems full overlap is by default at 200meters.

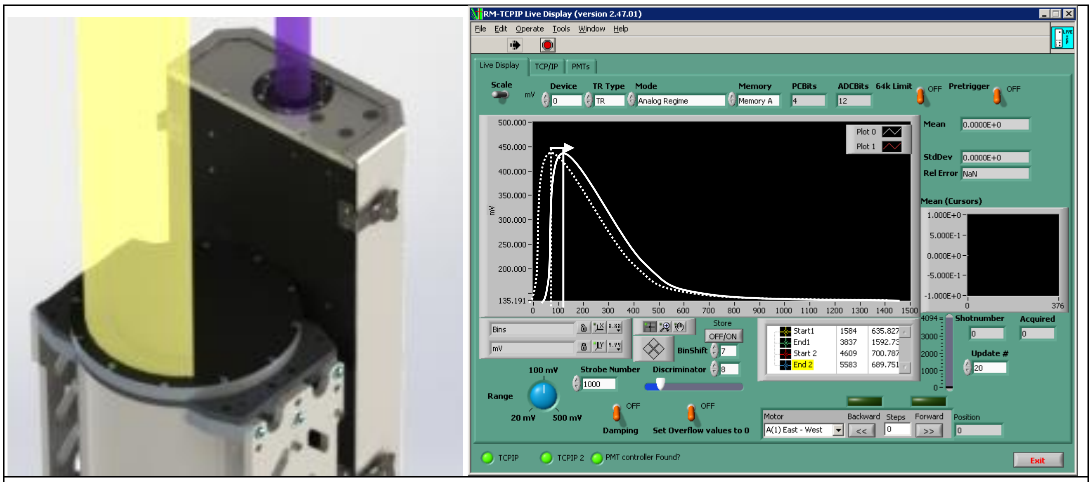


Fig. 6.21: Full Overlap Alignment

4. Rotate the cover so that light only from the east side enters the telescope. Place a cursor on the peak of the curve on the graph making sure that the cursor is unlocked.
5. Rotate the cover so that light enters only from the opposite side (west side).

6. Using actuator A try to achieve the same overlap as the cursor placed previously. Once you are close place another cursor there.
7. Finally rotate the cover back to the opposite side (east side) and repeat the last steps until the two curves have the same overlap. This means that the telescope is symmetrical to the laser beam.

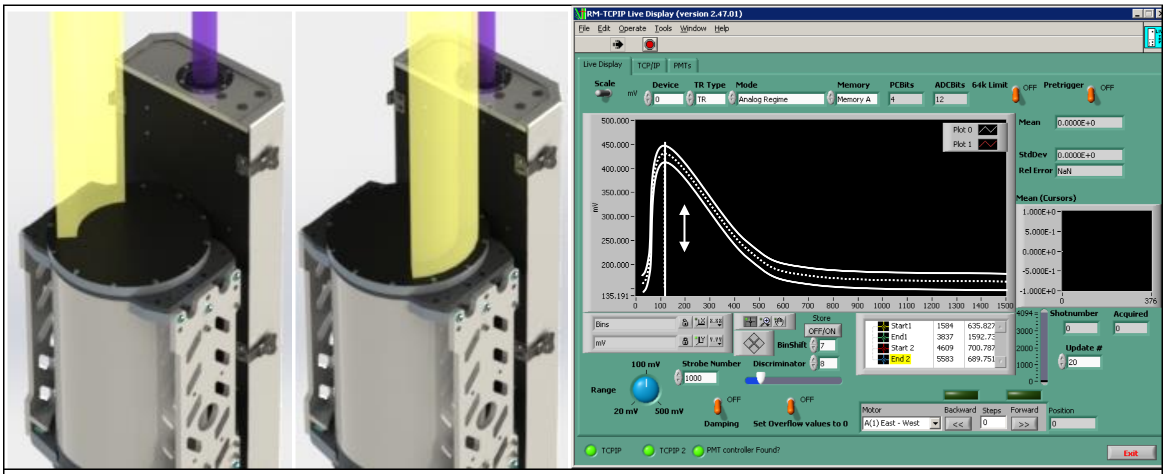


Fig. 6.22: Symmetry Alignment

CAUTION: Never leave the telecover tool on top of the window.

A quick way to establish whether the system is aligned, is to make a Telecover test using only the OS area. The results in the Lidar signals as seen in the image below

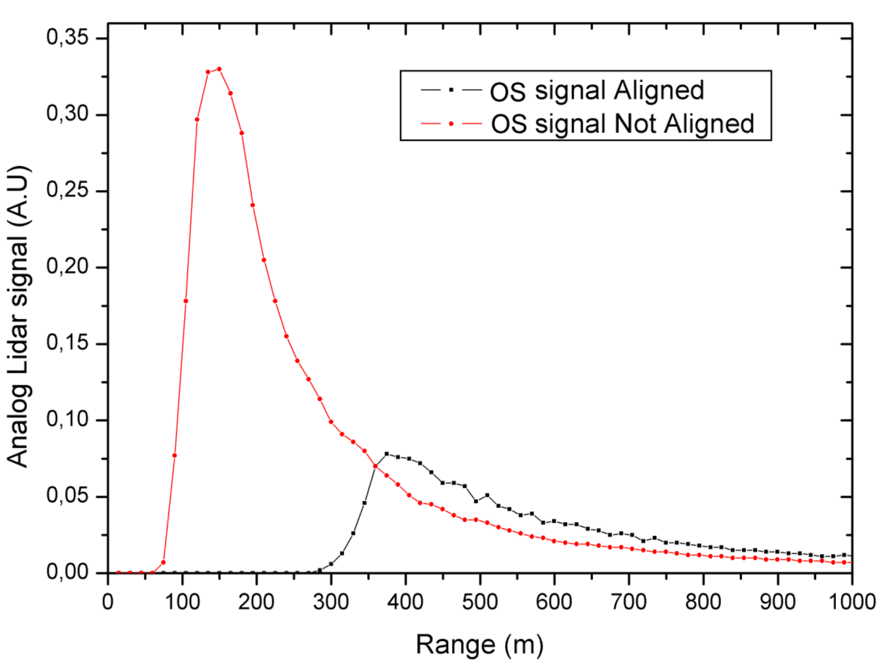


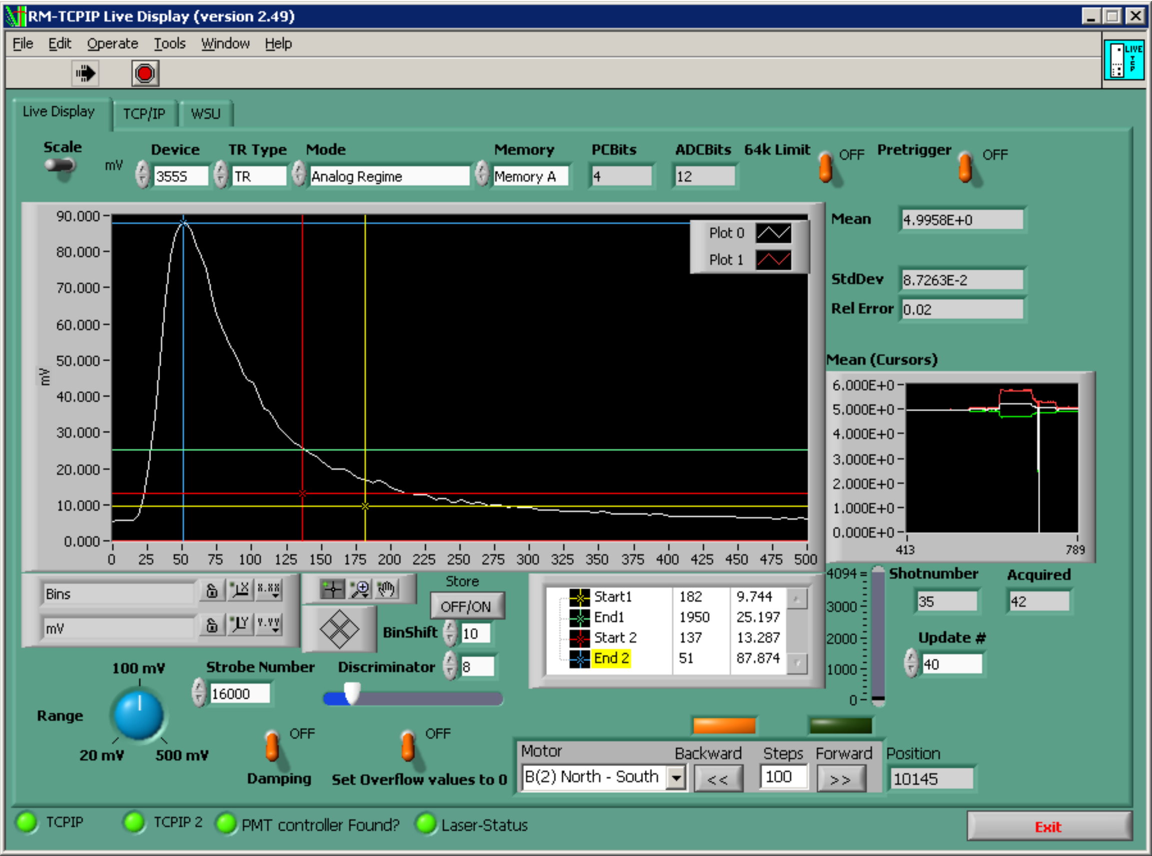
Fig. 6.23: Symmetry Alignment

The OS (outer south) part a signal from an improperly aligned Lidar gives an overlap of around 180 meters, whereas the signal from a properly aligned Lidar gives an overlap of around meters 380 which is the value that we expect based on theoretical calculations (for a D400 lidar). Therefore if an incorrect value is given for the overlap from the OS part of the signal, it indicates that the Lidar is not properly aligned. For this specific Lidar configuration the overlap should be around **200 meters** (with factory set value for the telescope FOV)

CHAMPAIGN 9/2/2015-REFERENCE TELECOVER SIGNALS

NORTH

High Voltage=850



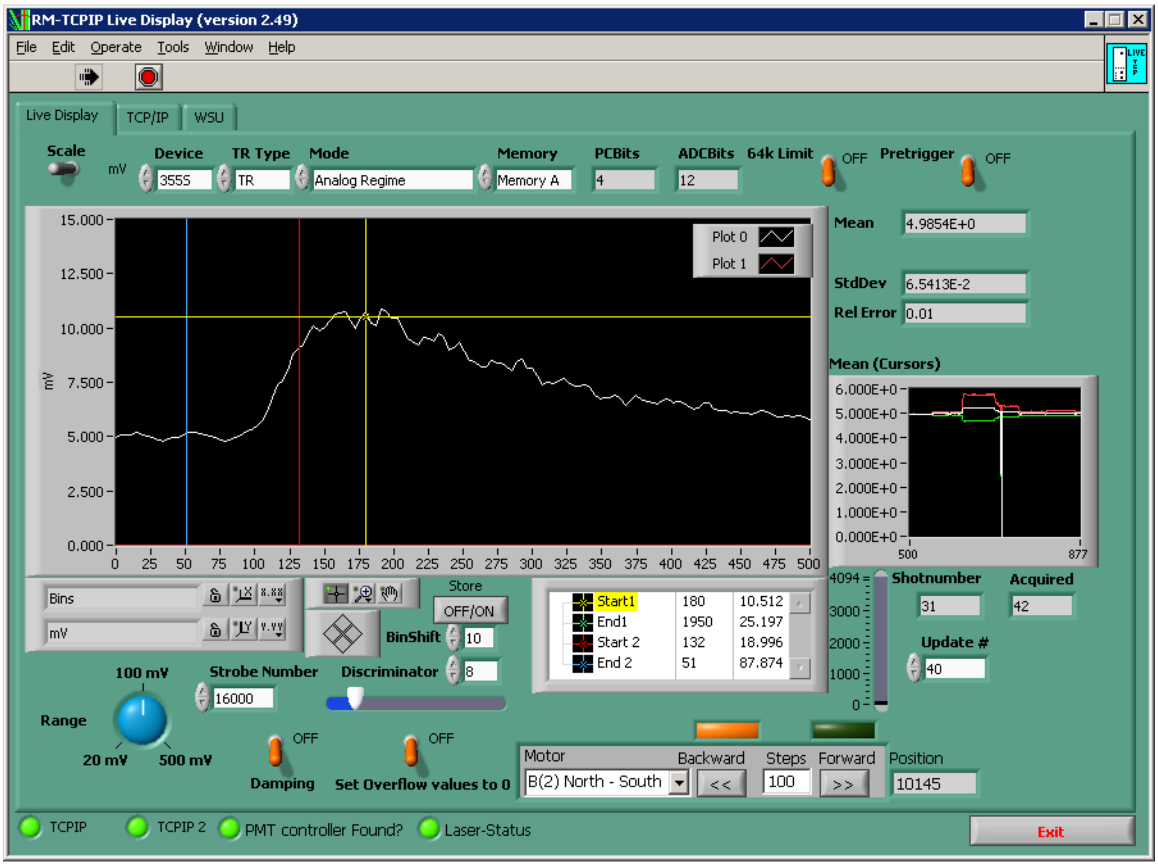
EAST


RM-TCPIP Live Display (version 2.49)
File Edit Operate Tools Window Help
Live Display
TCP/IP
WSU
Scale
Device
TR Type
Mode
Memory
PCBits
ADCBits
64k Limit
Pretrigger
OFF
3555
TR
Analog Regime
Memory A
Mean
5.0008E+0
StdDev
9.8854E-2
Rel Error
0.02
Mean (Cursors)
Plot 0
Plot 1
Bins
mV
Store
OFF/ON
BinShift
Strobe Number
16000
Discriminator
Start1
End1
Start 2
End 2
Shotnumber
17
Acquired
42
Update #
40
Range
100 mV
20 mV
500 mV
Damping
Set Overflow values to 0
Motor
Backward
Steps
Forward
Position
B(2) North - South
10145
TCPIP
TCPIP 2
PMT controller Found?
Laser-Status
Exit

WEST


RM-TCPIP Live Display (version 2.49)
File Edit Operate Tools Window Help
Live Display
TCP/IP
WSU
Scale
Device
TR Type
Mode
Memory
PCBits
ADCBits
64k Limit
Pretrigger
OFF
3555
TR
Analog Regime
Memory A
Mean
5.0100E+0
StdDev
1.1574E-1
Rel Error
0.02
Mean (Cursors)
Plot 0
Plot 1
Bins
mV
Store
OFF/ON
BinShift
Strobe Number
16000
Discriminator
Start1
End1
Start 2
End 2
Shotnumber
41
Acquired
42
Update #
40
Range
100 mV
20 mV
500 mV
Damping
Set Overflow values to 0
Motor
Backward
Steps
Forward
Position
B(2) North - South
10145
TCPIP
TCPIP 2
PMT controller Found?
Laser-Status
Exit

SOUTH



FULL : HV = 780

6.2.3 Using the Alignment Software

In section *4.3.1. Lidar Alignment* the Lidar alignment software was introduced. Below however is a more complete guide on how to use the software.

Open the 'Lidar Alignment' software.  When the program starts it automatically attempts to communicate with all devices. In this case there are seven devices to communicate with:

1. Transient Recorder
2. PMT High Voltage device
3. Laser
4. LMC-100
5. Motorized Mirror Mount
6. Positioner AZP200

When the Licel devices and the mirror mount communicate with the computer then the LEDs on the top of the window turn green. If for any reason they remain red consult section 9. TROUBLESHOOTING regarding communication errors.

At the last tab the user can control all hardware except from the transient recorder which is controlled in the first tab. The parameters for the communication port are read from the configuration file. The values in the file should not be changed, unless it is done by an experienced user.

In case of laser interlock the LED on the laser's control interface is On. Check the display of the remote control of the laser and refer to troubleshooting.

Except from the laser and PMT's high voltage the user here can also control the slide filter modules at the LMC100 control box. Simply click on the slide filter to be activated and wait until the reply is sent from the controller. Finally at the positioner control box the user can turn the Lidar head at an azimuth angle range from 7˚ to -90 ˚ degrees and at azimuth from 0˚ to 360˚ degrees. This enables the user to point the lidar at any direction of a hemisphere. Both devices are equipped with encoders to maximize the accuracy. When the power is off, the current position is lost. In this case when the program starts it will turn the motors to the home position.

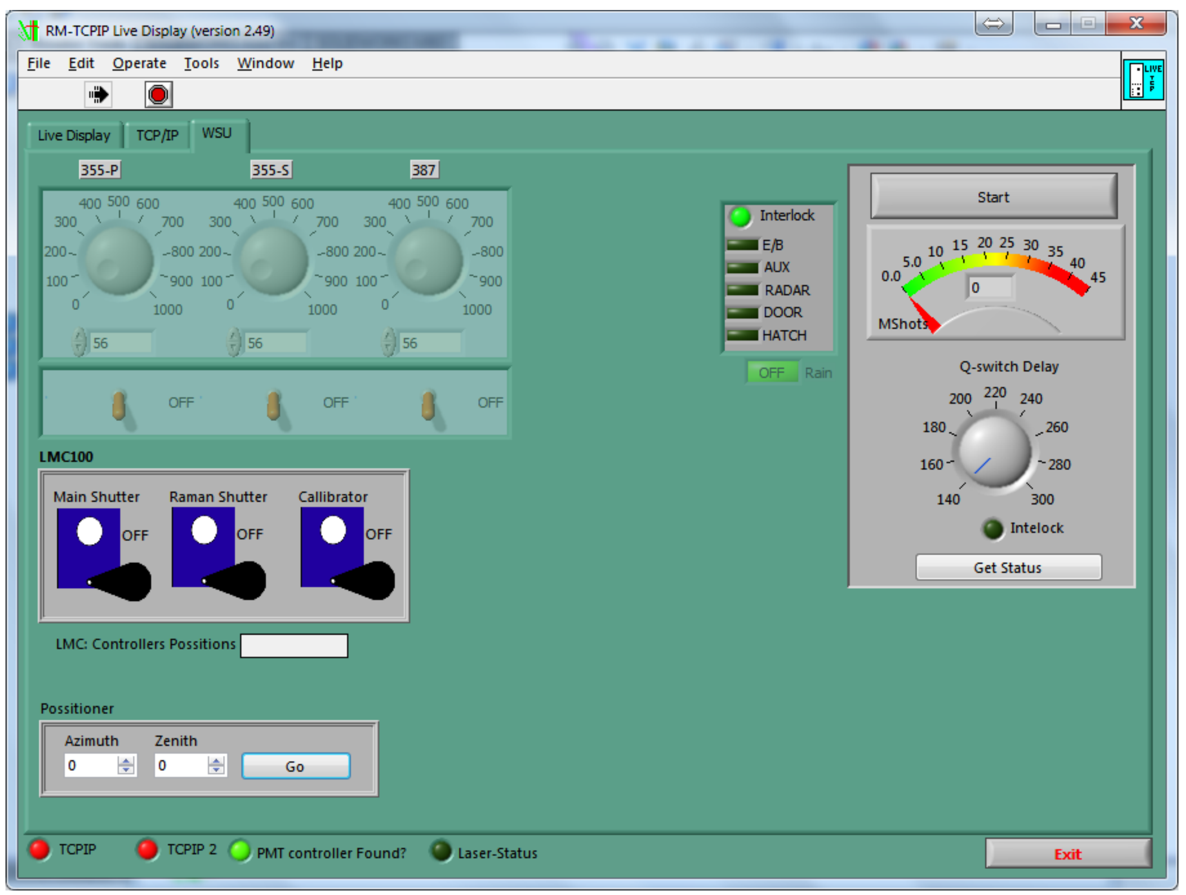


Fig. 6.24: Set up Interface

The settings under the TCP/IP tab allow for selection of the communication port of the transient recorder.

As previously noted the user can set high voltage at any PMT at the PMT control box. Also the laser starts firing when the user presses the start button. The laser requires a short delay for safety reasons before starting the Q-Switch.

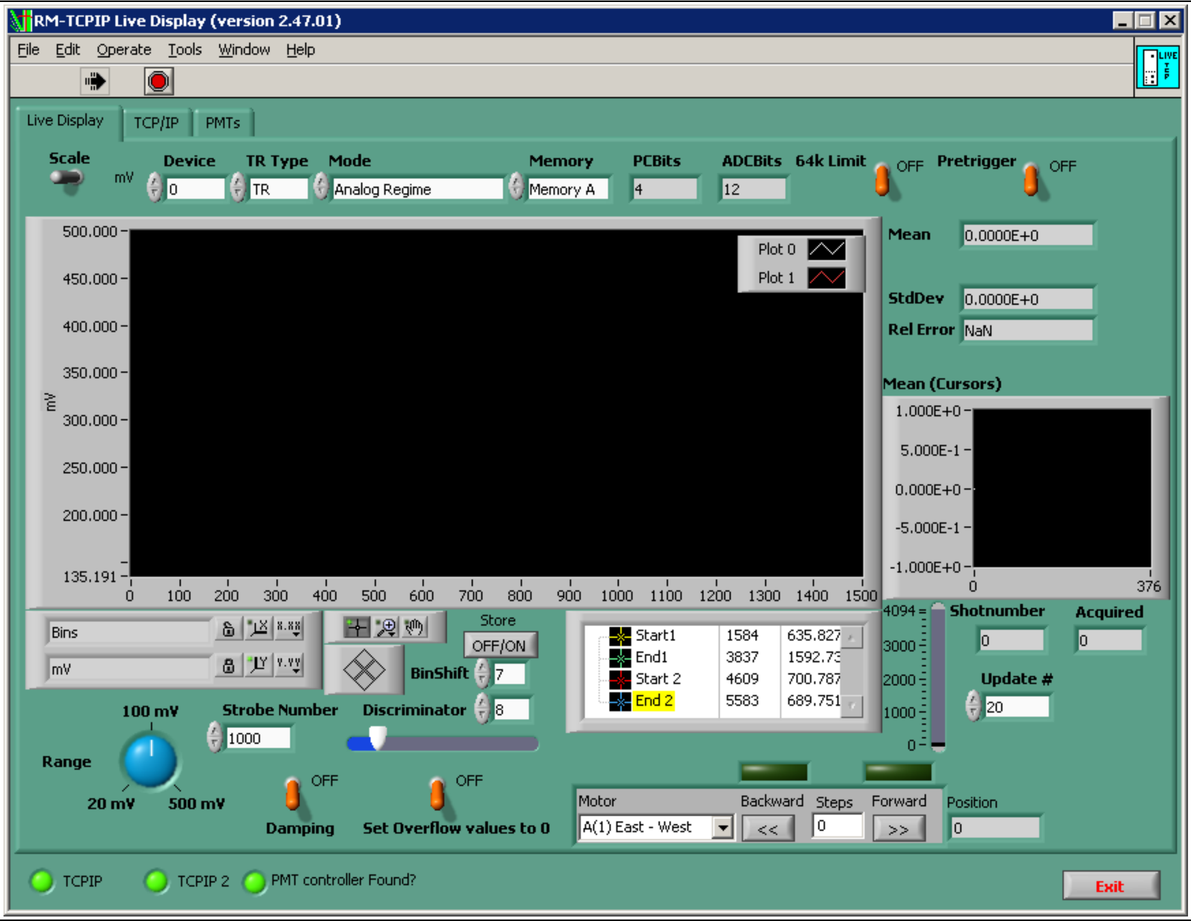
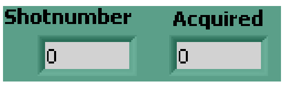


Fig. 6.25: Live Display Interface

When the laser is operating the 'Shot Number' indicator will increase for every trigger pulse Transient Recorder receives (or for each laser pulse if the recorder is triggered by the laser source). Next to this is the 'Acquired' indicator which shows how many profiles have been displayed.



Set the desired value using the 'Update' control. Setting this number to a high value will result in slower updates to the graph. If the value is too low however the graph will be affected strongly by the laser's energy oscillations resulting in a poor quality image. It is suggested to use a value close to the laser repetition rate which is 20Hz.

When the 'Shot Number' value is equal to the 'Update' value the data is read by the Transient Recorder and is displayed at the graph. The procedure then repeats until the laser is stopped or the exit button is pressed.

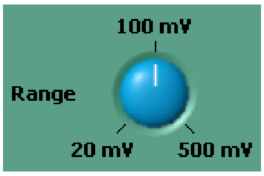
The 'Strob Number' indicates the number of bins to be transferred from the Transient Recorder to be displayed.

The dataset which is displayed on the graph depends on the selections made. Select device, TR type, and mode.

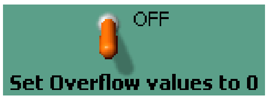
In order to change the High Voltage value for the PMT go to 'PMTs' tab as shown in **Fig. 6.15**. The desired value may be set either using the dial or the field directly below it. After this the PMT should be switched to the 'ON' position.

The discriminator level is a threshold for the PMT to recognize signal (either actual photons or random signal spikes coming from electronic noise or even temperature variations). In other words the sensitivity of the PMT can be set using the 'Discriminator' control.

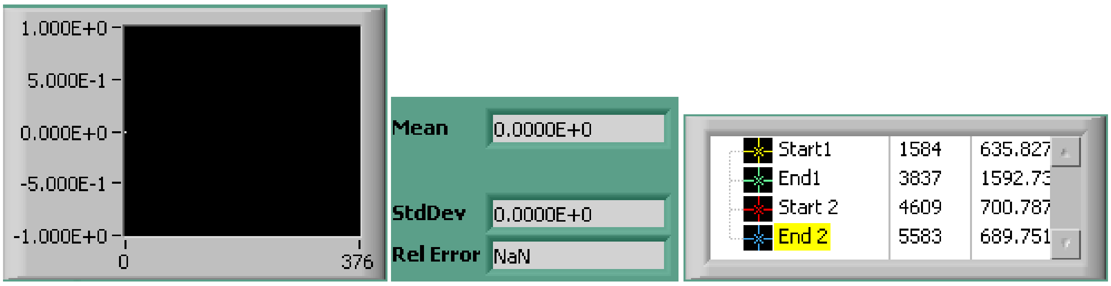
Set the analogue input range of the preamplifier (Range). The signal starts at 0 and extends to -20, -100, or -500mV. According to EARLINET suggestions the range has to be twice the peak signal. When the signal is too strong it becomes saturated and the range must be increased, otherwise the PMT will be damaged. If the maximum range is selected and the signal remains saturated refer to *6.2.4 Signal Intensity Reduction*.



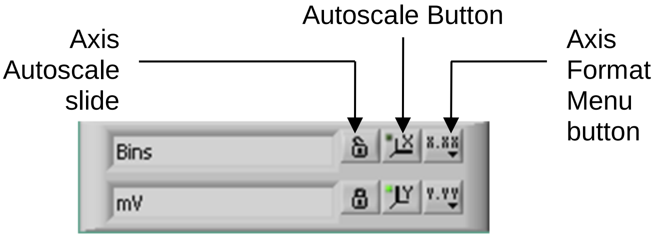
Turn on the overflow switch, to display all memory bins that overflow as 0.



The yellow and green cursors below the graph allow the selection of a region to average. The small graph in the right corner of the interface window shows the average of the region of interest. Above the graph the numerical values of the graph are displayed.



The x and y controls on the left of the window allow the user to autoscale the x or y axis. By clicking these buttons the scale is automatically adjusted to the highest value. The slide changes from autoscale mode to fixed mode. In autoscale mode the scale is adjusted to the highest value each time it is changed. In fixed mode the scale remains constant unless the user presses the x or y controls ('Autoscale' button). Default settings are autoscale for the y axis and fixed values for the x axis. The x.xx and y.yy controls allow for the specification of the format, precision and mapping modes of the x and y axis.

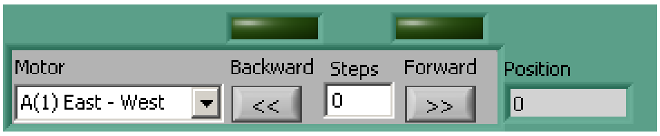


For more information about the wave-graph refer to the supplied Labview manual.

Below the graph is a 'Store' button. This can capture an image of the current profile and plot it with red colouring on the same graph. This option can be used to compare two different signals, which can be useful during the telecover test.

Below the 'Store' button is the 'Bin Shift' control. The analogue signal has a small delay compared to the photon counting signal. This difference comes from the time needed for analogue to digital conversion. In terms of signal the range is slightly increased, usually by 7 memory bins. What this control does is to shift the graph to the left so that the range shown on the graph is correct. The delay can be defined on the graph by locating a spike coming from an internal reflection.

Finally at the bottom of the window are controls for the motorized mirror mount. Select the motor (actuator) required in the first control from the left. Next set the step size (noting that a large step is around 200 and a small step is about 20). Press the left and right arrows to move the actuator forward and backwards.



CAUTION: NEVER BLOCK THE EMITTED LASER BEAM, WHEN THE PHOTOMULTIPLIERS ARE SWITCHED ON. REFLECTIONS FROM THE OBSTRUCTING OBJECT WILL DAMAGE THE PMTs. IF THERE IS A REQUIREMENT TO BLOCK THE LASER BEAM (e.g. for screening purposes during alignment) THE POWER SUPPLY OF THE PMT’s AND APD MUST BE SWITCHED OFF AND THE TELESCOPE MUST BE COVERED (with a piece of soft black cloth) IN ORDER TO PREVENT REFLECTED LIGHT FORM ENTERING THE TELESCOPE.

6.2.4 Signal Intensity Reduction

Having a strong signal may seem ideal but in fact it can damage the PMT. The High Voltage setting must be in compliance with the average maximum anode current of the PMT. The average current for Raymetrics Lidar systems is 100 μA which means 5 mV. The value of 5 mV should never be exceeded for longer than 30 seconds.

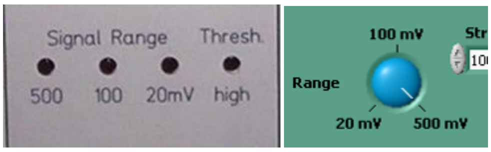
However the peak signal can significantly exceed the background average level as long as the integral current is below 100 μA. The analogue signal should fit into the input range of the preamplifier and the ADC. Due to the fluctuations of the Lidar signal the following rule of thumb will keep the signal inside the ADC range.

The analogue backscatter signal should be about half (+/-10%) of the preamplifier full range. This can be checked after the Lidar is fully aligned.

For a 20 mV range this corresponds to 10 mV. For a 100mV input range this corresponds to 50mV. For a 500mV input range this corresponds to 250 mV.

CAUTION: Peak signals should not exceed 500 mV for more than 10 μs (i.e. 3000 meters or 400 memory bins) or 100 mV for more than 50 μs (i.e. 15000 meters or 1200 memory bins).

The signal input range is user selectable through the software. Before concluding that the signal is too strong, it should be first ensured that the range is properly selected. By default the range is up to 100mV (i.e. not allowing voltages above that) and thus it will look as if the signal is saturated. In this case turn the dial to 500mV.



The max. cathode voltage of 1000V (High Voltage HV) should not be applied for more than 30 seconds.

Background and peak signals which are to high will introduce artefacts and shorten the lifetime of the PMTs. There are four ways to reduce the signal intensity:

- Laser energy reduction
- Field stop diameter reduction
- PMT HV reduction
- Use of filters in the eyepiece

The two first are not the best solutions because they affect all detected wavelengths including Raman signals which are by their nature already weak. If however only backscatter signals are being used, then these are the simplest solutions. Reducing the field stop diameter will also increase the overlap and reduce the effective range.

Reducing the applied HV appears to be useful at first glance, but is not an ideal long-term solution. The PMT cathode can accept only a limited number of photons over its lifetime; exposing the tube to a constant DC light will shorten its lifetime. The best solution is therefore to place neutral density filters (or a colour filter) in front of the PMT or to use a narrower interference filter (costly solution).

Below are presented all solutions. The most effective depends on the Lidar type and also on the user.

1. Decreasing the Laser Output Energy

Operation at a decreased energy level is useful when starting an experimental setup or testing equipment and extensive saturation in the Lidar signal is detected. A simple way to decrease the energy is to increase the flashlamp Q-Switch delay to a value that is higher than the optimum (highest power) delay using the Remote Box.

CAUTION: The laser manufacturer advises NOT to decrease the high voltage of the flashlamp(s) to reduce the output energy, as this will cause a change in beam characteristics. Divergence and alteration of the position of the focal point may cause damage to the laser’s internal optics. The user therefore does this at their own risk.

To adjust the output energy:

1. Select 'Q-Switch' from the Main menu on the Remote Box.

2. Press the 'Enter Menu' button.

3. Select 'Flashlamp / Q-Switch delay' (FLQS Dly) from the Q-Switch menu.

4. Use the 'Increase Value' or 'Decrease Value' buttons on the Remote Box to adjust the output energy to the desired value.

CAUTION: Do not attempt to modify the pumping power by increasing the flashlamp energy with the Remote Box of the PCC. This energy has been factory-set for optimal laser performance. Adjust the flashlamp energy with the Remote Box only if the flashlamp efficiency decreases. Please contact Quantel Customer Service Department to ascertain the origin of any efficiency decrease.

2. Field Stop Diameter Reduction.

This is only suggested for users who have advanced Lidar knowledge as reducing the field stop will affect the range and the overlap. This may drastically affect the Lidar's performance.

As shown in **Fig. 3. 8** Telescope Main Components", on top of the optical unit lies the focal plane. Where an adjustable calibrated iris is located. An Allen key can be used to unlock and turn the external ring to reduce or increase the diameter of the iris. The Optical unit must not be turned however as this will defocus telescope.

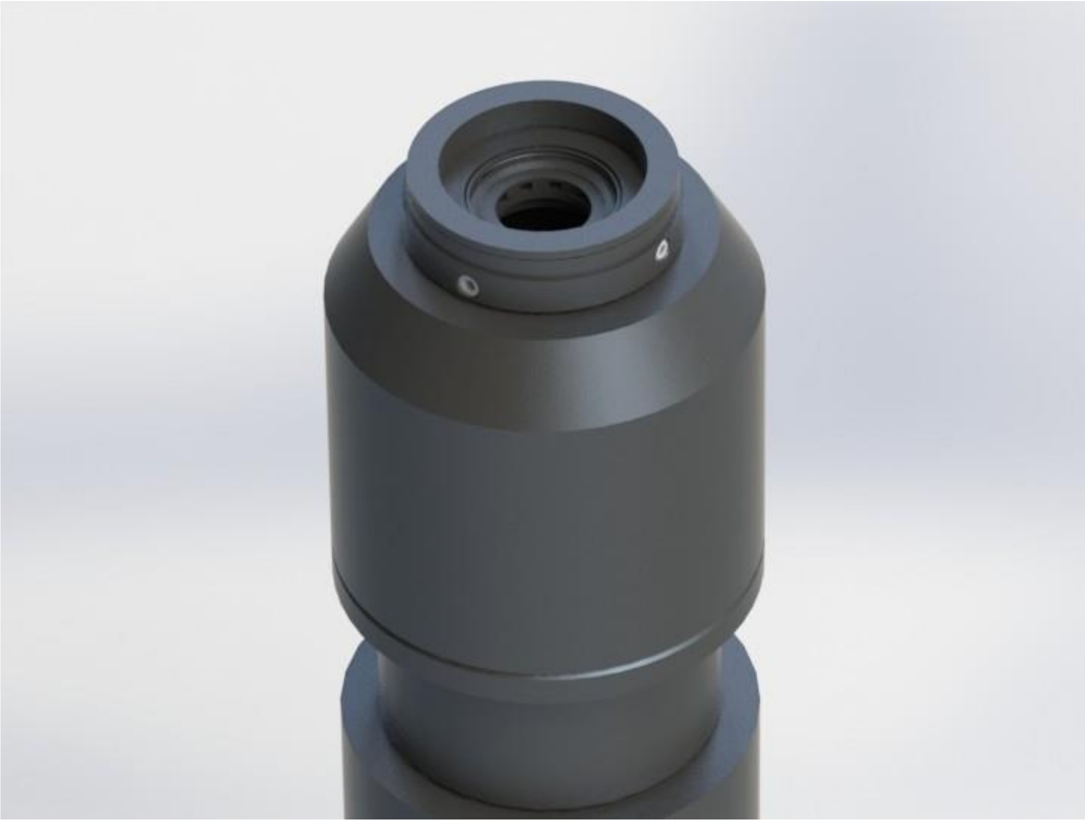


Fig. 6.26: Optical Unit with Iris

3. Decrease the HV Power Supply of the PMTs.

This is a good solution when the signal intensity is already close to the required level. The signal can be increased or decreased by changing the HV. However it should be noted that the value should not be lower than the suggested range (750-900V) in order to have a linear behaviour of the PMTs for every detected channel.

4. Use Colour or ND Filters

Absorptive ND filters are the suggested solution, although a reflective ND is also a good solution. Another good solution is to use colour filters. Interference filters can also be used which will decrease the OD however it is a costly solution. Please contact Raymetrics for the best suggestions for which filters are optimal. However before contacting us, note that we will require raw datafiles before providing a recommendation.

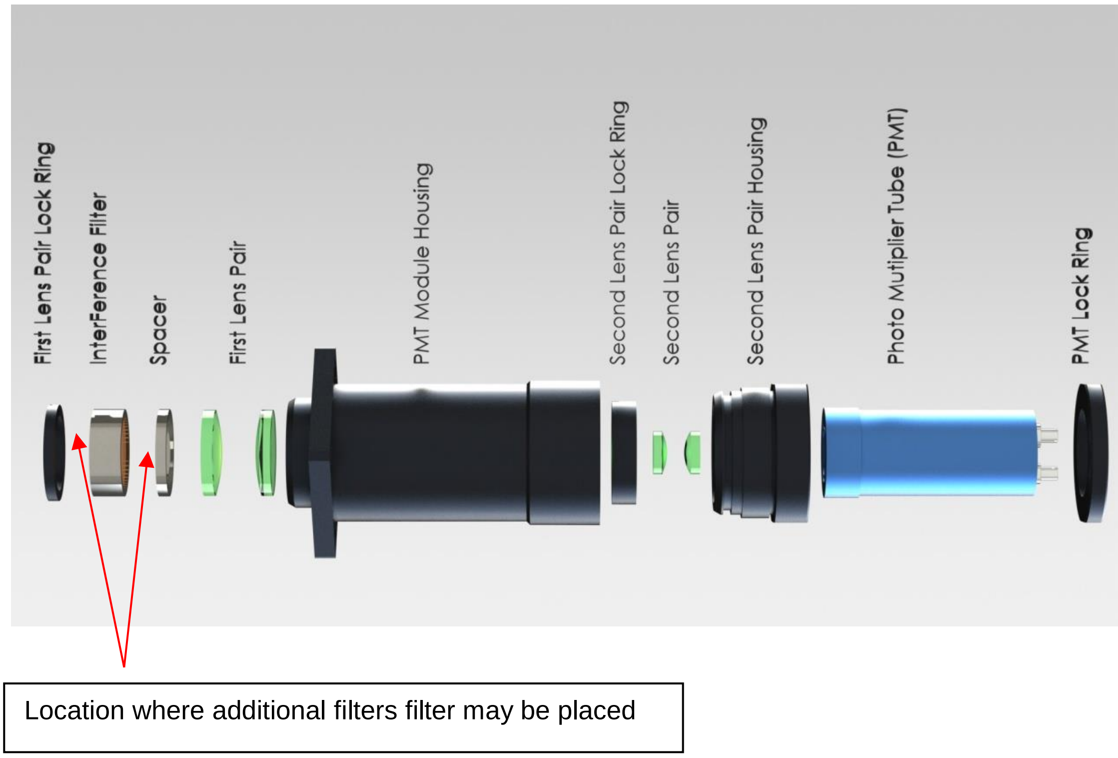
General Instructions for Adding Filters

1. Unplug both cables from the PMT

2. Remove the Detection Module from the Wavelength Separation Unit

3. Place the filter carefully in the appropriate position

4. Place the Detection Module back in position.



Attention: It is recommended that photomultipliers are protected from excessive light during installation of the colour filters. After illumination the dark current will be temporarily increased

Do not remove the interference filter which is located just in front of the PMT.

NOTE: Final optimization of the system will be done in-situ by Raymetrics engineers during the installation and training period.

6.3. DATA ACQUISITION

6.3.1 Introduction to the Acquisition Interface

To use the ‘Lidar Acquisition’ program, first exit the ‘Lidar Alignment’ program click on ‘Lidar Acquisition’ icon. Keep in mind that:

- This interface is for multiple measurements.
- Before starting a measurement all parameters have to be configured (see below).
- By default the system is set to automated mode. **This means that once the ‘Start’ button has been pressed the laser will start firing without any notice. Follow the safety rules.**
- **Exiting program without stopping a running multiple acquisition, may cause unpredictable entries into the main database.**

Below the main features of the ‘Lidar Acquisition’ interface are presented.

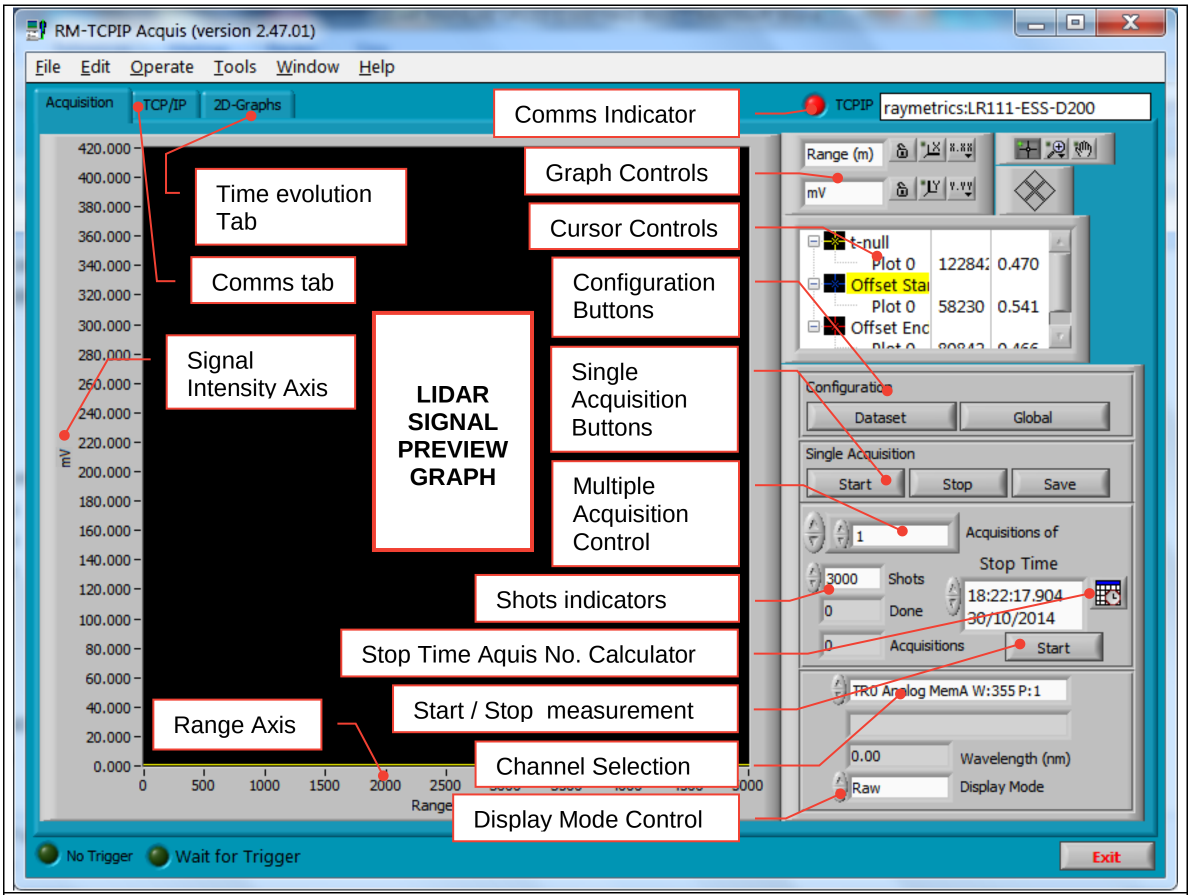


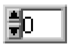
Fig. 6.27: Lidar Acquisition Interface

6.3.2 Configuring Measurements

The required parameters can be set using the ‘Dataset’ and ‘Global’ buttons. The dataset parameters are those related to the channels to be used. The global parameters are more general and usually do not require changing often. The global parameters are saved by default whereas the dataset can be saved as a configuration file which can be reloaded for future use. Most operators tend to make several different standard datasets (for example day time and night time) which can be re-used to save time and avoid mistakes.

Configuring the Transient Recorder

To configure the TR, start by determining the dataset. Click the 'Dataset' button, which will make a new window to appear. At the top of the window is a file menu which contains four options. To edit an existing file, select 'Load transient information' and select a file. After the data has been edited, the information can be saved by selecting 'Save transient information as...' and either choose the same file name, which overwrites the old file, or type a new name. If a mistake is made when editing the data, the original file can be reloaded by pressing 'Reset Information'. The current configuration file is shown in the display below the menu. If 'Exit without saving' is selected, the original dataset will be used.

Below the 'TR Data File Path' is a numeric control.  This selects the device. Pressing the up and down arrow will navigate though the devices. For instance here device 0 is selected.

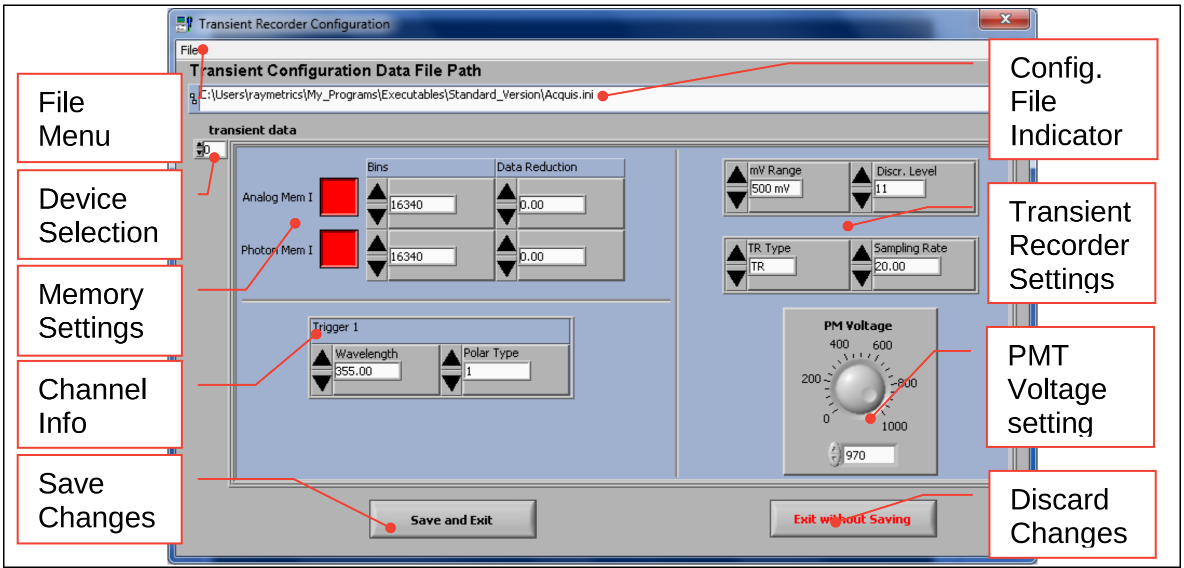


Fig. 6.28: Transient Recorder Configuration

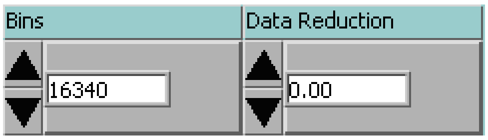
In the Transient data frame several inputs and controls can be found. The values set here must be different for each device, as each device measures a unique wavelength.

The memory settings are those which send the command to either write to memory or to not write to memory. When the button is red  the memory is activated and when grey it is deactivated. Here the user can independently select the memory required: 'Photon' or 'Analogue'. For the elastic backscatter channels both are required. For Raman only photon may be needed if the signal is weak. If a certain channel is not required uncheck (gray) both buttons. This may be useful for a Raman channel during day time to save data space, for example. Space may also be saved by reducing the memory bins. As already explained the memory bins are related to the range. The spatial resolution of the recorder depends on the sampling rate or in other words the recoding frequency. This system has a 20MHz recorder which means that every **!Undefined Bookmark, TR_FREQ**μs writes a memory bin. When a laser pulse is emitted the recorder starts the time counter. The first photons that arrive back are recorded after **!Undefined Bookmark, TR_FREQ**μs. However this time includes both the time spent for the photon to reach the target and the time for the return journey. So actually the time that the photon needed to reach the target was **!Undefined Bookmark, TR_FREQ**μs. The speed of light on the other hand is approximately $3x10^8$ m/s so the distance is 300 x **!Undefined Bookmark, TR_FREQ** = !Undefined Bookmark, TR_FREQ**m**. This is the minimum distance that the recorder can record, known as the spatial resolution. The memory limit of the 12bit TR is 64336bins. This gives a total of 64336 x **!Undefined Bookmark, TR_FREQ** = !Undefined Bookmark, TR_FREQ**m**. For most applications such high data range is not needed.

Another way to reduce the data size is by using the data reduction function. This function groups bins together to make a superbin. One level of reduction in value reduces the height resolution by half and doubles the number of bins that are combined together. A data reduction level of 0, 1 and 2 corresponds to 1, 2, and 4 bins per data point respectively. In this way the spatial resolution is increased but the maximum range remains the same. This also means that the maximum number of bins is reduced.

<table>
<tr><td rowspan="2">0 Data reduction</td><td>Bins</td><td>1</td><td>2</td><td>3</td><td>4</td><td>…</td><td>!Undefined Bookmark, BINS</td><td>!Undefined Bookmark, BINS</td><td>!Undefined Bookmark, BINS</td><td>64336</td></tr>
<tr><td>meters</td><td>!Undefined Bookmark, TR_FREQ</td><td>!Undefined Bookmark, TR_FREQ</td><td>!Undefined Bookmark, TR_FREQ</td><td>!Undefined Bookmark, TR_FREQ</td><td>…</td><td></td><td></td><td></td><td>!Undefined Bookmark, TR_FREQ</td></tr>
<tr><td rowspan="2">1 Data reduction</td><td>Bins</td><td colspan="2">1</td><td colspan="2">2</td><td>…</td><td colspan="2">!Undefined Bookmark, BINS</td><td colspan="2">!Undefined Bookmark, BINS</td></tr>
<tr><td>meters</td><td colspan="2">!Undefined Bookmark, TR_FREQ</td><td colspan="2">!Undefined Bookmark, TR_FREQ</td><td>…</td><td colspan="2">!Undefined Bookmark, TR_FREQ</td><td colspan="2">!Undefined Bookmark, TR_FREQ</td></tr>
<tr><td rowspan="2">2 Data reduction</td><td>Bins</td><td colspan="4">1</td><td>…</td><td colspan="4">!Undefined Bookmark, BINS</td></tr>
<tr><td>meters</td><td colspan="4">!Undefined Bookmark, TR_FREQ</td><td>…</td><td colspan="4">!Undefined Bookmark, TR_FREQ</td></tr>
</table>

The data reduction and the Bins number can be set to read from the memory bank. It must however be kept in mind that the maximum number of bins is given by 64336 / (2^data reduction).

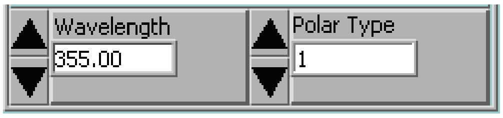


Below the memory setting is the channel information. Here the user must specify the detected wavelength and the polarization type. The polarization types are:

0 .... No Polarization

1 .... Parallel Polarization

2 .... Cross Polarization

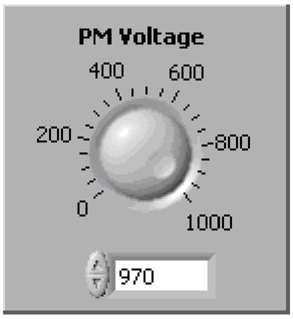


In the Transient Recorder settings the range values of the Transient Recorder, the discriminator level, the TR type and the sampling rate should be set. The ranges values are 0-20mV, 0-100mV and 0-500mV. These are selected based on the signal intensity observed when using the ‘Lidar Alignment’ program. According to EARLINET the range has to be twice the signal peak. For example if the signal peak is close to 50mV 0-100nV should be used; or if close to 250mV select 0-500mV. **Setting the wrong range may result in signal saturation and eventually PMT damage.**

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.

Transient Recorder devices may be of different types depending on the Lidar model. Each device must be set to the correct type TR (analogue and photon) or PR (only Photon). The sampling rate must also be set for each. This information can be found in section 10. LIDAR SYSTEM TECHNICAL SPECIFICATIONS.

The final parameter to set is the amount of voltage to be applied to the PMT during the measurement. The allowable range for linear behavior is 750-900V. Similarly to the range, this is set based on the signal intensity observed using the ‘Lidar Alignment’ program.



After the Transient Recorder units have been configured, the configuration window may be exited by either pressing the 'Save and Exit' button (to save the information to the file path shown), or, alternatively, by selecting 'Exit without Saving' to exit without saving changes. Please note that when exiting the program without saving, any unsaved data is lost! Thus if the dataset has been configured and may be of future use, the 'Save and Exit' button should be used. Alternatively the 'File->Save Transient information as...' option from file menu may be used before exiting the program. In this way, the user can create as many different configuration as files required. It is also possible to load a file from the menu, which is useful when working with the 'Scheduler' program where a different configuration file can be used for each set of measurements. To use the current Transient Recorder configuration as the default option the data must be saved as Acquis.ini in the installation path.

Configuring Global Parameters

The global parameters are more general settings. Here the user can set:

- the location information of the measurement site (8 characters length), longitude, latitude and altitude (in meters)
- The ground temperature (in Celsius) and ground pressure (in mhA)
- The emitted wavelengths and frequency from laser source
- The number of shots for each profile. In other words this setting determines how many profiles will be averaged to create a single averaged profile. The higher the value, the better the Lidar data you get, but higher values also mean longer times between profiles. The number of shots should be set high enough so that data files are not written faster than every ten seconds (i.e. 100 shots at 10Hz, 200 shots at 20Hz, etc.). This is due to a limitation of the naming convention. The maximum allowable value is 4094 due to Transient Recorder ram limitations.
- The direction is an indicator of the angle of the Lidar (azimuth and zenith angle). For a scanning Lidar the program gets the current direction from the positioner; if the user changes the values the positioner will move to the specified direction.

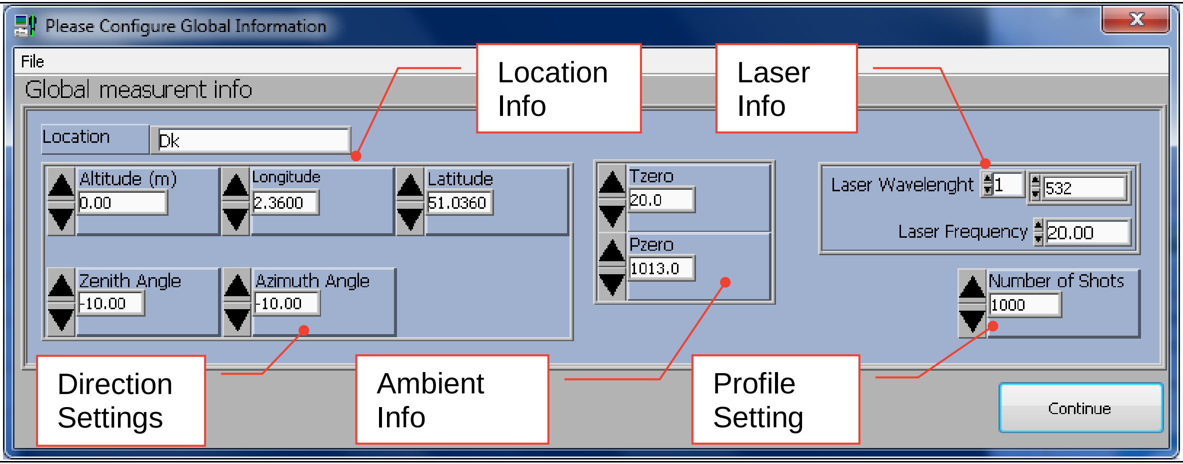


Fig. 6.29: Lidar Acquisition Interface

After each of the above steps has been completed, every parameter has been set. Note there two types of parameters; those for information purposes and those which configure the measurement. All informational parameters are stored in a header in the data files, so that the user can see what parameters were used for each measurement. 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. For example the location field could be used during a telecover test to state the different parts of the telescope used (‘East’, ‘West’ etc.) or ‘Dark’ may be entered during a dark current measurement. This makes it easier when viewing data in the *‘Lidar Analysis’* program.

6.3.2 Configuring the Working Directory

The working directory is the default directory where data is saved. To set or change the working directory, run the program *‘Config Lidar Acquis’*

As displayed in **Fig. 6.30** this is a very simple program which changes the most basic information for the acquisition (i.e. the TR model and the working directory).

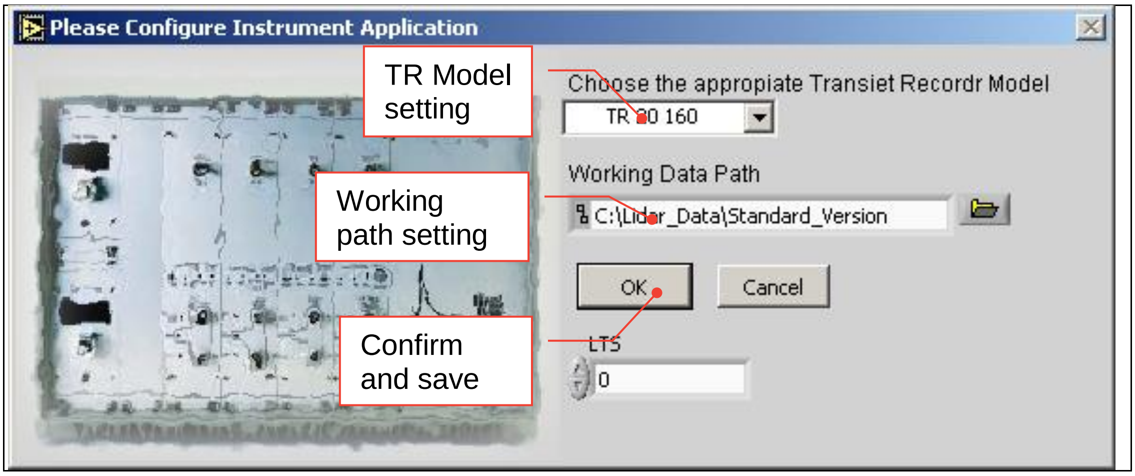


Fig. 6.30: Config. Lidar Aquis. Interface

To use this program, choose the TR 20 12bit and then select a working data path.

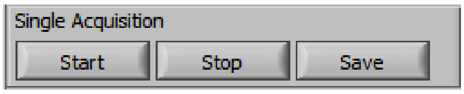
If the working data path to be used already exists and contains a datalog.dat file then the software will prompt the used to overwrite this file. If the user selects ‘Yes’ then a new empty datalog.dat will be created. **Note that the path must not contain spaces; these should be replaced with underscores.**

6.3.3 Lidar Measurements

There are three different ways to acquire Lidar measurements. Each one results in the same lidar data being acquired; what differs is the number of files created and the total time for a measurement. All three have been described below.

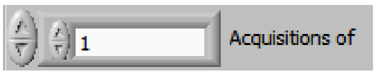
a. Single Acquisition

This option starts an acquisition and averages all shots until the ‘Stop’ button is pressed. However there is a memory limit which goes up to 4094shots. The ‘Save’ button saves the current profile on a record.



b. Multiple Acquisition

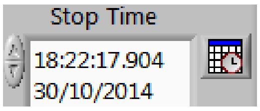
There are two ways to take multiple acquisitions; one is endless that is started and stopped by the user; the other has a limited predefined number of acquisitions. The user can select the ‘multiple’ for constant run option for the former, or can switch to the numerical control box to set the desired number of acquisitions for the latter. In the first case the user has to stop the measurement whereas in the second case the measurement is stopped when the desired number of profiles have been acquired. In either case the file is saved as one record containing many profiles.



Each profile is the average of single profiles which correspond to single laser shots. The number of shots can be set in the ‘Shots’ box. The ‘Done’ box indicates the current shot number. Immediately below this is the ‘Acquisition’ indicator which shows the current number of acquisitions.

c. Time Configured Multiple Acquisition

This is used to acquire data for a specific duration. To do this, the user has to set a stop time in the 'Time' box and press the button to calculate, based on the number of shots for each profile and the repetition rate, how many acquisitions are required. This is shown in the 'Acquisitions of' box which is automatically updated.

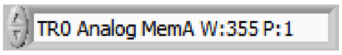


After this, for either b. or c. mode, the user should press the Start Button. This will change to a 'Stop' button, which if pressed will stop the measurement.

The Transient Recorders, which were activated at the datasets configuration stage, should now acquire data. If the acquisition has been started successfully, the number of shots completed in the 'Shots' indicator box should start increasing. When this number reaches the number set by the user, a new profile is shown in the graph area and a new unique file is saved containing the raw data. A new record is simultaneously created in the datalog file with the current start and stop time. When the next profile is acquired a new data file is created and the datalog is updated with the new stop time. If the stop button is pressed the running acquisition is rejected but all profiles before that are saved and registered in the datalog file. If it is the first acquisition then no file will be saved and no record will be registered in the datalog. When using the single acquisition mode press the 'Save' button to save acquired data to a unique file and register the record in the data log file.

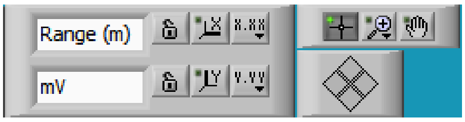
The naming convention is explained in section 7.1 DATA FILE HANDLING. The waveform graph is refreshed with the newly saved data and a new measurement is begun.

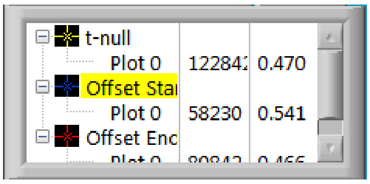
The desired dataset to be displayed can then be selected from the drop down list. Note that in the description 'P' stands for the polarization type.



The display mode can also be changed using the drop-down box to see the raw signal (raw), the offset corrected signal or the Range Corrected Signal (Pr2).

Beside the graph is a set of controls for the graph; the user can change the scale of the axes, the units, lock the axes or set to auto-scale, zoom in on a selected area or pan the graph. Also the user can place cursors on the graph by using the controls below. Each cursor has its properties like colours name behavior etc. The user can access the properties by clicking on the cursor sign.





In the bottom left corner are two indicators. The left one (‘No Trigger’) lights when the DAQ electronics are not triggered; either because the laser is not emitting or the cable is not connected. There are several reasons why the laser may not be emitting. The most common is an interlock which comes from the various interlocks connected to the BNC input of the laser. The second indicator (‘Wait for Trigger’), lights up when the program is waiting for the trigger to start again to continue with the measurement.

The TCP/IP tab contains the setup options. At the top is the option for whether the measurement will automatically start when the program starts. The measurement parameters (i.e. type of acquisition, number of shots, configuration file, etc) are saved in the program initialization file ‘RM-TCPIP Acquis.ini’. This file is saved when the exit button is pressed. This means that if the ‘Auto Start Measuring’ option is selected, the measurement parameters used are those that were saved the last time the program was used.

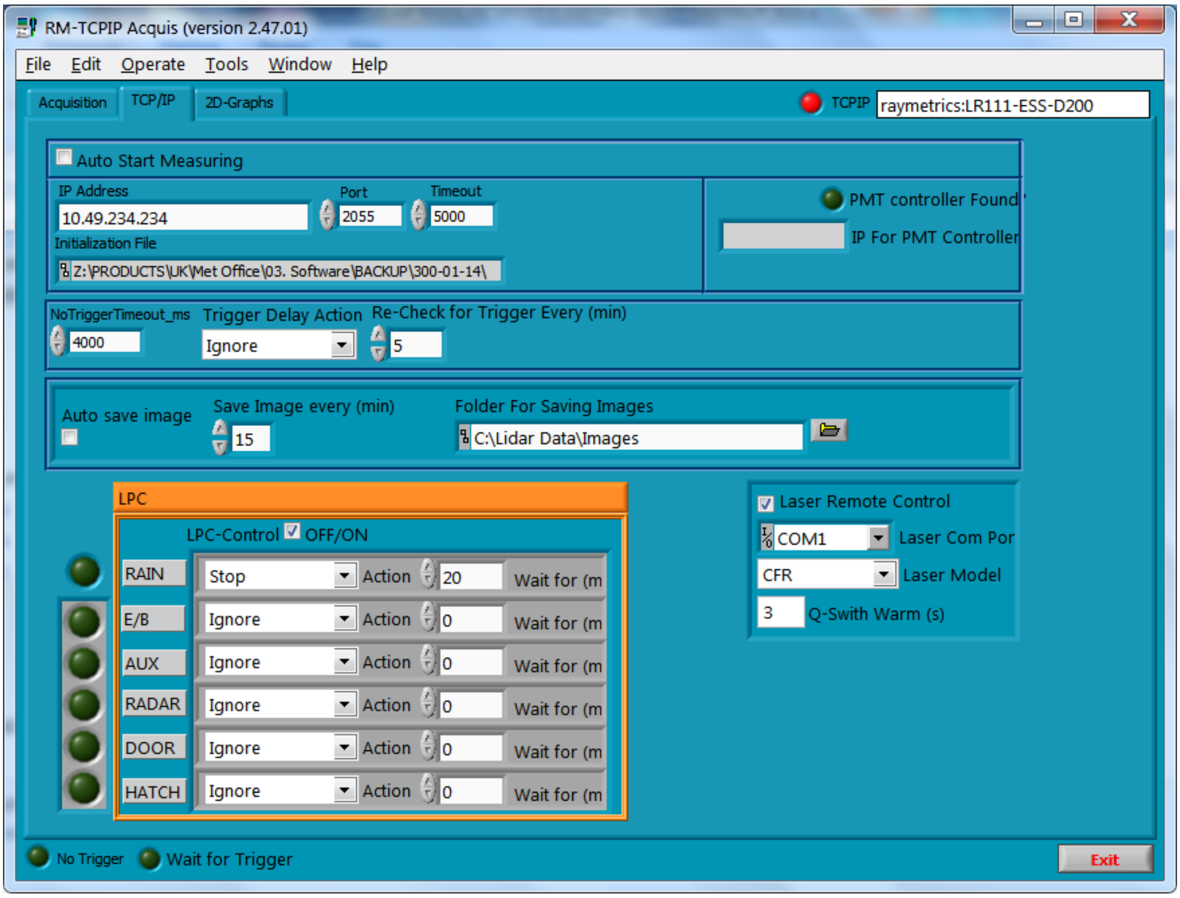


Fig. 6.31: Setup Tab Interface

Below are the settings for the TR and the PMT HV device. The IP address and port of the TR are by default 10.49.234.234 and 2055 respectively. If for any reason the TR has another IP address the user has to set in the box. The timeout refers to the time that the system will wait to establish the communication; if no communication is established by that time a dialog appears then the user can retry or cancel and change the address. The initialization file contains all of the information regarding the dataset. The user may create from the dataset many different files and can select here the path of the one to be used for the specific measurement.

The program will establish the communication also for the PMT HV controller. This may be just a module sharing the same device and IP address or it may be a different device with a different IP. In each case when the connection is established the indicator lights up and the IP address appears in the text box.

The option 'Auto Save Image' refers to the 2D plots from the third tab of the program. Here the user can set if the images displayed there will be saved or not, how often these will be saved and the folder where they will be stored.

The program constantly checks if the number of shots increase. If the shot number remains the same for a short period of time (which is set in milliseconds in the 'NoTriggerTimeout_ms' text box) the program automatically gets the status of the laser. If the laser has an interlock (other than an external one), it stops and writes the cause on the log file. It also sends an e-mail to the user if it is running from the scheduler. If the interlock is an external one*, the system will perform the action which is set in the adjacent control. There are four options;

a. Ignore: The program does nothing; it pauses the measurement. If the laser restarts the emission it continues writing to the same data file.

b. Stop Measurement: The program stops the current measurement, rejects the last profile and updates the log file, as if the user had pressed the stop button. To restart it requires the user's intervention.

c. Stop Measurement and Restart After: The program stops the measurement as in the previous option but it will try to restart after the time delay specified in the box at the right has elapsed. The measurement then starts in a new record.

d. Exit Program: The program stops the measurement as in the previous options and exits completely.

Furthermore if there is an LPC device included in the Lidar, the program establishes the type of the external interlock and handles each case individually. The user has to set the action for each case. If for example the door opens the user may decide that the measurement has to stop and the system should wait for the user's action to restart. But if it is raining the user may require the program restarts automatically when the rain stops.

*An external interlock is an interlock that is connected to the laser's BNC input connector. For example if there is a switch on the Lidar enclosure door connected to the BNC interlock, the laser emission will be stopped when the door opens.

Finally there is the option to set the laser type and communication port and whether this is to be controlled by the program or not.

The third tab titled '2D-Graphs' provides have an overview of the data acquired in a time evolution plot form. Here the vertical axis is the height and the horizontal is the time. The signal intensity is represented by an adjustable colour scale.

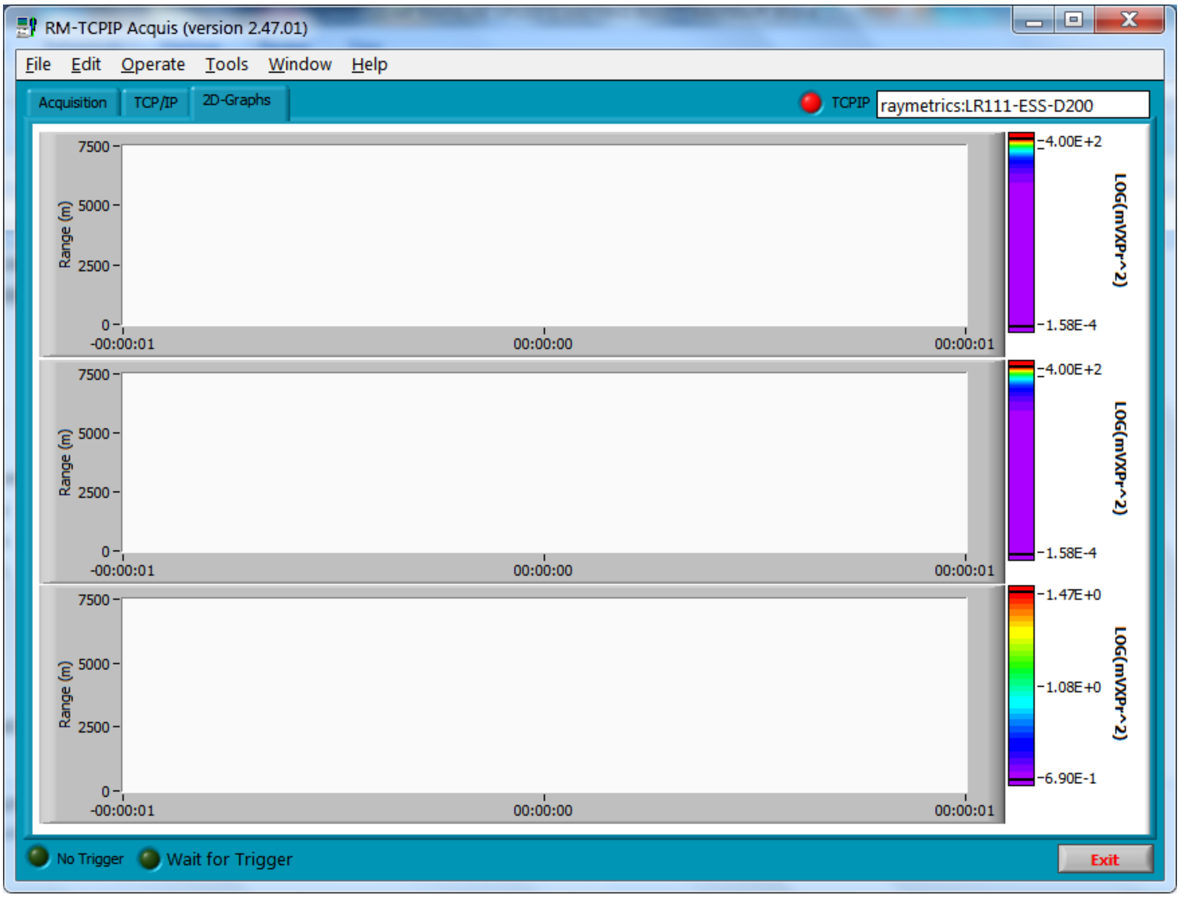


Fig. 6.32: 2D Graph Tab Interface

Every time a new profile is acquired it is added as a strip at the end of the graph and the image is refreshed. To reduce the memory required for the program, a limited number of profiles can be shown. When the limit is reached the first profile will disappear from the left of to make a space at the right for the new profile. For this reason the images can be saved at any time in the folder specified. These parameters (time and folder to save to) can be set in the settings tab.

6.4. MEASUREMENT SCHEDULING

The *‘Scheduler’* program is an extremely useful tool. With this software the user can set a series of pre-programmed measurements on a daily basis. The main purpose of this tool is to perform Lidar measurements without need of an operator. This, in combination with the remote setting and alert setup, allows for a fully remotely operated Lidar.

The interface has four Tabs. The main tab is the ‘Scheduler’ tab. This contains the timetable and the scheduler status information.

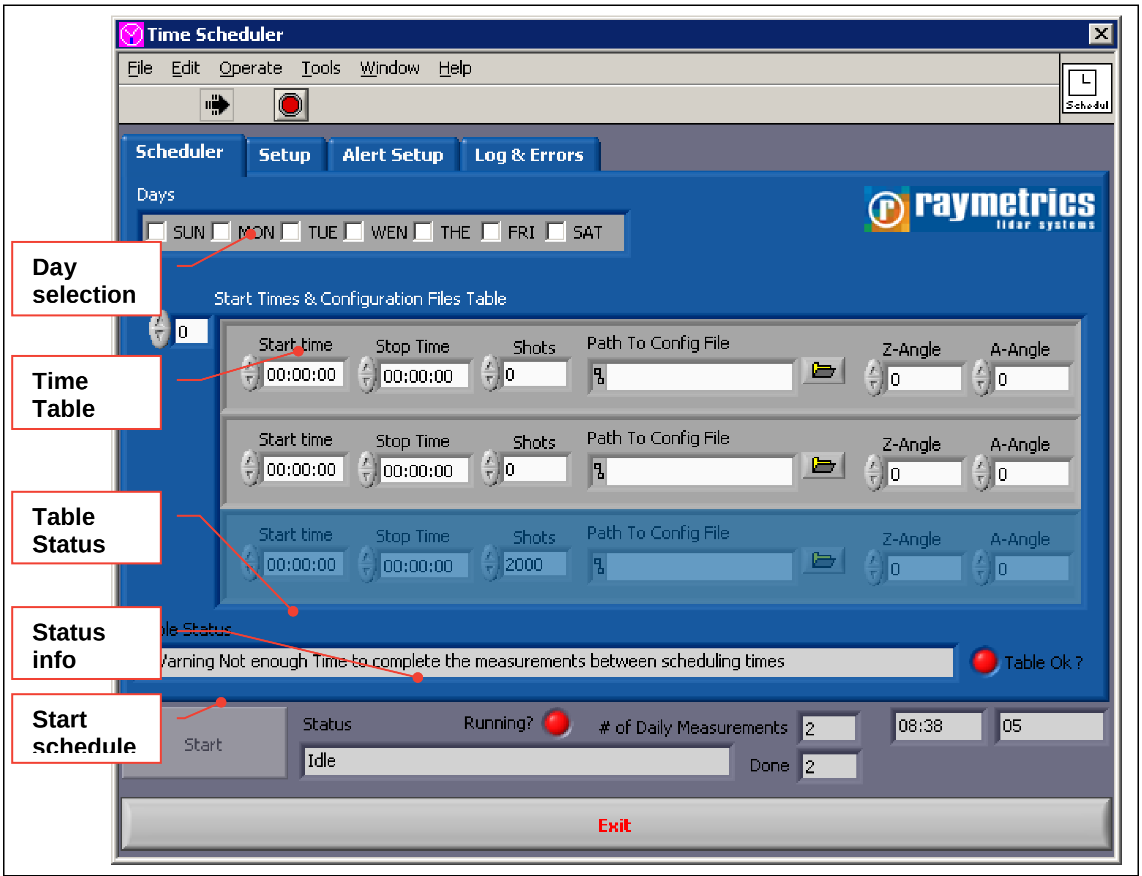


Fig. 6.33: Time Scheduler Main Interface

At the top of the window is the day selection area. Select here which day(s) of the week the programmed schedule will be run.

The timetable offers a wide array of inputs. As configurations and start and stop times as needed can be added, allowing the user to conduct any number of measurements of different types. The control beside the table allows the user to navigate though the timetable.

Each measurement requires five main parameters:

- Start time
- Stop time
- Number of shots for each profile
- Configuration (Dataset) file to be used
- Direction of lidar

To make a usable timetable the user has to bear in mind a few simple rules.

- The start time has to be earlier than the stop time.

- The number of shots divided by the laser repetition must not exceed the run time of the measurement.
- The configuration file and path have to be valid.

The Start time of the next measurement has to be later than the stop time of the previous one.

For example the timetable in the figure below, the stop time of the first measurement is later by two minutes or 120 seconds, which is OK, and also the shots is 200, which divided by the laser's frequency (20Hz) gives **!Undefined Bookmark, REP_RATE** seconds for each profile, which is enough to acquire **!Undefined Bookmark, REP_RATE** profiles. If however the shots was set to more than **!Undefined Bookmark, REP_RATE**, the table would show an error and the green led 'Table Ok?' would turn red. The same will happen if the start time of the next measurement is set earlier than the previous one, or if the configuration file is in some way invalid.

Note that the user can create a configuration file using the configuration tool of the acquisition program, as explained in section *6.3.2 Configuring Measurements*.

The scheduler starts when the user presses the start button.

The status of the scheduler can be checked at the bottom of the tab where information about errors and the measurements made is available.

The direction of the Lidar refers mainly to scanning systems. For a vertical pointing lidar the zenith angle is -90º and the azimuth is 0º. For a scanning system, the user can set the desired direction here and the Lidar will move to this position and start a fixed position measurement. For a scanning measurements a separate program is provided.

The laser frequency can be set in the 'Setup' tab to estimate the time needed to complete the measurement. If a GSM device is connected to the lidar it can send critical information by SMS to the number specified in the 'Alert Set-up' tab. The final tab can be used to view the log of the scheduler; i.e. when the measurement started and stopped or if there was an unexpected error. The user can also select where to save this log file.

6.5. REMOTE LIDAR OPERATION

The Lidar can be fully remotely controlled. When it is connected to a network it automatically acquires an IP address. Any user in the same network should then be able to connect to the Lidar’s computer. If this network also has internet access with the appropriate permission from the network administrator it is possible to connect externally to the Lidar from anywhere in the world. In this section there are some practical guides how to connect and operate the computer remotely.

6.5.1 Establishing a Connection

Once the Lidar is connected to an external network, Windows Remote Desktop software (or other remote desktop software) can be used to control the Lidar’s computer. Follow the steps below to establish a connection from a Windows 7 Operating System.

1. Open the network to browse all computers connected to your network.
2. Locate the computer named 'LIDAR-200-04-15’ and right click.
3. In case you cannot find the Lidar computer, first make sure that the Lidar is powered on, and that the connection cable is connected to the Lidar and to the wall socket or to an external computer; i.e. a laptop connected directly with a cross link cable. If this does not fix the problem, try using another cable or another wall socket. Note that when the lidar computer is powered on, a certain time is required for Windows to boot and connect to the network.

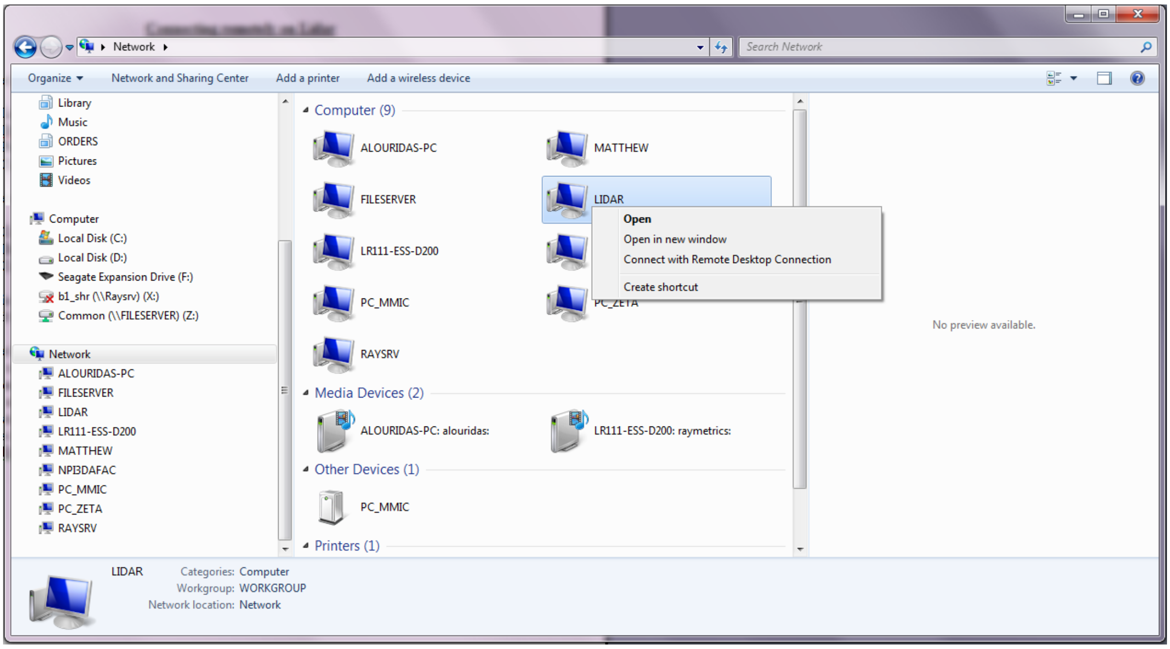
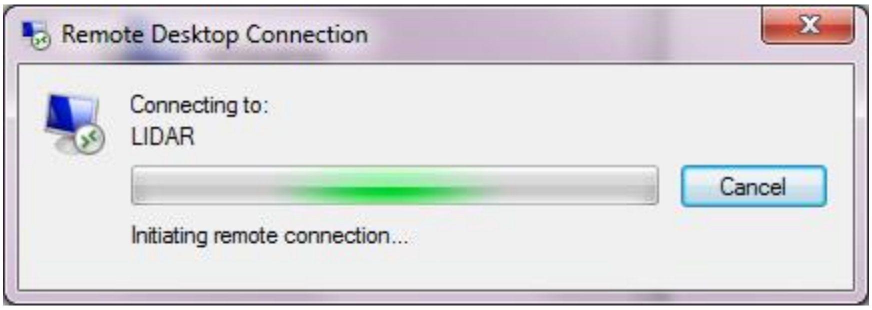
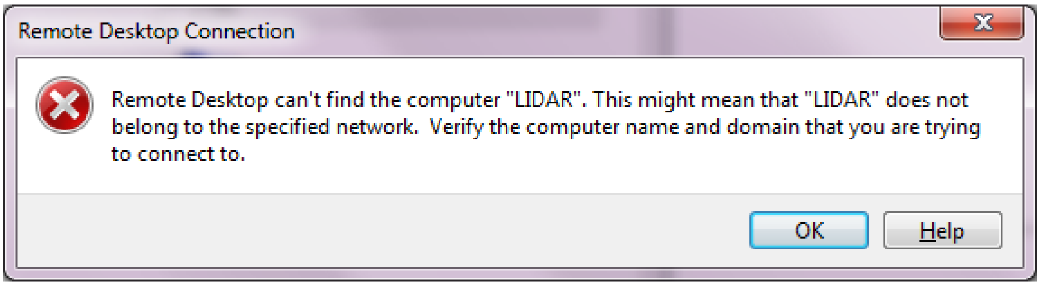


Fig. 6.34: Lidar Computer On A Network

4. Right click on the Lidar's Computer icon and select "Connect with Remote Desktop Connection" (RDP). The window below should appear.



5. Wait for a couple of seconds. If it takes longer than one minute then the connection probably cannot be established and the window below will appear.



6. The most common reason for this is that the computer is turned off. You can see how to remotely wake up the computer in the section '*6.5.2 Shutdown and WOL*'. If the problem persists refer to the section '*6.5.3 Remote Connection*'.

7. Key in the username and password when prompted and check ‘Remember my Credentials’.

   By default the account used has the credentials below:

   Username: **User**

   Password: **Lidar**

8. A new window will open showing the Lidar’s desktop. Use the mouse and keyboard to control the Lidar.

NOTE: that this is a window which you can resize, minimize and close like all windows. When you resize keep in mind that you are no longer viewing the whole screen. There might be icons missing or the taskbar may be missing, which you can view by using the scroll bars.

Also keep in mind that when the user closes the window the Lidar computer does not turn off but only the connection is closed. The computer logs off and remains turned on. If it is required to shut down the computer refer to the section '*6.5.2 Shutdown and WOL*'

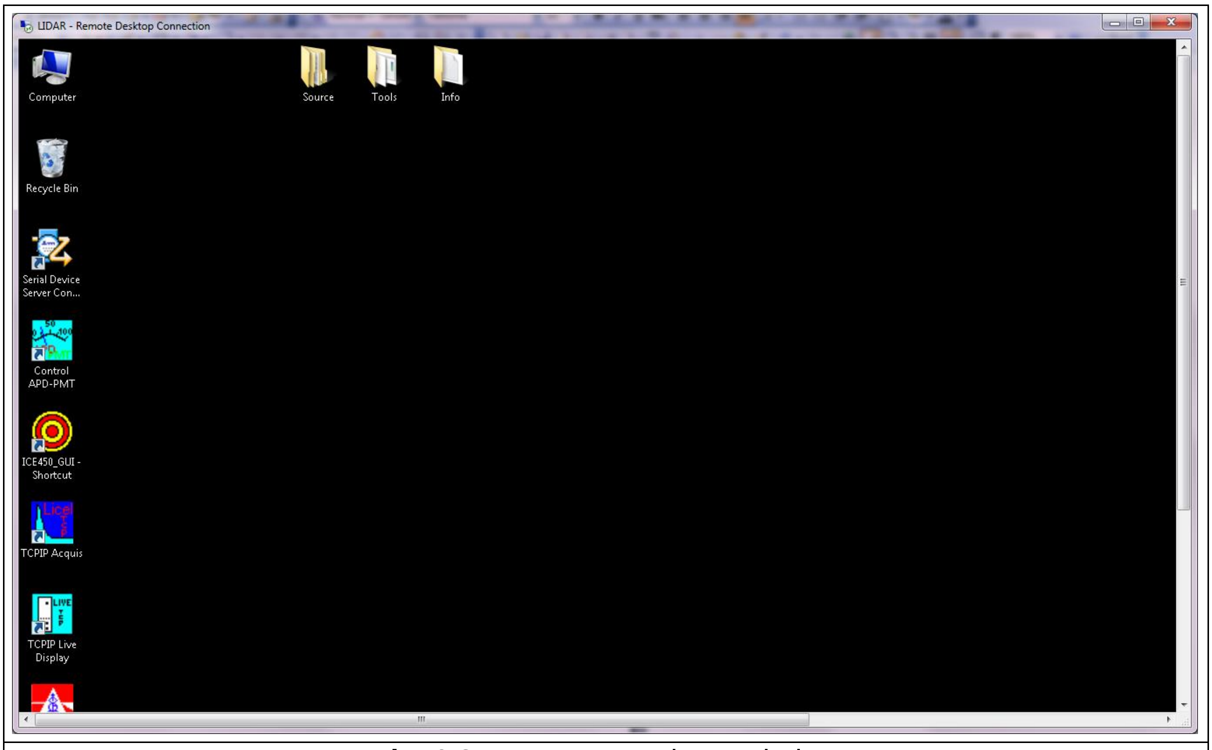


Fig. 6.35: Remote Desktop Window

6.5.2 Shutdown and WOL

Once connected, the options in the 'Start' menu are limited to 'Disconnect' and 'Lock'.

Fig. 6.36: Limited Shutdown Options

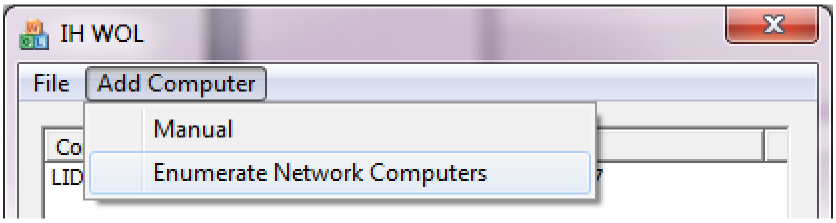
In order to shut down the computer, click 'Windows Security' right above the 'Log off' button. This will open a new screen which is shown when 'Alt+Ctrl+Delete' is press in Windows 7. From there select to shut down safely the Lidar computer.

NOTE: By default the key shortcut 'Alt+Ctrl+Delete' refers to the local computer and not the Lidar's computer. There is however the option to use this shortcut also in the remote connection. Please refer to the '*6.5.3 Remote Connection*' section.

Fig. 6.37: Windows Security

The next step is to turn the computer ON remotely through the LAN. This procedure is called 'Wake on LAN' and it is an event that wakes up the computer using the local network or even the internet. To do this a packet of codes must be sent from the local computer to the Lidar's computer, which is called 'Magic Packet'. This packet is produced and sent with very simple software which is called in general 'Magic Packet Sender'. You can find many free programs over the internet. All of these programs need the Lidar's IP and MAC address to work; however some require more information.

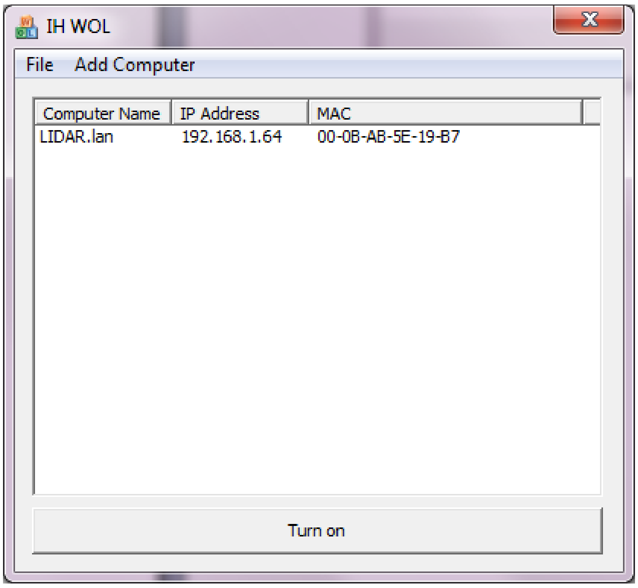
Many of these programs can scan the network and find all computers which are currently turned on and acquire automatically the Name, IP and MAC address. Below is an example of such a program.



NOTE: The program will not find the computer if it is turned off. Therefore the first time the program is run, the computer must be switched on. Then the information needed can be saved to the program so that it can be used again in the future.

NOTE: To scan the network, permission has to be given from Windows. If prompted about security issues for this operation check the option to allow the program to perform the scan.

Once the computer's information is known, select the correct name and turn it on.



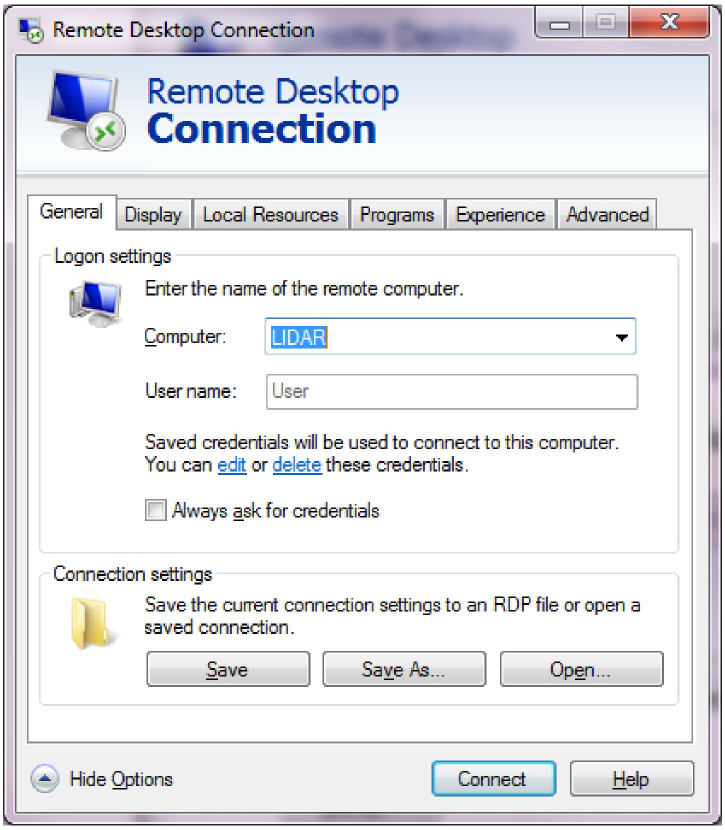
NOTE: The user will have to wait for a moment to let the computer start Windows before a connection can be established.

There is also the option to perform this task from a distant computer over the internet but in this case the Lidar's computer has to have a static external IP address, which can be set at the network router's options. Also it is necessary to set an access port in the firewall options. **Please consult your IT department before attempting this.**

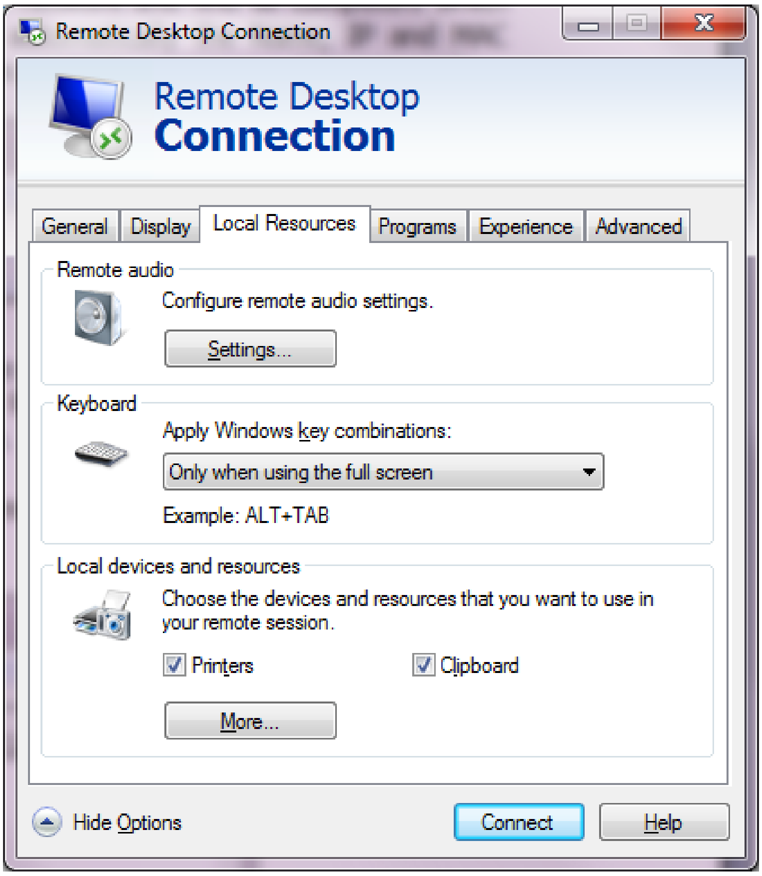
6.5.3 Remote Connection

The procedure described in the section 'Establishing a Connection' is the fast way to connect. However all options are not available this way. For more options go to 'Start -> All Programs -> Accessories -> Remote Desktop Connection' or simply type 'Remote' in the search box in the Start menu.

Click 'Show Options' to view the options tabs. There are options as to save the connection settings, select the quality of the connection, set the local resources options and set more advanced options.

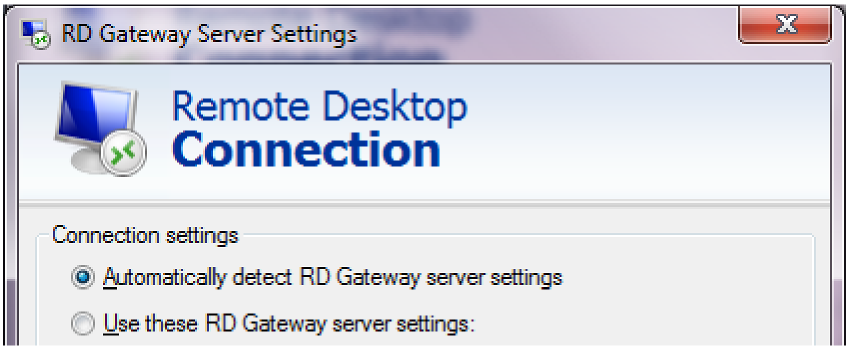


In the ‘Local Resources’ tab the user can choose how the key combinations behave such as the 'Alt+Ctrl+Delete' function. If the 'More' button is pressed the user can select to share a drive while connected, which come in handy when transferring data.



In the ‘Experience’ tab the user can select the performance depending on the connection's speed.

NOTE: If there is a connection problems check at the advanced tab the settings for the ‘Connect from Anywhere’ option. When using a local network select the 'Automatically Detect RD Gateway server Settings'. In some cases this might change on its own and cause a connection problem.



7. LIDAR DATA PROCESSING

For data preview analysis, processing and asci conversion two free software program are provided.

These programs are Lidar_Analysis.exe and Advanced_Viewer.exe (for scanning measurements. They do not need any special installation.

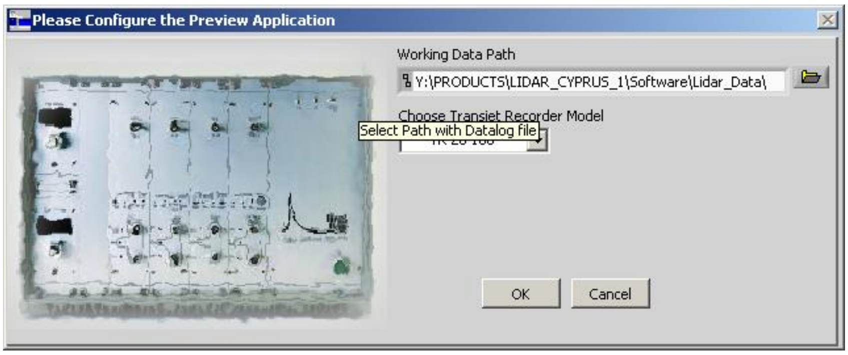
However, before you can use the software you need…

a) to install (if not already) the Labview Runtime engine (you can download this free from the internet or you can use the exe file that comes with the software – LVRunTimeEng.exe)
b) to have some data

2) After installing the runtime engine, copy Lidar_Analysis.ini, Lidar_Analysis.exe and data folder to any place at your PC (any location).

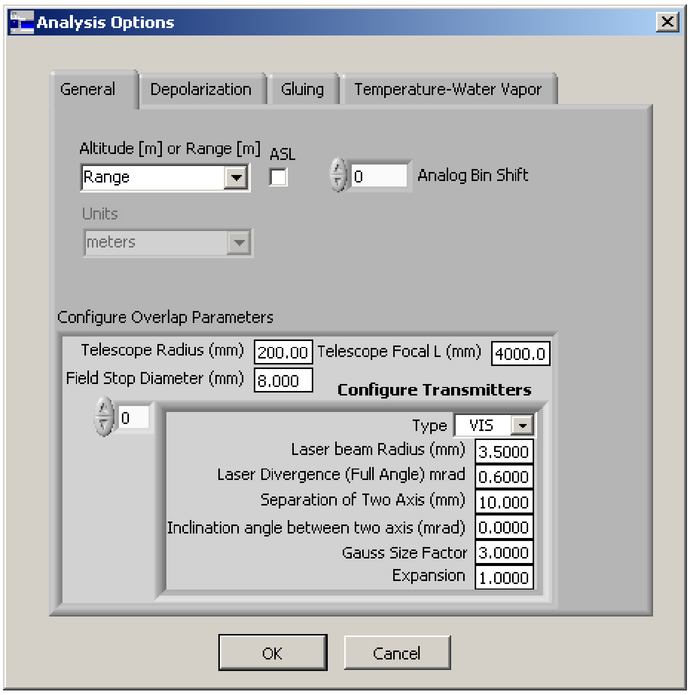
3) Open the Raymetrics folder on your PC and run the Lidar_analysis.exe program.
If you are running the software for the first time then you will be asked to configure the system. Click ok on the message “Please configure the system” and then do the following:

a) Select a working path (where your data is located - click the “Select Current Location” button when you have navigated to the correct folder)
b) Select the correct model of the transient recorder (for example TR20-160)



c) Go to the File Menu and select Tools -> Preferences.

d) When the Analysis Options box appears, click the ok button. This adds a registry entry for the default preferences.



Now software is ready to be used.

Data processing can be fairly complicated. The following information explains:

- The form of the data
- A guide on how to work and edit the database
- A guide on how to perform a basic analysis using the *'Data Preview and Analysis'* program

Performing a really precise Lidar analysis lies on the verge of art since the user has to select through many parameters that eventually alter the final result. Experience in combination with the capabilities of the analysis software, can create exceptional Lidar results provided the raw data is of good quality.

The first section below refers to the data file format which is useful if the Lidar analyst wants to use another program for the analysis. The data is saved in binary form to reduce space. Even though the format is given there is also an extra tool embedded in the *'Data Preview and Analysis'* program which converts the binary files to ASCII.

However you decide to work make sure that the database is not affected and always keep a back up of Lidar data. Remember that raw data is irreplaceable.

7.1 DATA FILE HANDLING

The data files are saved in the folder set by the user. Apart from the data files a datalog file is also saved which contains the main information of each data file. This is automatically updated whenever a new profile is acquired and a new data file is created.

The name of the data files is given by the acquisition software automatically using the date and time of the measurement. The general format is RMyyMddhh.mms and is explained below.

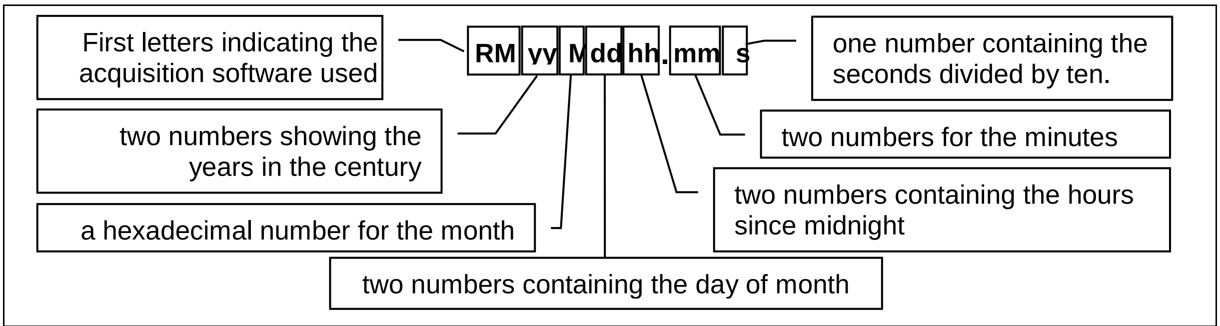


Fig. 7.1: Data File Name Explanation

For example the file RM12C2815.572 is created by Raymetrics software (RM), in year 2012 (12), month December (C), day 28th (28) at 15:57 (15.57) past 20 seconds (2).

The file format is a mixed ASCII-binary format where the first lines describe the measurement situation; below follows the dataset description and then the raw data itself as 32-bit integer values.

```
RM12C2815.572
ATHENS 28/12/2012 15:57:02 28/12/2012 15:57:22 0180 0029.0 0032.0 -90 00 20.0 1013.0
0000200 0010 0000200 0010 08
1 0 1 16380 1 0850 7.50 00355.p 0 0 00 000 12 000200 0.500 BT0
1 1 1 16380 1 0850 7.50 00355.p 0 0 00 000 00 000200 4.3651 BC0
1 0 1 16380 1 0850 7.50 00355.s 0 0 00 000 12 000200 0.500 BT1
1 1 1 16380 1 0850 7.50 00355.s 0 0 00 000 00 000200 4.3651 BC1
1 0 2 16380 1 0850 7.50 00387.o 0 0 00 000 12 000200 0.500 BT2
1 1 2 16380 1 0850 7.50 00387.o 0 0 00 000 00 000200 4.3651 BC2
1 0 2 16380 1 0850 7.50 00408.o 0 0 00 000 12 000200 0.500 BT3
1 1 2 16380 1 0850 7.50 00408.o 0 0 00 000 00 000200 4.3651 BC3
```

Fig. 7.2: Sample file header

The first line contains the measurement's name which is exactly the same as the file name, as explained above.

The second line contains more information about the location, start and stop time and the external conditions.

- Location String with 8 Letters
- Start Time dd/mm/yyyy hh:mm:ss
- Stop Time dd/mm/yyyy hh:mm:ss
- Height asl. four digits (meter)
- Longitude four digits (including - sign). One digit for decimal grades.
- Latitude four digits (including - sign). One digit for decimal grades.
- Zenith angle two digits in degrees
- Azimuth angle two digits in degrees
- Ground Temperature (Celsius)
- Ground Pressure (hPa)

The third line contains information about the laser.

- Laser 1 Number of shots integer 7 digits (how many laser shots were averaged in one profile)
- Pulse repetition frequency for Laser 1 integer 4 digits (Usually 10 or 20)*
- Laser 2 Number of shots integer 7 digits
- Pulse repetition frequency for Laser 2 integer 4 digits
- number of datasets in the file integer 2 digits

The next lines that are in ASCII format are the dataset description. The parameters are divided by a space.

- 1 digit integer: 1 if dataset is present, 0 otherwise
- 1 digit integer: 0 for Analogue / Photon counting, 1 for Photon counting
- 1 digit integer: 1 for Laser source 1, 2 for Laser source 2.
- 5 digits integer: Number of bins (example 16,380 x 7.5m each bin = 122,850m)
- 1 digit integer: N/A
- 4 digits integer: PMT High Voltage in volts
- 2 digit real with 2 decimal: Bin width in metres
- String with 5 digits: Laser wavelength in nm
- dot and letter: Polarization, o _ no polarization, s _ perpendicular, p _ parallel

- 0 0 00 000 backward compatibility
- 2 digits integer: number of ADC bits in case of an analogue dataset, otherwise 0
- 6 digits integer: number of shots
- 1 digit real with 3 decimal: input range in mVolt in case of analogue dataset, discriminator level in case of photon counting.
- String with 2 letters: Dataset descriptor BT=analogue dataset, BC=photon counting
- And one hexadecimal number: the Transient Recorder number.

The dataset description is followed by an extra CRLF. The datasets are 32bit integer values. Datasets are separated by CRLF. The last dataset is followed by a CRLF. These CRLF are used as markers and can be used as check points for file integrity.

Using the analysis software presented below the user can translate all binary files to ASCII so that external software can be used for the data analysis.

7.2. DATA PREVIEW

Once the *'Data Preview and Analysis'* program is open the user can see the main interface. The window consists of a menu bar and a toolbar

Click 'Preview DB' to open the main DB interface.

With Preview DB' the user can have a quick look at the database whereas through the 'DB interface' the database can be edited. Furthermore under 'Tools' in the main menu the user can convert automatically database files to an ASCII format to use them with other programs.

7.2.1 Database Interface

The Database Interface is consisted of:

- the measurements table on top which shows all measurements in the database,
- a list on the right with the data files that were written during this measurement,
- an information field below the measurements table, which contains the global information of the measurement,
- another table with the recovered channels (right above the measurement table),
- two dropdown lists and a text box on the right of the window, which are used as filters,

- below this the edit database, the play and the close buttons
- and at the bottom a graph to preview the raw data of each selected channel

In the measurement table, every record represents a set of measurements. Each record has the following fields:

- User Name: The username that is entered when someone calls up the data acquisition interface.
- Location: The location which is entered during global information configuration procedure.
- Start and Stop Time and Date

Whenever a measurement is finished, a new record is added to the main table with the start date and time from the first filename of the measurement's set, and the stop date and time fields from the last saved file.

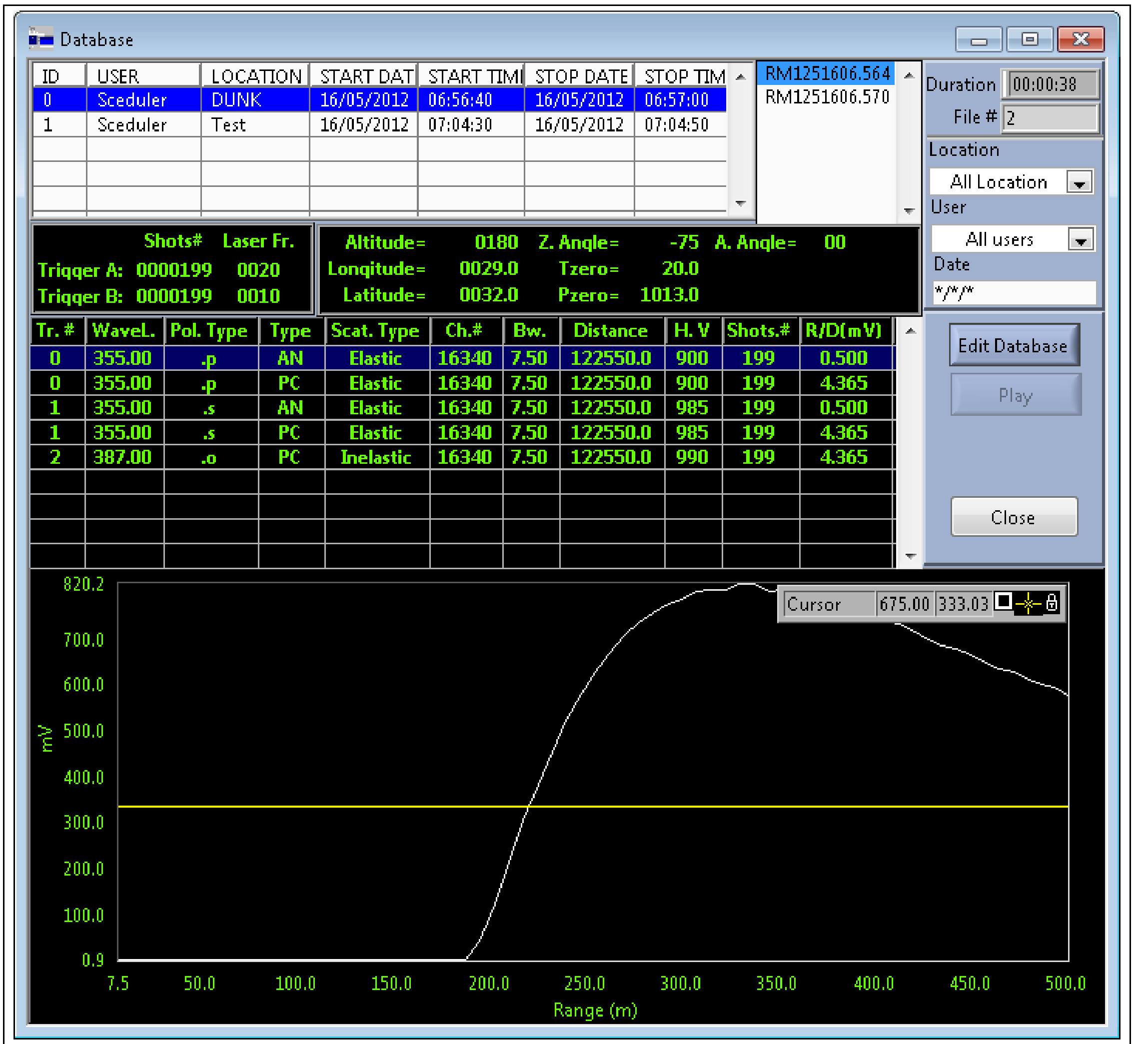


Fig. 7.3: Database Interface

Choose the file on the right to be previewed and below in the table you will find the dataset description of the selected file, or in other words which channels were recorded during each measurement. Select a row to view a corresponding plot. Every row consists of eleven shells that are:

- Tr.: Transient Recorder device
- Wave L.: Detected wavelength
- Polarization Type: p-parallel, s – cross, o – no polarization
- Type: AN-analogue, PC – photon counting
- Scat. Type: scattering type, elastic (emitted wavelength equal to detected wavelength) inelastic (emitted wavelength not equal to detected wavelength)
- Ch#: Number of channels recorded
- Bw.: Bin width = 2 ^ (reduction number) * resolution (in metres)
- Distance: maximum distance in metres
- H. V: PMT High Voltage (V)
- Shots#: Number of shots
- R/D: For analog: input range (mV), for photon counting discriminator level.

In the next sections there are step by step tutorials on how to edit the database.

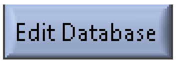
- How to copy raw data files to create a new datalog file.
- How to work with a different database
- How To manually create a new record in the datalog.dat
- Exporting and converting data from a database

For context help just click <Control>+H

For getting help for the active window click <Control>+<Shift>+H

7.2.2 How to copy raw data files to create a new datalog file

Open the 'Preview DB' window and click on the 'Edit Database' Button on the right.



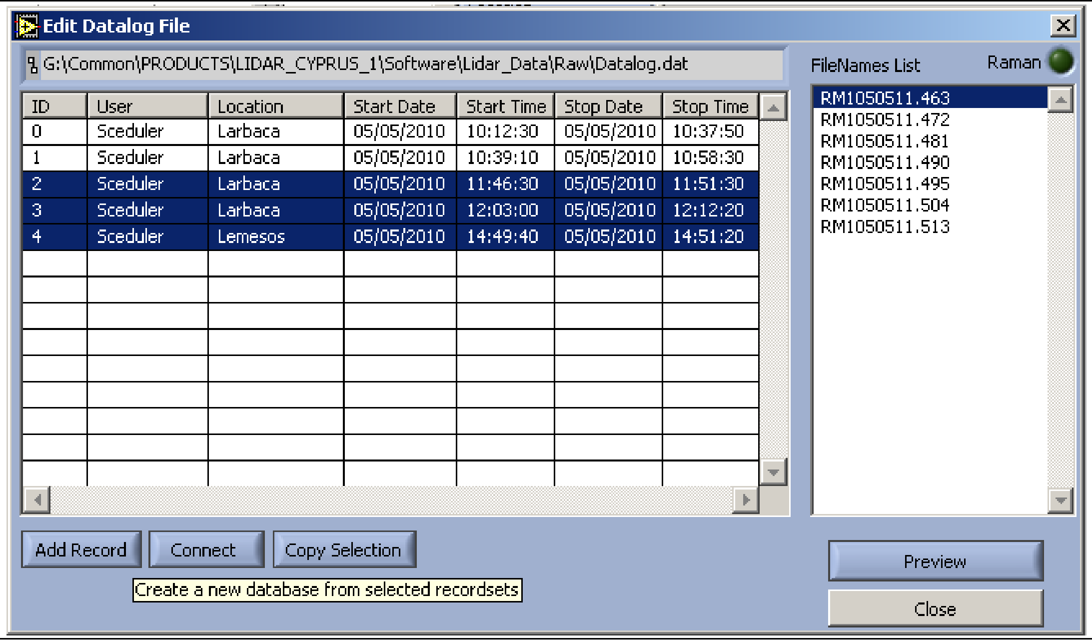


Fig. 7.4: Edit Datalog File Interface

In order to create a new datalog file with part of your database (for example to distribute it to your partners) you have to first select one or more records (by holding down the 'left Shift' button on your keyboard), followed by pressing the 'Copy Selection' button in the 'Edit Datalog File' interface. A 'Save As' common explorer interface appears. Choose an empty directory (or create a new one).

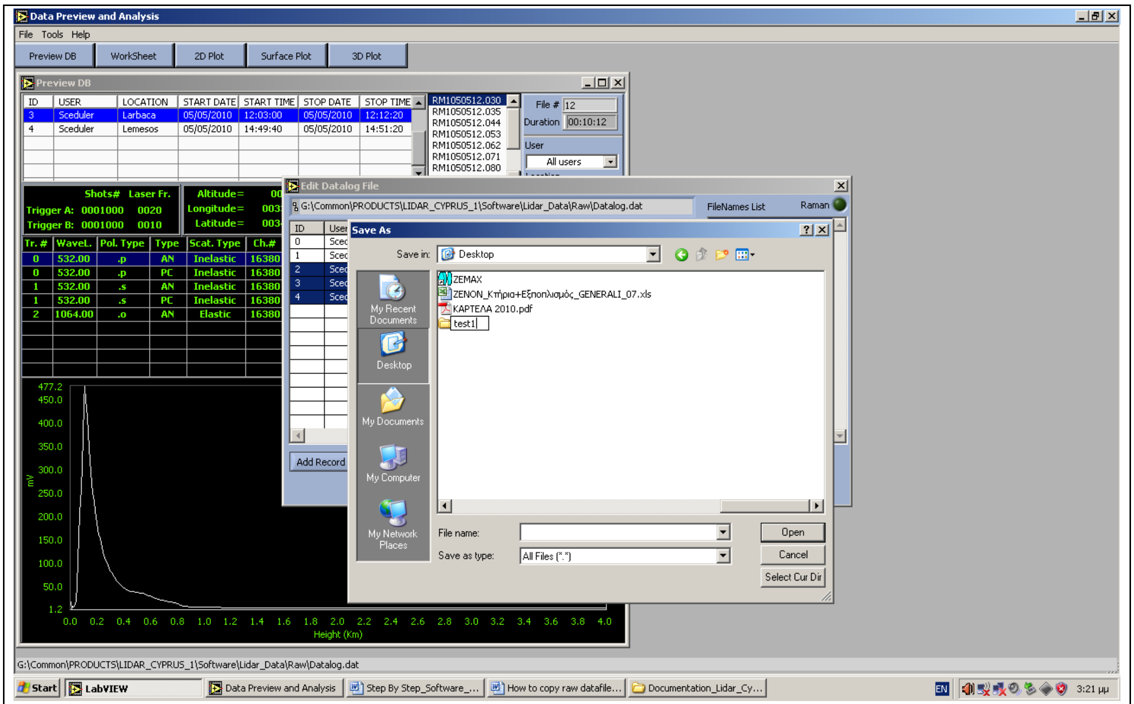


Fig. 7.5: Select Directory For the New Database

Double-click on the icon for this directory (in order to get into it) and then click the 'Select Cur Dir' button.

A new datalog.dat file will be created with only the previously selected records. All of the associated raw datafiles will be copied inside this newly created folder (directory).

7.2.3 How to manually create a new record in datalog.dat

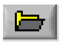
Sometimes users may forget to click on 'Stop' button before they exit the acquisition program (and the same problem occurs during a power failure). In that case, although all the acquired raw data files have been saved to the default location, the software fails to add a new record to the datalog.dat file describing the last measurement.

In this case, the user has to manually add this new record by following the procedure below.

NOTE: It is suggested to make a backup of your datalog.dat file before you proceed.

Open ‘Preview DB’ window and click on the ‘Edit Database’ button as in section *7.2.2 How to copy raw data files to create a new datalog file*.

Click the 'Add Record' button as you see in Fig. 7.4 

Click the folder icon  to open a Windows selection dialog.

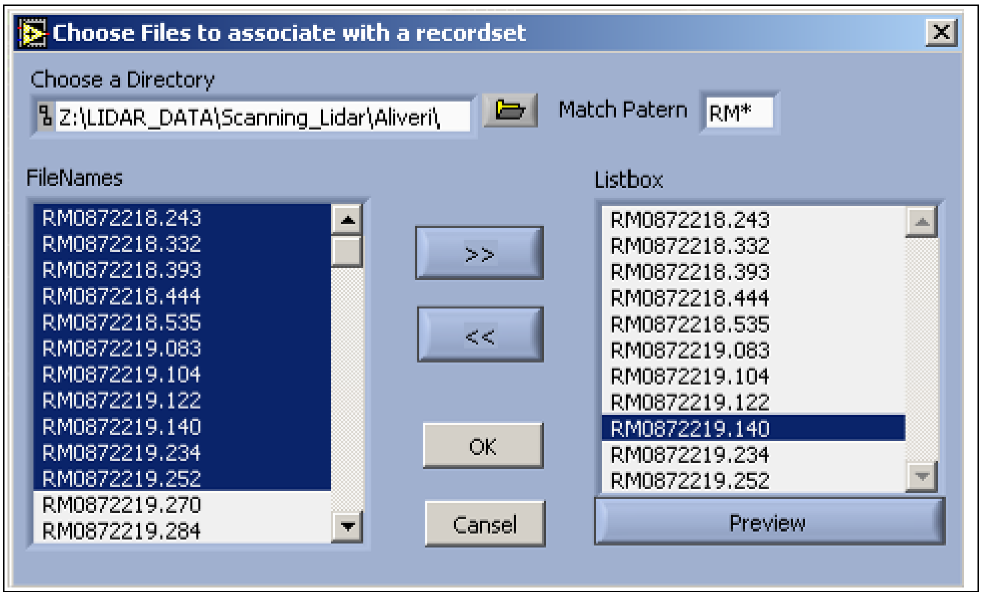


Fig. 7.6: Add Data Files to Recordset

Choose the directory where the raw data files are located (For example C:\lidar_data\Raw\), navigate into it and click on the 'Select Cur Dir' button.

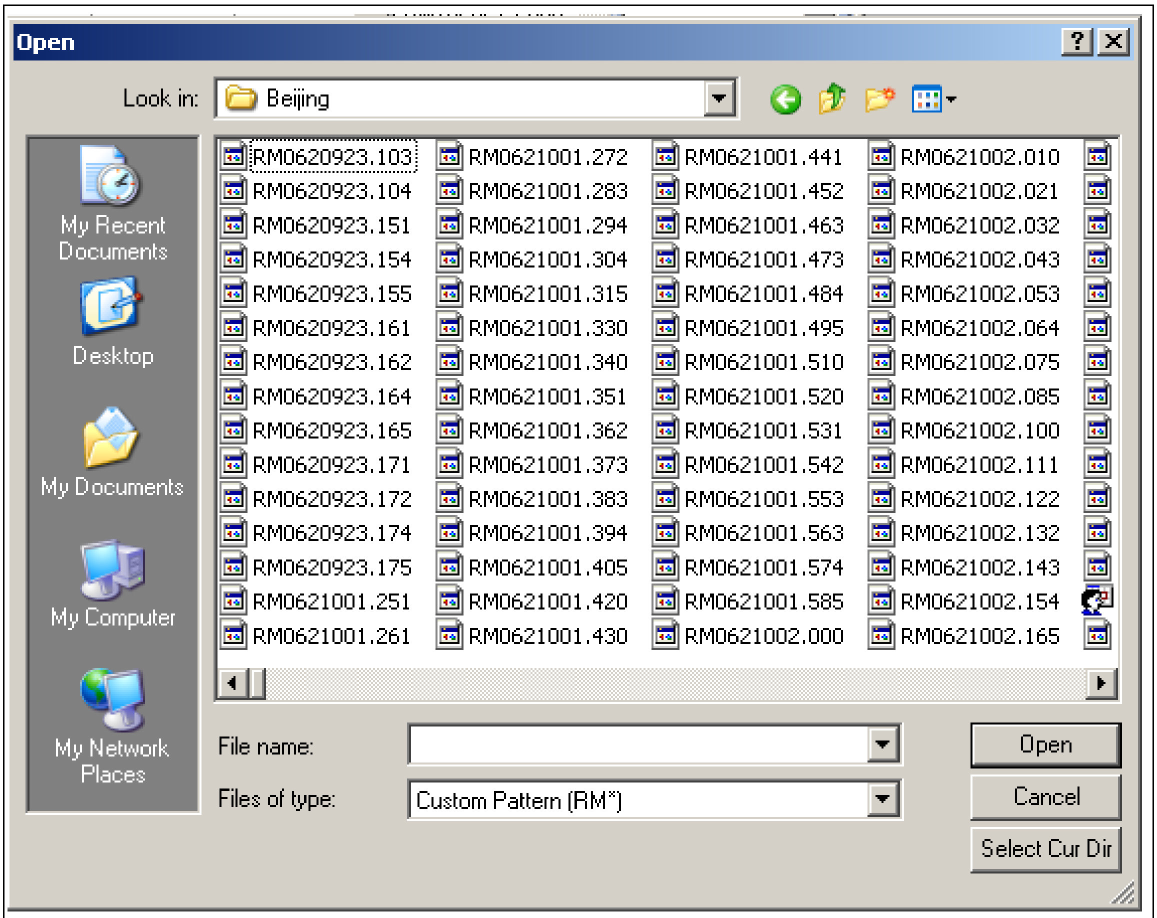


Fig. 7.7: Directory of Measurements Selection Dialog

All the RM files will be displayed in the list box on the left.

Select all the files you want (be sure that they are sequential and belong to the same measurement)

Click the >> button to transfer them to the list on the right and click ‘Ok’

Then software then prompts the user to enter a User and a Location. Anything can be entered but it must be less than 10 characters without spaces. Click ‘Ok’.

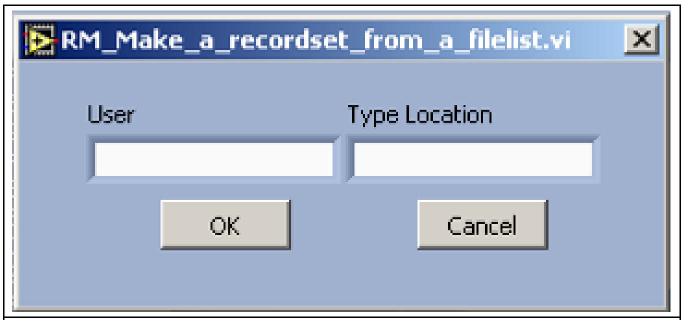


Fig. 7.8: Add Data Files to Recordset

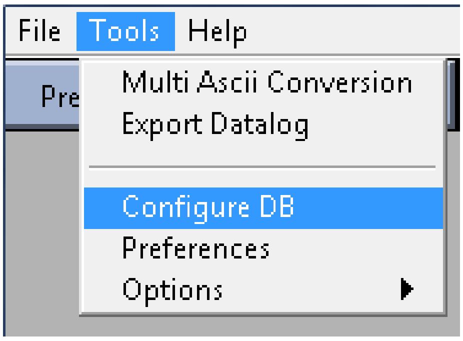
Click once more the 'Ok' button in the 'Edit Datalog File' interface (Fig. 7.4)

If you now reopen the 'Preview DB' window the new record will also appear.

7.2.4 How to select a different database

When you have multiple databases saved in different folders you can work with any number at any one time. Go through these steps to select another database to work with.

Close the 'Preview DB' window if it is open and go to Menu Bar and click 'Tools->Configure DB'



A dialog opens that prompts you to configure the 'Preview Application'.

Click the Folder Icon (top right corner) of the 'Working Data Path' text box.  A normal Windows selection dialog opens and prompts the user to select the directory.

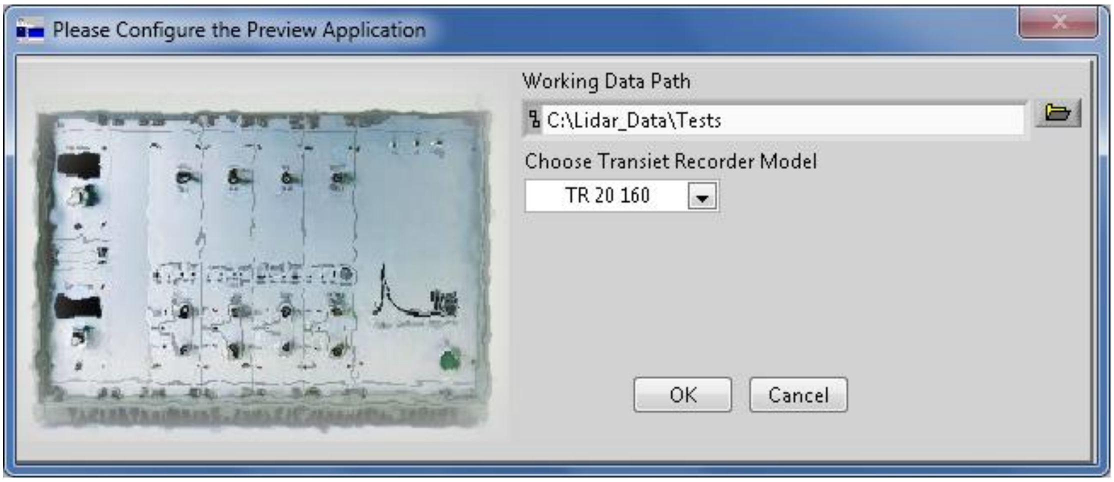


Fig. 7.9: Configure Preview Application Interface

Locate the directory where another datalog.dat file (with all the raw data files) exists. Note that by default there is a filter and you can only see the .dat files.

Fig. 7.10: Database Directory Selection

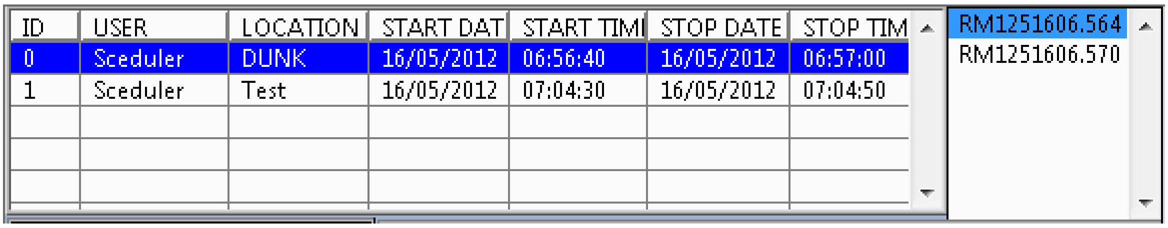
Double-click the icon of that folder in order to get into it and click the 'Select Cur Dir' button.

NOTE: Do not forget to choose the correct Transient Recorder type.

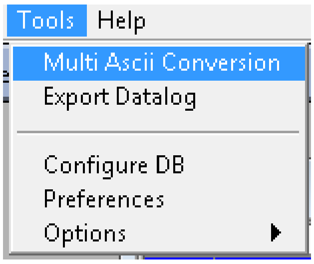
7.2.5 Converting binary files to ASCII

The software provides a function to convert all files of a record (measurement) from binary to ASCII format. This is useful when you want to read the files with external software.

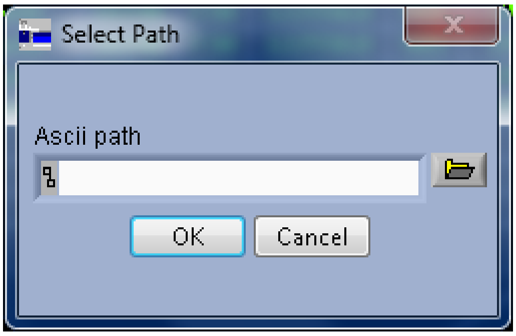
Click first the ‘Preview DB’ button to open the database. At the top of the window select in the measurement table which record to convert.



Next go to 'Menu' -> 'Tools' -> 'Multi ASCII Conversion'.



A window opens that prompts the user to select the folder where the converted data will be stored. Select a folder and click 'Select Current Dir.'



Wait until the status bar reaches the end. The data is now saved in an ASCII format. Verify if the data has been written correctly by opening one file with notepad. Note that these files have no extension so they do not belong to any program. Because there is a dot before the last three digits on the filename Windows recognizes the last three digits as the type of the file.

You may also save the datalog file as a text file to use it with the converted files by going to 'Menu' -> 'Tools' -> 'Export Datalog'

7.3. DATA ANALYSIS

As already explained the analysis software is what analysts use to extract all the useful information from their Lidar data. Even though it provides a lot of information and functions the user has to first understand the theory that lies beneath the software in order to understand the way things are calculated.

With the series of buttons shown above the user can:

- Use the 'Worksheet' interface to insert data from external files or an external database into a worksheet.
- Plot directly database data (or plot from external files) using the '2D Plot' interface.
- Create surface graphs from acquired data using 'Surface Graph' Interface
- Plot temporal data in a 3D graph using the '3D Plot' interface.

The following section contains a series of tutorials on:

- How to plot data
- How to calculate backscatter coefficient
- How to calculate aerosol extinction coefficient
- How to check lidar alignment
- How to calculate water Vapour profiles
- How to subtract the background
- How to glue analogue and photon counting signals
- How to make a 3D graph
- How to use soundings from global model data

With these 9 tutorial lessons the user will understand fully how to use the program. As the analyst goes deeper into the software's capabilities more background theory is required. In some lessons the basic theory required is given as introduction, but the analyst should look into the references in order to build a stronger Lidar knowledge.

7.3.1 How to Plot Data

Here is shown the way to plot your data. There are three ways to represent the data. One is a single 2D graph which can be data from a single file or a summation of multiple files. Another way is to plot the data on a surface that shows multiple files one next to the other as they evolve through time. The last is a 3D plot which also shows multiple files but in a 3D graph.

In this section you will learn how to make a surface plot. Once you understand this you can easily also plot a 2D graph.

1. Click 'Surface Plot'.

2. Click 'Import Data'.

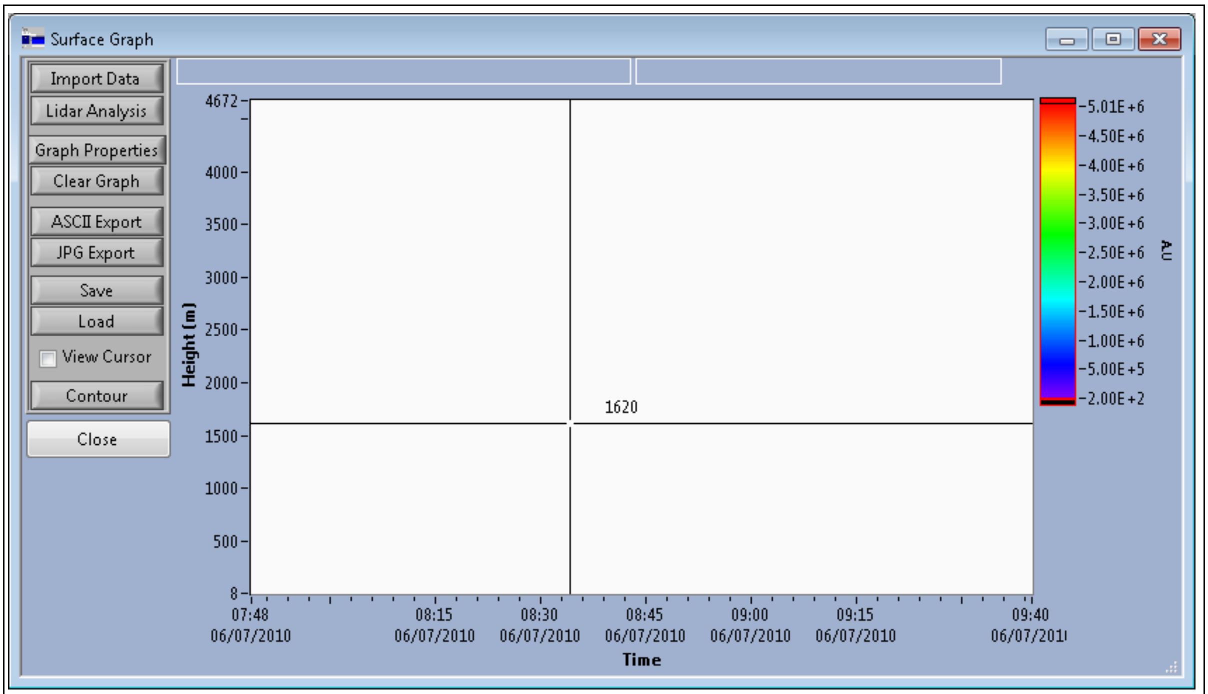


Fig. 7.11: Surface Graph Interface

3. Scroll up in the table if you do not see your data. Select the data in the table you wish to plot. In the right-hand column, hold the shift key to select the measurements you wish to plot. Click 'Next'.

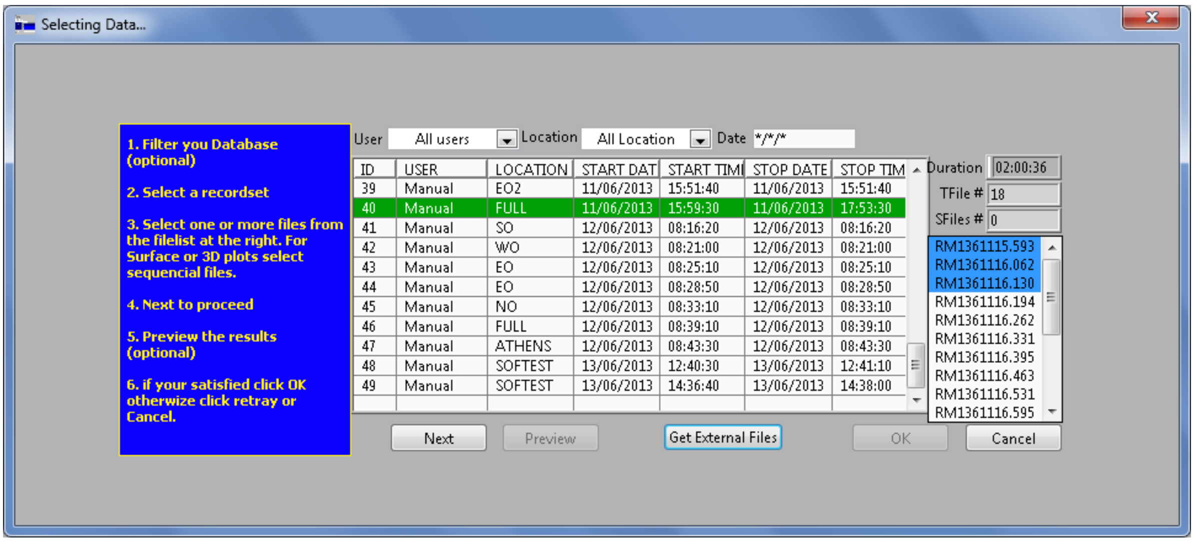


Fig. 7.12: Select Data Interface

4. Click 'Basic Analysis' option.

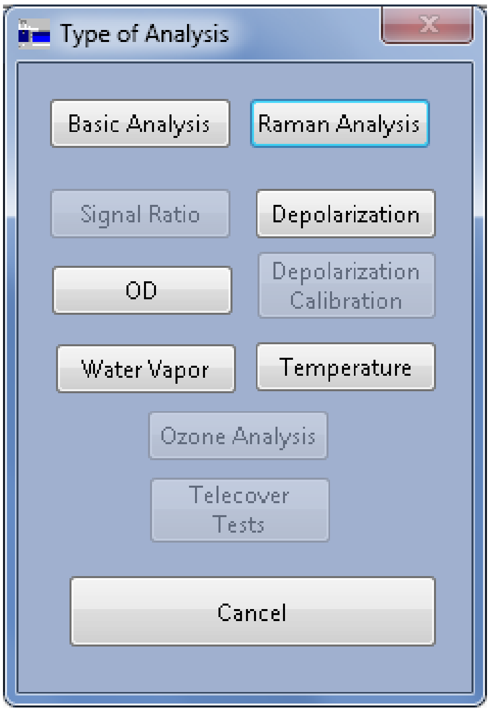


Fig. 7.13: Analysis Type Selection

5. Select the data type you wish to plot. For example '355.00.p.AN' from the list on the left. From the list on the right, select 'RCS'.

NOTE: '532.00.p.AN' – 532.00 = wavelength in nm, p = primary (as opposed to secondary - depolarization), AN = analogue (as opposed to Photon Counting or Glued – PC and GL). Other options include calibrated signal for depolarization (b). RCS = Range Corrected Signal.

NOTE: Hold down the 'Ctrl' key and press 'h' for help.

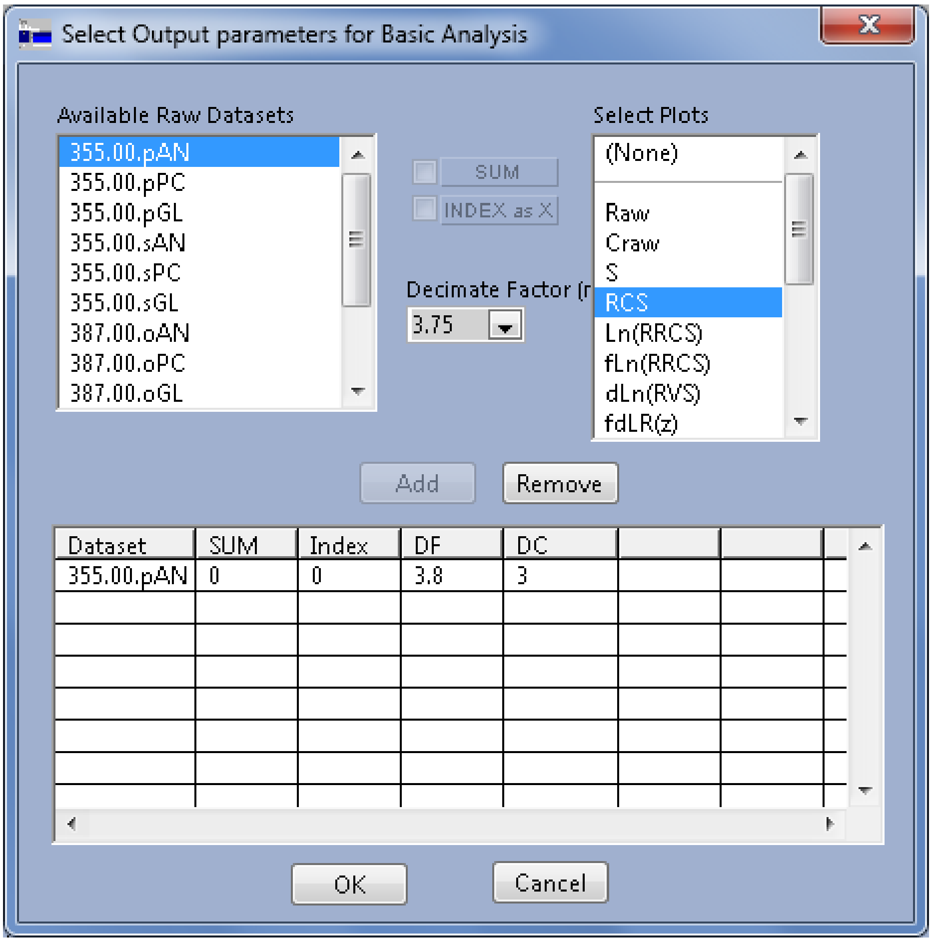


Fig. 7.14: Output Selection Interface

6. Click the 'Add' button. Your selection will now appear in the small data table.

7. Click 'OK' button. The software will now load your requested data.

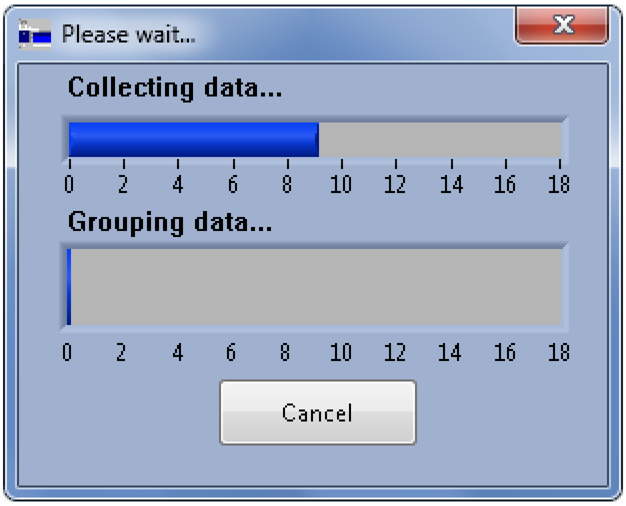


Fig. 7.15: Data Collection

8. After a few seconds, you will see the following blank graph.

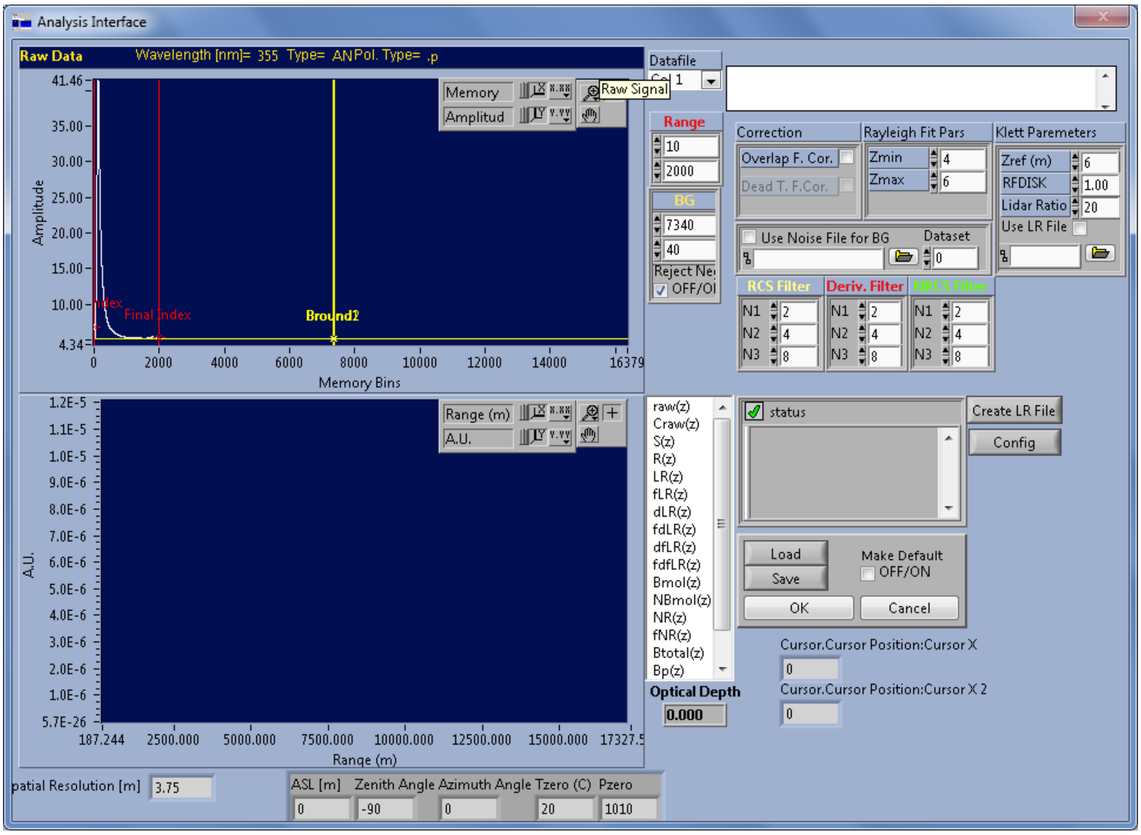


Fig. 7.16: Analysis Interface

9. In order to see the results, select a parameter from the parameter list to the right of the bottom graph (e.g. R(z) – Range Corrected Signal).

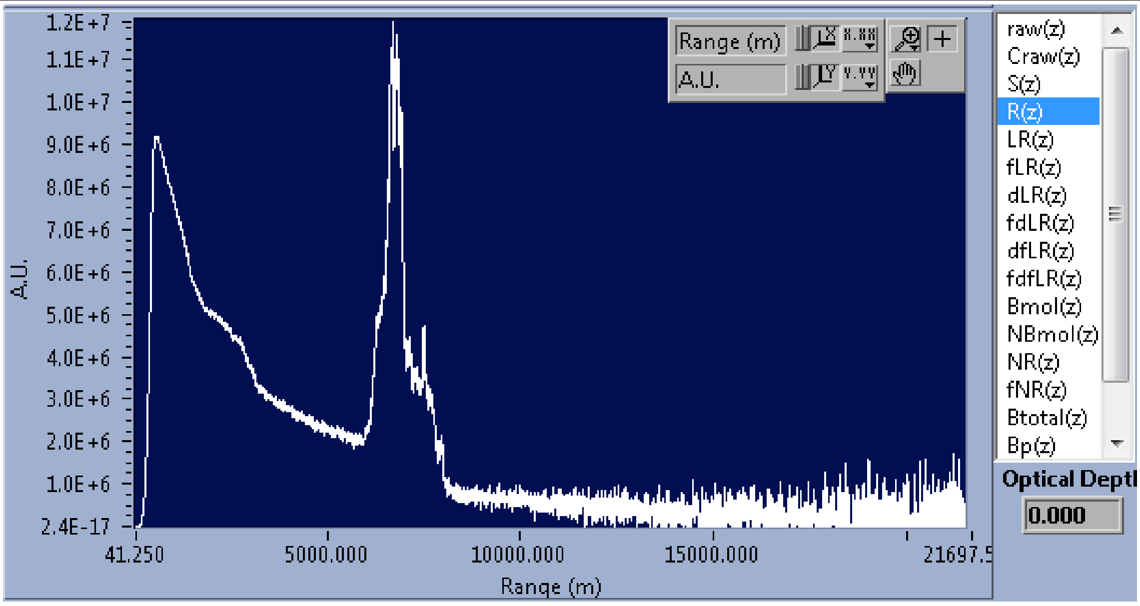


Fig. 7.17: Output Preview Graph

10. Click on the two red bars on the top graph and drag them to define the range (height) of interest. As you drag the bars, you will see the data change on the bottom graph.

You can also change the scales of the graph by simply clicking on any value on the x or y axis and typing a new value. The graph will then automatically rescale.

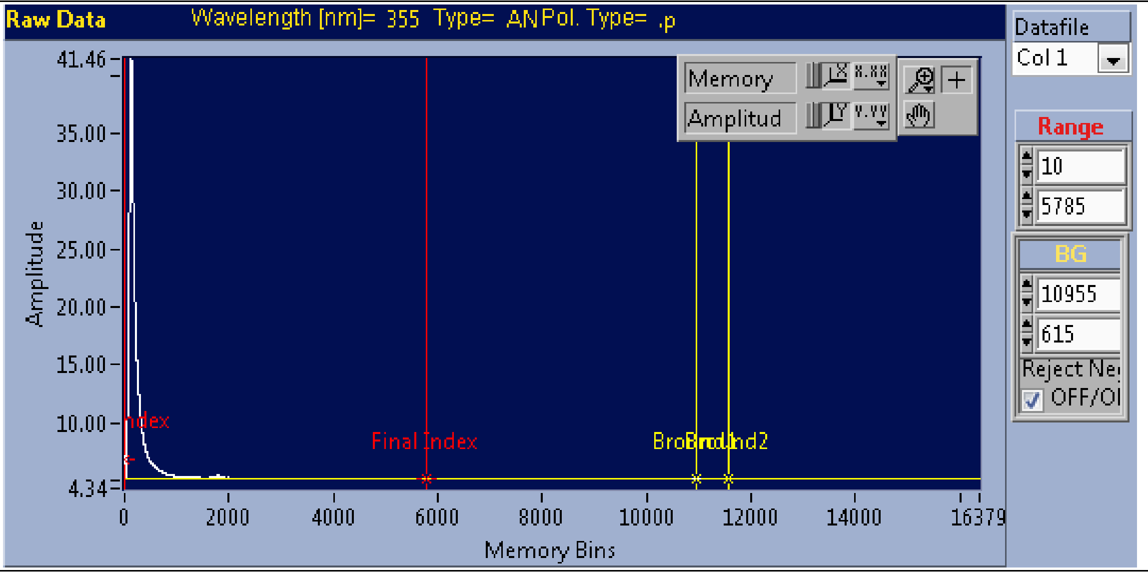


Fig. 7.18: Raw Data Graph – Limits and Background Selection

11. When you have the range desired, click the 'OK' button. The previous window 'Selecting Data…' (See Fig. 7.12) will appear back. Click the 'OK' button again.

12. The selected data and parameters will now be displayed on a graph. Time is on the x axis, range on the y axis, with colour values showing the intensity of the signal.

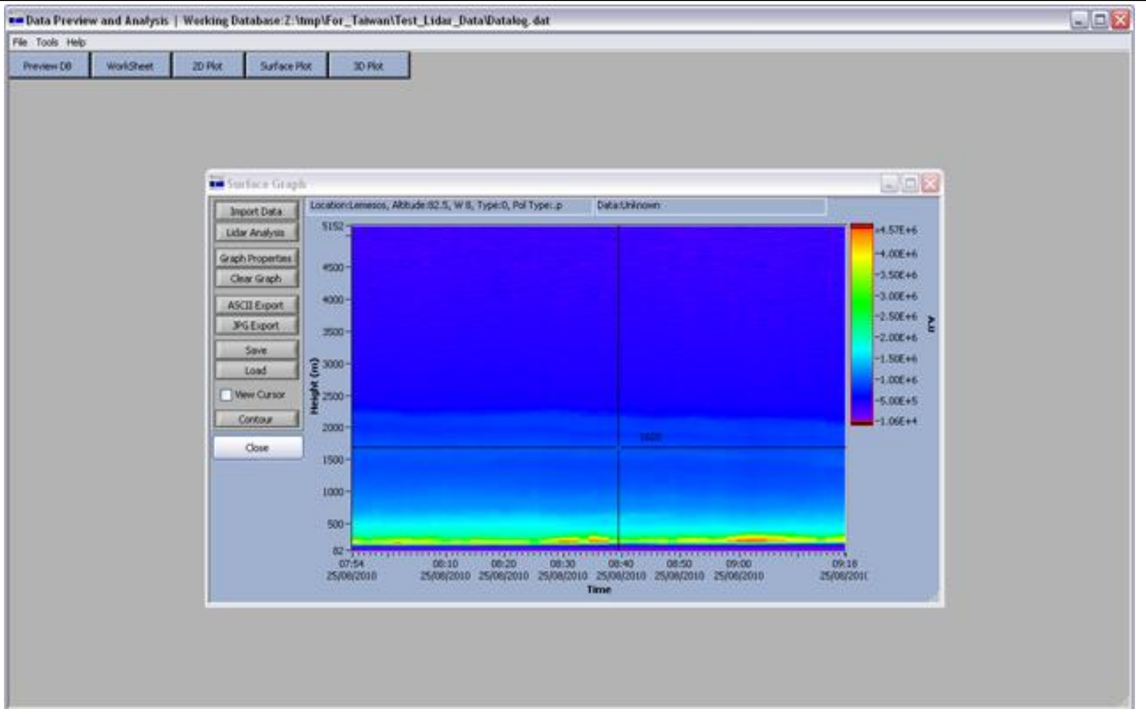


Fig. 7.19: Output Surface Graph

13. The image on the screen can be re-scaled by dragging on the bottom right corner of the window.

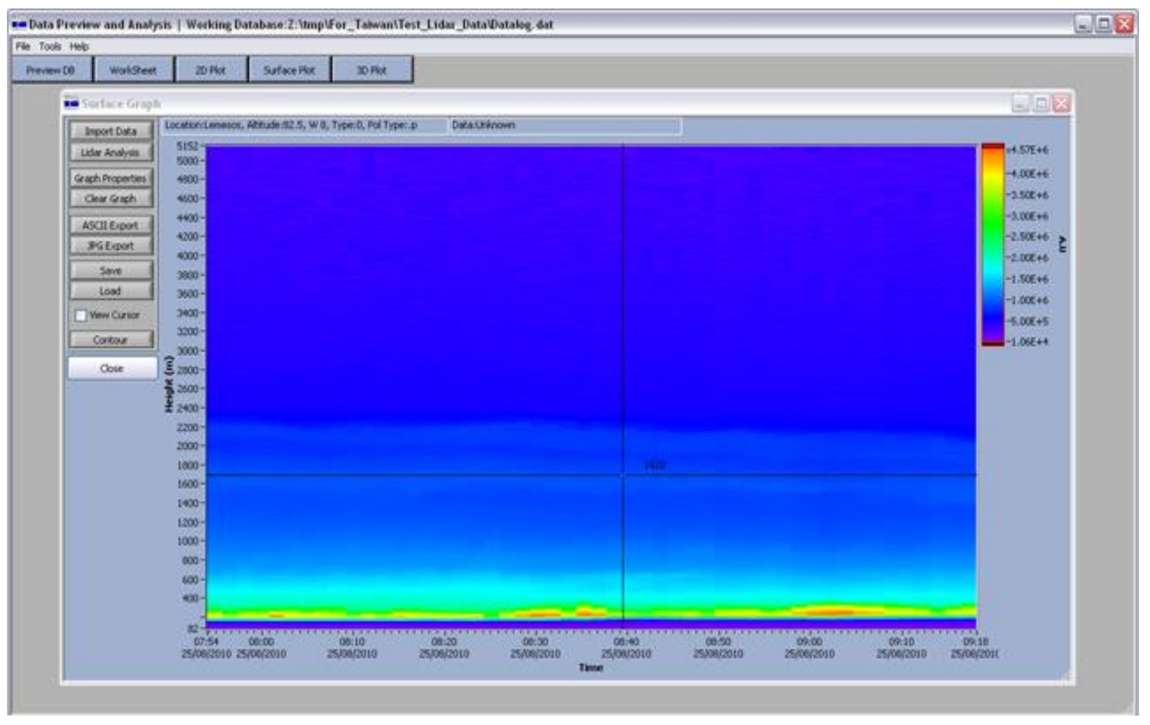


Fig. 7.20: Window Resize

14. Adjust the colour scale of the graph by clicking on 'Graph Properties' on the left and selecting the tab 'Z-sc' (z scale).

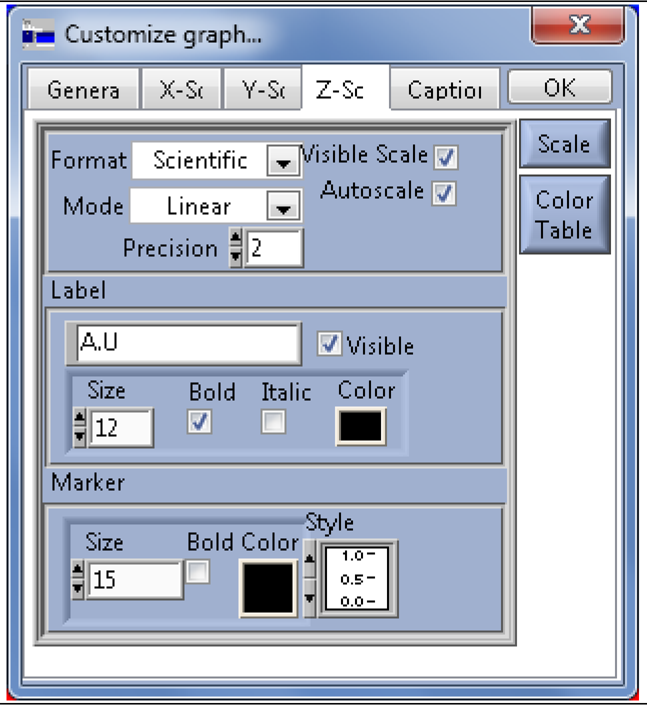


Fig. 7.21: Customize Graph

15. Click on the 'Colour Table' button on the right. At the top of the window, click 'Choose C. Table'. Select a new colour scheme (if desired) from the options (e.g. 'fire' or 'rainbow'). Click 'OK' and 'OK' again.

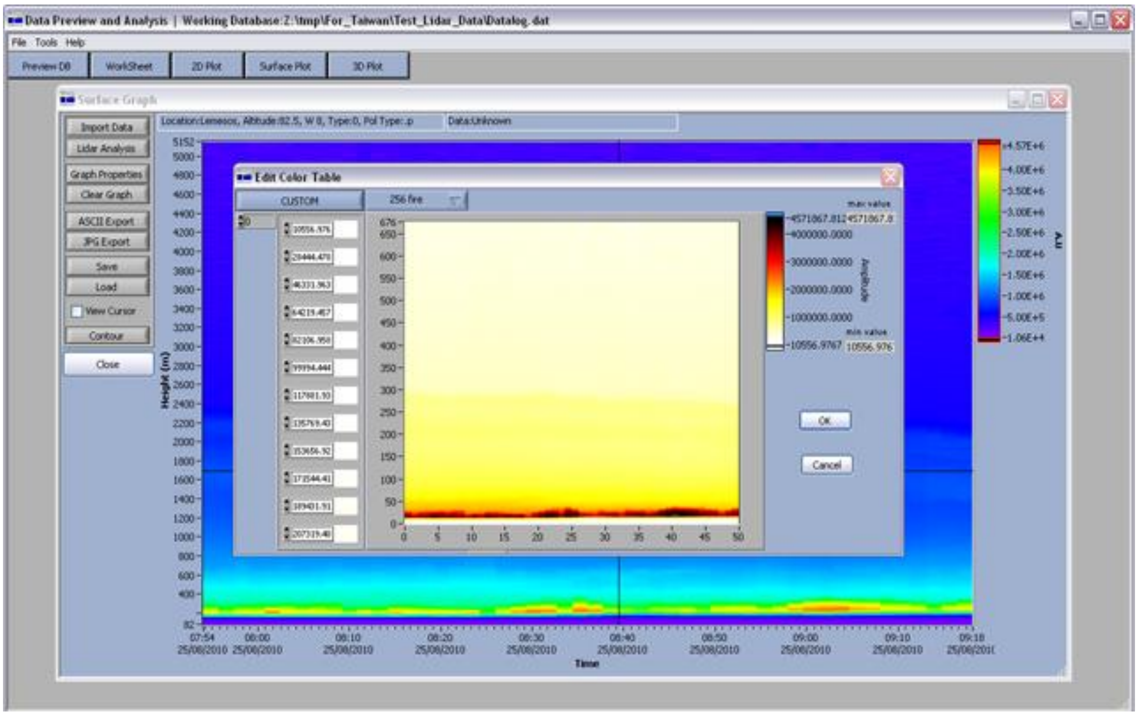


Fig. 7.22: Edit Colour Table

16. If required, manually change values of range and signal intensity by clicking on the values on the graph axes and/or on the z scale to the right of the graph.

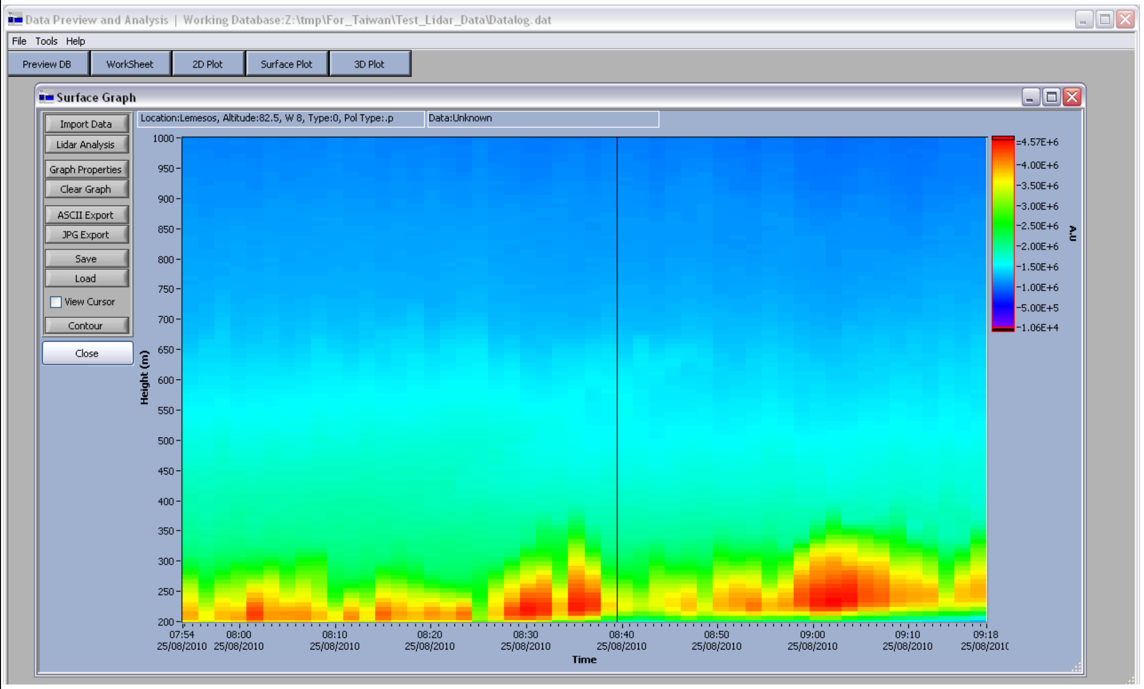


Fig. 7.23: Range Rescale

7.3.2 How to Calculate Backscatter Coefficient

1. Click '2D Plot'. 

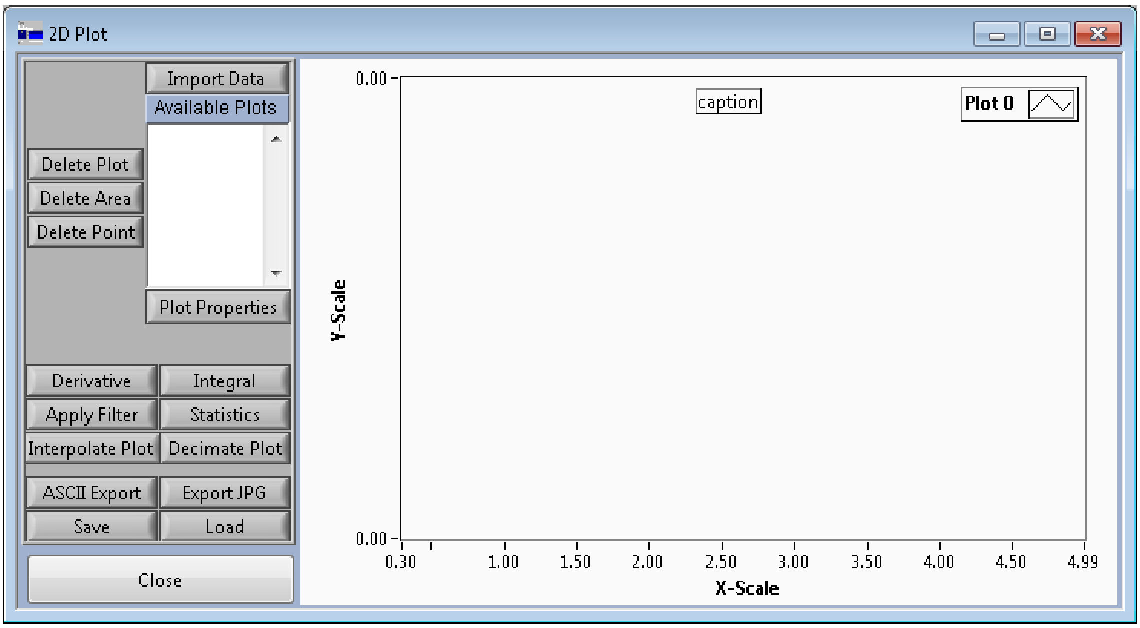


Fig. 7.24: 2D Plot Interface

2. Click 'Import Data' and ensure Data Source is set to 'From DB' in the drop-down list. Click 'OK'.

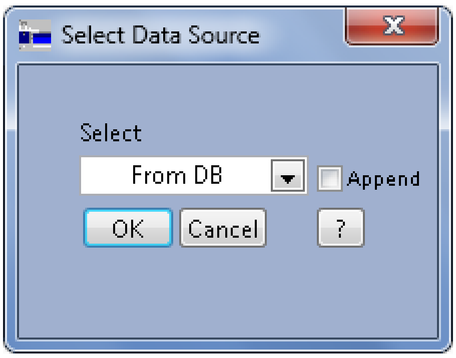


Fig. 7.25: Data Source

3. Select the record and the data you want to calculate aerosol backscatter coefficient for (as in previous tutorial Fig. 7.12). Make sure that the data files that you select are free of clouds. By holding the shift key you can select multiple files which are going to be averaged (if you choose this option in the next step). Click 'Next' and select 'Basic Analysis' option (as in previous tutorial Fig. 7.13).

4. Select '355.00.p.AN' dataset. Click 'Sum' check box (if you need the average over time). Select 'Baer>0' (backscatter aerosols – positive values only) from the list on the right. Click 'Add' button and then 'OK' button.

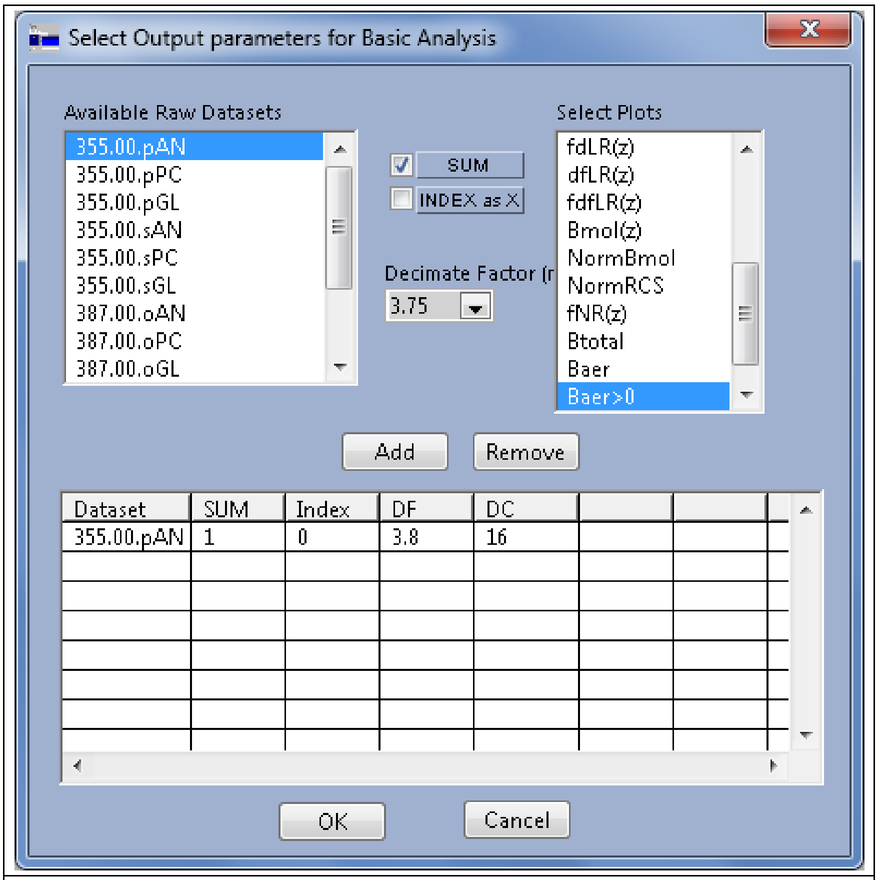
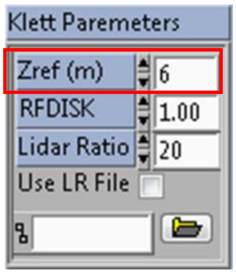


Fig. 7.26: Data Source

5. Define the range of interest with the two red cursors from the top graph (as in previous tutorial Fig. 7.18).

6. Insert the maximum range (altitude in kilometers) for calculating Aerosol Backscatter coefficient in the Zref (km) box in the top right corner of the window.



7. Select Bp(z) from the list in order to preview the Backscatter coefficient on the bottom graph. (Re-scale the graph if required by clicking on any value and typing a new value.)

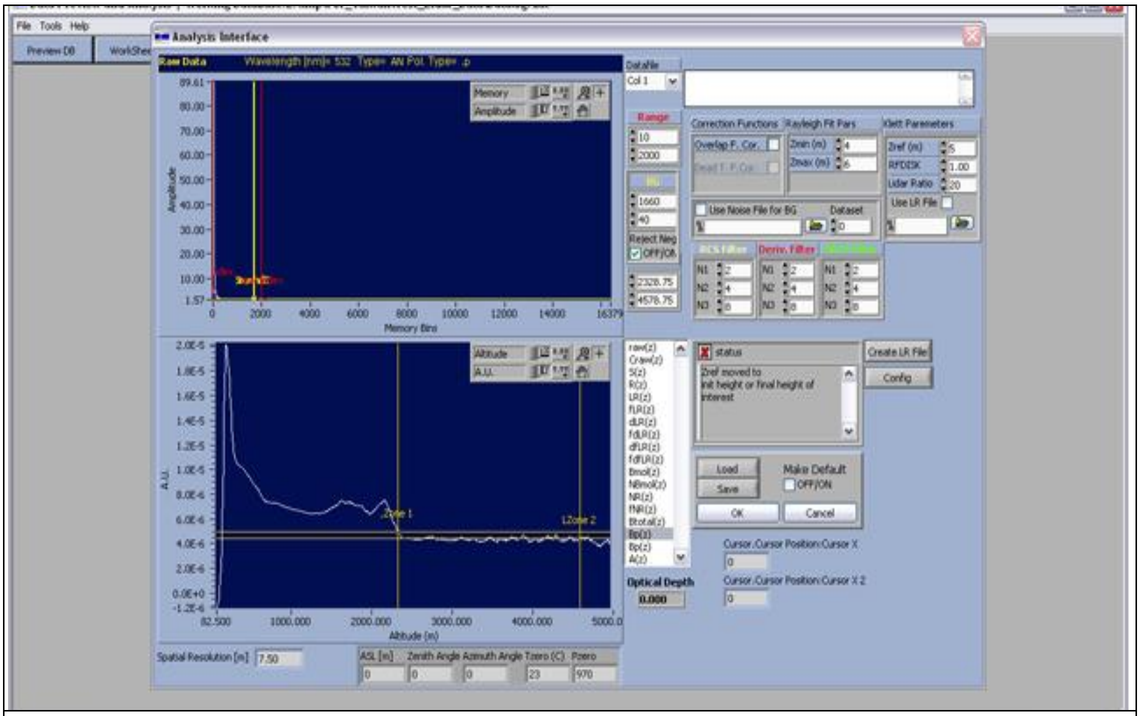


Fig. 7.27: Back Scatter Coefficient Preview

8. In order to check the maximum altitude to which Backscatter coefficient can be calculated without errors, select LR(z) from the list.

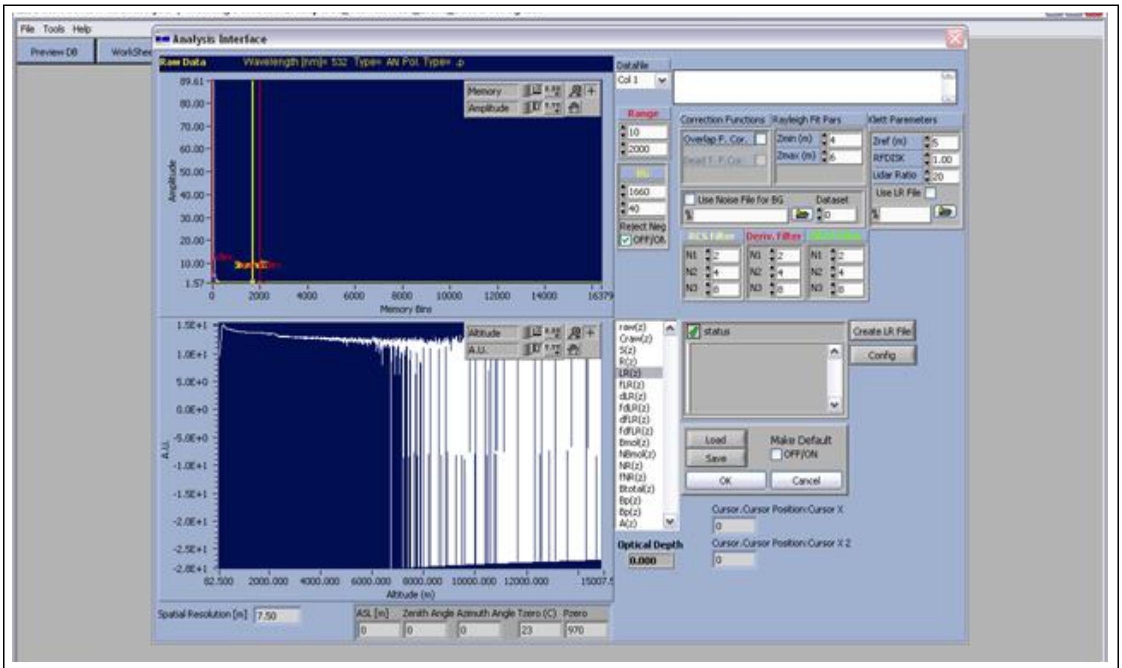


Fig. 7.28: Backscatter Coefficient Max Altitude

9. Locate the altitude where the first negative values appear (for example close to 7 km in Fig. 7.28). **This is the maximum altitude to which you can calculate backscatter coefficient without errors for the selected data.**

7.3.3 How to Calculate Aerosol Extinction Coefficient

1. The procedure is the same in the above tutorial *7.3.2 How to Calculate Backscatter Coefficient* until point 7. At this stage, instead of selecting Bp(z) the user has to select A(z).

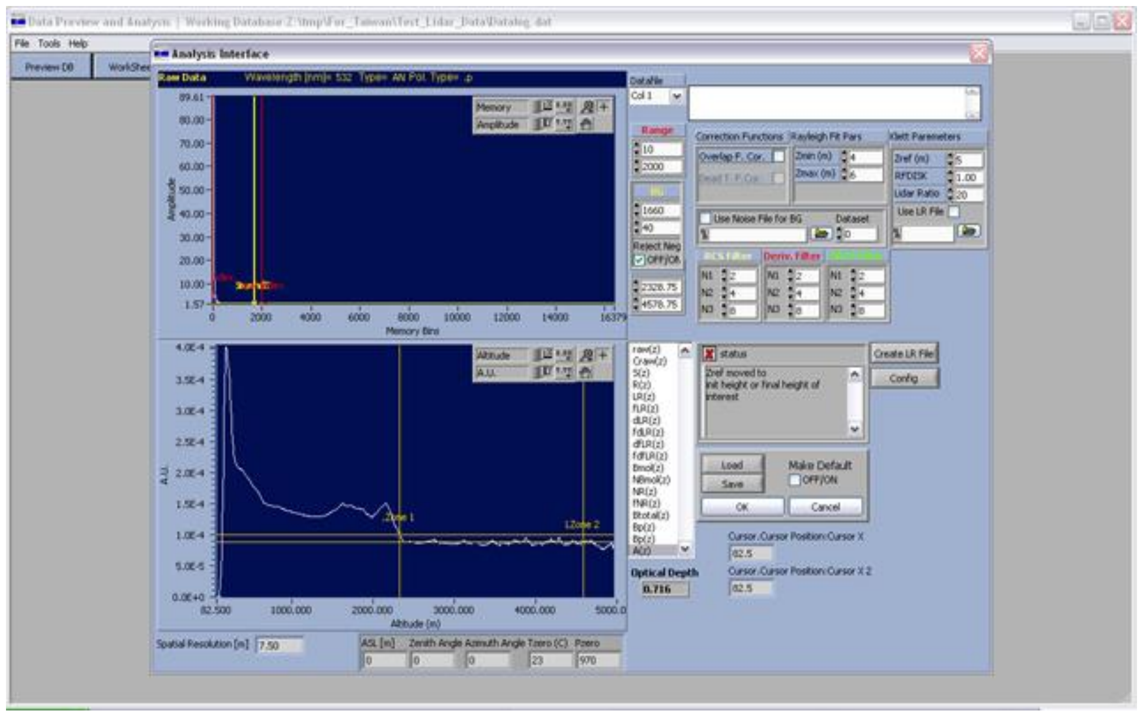
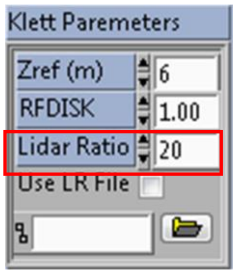


Fig. 7.29: Aerosol Extinction Coefficient

2. Please notice that A(z) depends strongly on the assumption of the Lidar ratio.



3. Continue with the rest of the procedure as described in the previous tutorials.

7.3.4 How to Check Lidar Alignment

For the 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 $\beta_{cor} = \beta_{Ray} \times z^2 \times \exp\left(-\int a_{Ray} dz\right)$, 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 during daytime or night-time measurements and it is very accurate.

NOTE: clear sky without clouds is important, since if clouds are present the Lidar signal extinct very fast and it is not then possible to calculate the molecular signal from experimental results.

In Fig. 7.30 a typical Lidar aligned signal is shown 'matching' the pure molecular atmosphere.

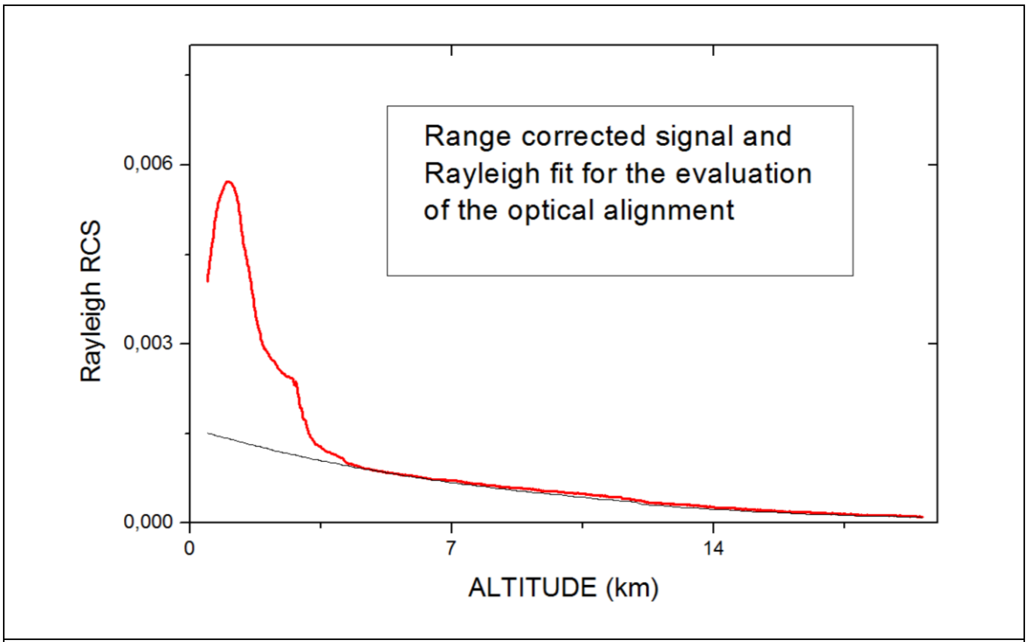


Fig. 7.30: Lidar Signal 'Matching' the Pure Molecular Atmosphere.

Now in the software NBr(z) is actually the β_{cor} from the equation above and NR(z) is the normalized Range Corrected Signal. RCS(z) is the range-corrected Lidar signal P_{cor}.

$$NR(z) = RCS(z) * \frac{\sum_{Z1}^{Z2} RCS(z) \Big/ Z_2 - Z_1}{\sum_{Z1}^{Z2} \beta_{cor}(z) \Big/ Z_2 - Z_1}$$

Where Z_2 and Z_1 define a range clear of aerosols (From Rayleigh Parameters Section: MinR(km), MaxR(km))

To check the alignment of the Lidar, follow the steps below.

1. Follow the same steps in tutorial *7.3.2 How to Calculate Backscatter Coefficient* until point 4. Then select 355.pPC (Photon Counting Data at 355nm). Select NBmol and fNr(z) parameters to plot (by holding <Ctrl> to select multiple options).
2. Define a range in the atmosphere where it is assumed to be free of aerosols (for example 10 to 14 km in the above image-example).

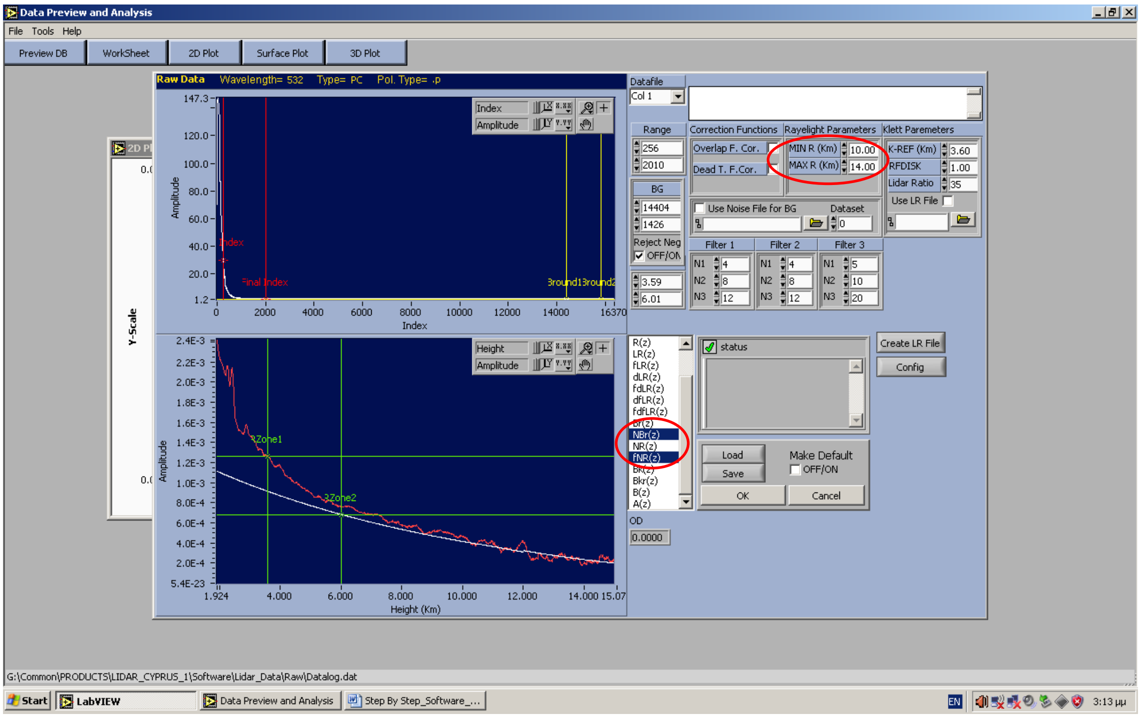


Fig. 7.31: Lidar signal 'matching' the pure molecular atmosphere.

A. Note that the Lidar signal fits the molecular atmosphere up to 15 km

B. All the signal bellow 10 km is higher than the molecular atmosphere

7.3.5 How to Calculate Water Vapour Profiles

Before you go through this section of the document, make sure that your system can measure water Vapour. To measure water Vapour your Lidar should be able to measure both 408nm and 387nm Raman backscatter wavelengths.

Intro:

Water vapour profile is calculated by using the following equation:

$$m(z) = \frac{P_{\lambda,H_2O}(z)}{P_{\lambda,N_2}(z)}K = \frac{P_{\lambda,408}(z)}{P_{\lambda,387}(z)}K \qquad \text{eq.1}$$

Where K is the overall system calibration constant, and P(z) is the Range Corrected Signals.

The overall system calibration constant (K) can in principle be deduced from the known Raman cross sections and the measured properties of the spectrometer used, but in practice it is determined from the comparison of the Lidar measurement with critically evaluated data from a radiosonde ascent. In the calculation of the emission ratio, there is an effect of the particle extinction which can be negligible on the mixing ratio determination under clear air conditions but must be taken into account if an optically dense medium like a water cloud is present.

A new and easier way for the calculation of water Vapour profiles has been developed, which is embedded in the software. Here is shown a tutorial on how to plot a 2D graph. If you want to display the temporal evolution of water vapour, open a surface graph, if you wish to analyze and do additional calculations open a worksheet.

1. Follow the same steps in tutorial *7.3.2 How to Calculate Backscatter Coefficient* until point 3., **but** select 'Water Vapour Analysis' in the 'Type of Analysis' dialog (as shown in Fig. 7.13.) If the selected record set does not contain any Water Vapour info (channel 408nm) the 'Water Vapour Analysis' button will not be available.
2. Select 355.pPC (Photon Counting Data at 355nm). Select NBmol and fNr(z) parameters to plot (by holding <Ctrl> to select multiple options).
3. A new interface appears. Using this interface is straightforward. Depending on the detected channels and the type of detection several options can appear in the Data Type list box in the top left corner of the window. For example if your system detects only Photon Counting signals for the 408nm channel and only Photon Counting signals for 387nm channel, then you have only one option: To calculate the water

vapour profile by using only Photon Counting signals. If for example your system detects Analogue and Photon Counting signals for 387 nm then you have two options to calculate the water Vapour profile. One by using only the photon counting signals for both channels and two by using Photon Counting for the 408 nm channel and Glue data for 387nm (about Gluing please take a look at Licel manual and at section *7.3.7 How to Glue Analogue and Photon Counting Signals*).

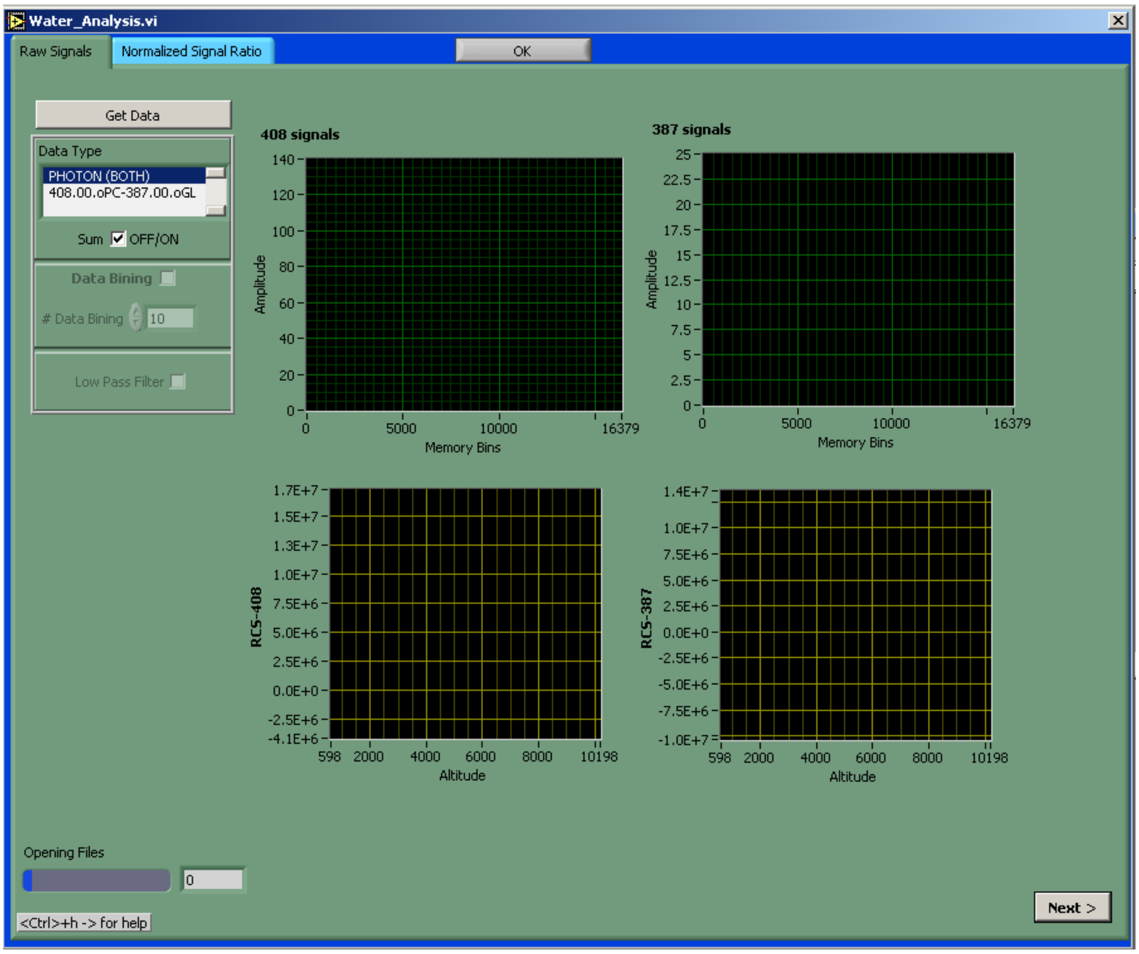


Fig. 7.32: Water Vapour Analysis Interface – 'Raw Signal' Tab

4. Click on the 'Sum' check box to average all the selected datafiles. In this case the temporal resolution decreases but the signal to noise ratio greatly improves, so the effective range of the profile will be increased.

NOTE: For surface plots (temporal evolution) this option is deactivated.

5. Click on the 'Get Data' button and a new interface will appear ('Data Pre-process') where you can subtract the background and select the range of interest (by using the two red cursors from the top graph). This process will be done twice. Once for 387nm and once for 408. After this the Range Corrected Signal will be calculated for both channels.

NOTE: Take into consideration that the calculations of the Range Corrected Signals for the 387nm and the 408nm must be made at the same range of interest. An easy way to select the same range, is to click on the 'Make Default' check box and then on the ‘Save’ button. The next time that this interface will appear it will retain the same range of interest.

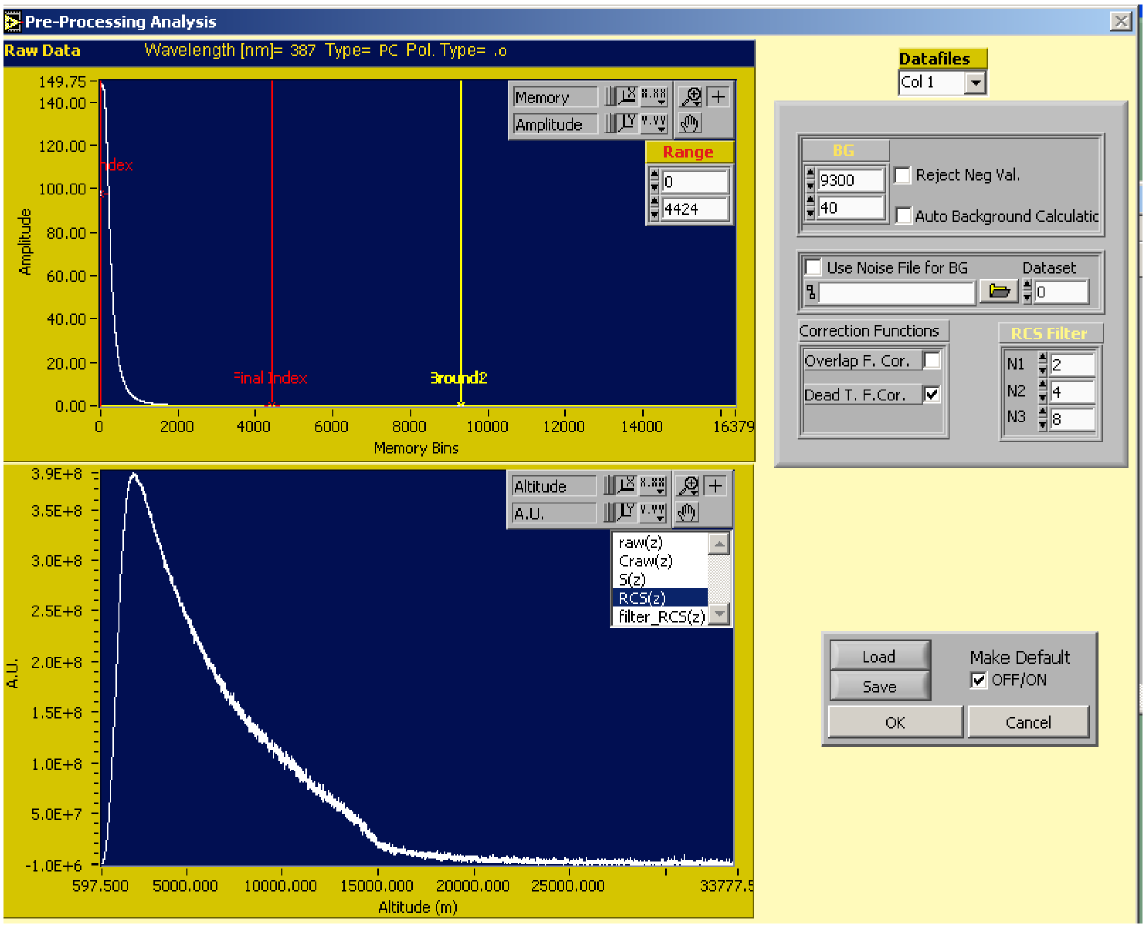


Fig. 7.33: Pre-processing Analysis Interface

6. When both Range Corrected Signals have been calculated the ‘Pre-processing Analysis’ interface closes and the program returns to the main interface. The graphs are updated and you can preview all in one graph (the 387nm and 408nm - Raw and RCS signals). Click on the 'Next' button or on the ‘Normalized Signal Ratio’ tab.

7. There are two graphs in the ‘Normalized Signal Ratio’ tab. The top one shows the signal ratio. The bottom one shows the calculated water vapour profile. Use the two yellow cursors from the top graph in order to zoom in to the range where the ratio profile is strong enough to calculate the water vapour profile.

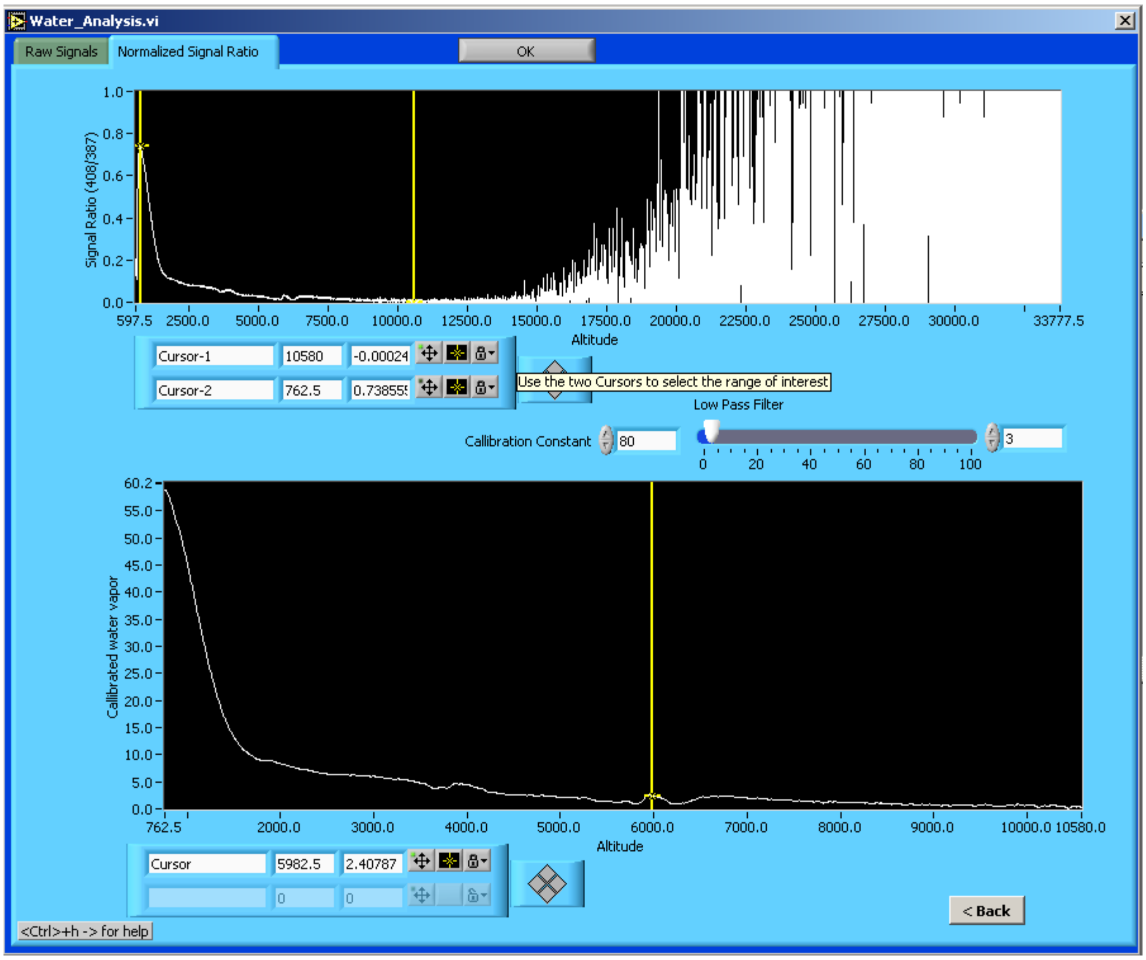


Fig. 7.34: Water Vapour Analysis Interface – 'Norm Signal Ratio' Tab

8. In this tab you can adjust the calibration constant or even apply a low pass filter to the final product (zero means no filter). Finally click on the 'OK' button located at the top of this interface.

NOTE: In cases where the signal to noise ratio is too low you can try improving it by data binning of raw signals or even by applying a low pass filter. You can do this in the 'Raw Data' tab.

How data binning works:

Every value of the input signals corresponds to 7.5 metres (one bin) by calculated the average signal of a number of sequential bins (number of data binning) then the resulting signal has a spatial resolution of 7.5 * (number of data binning).

7.3.6 How to Subtract Background Noise

Intro:

Background noise is due to atmosphere (solar or lunar background light) and due to electronic noise.

There are several methods for removing the background noise from a Lidar signal. The most common method is to locate a range where there is no Lidar signal and calculate the mean value at that range. Then this value is subtracted from the Lidar signal. Usually this range is at the far range (very high altitude) or at very low altitude (a few metres) if your Lidar supports pre-triggering.

However using only very high altitudes is not best practice. Experience shows that sometimes when the signal (analogue) is too weak or decreases very fast (after a cloud) the signal suffers from lack of linearity. In this case is better to select a range where the signal is quite stable and the mean value at that range is minimal.

Of course in this case the effective range of the signal is restricted until that range.

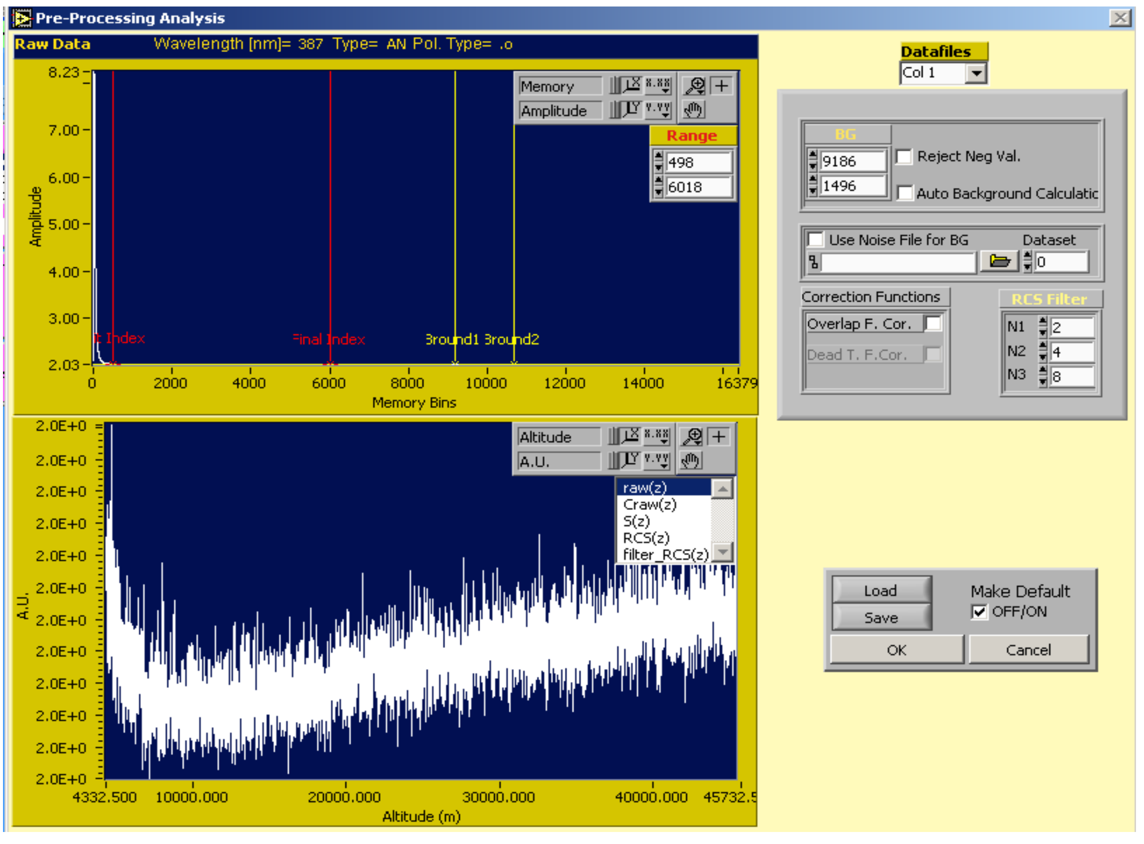


Fig. 7.35: Example of a Signal with Non-Linear Behaviour

To calculate the background mean value at a range where the signal is minimal, the two red cursors can be used to do this by zooming.

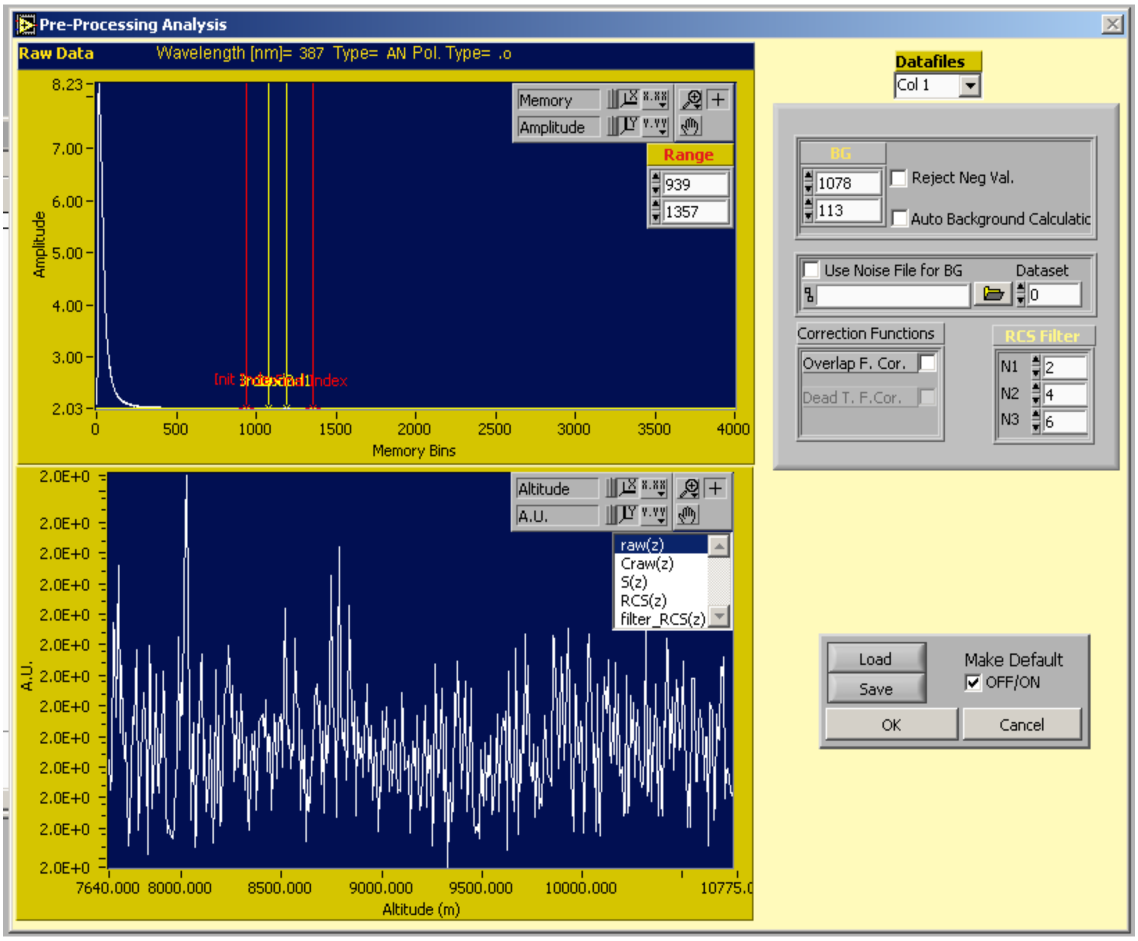


Fig. 7.36: Boundaries Selection

Then place the two yellow cursors somewhere in between (as shown in Fig. 7.36) in order to calculate the mean value.

For analogue measurements it is suggested to use a background profile to avoid ADC slopes or electromagnetic interference being taken as a real atmospheric response. A background profile can be taken by covering the telescope and starting a normal measurement. If no light enters through the telescope the only thing that is measured is the noise from the electronics. Alternatively you can use an external trigger to initiate a measurement without using the laser at all. In this case you measure the electronics noise and the sun's radiation.

Note: Make sure to note which measurement is the background noise measurement (or Dark Current Measurement) so that you can select it afterwards in the software interface in order to subtract the background profile from the signals.

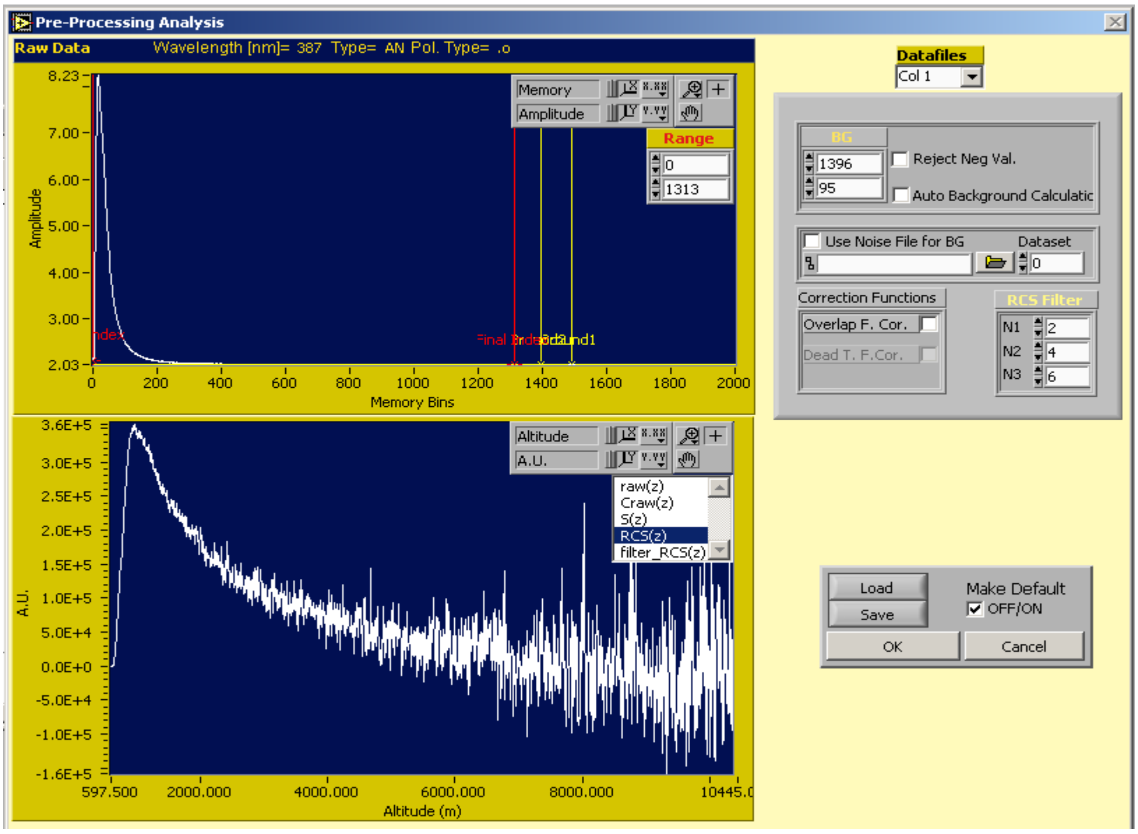


Fig. 7.37: Range Corrected Signal

You can see how the Range Corrected Signal (RCS) looks in Fig. 7.37.

7.3.7 How to Glue Analogue and Photon Counting Signals

Intro:

Depending on your Lidar configuration many detected signals are recorded simultaneously by two methods; Analogue and Photon Counting method.

The combination of both signals allows for high linearity of the analogue signals for strong signals (near fields) and high sensitivity of the photon counting for weak signals (far fields). The idea is to combine the signals, at a region where both signals (analogue and photon) are valid and have a good signal to noise ratio. For a typical case this region extends from 0.5 to 20 Hz in photon counting mode.

Before we glue signals the photon counting data should be dead-time corrected (Raymetrics software does this). The dead-time corrected photon counting signal is given by the following equation:

$$S = \frac{N}{1 - N * \tau_d}$$

Where S is the corrected counts, N is the observed count rate and τ_d is the system dead-time. Raymetrics software uses a value of 260 MHz for τ_d

For detailed discussion of the theory of photon counting dead-time correction please see the following paper: D. P. Donovan, et.al. 'Appl. Opt. 32, 6742-6753 (1993).

The Gluing

In the region where both signals are valid (between the lower toggle frequency – typically 0.5 MHz and the upper toggle frequency – typically 20 MHz) the linear regression coefficient must be found to transfer the analogue data into photon counting data.

After transferring analogue to photon the scaled analogue signal is used above the upper toggle frequency and the photon counting signal

When Gluing is Possible:

Gluing is possible when the peak value of the dead-time corrected photon counting signal is above the maximum toggle frequency (safe values for maximum toggle frequency are between 10 MHz and 70 MHz for the dead-time corrected signal) and the background of the dead-time corrected photon signal is below the minimum toggle frequency.

If the signal is too weak (maximum peak of photon counting signal less than 20 Hz) use only photon (gluing is not useful)

If the signal is too strong (background of the dead-time corrected signal is more than 20 MHz) use only analogue.

Raymetrics Software

The first step for gluing is to figure out the maximum range at which the analogue signal has good signal to noise ratio. A suggested way to do this is to remove the background noise and then to figure out the maximum height where the signal is 2 to 5 times more than LSB (the minimum change in voltage required to guarantee a change in the output code level is called the least significant bit (LSB) voltage). The resolution *Q* of the ADC is equal to the LSB voltage and depends on the full range of the pre-amplifier that you have select during the measurements. There are three possible values for the full range, 500, 100 and 20 mV and the LSB is $500/2^{12}$=122 mV, $100/2^{12}$=24.4 mV, $20/2^{12}$=4.8 mV.

Let's assume that the maximum memory bin where the signal is 5 times the LSB is Xa.

In addition let's assume that the Photon Counting signal has a value of 50 MHz at memory bin Xp. If Xp < Xa then gluing is possible. If not then gluing is not suggested.

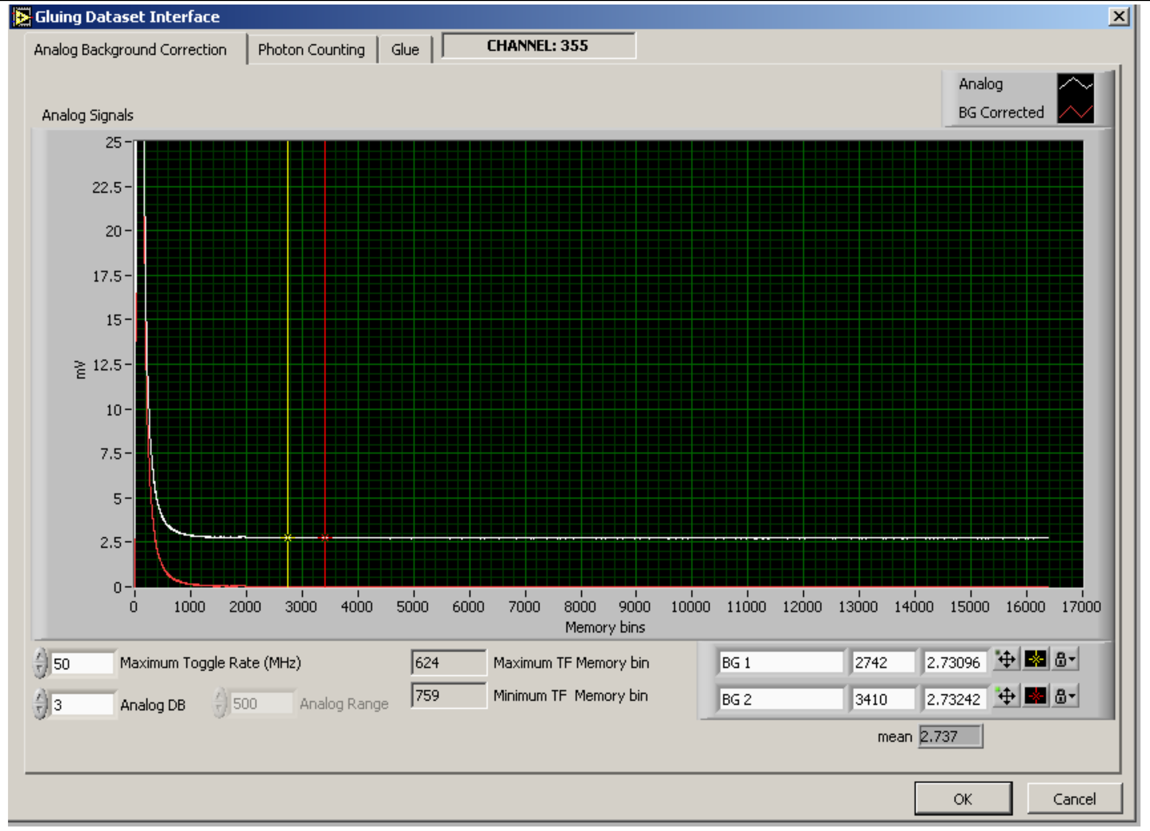


Fig. 7.38: Analogue Background Correction

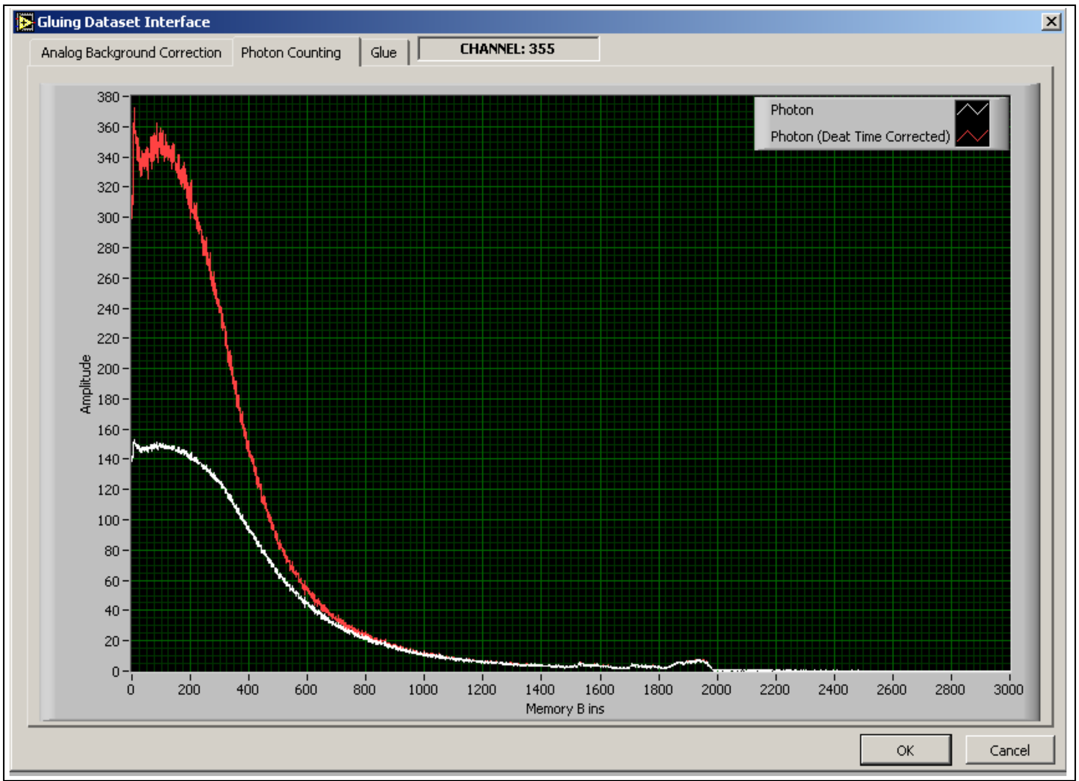


Fig. 7.39: Photon Counting and Dead-Time Photon Counting

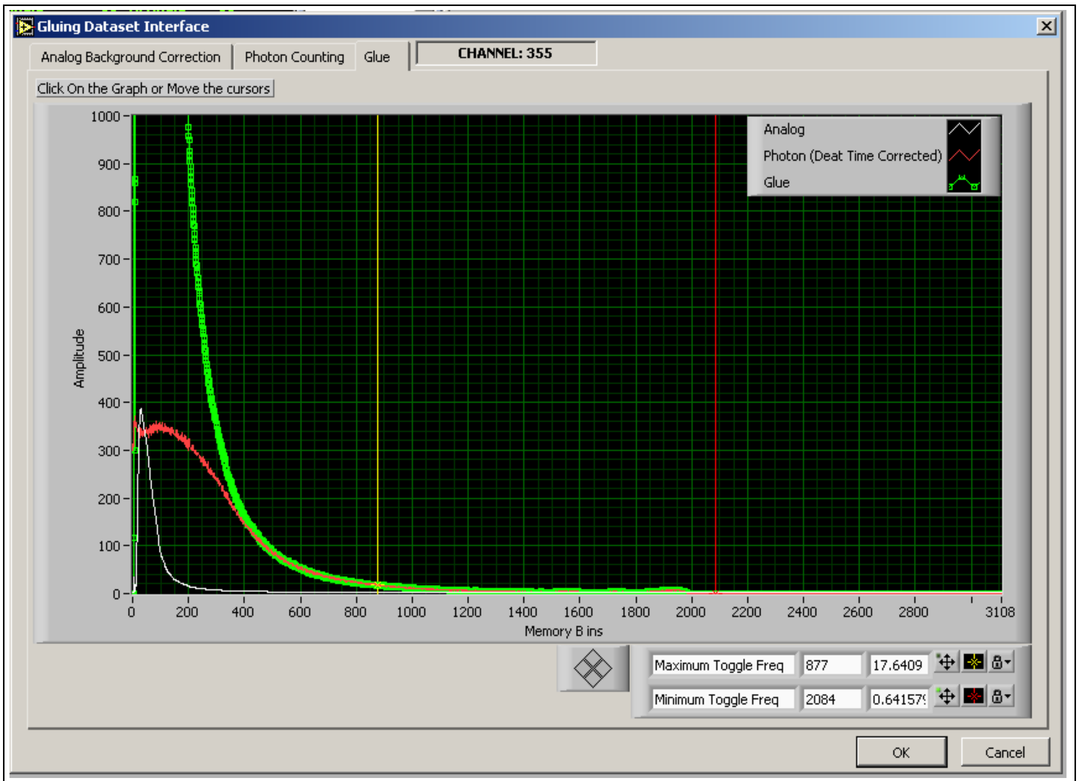


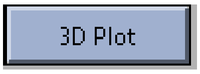
Fig. 7.40: Glued Signal

Use the two cursors to change the Maximum and/or Minimum Toggle Frequency (if required), or just click on the graph and then OK button.

7.3.8 How to Make a 3D Graph

In many studies analysts are interested in structures related to clouds. In most cases these are represented in a surface plot that shows the time evolution of the phenomenon. There is another way however to illustrate the measurement. By plotting the data in a 3D graph which can be rotated, panned and zoomed. This may give a better understanding of the structures. This tutorial will teach you how you can make such a plot.

1. Preview the database and find a record that has interesting cloud structures. Close the Preview and click the '3D Plot' button.



2. A new interface appears with an empty 3D Graph. Click on the *Insert Data from DB* button (as you can see in Fig. 7.41)

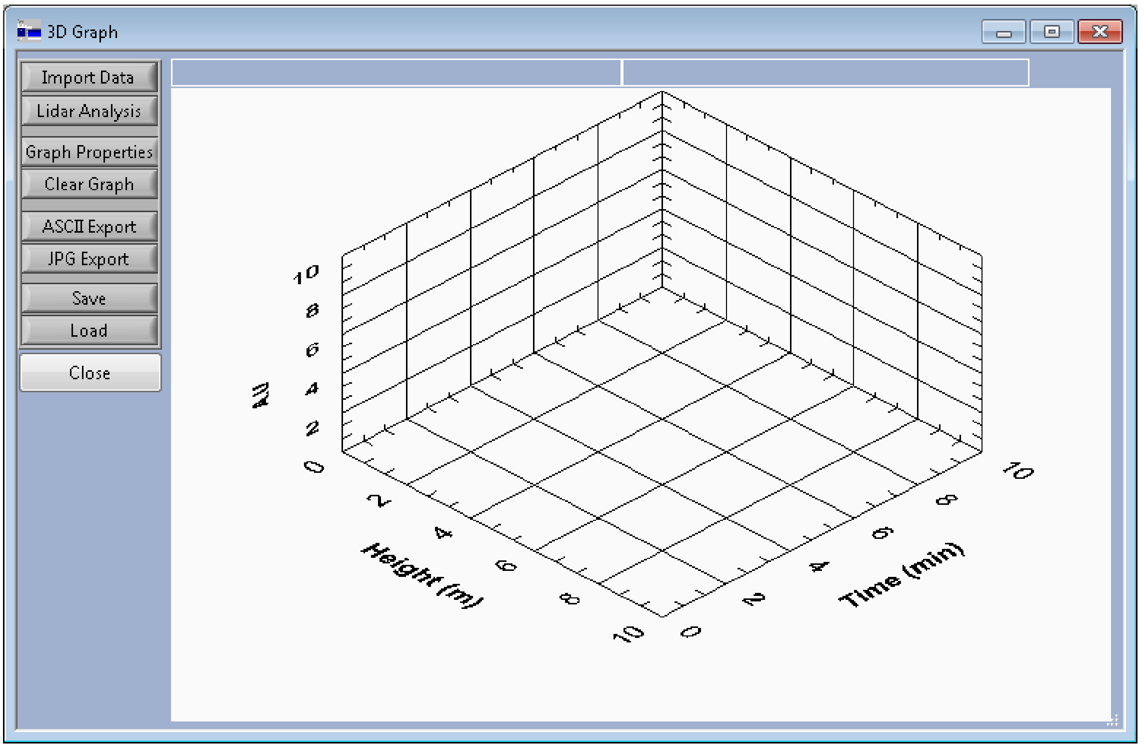


Fig. 7.41: 3D Graph Interface

3. Follow the same procedure explained earlier in section *7.3.1 How to Plot Data* to make the analysis and plot. Keep in mind that since you are interested in the area where the structures are, you can select with the red cursors the boundaries of the graph from the beginning. This way the plot is going to be focused where you want.

NOTE: In the analysis interface you can see all the files that are selected for plotting if you select the data file in the list box next to the raw signal graph.

4. Once you complete the analysis you will have an image similar to the one in Fig. 7.42

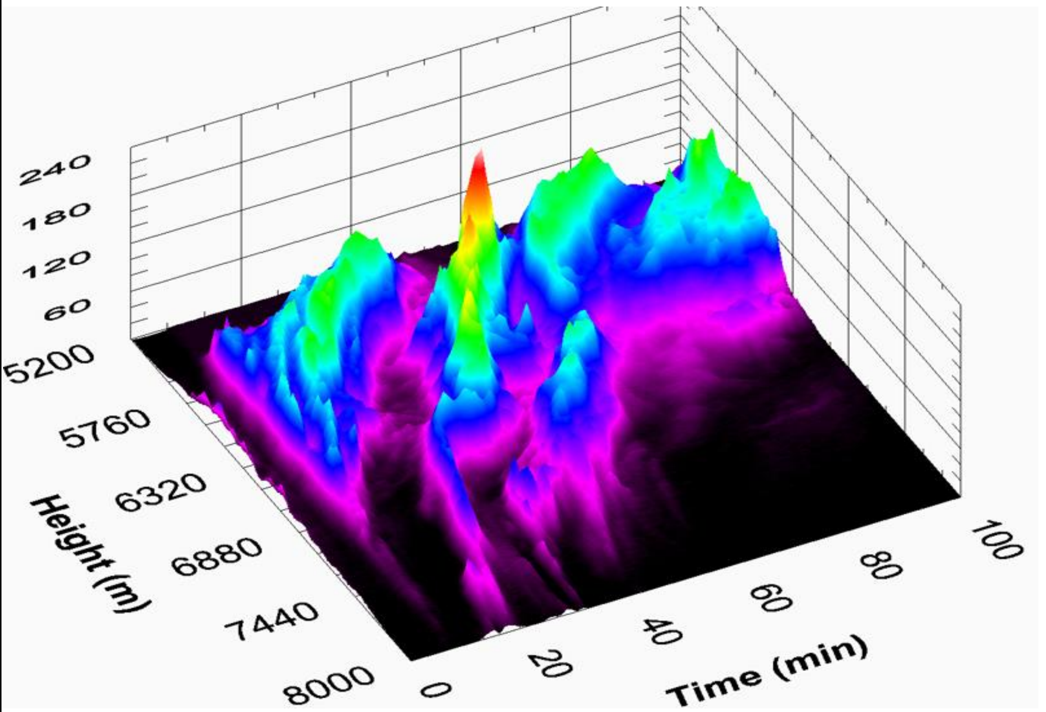


Fig. 7.42: 3D Plot

5. Hold the mouse left button down and drag to rotate the graph.
6. Hold 'Alt' key with the left mouse button and drag to resize.
7. Hold 'Shift' key with the left mouse button and drag to pan.

You can modify the properties of the graph by selecting 'Graph Properties' or save the graph as an image by selecting 'JPG Export'.

7.3.9 How to Use Soundings from Global Model Data

Accurate radiosonde data from model analyses (and forecasted data) are much better than data calculated with standard atmospheres. You can find this information for free on the internet. The following section shows where you can find and how you can use the data.

1. Go to the website: http://rucsoundings.noaa.gov/, to get model data for every location on earth on a 0.5° grid.

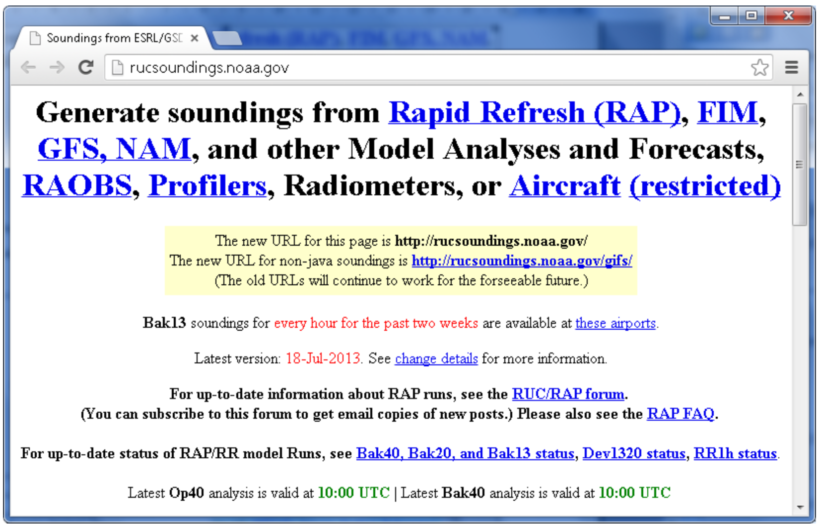


Fig. 7.43: Rucsoundings

2. Select FIM, 24, 12 or 8 for No. of Hours, plus your latitude and longitude (e.g. 34.7, 33.07)

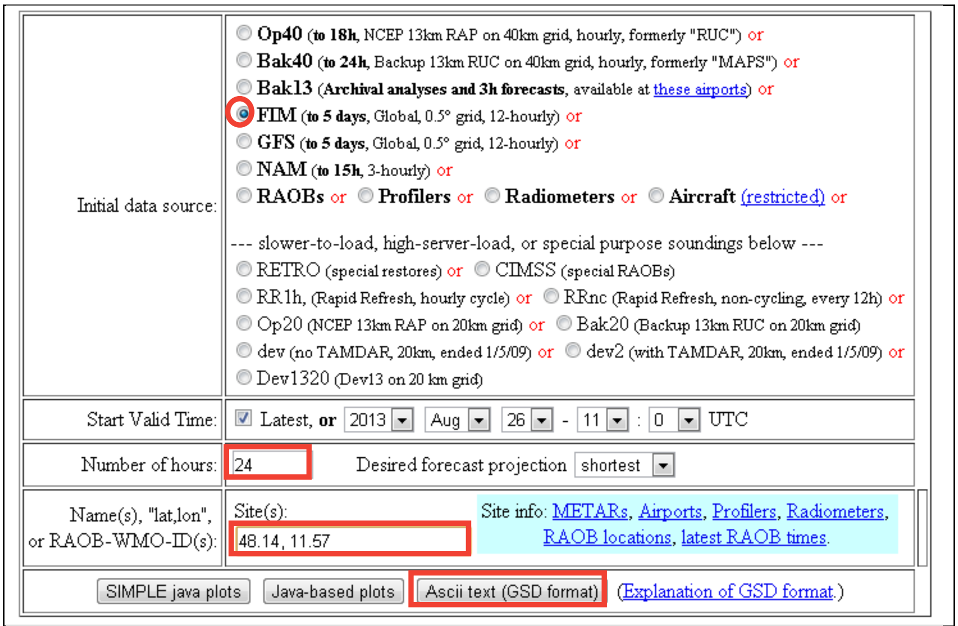


Fig. 7.44: Rucsoundings

3. Click on the ASCII Format (GSD).

4. On the new page that will appear use your mouse to select the data that you want.

```
FIM analysis valid for grid point 12.5 nm / 196 deg from 34.7,33.07:
FIM          0       1       Apr     2011
   CAPE      0      CIN       0  Helic       0      PW        0
      1  23062  99999  34.50 -33.00  99999  99999
      2  99999  99999  99999      68  99999  99999
      3          34.7,33.07               12     kt
      9  10061     88    201     71     45     13
      5  10019    123    205     57     46     14
      5   9946    186    207     35     48     15
      5   9846    271    211     10     52     16
      5   9735    367    212    -10     55     16
      5   9614    472    210    -29     58     17
      5   9485    586    204    -44     61     17
      5   9350    708    197    -61     64     16
      5   9210    836    191    -77     67     15
      5   9066    969    184    -93     69     14
      5   8921   1106    176   -108     71     13
      5   8775   1245    166   -123     72     12
      5   8631   1385    157   -134     72     10
      5   8489   1525    150   -139     72      9
      5   8349   1663    141   -139     73      8
      5   8212   1802    131   -136     77      7
      5   8078   1939    121   -131     82      6
      5   7946   2077    111   -129     90      5
      5   7816   2213    100   -129    103      4
      5   7688   2350     89   -129    118      4
      5   7561   2486     77   -130    137      4
      5   7437   2626     66   -130    157      4
      5   7163   2900     41   -127    187      5
      5   6537   3621    -10   -131    230     11
      5   5811   4621    -85   -179    245     19
      5   5087   5696   -168   -267    252     19
      5   4327   6862   -267   -359    249     27
      5   3571   8197   -382   -426    244     35
      5   2910   9487   -499   -548    245     40
      5   2588  10218   -560   -615    246     47
      5   2464  10554   -579   -647    247     49
      5   2352  10852   -594   -677    249     52
      5   2251  11133   -607   -697    251     54
      5   2153  11421   -615   -705    253     55
      5   2055  11719   -619   -712    254     56
      5   1954  12034   -617   -718    255     58
      5   1851  12373   -612   -722    255     62
      5   1747  12730   -604   -727    255     66
      5   1640  13125   -595   -733    256     68
      5   1510  13648   -592   -735    257     67
      5   1354  14347   -602   -746    256     63
      5   1196  15135   -617   -790    255     57
```

Fig. 7.45: Results Page

5. Copy the data (select and right click to copy)

6. Open a text editor and paste the data. Save the file with any name desired (e.g. Road_Data.txt). The data columns that we are interested in are column 2 (pressure in tenths of milibars), column 3 (altitude in meters) and column 4 (temperature in tenths of Celsius). Note: Raymetrics software needs to read an ASCII file with three columns separated by tab.

   a. First Column: Altitude in meters

   b. Second Column: Temperature in K

   c. Third Column: Pressure in hPa.

7. Now we need to convert the Road_Data.txt file to another ASCII formatted file suitable to be read by Raymetrics software. To do so locate the Rm_Utils.llb and run the **ROAD_GSD_to_Ascii_Format.vi**.

8. Select the file that you want to convert e.g. Road_Data.txt.

9. The software will ask to save the formatted data to another file. Then give another filename for the formatted file e.g. 'Road_Data_formated.txt' (if you like you can overwrite the original file).

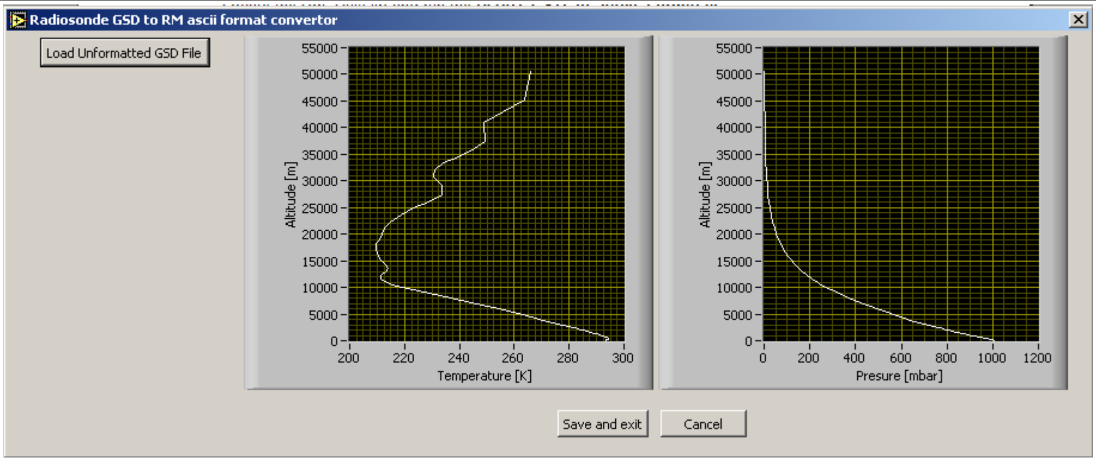
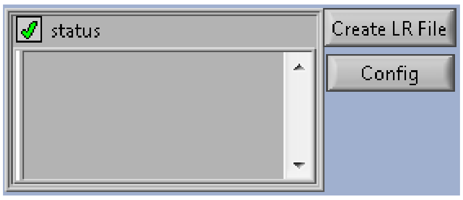
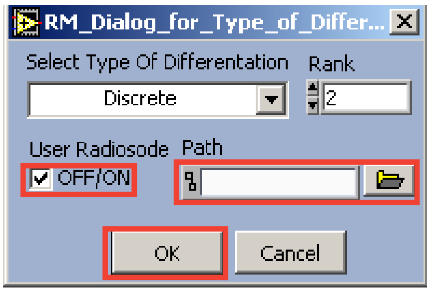


Fig. 7.46: Radiosonde File Convertor

10. Now in the analysis interface you can click on the Config button



11. Then click on the 'Use Radiosonde' check box and then load the formatted ASCII file by clicking on the folder icon. Then click 'Ok'.



8. LIDAR SYSTEM MAINTENANCE

8.1. LASER SYSTEM

The laser system requires minimal maintenance, if it is operated in a standard laboratory environment with specified power and in the correct ambient temperature conditions (see 10. LIDAR SYSTEM TECHNICAL SPECIFICATIONS). Please, refer to the Laser instruction manual for a detailed description of the laser's maintenance procedures (alignment verification, flashlamps replacement, etc).

To access the laserhead or power supply back panel slide the trays out as described in section **Error! Reference source not found.**. Shut down the laser and remove the covers from the emission unit.

CAUTION: Check the number of flashlamp frequently and replace whenever needed (after no more than 50 million shots). Operating the laser with a flashlamp that has exceeded its nominal lifetime will damage the laser cavity.

CAUTION: Never operate the laser using water of a different specification than is stated in the manuals. Frequently replace the deionizing cartridge and water to keep the water's purity as high as possible.

8.2. REFLECTIVE MIRRORS

The reflective mirrors of the emitter are aligned in factory and they should not be touched. however if the laser output beam profile is not circular, it means that the beam is probably being cropped at the beam's expander input. Operating the lidar in such condition will eventually damage the beam expander. To realign the mirror, first reduce the energy of the laser and then place a piece of white paper in front of the beam's expander output. Thos reveals the shape of the laser beam profile. Move the actuators of the mirror in front of the beam expander until the beam becomes circular again. Next check that the output beam is close to the centre of the laser window. The lidar can now be aligned using the final mirror.

8.3. TELESCOPE

If a lidar is relocated regularly, the telescope may eventually become misaligned. The key indication of a misaligned telescope is a low lidar signal for all channels which cannot be fixed by aligning the lidar. If this occurs, do not attempt to align the telescope, contact Raymetrics.

8.4 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 dust on the surface.

Although the Lidar structure provides dust protection for the optical components, it is preferable that in open air the Lidar system should be operated with the protective housing closed and sealed. Depending on the type of dirt follow the instructions below to clean the optics.

Hard particles:

Use of oil-free dry air or nitrogen under moderate pressure is the best tool for removing hard particles that can scratch the surface of your optics. In case these are not removed rinse with distilled water.

Soft particles or dust:

In cases of dust, which is common for the windows, flood the surface of the optical part with distilled water and remove gently with a clean and soft cotton cloth. Do not leave any drops of water on the surface as these will leave a stain once they have dried out. Use an absorbent towel such as Kimwipes™, to finish the drying process.

Oil stains or fingerprints:

This case is the most difficult to clean. Please follow the procedure described below carefully to avoid damaging the coating:

1. The use of powder-free gloves will help to keep fingerprints off the optics during cleaning.
2. Clean the optical part using an absorbent tissues such as Kimwipes™, not lens paper. Use enough tissues so that solvents do not dissolve any dirt from your gloves which can penetrate the tissues onto the coated surface.
3. Soak the tissues el with an anhydrous reagent grade ethanol.
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 Kimwipes before repeating the process.

The purpose of the solvent is only to dissolve any adhesive contamination that is holding the dust on the surface. The towel needs to absorb both the excessive solvent and entrap the dust 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.

NOTE: In many cases, the AR coatings that are provided to give maximum light emission amplify the appearance of contamination on the surface.

9. TROUBLESHOOTING

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

9.1 LIDAR

PROBLEM	POSSIBLE CAUSES	CORRECTIVE ACTION
LIDAR dead (no power)	AC mains	Check power source. Inspect power cord.
	Main circuit breaker	Check the main circuit breaker and the protection breaker.
	UPS OFF	If the UPS has power but does not turn ON, please refer to the manufacturers manual.
Computer is down	Primary line	Make sure that the primary line is connected to the LPC (if available) and that it has power.
	Power supply	Verify that the power LED of the 12V PSU is on otherwise it needs replacement .
	Computer failure	If the computer has power but does not turn on it needs to be sent back to the factory.
Air cooling heating not working	No power	Turn the breaker on and check the connection and power cable.
	Temperature set	Remove the plastic cover of the electrical box and set a different temperature.
Laser has external interlock	Bad connection	Check that the BNC cable from the LPC to the Laser's interlock is connected.
	External panel	Verify that the switches connected to the external panel are functioning properly.

9.2 EMISSION

PROBLEM	POSSIBLE CAUSES	CORRECTIVE ACTION
Laser dead (no power)	AC mains	Check power source. Inspect power cord
	Blown fuse(s)	Check fuses on back panel T10A/250V, QTY 2 and replace if necessary.
NO Simmer, NO Interlocks Three audible clicks from ICE450	Faulty laser I/O cable	Verify laser I/O cable connectors are fully inserted and thumbscrews are tightened. Visually inspect high current contacts on both ends of the laser I/O cable for carbon film or pits caused by poor connector insertion and arcing.
The control unit starts and after a few seconds turns off.	Low coolant level	If the reservoir is not filled a flow interlock appears in the LCD screen. Add coolant to the reservoir.
Flashlamp does not lamp.	Flashlamp is not enabled	Verify that both the 'flashlamp ready' light and the 'flashlamp start' light on the Remote Box are illuminated.
	Simmer Problem	Either ionized, or contaminated coolant, or a degraded flashlamp may be the cause. Coolant should indicate a resistivity of 100kΩ-cm to 5MΩ-cm for proper operation. If coolant resistivity is less than 100kΩ-cm, replace the coolant. If the lamp still does not simmer replace the flashlamp.
	Charger Latch-up	If the ICE450 makes a squealing or hissing sound when the high voltage is enabled, and the simmer LED is illuminated but the flashlamp does not flash, **disable the high voltage immediately**. A component inside the ICE450 has most likely failed and the high voltage charger is attempting to charge into a short circuit. If the ICE450 is operated in this mode for longer than a few seconds additional electronics damage may occur.
Flashlamp does not fire. NO Interlocks	Flashlamp is not in Internal Mode	Verify that 'Internal sync' is selected in the flashlamp menu.
	Flashlamp is broken	If, after pressing the 'Flashlamp Ready' button, the 'ready' light does not light, nor is there a visible flashlamp flash, the flashlamp may need to be replaced.
Flashlamp does not fire. Interlock **'emergency stop button pushed'**	The red button on Remote Box is pushed in.	Pull the button out. If that does not work, there may be an open circuit in the Remote Box, cable, or internal harness.
Flashlamp does not fire. Interlock **'BNC Intlk in on ICE450 front panel'**	The 'INTLK In' connector on the front panel is open.	Connect a shorting plug, to the 'Interlock In' BNC on the front panel. If that does not work, there may be a problem with the shorting plug.
Flashlamp does not fire. Interlock **'thermal sensor on Laserhead'**	The thermostat in the Laserhead is open.	Allow the head to cool down. If that does not work, there may be an open-circuit in the Laserhead or in the Laserhead I/O cable
Flashlamp does not fire. Interlock **'flashlamp disabled time out delay expired'**	The flashlamp timeout has expired.	Either disable timeouts or change the flashlamp timeout to 00:00.
Flashlamp does not fire. Interlock **'heater over temp'**	The coolant heater is too hot.	Turn off power to the ICE450 and allow it to cool down. If that does not work, contact Raymetrics.
Flashlamp does not fire. Interlock **'charger/simmer over temp'**	The Charger inductor is too hot.	Turn off power to the ICE450 and allow it to cool down. Verify that air flow is not obstructed at the front or back of the ICE450 and correct if necessary. If that does not work, contact Raymetrics.

Flashlamp does not fire. Interlock **'low coolant temperature'**	The coolant is not warm enough for proper operation.	Give the ICE450 time to warm the coolant. If that does not work increase the temperature of the cabinet's thermostat.
Flashlamp does not fire. Interlock **'high coolant temperature'**	The coolant is too warm for proper operation.	Turn off the ICE450 and allow it to cool down and decrease the temperature of the cabinet's thermostat.
Flashlamp does not fire. Interlock **'low coolant flow'**	The coolant is not flowing properly.	There may be an obstruction in the coolant lines. Examine the lines and make sure they are not kinked or otherwise obstructed.
Q-Switch does not start. Interlock **'Q-S disabled Please wait for 8 seconds'**	There is no problem. This is normal.	Wait until the 8 second timeout expires, then activate the Q-Switch.
Q-Switch does not start. Interlock **'Q-S disabled coolant temperature under limit'**	The coolant temperature is below the minimum Q-Switch operating temperature.	Allow the coolant to warm up.
Q-Switch does not start. Interlock **'Q-S disabled time out delay expired'**	The user-set timeout period expired.	Disable timeouts or set the Q-Switch timeout to 00:00.
Energy is low	Cold Flashlamp	This is normal wait for 10 minutes to reach the desired energy.
	Flashlamp Degradation	If output energy is slightly below normal level, it may suggest gradual lamp degradation. If significant lamp degradation is suspected, replace the flashlamp.
	Coolant Degradation	Inspect the coolant for clarity. Replace if necessary.
	Incorrect Q-Switch Delay	Check that the Q-Switch delay is set to 135μs with respect to the flashlamp.
	Resonator Misaligned	If beam quality has degraded, it may suggest that the resonator needs realignment. Contact raymetrics or Quantel for more details.
Coolant leak	DI Cartridge installation	Verify that DI cartridge is locked in place and fittings are fully inserted.
	Laserhead o-rings	Inspect o-rings on coolant line connectors at Laserhead for damage and replace if necessary.
RS232 port does not operate: no communications.	Serial port disabled	For safety reasons, the serial port is disabled when any button is pressed on the Remote Box. In the 'system' menu, turn serial port ON.
	Baud rate incorrect.	See ICE450 User's manual Chapter 5, Serial Protocol Description for correct baud rate setting.

For further information on laser troubleshooting please refer to the laser's instruction manual for an additional troubleshooting list.

9.3 DETECTION

PROBLEM	POSSIBLE CAUSES	CORRECTIVE ACTION
Dead (no power)	AC mains	Check power source. Inspect power cord
	Blown fuse(s)	Check fuses on back panel and replace if necessary.
No signal for all channels	HV Power supply off.	Turn on the PMT power supply and apply the specified voltage.
	No connection.	Check that all connectors are in place.
	Laser is not emitting.	Turn on the laser (flashlamp – Q-switch)
	Lidar is misaligned.	**Reduce the energy** of the laser so that the light can be hardly seen when placing a piece of white paper above the widow of the emission unit. Raise the paper and tilt it in a way so that the light is reflected directly into the telescope. If the Lidar is misaligned then you should see the signal changing. Realign the Lidar (see section 6.2. LIDAR ALIGNMENT) **CAUTION! If the energy is high the PMTs will be destroyed.**
No signal at one of the channels.	Broken connector or cable.	To verify which cable is fault, connect the HV and signal cable (one at a time) to another working device.
	HV power supply broken.	If the cables are OK connect the HV cable of a working channel to the HV power supply that is not working. If there is no signal then the HV power supply is broken.
	TR Device broken.	If the cables are okay connect the signal cable of a working channel to the TR device that is not working. If there is no signal at the non-working channel then the TR is broken.
	The PMT is burned.	If the cables, the HV power supply and the TR device are okay then the PMT is burned probably due to excess of light exposure.
No acquisition in one of the channels	Wrong dataset configuration.	Verify that the button is red next to 'analogue or photon Mem I' for the corresponding device in the dataset of the acquisition program.
Cannot change high voltage	HV power supply switch.	Switch to manual position for manual HV application or to remote for application via the computer
High voltage is unstable	Bad connection.	If the variation is higher than 5 volts **switch off the HV power supplies immediately**. The connector is broken.
No TCP/IP connection	Ethernet switch off.	Turn on the 'LAN' switch on the energy box. Make sure that the green light on the power supply illuminates
	Communication crash	Run Licel's 'Search Controllers' program. If all devices are detected the buffer is full. Restart all the devices.
	Wrong IP address.	Run Licel's 'Search Controllers' program. If the devices are not detected make sure that the computer's IP address belongs to the same network as Licel's device and change the computer's IP if necessary.
	Broken connector or cable.	Check that the lights illuminate on the Ethernet switch. Make sure that the cable clicks when it is connected on the switch, if not change the cable.

For further information on Licel's electronics please refer to Licel's instruction manual for an additional troubleshooting list.

10. LIDAR SYSTEM TECHNICAL SPECIFICATIONS

S/N 200-04-15

Emitter	
Pulsed Laser Source	Nd:YAG (Quantel ULTRA100 Series)
Laser Class	IV
Primary Wavelength	**355 nm** & 532nm and 1064 damped
Energy / Pulse	32.7mJ @ 355 nm
Polarization state	Linear - vertical
Polarization purity	0.998 (99.8%)
Repetition Rate	20Hz
Near Field Beam Diameter	3.27mm
Pulse Width	5.37nsec
Beam Expansion	X10
Laser Beam Divergence	<0.35 mrad
Motorized Alignment	Yes

<table>
<tr><th colspan="4">Receiver</th></tr>
<tr><td>Telescope Type</td><td colspan="3">Cassegrain</td></tr>
<tr><td>Primary Diameter</td><td colspan="3">200mm</td></tr>
<tr><td>Secondary Diameter</td><td colspan="3">48mm</td></tr>
<tr><td>F#</td><td colspan="3">F5</td></tr>
<tr><td>Focal Length</td><td colspan="3">800mm</td></tr>
<tr><td>Emitter–Receiver Distance</td><td colspan="3">165 mm</td></tr>
<tr><td>Default Field Of View</td><td colspan="3">2.9 mrad (adjustable from 2 to 4 mrad)
2.4/800</td></tr>
<tr><td>Overlap</td><td colspan="3">200m (Nominal)</td></tr>
<tr><td rowspan="2">Detected Elastic Backscatter Wavelengths</td><td>355nm P</td><td colspan="2">Analogue + Photon Counting
Analog Bin-Shift= 10
Optical ND:
NE10B-A + NE03B-A</td></tr>
<tr><td>355nm S
Depolarization</td><td colspan="2">Analogue + Photon Counting
Analog Bin-Shift= 10
Optical ND: NE06B-A</td></tr>
<tr><td>Detected Raman Wavelengths</td><td>387nm (N_2)</td><td colspan="2">Analogue + Photon Counting
Analog Bin-Shift= 10</td></tr>
<tr><td rowspan="5">Interference Filter Bandwidth</td><td rowspan="3">IFF355</td><td colspan="2">CWL 354.78nm</td></tr>
<tr><td colspan="2">BW 0.57nm</td></tr>
<tr><td colspan="2">OD<6</td></tr>
<tr><td rowspan="2">IFF387</td><td>CWL 386.85nm</td><td>CWL 386nm</td></tr>
<tr><td>BW 0.9nm</td><td>BW 14nm</td></tr>
</table>

	OD<12					
PMT Characteristics						
SERIAL	**TYPE**	**CATHODE LUMINOUS SEN (μA/lm)**	**ANODE LUM. SENS A/lm**	**ANODE DARK C (nA)**	**CATHODE BLUE SEND INDEX**	**REC. OPERATING VOLTAGE Volts**
* BPA0173	R9880U-110	92	280	0.02	12.4	750-850V
BPA3586	R9880U-110	112	951	0.08	12.9	750-850V
BPA3588	R9880U-110	106	919	0.08	12.8	750-850V

* For 387 channel detection

Control Unit		
Transient Recorder	Manufacturer	Licel
	Type	40-12bit
	Raw Spatial Resolution	**!Undefined Bookmark, TR_FREQ** m
Computer	Manufacturer	Advantech
	Model	ARK-3360F-D5
	CPU:	Intel® Atom™ D510 1.66GHz
	VGA:	Integrated in N450
	Ethernet:	10/100/1000Base-T
	Storage:	SATA HDD 320Gb
	RAM:	2Gb
	Safety:	FCC Class A CE certificated The front bezel is compliant with NEMA 4 and IP65
Software	OS:	MS Windows 7 Professional
	Backup:	Software for data backu
	Alignment:	Lidar System Checking and Alignment
	Acquisition:	Data Acquisition (with real time data display)
	Analysis:	Data Analysis
	Control SW	Laser Control, Scheduler, PMT HV Control
Enclosure	Manufacturer:	GSK
	Material:	Plastic
	Ethernet:	Advantech EKI-2525 5-port Industrial Switch
	Main Plug:	Bulgin IP68 panel mount industrial plug 16A
	Main Switch:	Schneider electric IP66 industrial emergency switch
	External USB	Bulgin IP68 panel mount USB A Type
	Ext. Ethernet	Bulgin IP68 panel mount RJ45
	Ext. VGA	Encitech IP68 HD-SUB RA PCB connector
	Ext. RS232	Encitech IP68 D-SUB RA PCB connector

	Ext. Interlocks	Binder IP67 2 pin female socket Straight PCB
General	IP protection:	IP55 to EN 60 529/10.91
	HVAC	NA
	Dimensions:	885mm x 665mm x 710mm WxHxD (Electronics) Surface: R=1215 mm (Tripod) Height @ horizontal Position = 1590 mm Height @ Vertical Position = 1800 mm
	Weight:	325 kg
	Voltage	220~240VAC 50/60Hz
	Power	500Watt Idle, 1100 Watt Operation 16A Peak current
	Temperature	Operating: -5 to 40^{o}C Storage: 5 to 55^{o}C
	Humidity	Operating: 10 to 80% non condensing (+5 to 28^{o}C) Storage: 10 to 90% non condensing (+5 to 28^{o}C)

LIDAR Performance	
Lidar type	Biaxial
SNR > 10	(10 minutes average for backscatter) 10000 (m)
SNR > 5	(10 minutes average for Raman N2) 5000 (m)
Depolarization Calibration (+/- 45 degrees)	Mechanical
Depolarization offset correction	Mechanical DEPOL CALIBRATION FILTER: NE06B-A
Upgradable	N/A
Scanning 3D	YES
Max Backscatter Effective range*	10 Kmeters
Max N2 Raman Effective range (night Time)*	3-5 Kmeters
Max N2 Raman Effective range (Day Time)*	1-1.5 Kmeters

*Depending on the atmosphere’s conditions

11. 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), computer, Digital acquisition PC-card and cables) guarantee 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 site (for details see the Instruction Manuals of the Lidar sub-systems providers). Laser flashlamps are guaranteed for 30 millions shots or 1 year whichever comes first.

This warranty does not cover:

- equipment or components where the original identification 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.

RETURNS, ADJUSTMENTS AND SERVICE

If warranty, service or general repair of a Raymetrics SA Lidar system is requested by the customer which requires 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 laserhead 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. If the product has suffered damage during the shipment Raymetrics SA has no obligation 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.
g) In cases where components must be shipped back to the original manufacturer for analysis or repair, the manufacturer’s decision on the cause of damage shall be final. Reports from manufacturers can be supplied.

REFERENCES

1. Ancellet, G., A. Papayannis, G. Mégie, J. Pelon, '*Tropospheric Ozone Measurements Using a Nd:YAG Laser and the Raman Shifting Technique*', Journal of Oceanic and Atmospheric Technology, 6, 832-839, 1989.

2. Measures, R., *Laser Remote Sensing: Fundamentals and Applications*, Wiley, New York, 1984.

3. Klett, J., '*Lidar inversion with variable backscatter/extinction ratios*', Applied Optics, 24, 1638-1643, 1985.

4. Ansmann, A., U. Wandinger, M. Riebesell, C. Weitkamp, and W. Michaelis, '*Independent measurements of extinction and backscatter profiles in cirrus clouds using a combined Raman elastic-backscatter Lidar*,' Applied Optics, 22, 2257-2264, 1992.

5. Chazette, P., David, C., Lefrere, J., Godin, S., Pelon, J. and Megie, G., *Comparative Lidar study of the optical and dynamical properties of stratospheric post-volcanic aerosols following the eruption of the El Chichon and Mount Pinatubo*, J. Geophys. Res., 100, 23, 195-207, 1995.

6. Boesenberg, J., Timm, R., and Wulfmeyer, V., *Study of retrieval algorithms for a backscatter Lidar*. Final Report, MPI Report No 226, pp. 1-66, 1997.

7. *U.S. Standard Atmosphere*, NOAA, NASA, USAF, U.S. Government Printing Office, Washington D.C., 227, (1976).

Also

8. V. Matthias, V. Freudethaler, A. Amodeo, I. Balin, D. Balis, J. Bosenberg, G. Chourdakis, A. Comeron, '*Aerosol Lidar intercomparison in the framework of EARLINET: Part I- Instruments*', Applied Optics, 43, 961-976, 2004.

9. G. Chourdakis, A. Papayannis and J. Porteneuve, '*Analysis of the receiver response for a non-coaxial Lidar system with fiber-optic output*', Applied Optics, 41, 2715-2723, 2002.

10. A. Papayannis, G. Chourdakis, 'The EOLE project, Part II: *Aerosols measurements over Athens, Greece', International Journal of Remote Sensing*, 23, 179-196, 2002.

11. D. Balis, C. Zerefos, V. Amoiridis, C. Meleti, A. Bais, A. Kazantzidis, A. Papayannis, G. Chourdakis, G. Tsaknakis and T. Trickl, '*Study of the aerosol effect on the UV-B irradiance at the earth's surface cases studies selected from urban sites in the frame of the Earlinet project*', Journal of Aerosol Science, 32, 391-392, 2001.

12. V. Matthias, V. Freudethaler, A. Amodeo, I. Balin, D. Balis, J. Bosenberg, A. Chaikovski, G. Chourdakis, A. Comeron, Arnoud Delaval, F. Di Tomasi, R. Eixman, A. Hagard, L. Komguem, S. Kreipl, R. Matthey, V. Richi, J. A. Rodrigues, U. Wandiger, X. Wang, '*Intercomparison of 15 aerosol Lidar systems in the frame of EARLINET*', Journal of Aerosol Science, 32, 397-398, 2001.

APPENDIX A

A1 HOW TO CONTROL THE LASER

Intro

Basically there are three major ways to control laser. The first is to use the Remote Box; the second is to use 'LaserControl' program from Raymetrics; the third is to use the external trigger. The section below describes mainly the second and the third options. For more info about the Remote Box please read the Laser Manuals.

NOTE: For optimum laser energy

1. The resulting Q-Switch Delay should be 135μs.
2. Do not change the frequency. For GRM lasers this should be 20Hz.

Communication

The primary communications and control is via the RS-232 port located on the ICE450 front panel (for the Rack mounted version of the ICE450 it is on the back panel). The ICE can be set to lock out front panel key control and avoid conflict with RS-232 communications.

The serial communications configuration is:

- 9600 baud
- 8 data bits
- no parity
- 1 stop bit
- no flow control
- No hardware handshaking is utilized.

Important Note: Usually the ICE450 is connected physically (through RS-232) to the Lidar computer. In that case you have to use remote desktop to connect to the Lidar's computer and then use the *'LaserControl'* program (or the *'ICE450_GUE'* program). In some cases the Laser is connected to a Serial-To-Ethernet converter. If this is the case you have to create a virtual com port to your computer (by using Serial Device Server Configuration Utility) and run the *'LaserControl'* program from your computer. In most of the cases the Laser is connected on Port 2 of the Serial-to-Ethernet converter with IP address 10.49.234.232.

A1.1 Manual Laser Operation Mode

Use Manual Mode for the normal operation of the Power Supply and flashlamp. Press the 'ready' button on the Remote Box to initiate simmer current in the flashlamp. The PCC generates a flashlamp discharge as part of establishing simmer. Verify that the LASER ON indicator is illuminated on the front panel of the PCC. Please be advised not to perform laser emission (Q-switching) in this mode.

1. Press the Flashlamp Start button.
2. The PCC generates flashlamp pulses at the rate specified by the 'frequency' setting in the Flashlamp menu. This setting is adjustable.
3. For Gaussian Resonator (GRM) type Laserheads, the frequency is pre-set by Quantel. **Please do not adjust the frequency setting for GRM heads.**
4. Wait for 2 sSeconds
5. Press the Q-Switch Start button (Figure 5, [7]).
6. The PCC starts generating Q-switch pulses internally. These occur after the flashlamp pulse at a time specified by the 'FLQS delay' setting in the Q-switch menu.

   Adjusting this delay is one method of adjusting the optical energy of a laser pulse.

NOTE: For this mode the only necessary physical connection between the PCC and the Transient Recorder is a BNC 50-Ohm cable from Q-Switch out to the Rack Trigger input of the Transient Recorder

NOTE: Q-Switch Out: This BNC Connector allows synchronization to the laser Q-Switch trigger. The Q-Switch trigger corresponds to the rising edge of this positive signal (5V, 50 mA max, and > 10 μS pulse width).

A1.2 Laser Control Program

The *'Laser Control'* Program provides a user friendly GUI for every day operation and control of the laser. The program actually does not require installation to your computer. To run it copy the .exe and .ini files to your computer.

When the program starts first it tries to find the laser at the serial port as specified in the ini file. In our example this is COM8

Example of Laser_Control.ini

[Laser_Control]
prefDlgTestData=1234

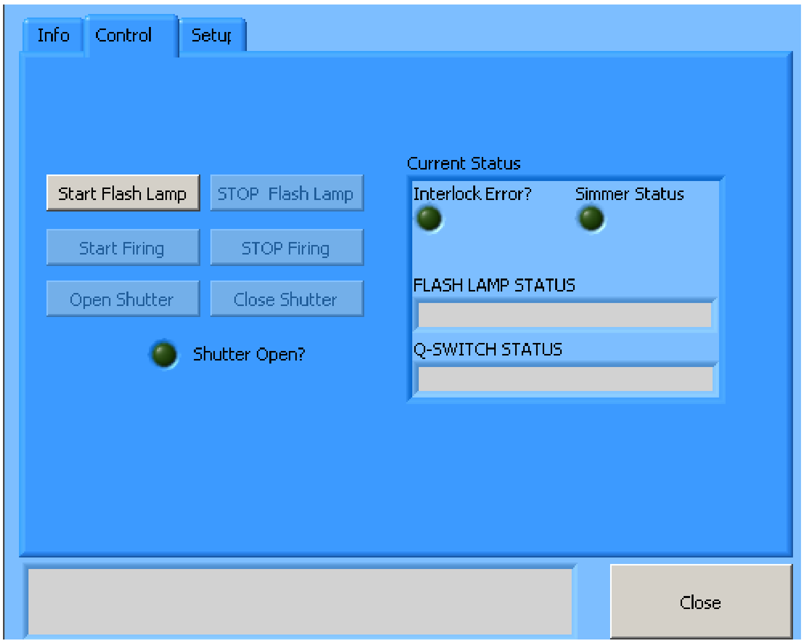
useLocaleDecimalPt=False

postScriptLevel2=False

[Communication]

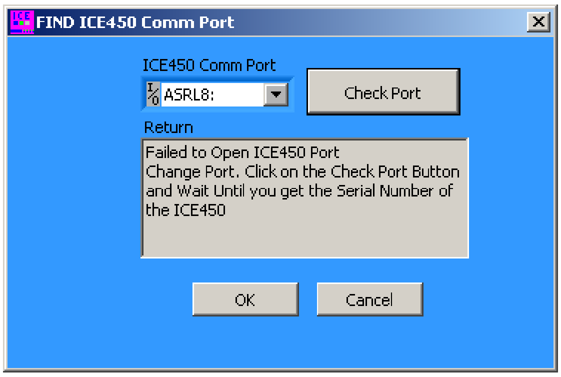
Com Port=ASRL8::INSTR

If successfully connected, the program starts and the version of the laser and its status appears.



After this click the 'Start Flash Lamp' button to start the flash lamp. Wait until 'Simmer Status' Led goes green. Wait a couple of seconds more and then click on the activated 'Start Firing' button to start emission of laser pulses. (Note: To stop the laser, follow the directions in reverse direction. If the laser is equipped with an automated shutter, click on the 'Open Shutter' button in order to start emission.

However if the program fails to connect with the laser then another window appears giving user the option to try a different COM port.



Select an available COM port from the drop down list and click the 'Check Port' button. If successfully connected (in which case the message returned should be similar to ‘ICE450 x.xx’) click the OK button. If the connection was unsuccessful try a different COM port.

For more information about ‘INFO and Setup’ please read the laser manual.

Troubleshooting

1. The software fails to start
   - Make sure that your computer has the correct Labview runtime engine installed.
2. The software starts successfully but cannot communicate with the laser.
   - Make sure that your laser is powered on.
   - Make sure that you have assigned the correct COM port
   - Make sure that laser serial cable is correctly attached to the Lidar's computer or to the Serial-to-Ethernet converter as well as to your computer.
3. Software runs and communicates successfully but the laser does not start firing (or there is an interlock error message)
   - In these cases try to control your laser manually (by using the remote box or the software provided by laser manufacturer). Consult the Laser user manual.

Before contacting Raymetrics please try to identify the problem and send screen shots and a detailed description of the message that can be found on the LCD display of the Lasers Remote Box.

A1.3 Flashlamp in Internal Mode and Q-switch in External Mode

In this configuration, the PCC generates the flashlamp pulse signals and an external source (Trigger Generator) generates the Q-switch trigger signals. This may be useful when you:

a. Require better resolution for the Q-switch delay than is available using the PCC since the Lamp Out signal is a copy of the actual flashlamp trigger.

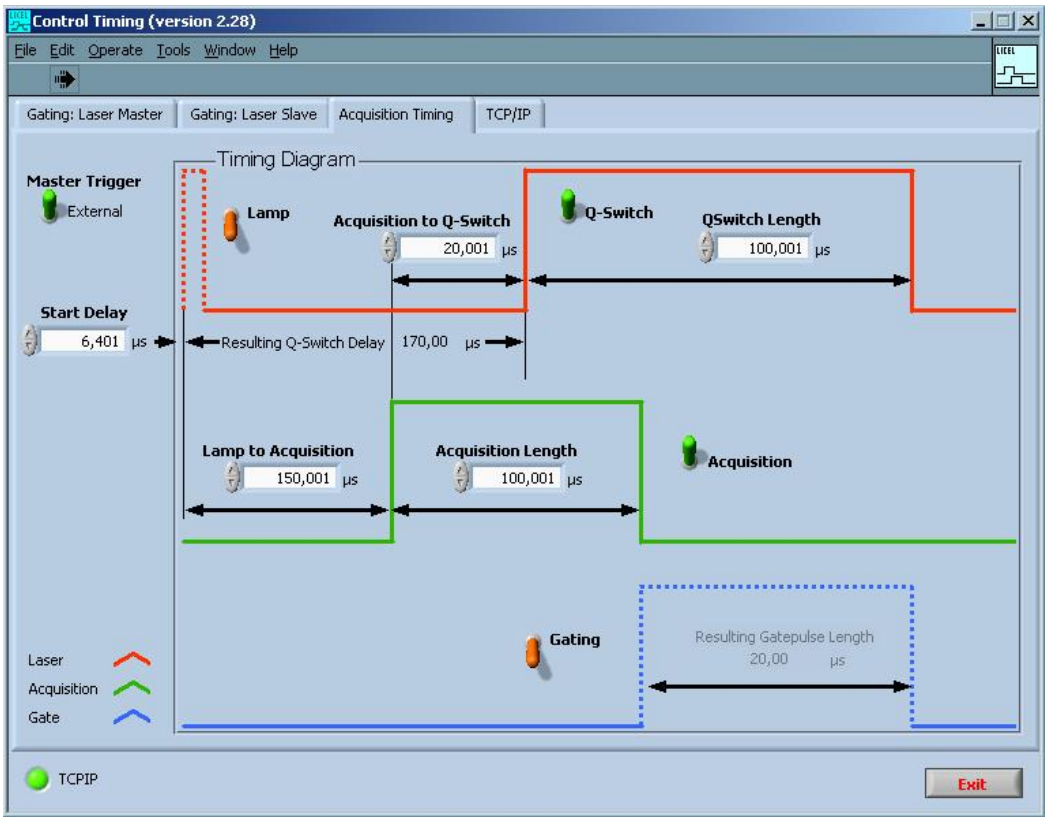
b. Require pretrigger function.

To use this mode, select internal flashlamp sync and external Q-switch sync as follows:

1. From the main menu, go into the Flashlamp menu and select flash sync 'INT'.

2. Return to the main menu.
3. Enter into the Q-switch menu and select QS Sync 'EXT'.
4. Open *'Control Timing*' program (from Licel menu)
5. Click on the 'Acquisition Timing' tab.
6. Switch 'Master Trigger to External' (up position)

For optimum laser energy the resulting Q-Switch Delay should be 135µs. For example if you need 20 µs of pretriggering then Lamp to Acquisition should be **!Undefined Bookmark, QS_DLY**µs + 20µs Acquisition to Q-Switch. If no pretrigger is required then put Lamp to Acquisition at 135µs and Acquisition to Q-Switch at 0 µs.



Now you can switch the laser on and off by switching the 'Q-Switch' knob.

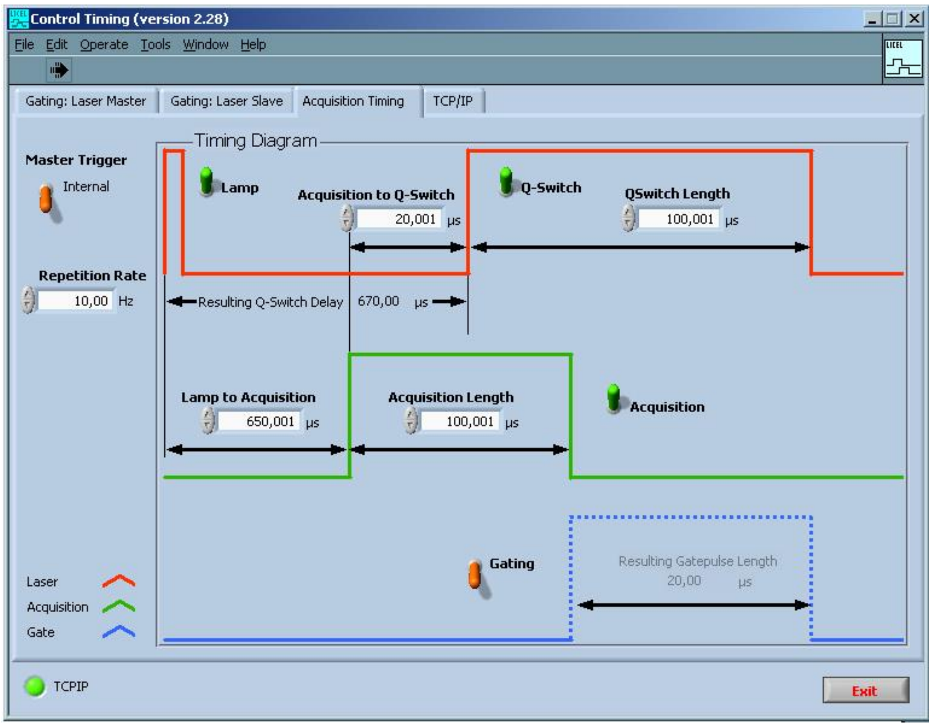
A1.4 Flashlamp and Q-switch in External Mode

In this configuration, an external source (Trigger Generator) generates both the flashlamp trigger and the Q-switch trigger.

To use this mode, select external flashlamp sync and external Q-switch sync as follows:

1. From the main menu, go into the Flashlamp menu, and select flash sync 'EXT'.
2. Return to the main menu.
3. Enter into the Q-switch menu and select QS Sync 'EXT'.
4. Open *'Control Timing*' program (from Licel menu)
5. Click on the 'Acquisition Timing' tab.
6. Switch 'Master Trigger' to Internal (up position)

For example if you need 20μs pretriggering then Lamp to Acquisition should be **!Undefined Bookmark, QS_DLY**μs + 20μs Acquisition to Q-Switch. If no pretrigger is required then set Lamp to Acquisition at **!Undefined Bookmark, QS_DLY**μs and Acquisition to Q-Switch at 0μs. **Note:** There is a processing delay of 500μsec between the external flashlamp trigger input and the actual flashlamp activation.



NOTE: Always switch off the Q-Switch knob before you switch off the 'Lamp' knob.

A2 HOW TO WORK VIA AN EXTERNAL COMPUTER

If for any reason you want to use another computer you have to setup the communications and install the programs for the Lidar. You can use any computer that you want that has Windows XP OS and later.

Communications Setup

Communications are with Licel's controllers, the Laser and positioner (if your system is equipped with one).

Licel has a LAN based communication. Lidar's TR IP address is by default: 10.49.234.234. Therefore the user's PC should belong to the same subnet class:

10.49.234. xxx

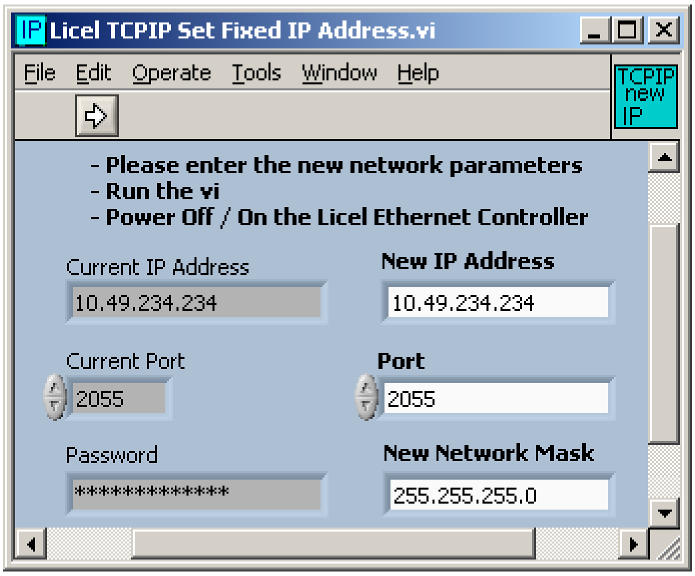
Where xxx is any number from 0 to 254.

NOTE: Do not use numbers for xxx from 230 up to 237. These ranges are reserved for Lidar hardware.

To change the user's or Lidar's PC TCP IP address, read windows documentation or consult your system administrator

To change the Transient Recorder TCP IP address, run the program *'TCPIP Set Fixed IP Address'* program.

Usually this is located in the following folder on the Lidar PC: C:\Program Files\Licel\Configure\ TCPIP Set Fixed IP Address.exe



For more information please refer to Licel's documentation

The laser and positioner (if applicable) have an RS232 communication so they require serial ports unless there is an Serial-to-Ethernet converter installed in your system. This device needs separate installation but gives the option to connect all devices on an Ethernet switch to which you also connect your computer. This makes the connection very easy. Otherwise you have to use the external USB port with an RS232 to USB adaptor to connect to your computers USB port. If there is more than one device with an RS232 port use a hub and separate RS232 to USB adaptors for each device.

Lidar Software Installation

First install Licel's software (this step is not absolutely required but it is recommended)

If your PC does not have Labview runtime library (*LVRunTimeEng*) version 7 or later, it must be installed. You can download this file from www.ni.com or you can find it into programs folder that Raymetrics supplies to users.

In addition, if the user's PC does not have visa301 runtime library (*visa301runtime*), this also must be installed. You can download this file from www.ni.com or you can find into programs folder that Raymetrics supplies to users.

APPENDIX B

SUMMARY OF LIDAR THEORY

CONTENTS

B1 INTRODUCTION

In its simplest from, the detected Lidar signal can be written as

$$P(R) = KG(R)\beta(R)T(R) \quad \text{eq. 1}$$

The power P received from a distance R is made up of four factors.

1. The first factor, K , summarizes the performance of the Lidar system

2. The second, G(R), describes the range-dependent measurement geometry

NOTE: These two first factors are completely determined by the Lidar setup and can thus be controlled by the experimentalist. The information on the atmosphere, and thus all the measurable quantities, are contained in the last two factors.

3. The term β (R) is the backscatter coefficient at distance R.

4. The term T (R) is the transmission term and describes how much light gets lost on the way from the Lidar to distance R and back.

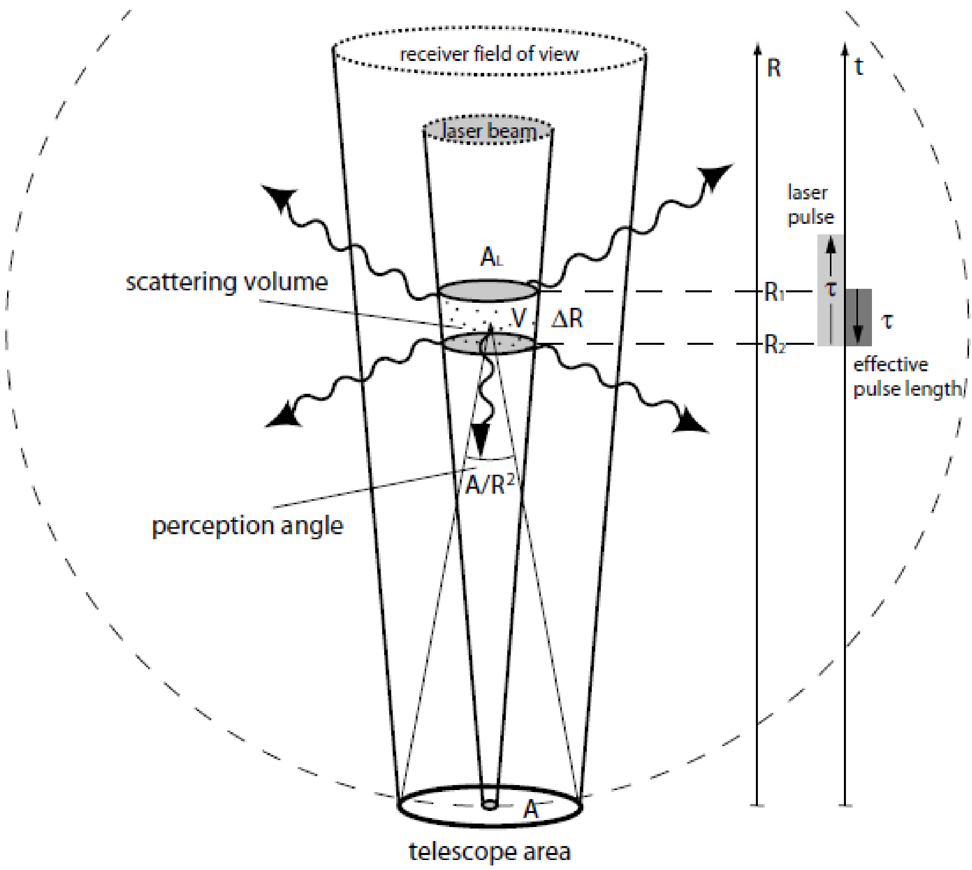


Fig. B1

In a more analytic form the term K is given by the following equation

$$K = P_0 \frac{c\tau}{2} An \quad \text{eq. 2}$$

P_o is the average power of a single laser pulse and τ is the temporal pulse length.

Hence $E_o = P_o * \tau$, is the pulse energy and c*τα is the length of the volume illuminated by the laser pulse at a fixed time. The factor ½ appears because of an apparent 'folding' of the laser pulse through the backscatter process. A is the area of the primary receiver optics responsible for the collection of backscattered light (usually the primary mirror of a telescope) and n is the overall system efficiency which includes the optical efficiency of all the elements that transmit and receive light.

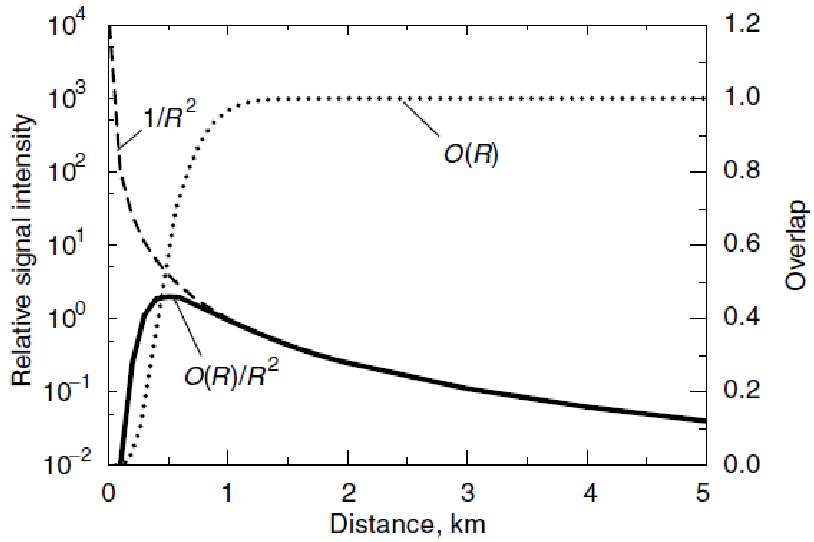
The geometric factor G(R) can be given from the following equation:

$$G(R) = \frac{O(R)}{R^2} \quad \text{eq. 3}$$

and includes the laser-beam receiver-field-of-view overlap function O(R) described before and the term R^{-2}. The quadratic decrease $1/R^2$ of the signal intensity with distance is due to the fact that the receiver telescope area makes up a part of a sphere’s surface with radius R that encloses the scattering volume. If we imagine an isotropic scattered at distance R, the telescope area A will collect the fraction I_C:

$$\frac{I_C}{I_S} = \frac{A}{4\pi R^2} \quad \text{eq. 4}$$

of the overall intensity I_S scattered into the solid angle 4π . In other words, the solid angle A/R^2 is the perception angle of the Lidar for light scattered at distance R. The factor 4π does not appear explicitly in the Lidar equation because it cancels out by the definition of the backscatter coefficient β as we will see below. It is primarily the $1/R^2$ dependence that is responsible for the large dynamic range of the Lidar signal. If we start detecting a signal with O(R)=1 at a distance of 10 m, the signal will be 6 orders of magnitude lower at 10 km distance just because of the geometry effect. To what extent Lidar is a *range-resolving and remote* measurement technique depends on our ability to compensate for this effect.



Graph 1: Influence of overlap function O(R), at Lidar signal

B1.1 About Backscatter Coefficient β(R,λ)

The backscatter coefficient β(R, λ) is the primary atmospheric parameter that determines the strength of the Lidar signal. It describes how much light is scattered into the backward direction, i.e., towards the Lidar receiver. In the atmosphere, the laser light is scattered by air molecules and particulate matter, i.e., β (R, λ) can be written as

$$\beta(R,\lambda) = \beta_{mol}(R,\lambda) + \beta_{aer}(R,\lambda) \quad \text{eq.5}$$

Molecular scattering (index mol), mainly occurring from nitrogen and oxygen molecules, primarily depends on air density and thus decreases with height, i.e., backscattering decreases with distance if the observation is made from the ground. Particulate scattering (index aer for aerosol particles) is highly variable in the atmosphere on all spatial and temporal scales. Particles represent a great variety of scatterers: tiny liquid and solid air-pollution particles consisting of, e.g., sulfates, soot and organic compounds, larger mineral-dust and sea-salt particles, pollen and other biogenic material, as well as comparably large hydrometeors such as cloud and rain droplets, ice crystals, hail.

B1.2 About Extinction Coefficient, α(R,λ)

The last term in the Lidar equation, we have to consider the fraction of light that gets lost on the way from the Lidar to the scattering volume and back. The transmission term T(R) can take values between 0 and 1 and is given by

$$T(R,\lambda) = \exp\left[-2\int_0^R a(r,\lambda)dr\right]$$ eq. 6

This term results from the specific form of the Lambert–Beer–Bouguer law for Lidar. The integral considers the path from the Lidar to distance R. The factor 2 stands for the two-way transmission path. The sum of all transmission losses is called light extinction, and α(R,λ) is the extinction coefficient. Extinction can occur because of scattering and absorption of light by molecules and particles.

B1.3 The Lidar Equation

Below is the extensive form of the well known Lidar equitation

$$P(R,\lambda) = P_0 \frac{c\tau}{2} An \frac{O(R)}{R^2} \beta(R,\lambda) \exp\left[-2\int_0^R a(r,\lambda)dr\right]$$

eq. 7.1

Or

$$P(R) = \frac{n \times P_o \times A \times O(R) \times [\beta_{mol}(R) + \beta_{aer}(R)] \times \exp[-2\int_0^R [a_{mol}(r) + a_{aer}(r)]dr}{R^2} + P_{bgr}$$

eq. 7.2

In equation 7.2 wavelength dependence λ have been omitted for simplicity. In addition a new term P_{bgr} is the background noise that comes from atmospheric defused light (daytime) and the electronic noise.

In any form of the eq. 7 has two unknown quantities (β and α). So this is an intrinsic problem of an elastic backscatter Lidar. One has to measure two quantities with only one equation. Several solutions (depending on different assumptions) have been proposed in literature in order to solve the Lidar equation.

NOTE: Raymetrics Software uses the Inver Klett-Fernard method (Far-end solution)

B2 SUMMARY OF SOLUTIONS TO THE LIDAR PROBLEM

There are three basic inversion methods commonly used to find extinction coefficient. These methods are:

B2.1 The Slope Method.

This method is useful for homogeneous atmospheres. In many cases, atmospheric horizontal homogeneity is a reasonable assumption. With the slope method, a mean value of the extinction coefficient over the examined range in a homogeneous atmosphere is obtained.

One can reform the eq. 7.1 at the following form:

$$P(R) = C_0 T_0 \frac{\beta(R,\lambda)}{R^2} \exp\left[-2\int_{R_0}^{R} a(r,\lambda)dr\right]$$ **eq. 8**

C_0 is the system constant and T_0 is an unknown, two-way transmission term from ground to R_0 (R_0 is where the overlap function O(R)=1).

$$T_0(R) = \exp\left[-2\int_{0}^{R_0} a(r,\lambda)dr\right]$$

In a homogeneous atmosphere we can assume that

α(r)=α=constant and β(r)=β=constant

In that case we get

$$P(R) = C_0 T_0 \frac{\beta(R,\lambda)}{R^2} \exp[-2(R-R_0)a]$$

Then we define the Range Corrected Signal as:

$$RCS(R) \equiv P(R)R^2 = C_0 \beta e^{-2aR},$$

Taking the natural logarithm we get the following (singe β and α are assumed range independed for homogeneous atmospheres:

$$Z(R) = B - 2\alpha R$$ **eq. 9**

Where

$$B \equiv \ln(C_0 \beta)$$

The linear dependence of Z(R) on range R, is a key factor when seeking the simplest solution to the Lidar equation. It allows determination of the α by linear square fit. In addition the estimate of the standard deviation of the linear fit for Z(R) can be used to estimate the degree to which the assumption of atmospheric homogeneity is valid.

NOTE: As always before you apply such a solution you have first to subtract background noise from the Lidar signals

B2.2 Inverse Klett-Fernard Method (Using Raymetrics Software)

$$\beta(R) = \frac{RCS(R) * \exp\left(2*(L - L_{mol})* \int_R^{R_{ref}} \beta_{mol}(r)dr\right)}{\frac{RCS(R_{ref})}{C*\beta_{mol}(R_{ref})} + 2*L*\int_R^{R_{ref}} RCS(R')*\exp\left(2*(L-L_{mol})*\int_{R'}^{R_{ref}} \beta_{mol}(R'')dR''\right)dR'}$$

eq.10

Where

$$C = \frac{\beta_{mol}(R_{ref}) + \beta_{aer}(R_{ref})}{\beta_{mol}(r)}$$ **eq.11**

if the reference point R_{ref} is in a clean atmosphere (for example free troposphere without aerosols) then it is safe to assume that $\beta_{aer}(R_{ref})=0$ so C=1

$$L_{mol}(r) = \frac{a_{mol}(r)}{\beta_{mol}(r)} = \frac{8\pi}{3}$$ **eq.12**

and

$$L(R) = \frac{a_{aer}(R)}{\beta_{aer}(R)} = const$$ **eq.13**

L(R) is the aerosol Lidar ratio and depends on particle size distribution, complex refractive index, the shape of aerosols, relative humidity height and wavelength.

B3 AN INTRODUCTION TO RAMAN LIDAR

As we saw above by measuring only the elastically backscattered signal we have to make an assumption for the Lidar ratio in order to solve the Lidar equation. This introduces errors since we know that the Lidar ratio is not constant and depends on height relative humidity (which varies strongly by height) and other microphysical parameters.

However by measuring simultaneously the inelastically (Raman) backscattered signal by Nitrogen we get two equations with two unknowns. So the problem now can be solved. The determination of the particle extinction coefficient from molecular backscatter signal is rather straightforward and there is no need for Lidar-Ratio assumptions. However it should be pointed out that Raman signals can be 1000 times weaker than elastic signals so the background noise reduces significantly the range of measurements of such signals. Practically speaking, Raman signals can only be detected at night time.

As shown previously the power received from the distance R for an elastic channel is given by the equation:

$$P(R) = \frac{n \times P_o \times A \times O(R) \times [\beta_{mol}(R) + \beta_{aer}(R)] \times \exp[-2\int_0^R [a_{mol}(r) + a_{aer}(r)]dr}{R^2} + P_{bgr}$$

For simplicity we rewrite the equation in the following form (for the $R>R_0$ where O(R)=1)

$$P(R,\lambda_L) = \frac{C \times [\beta_{mol}(R,\lambda_L) + \beta_{aer}(R,\lambda_L)] \times \exp[-2\int_{R_0}^R [a_{mol}(r,\lambda_L) + a_{aer}(r,\lambda_L)]dr}{R^2}$$

eq. 14

where λ_L is the laser emitted wavelength.

The power received from distance R from a Raman channel is given from the following equation:

$$P(R,\lambda_R) = \frac{C \times \beta(R,\lambda_L,\lambda_R)}{R^2} \exp\left[-\int_0^R [a(\lambda_L,r) + a(\lambda_R,r)]dr\right]$$

eq. 15

$$\beta(R,\lambda_L,\lambda_R) = N_R(R)\frac{d\sigma(\lambda_L,\lambda_R,\pi)}{d\Omega}$$

eq. 16

Where λ_R is the Raman shifted wavelength from the Raman-active gas (usually nitrogen at 387 nm)

Eq.15 has two main differences from eq.14. First the -2 factor is no longer present since the extinction in this case happens only one way (returning to the Lidar receiver). The Raman backscatter coefficient (eq.16) is given by the molecular number density N(R) of the Raman-active gas (usually nitrogen at 387 nm) and the differential Raman cross section for the return direction.

By using the above three equations we can get:

$$a_p(\lambda_L,R)=\frac{\frac{d}{dr}\left[\ln\frac{N_R(R)}{R^2P(R)}\right]-a_{mol}(\lambda_L,R)-a_{mol}(\lambda_L,R)}{1+\left(\frac{\lambda_L}{\lambda_R}\right)^k}$$

eq. 17

The above equation is valid for $R>R_o$ in other words where O(R) = 1

In addition:

$a(\lambda_L,R)=a_{aer}(\lambda_L,R)+a_{mol}(\lambda_L,R)$ and $a(\lambda_R,R)=a_{aer}(\lambda_R,R)+a_{mol}(\lambda_R,R)$

and

$$\frac{a_{aer}(\lambda_L,R)}{a_{aer}(\lambda_R,R)}=\left(\frac{\lambda_R}{\lambda_L}\right)^k$$

The aerosol backscatter coefficient is given from the following equation:

$$\beta_{aer}(\lambda_L,R)=-\beta_{mol}(\lambda_L,R)+\left[\beta_{aer}(\lambda_L,R_{ref})+\beta_{mol}(\lambda_L,R_{ref})\right]\times\frac{P(\lambda_R,R_{ref})P(\lambda_L,R)N_R(R)}{P(\lambda_L,R_{ref})P(\lambda_R,R)N_R(R_{ref})}\times$$

$$\frac{\exp\left\{-\int_{R_{ref}}^{R}[a_{aer}(\lambda_R,r)+a_{mol}(\lambda_R,r)]dr\right\}}{\exp\left\{-\int_{R_{ref}}^{R}[a_{aer}(\lambda_L,r)+a_{mol}(\lambda_L,r)]dr\right\}}$$

Eq.18

Once more usually at R_{ref} $\beta_p(\lambda_L,R_{ref})+\beta_{mol}(\lambda_L,R_{ref})\cong\beta_{mol}(\lambda_L,R_{ref})$

B3.1 Molecular Backscatter Coefficient

For elastic or Raman backscatter Lidars one has to calculate the molecular backscatter coefficient.

$$a_m(R) = N(R)\sigma = \mathrm{N}(R)\frac{24\pi^3}{\lambda^4 N_s^2}\frac{\left(n_s^2(\lambda)-1\right)^2}{\left(n_s^2(\lambda)+2\right)^2}F_k$$

Since

$$L_{mol} = \frac{a_m}{\beta_m} = \frac{8\pi}{3}$$

Then

$$\beta_m(R) = \mathrm{N}(R)\frac{9\pi^2}{\lambda^4 N_s^2}\frac{\left(n_s^2(\lambda)-1\right)^2}{\left(n_s^2(\lambda)+2\right)^2}F_k$$ **Eq.19**

The values for n_s and F_k can be taken from the table below

λ	ns-1	Fk	ns	(ns^2-1)^2/(ns^2+2)^2
nm	x1E-8			
266		**1,06**	**1,000294650**	**3,85823E-08**
289		**1,057**	**1,000291880**	**3,78603E-08**
299		**1,056**	**1,000290860**	**3,75961E-08**
308	29047,7	1,05575	1,000290513	3,75065E-08
316		**1,0551**	**1,000289140**	**3,71528E-08**
351	28602,7	1,05308	1,000285983	3,63460E-08
354,814	28572,4	1,0529	1,000285745	3,62854E-08
355	28570,2	1,05289	1,000285745	3,62854E-08
386,8	28350,2	1,05166	1,000283480	3,57125E-08
400	28275,2	1,05126	1,000282764	3,55325E-08
407,663	28235,1	1,05105	1,000282407	3,54427E-08
510,6	27869,4	1,04922	1,000278711	3,45212E-08
532	27819,9	1,04899	1,000278235	3,44032E-08
532,221	27819,4	1,04899	1,000278235	3,44032E-08
607,6	27686,3	1,04839	1,000276804	3,40504E-08
710	27570,4	1,0479	1,000275731	3,37870E-08
800	27503,8	1,04763	1,000275016	3,36119E-08
1064	27397,5	1,04721	1,000273943	3,33502E-08
1064,442	27397,4	1,04721	1,000273943	3,33502E-08

N(R) is the atmospheric number density and can be easily calculated by using several atmospheric models or by using Radiosonde measurements.

$$\mathrm{N}(R) = \mathrm{N}_s \frac{T_o}{P_o} \frac{P(R)}{T(R)}$$

N_s molecular number density for standard atmospheric conditions at ground level. $N_s=2.5477*10^{19}cm^{-3}$, P_o=1013.25 hPa and T_o=15 °C

B3.2 Other Lidar Equation Solutions

B3.2.1 Solutions for one component atmospheres:

In a more generic form the equation 8 can be written as below:

$$P(R) = C_0 T_0 \frac{\beta_{aer}(R) + \beta_{mol}(R)}{R^2} \exp\left[-2\int_{R_0}^{R} [a_{aer}(r) + a_{mol}(r)] dr\right] \quad \textbf{Eq. 20}$$

Now we define two new quantities

$$\bar{L}(R) = \frac{\beta_{aer}(R)}{a_{aer}(R)}$$

Where

$$\beta_{aer}(R) \equiv \beta_{aer}(R, \theta = \pi)$$

backscatter coefficient (θ=π) and

$$a_{aer}(R) = \beta_{aer}(R, \theta) + \alpha_{aer}^{A}(R).$$

So we can write

$$\bar{L}(R) = \frac{\beta_{aer}(R)}{\beta_{aer}(R, \theta) + a_{aer}^{A}(R)}$$

Here the extinction is split into scattering in all directions and into extinction because the absorption processes. In the same way we define

$$\bar{L}_{mol}(R) = \frac{\beta_{mol}(R)}{\beta_{mol}(R, \theta) + a_{mol}^{A}(R)}$$

In the case of one component atmosphere with no absorption, the solution to the Lidar equation can be written as

$$a_{aer}(R) = \frac{RCS(R)}{C' - 2\int_{R_0}^{R} RCS(r)dr} \quad \text{eq.21}$$

Where

$$C' = C_0 T_0 \overline{L}_{aer} \quad \text{eq. 22}$$

for a single component atmosphere well mixed $\overline{L}_{aer}$ does not depend on range (R).

To find aerosol extinction coefficient from eq. 21 we need to know C' (which is called sometimes Lidar calibration constant). This is not an easy task. Even if we know C_0 the other two parameters can be determined only during measurements. However in order to calculate α_{aer} we need two know only the product which means only the C' and not the individual components of eq. 22. The simplest way to determine the C' is to establish a boundary condition of the equation at some point of the Lidar measurement range. This makes it possible to find the constant C' and then to use it to determine α_{aer} over the total measurement range.

If we know the value of α_{aer} at a specific point R_{ref} which is inside the measuring range then

$$C' = \frac{RCS(R_{ref})}{a_{aer}(R_{ref})\exp\left[-2\int_{R_0}^{Rref} RCS(r)dr\right]}$$

We are reminded here that R_0 is the range where O(R)=1

By replacing C' into eq. 21 we get finally

$$a_{aer}(R) = \frac{RCS(R)}{\frac{RCS(R_{ref})}{a_{aer}(R_{ref})} + 2\int_{R}^{R_{ref}} RCS(r)dr} \quad \text{Far range solution } R_{ref} > R$$

$$a_{aer}(R)=\frac{RCS(R)}{\dfrac{RCS(R_{ref})}{a_{aer}(R_{ref})}-2\int_{Rref}^{R}RCS(r)dr}$$ Near range solution R_{ref} < R (and close to R_0)

Eq. 23

The most stable solution for α_{aer} is the far range solution. Such solution is given by Klett.

Optical Depth Solution

Another way to solve the problem is to use total path transmittance over the Lidar operating range as a boundary solution. Once more this solution is applied with the assumption that the Lidar ratio is constant (one component atmosphere). We define the upper Lidar measuring limit R_{max} which is usually taken as the range at which the signal-to-noise ratio reaches a certain threshold value. In this solution the two way transmittance T_{max} is used as a boundary solution.

$$T_{\max}=\exp\left[-2\int_{R_0}^{R_{\max}}\alpha_{aer}(r)dr\right]$$ **eq. 24**

$$a_{aer}(R)=\frac{1}{2}\frac{RCS(R)}{\dfrac{I_{\max}}{1-T_{\max}}-\int_{R_0}^{R}RCS(r)dr}$$ **eq. 25**

$$I_{\max}=\int_{R_0}^{R_{\max}}RCS(r)dr$$ **eq. 26**

If we define the aerosol optical depth as

$$AOD=\int_{R_0}^{R_{\max}}\alpha_{aer}(r)dr$$ **eq.27**

Then we get $T_{\max}=\exp(-2AOD)$

T_{max} is the quantity we need to know in order to calculate α_{aer}. For real atmospheric conditions it is a finite positive value ($0<T_{max}<1$).

B3.2.2 Solutions for two component atmospheres:

$$P(R) = C_0 T_0 \frac{\overline{L}_{aer}(R) * a_{aer}(R) + \overline{L}_{mol}(R) * a_{mol}(R)}{R^2} \exp\left[-2\int_{R_0}^{R}[a_{aer}(r) + a_{mol}(r)]dr\right]$$

Far-end boundary point solution

$$a(R) = \frac{RCS(R)}{\frac{RCS(R_{ref})}{a(R_{ref})} + 2\int_{R}^{R_{ref}} RCS(r)dr}$$ **eq.28**

where

$$a_{aer}(R) = a(R) - L(R)\beta_m(R)$$ **eq.29**

If Rref is in the free troposphere (atmosphere without aerosols) then

$a_{aer}(R_{ref}) = 0$ and $a(R_{ref}) = L(R_{ref})\beta_m(R_{ref})$

Optical Depth Solution:

$$a_{aer}(R) = \frac{1}{2}\frac{RCS(R)}{\frac{I_{\max}}{1 - V_{\max}^2} - \int_{R_0}^{R} RCS(r)dr}$$

Where once more the Imax is given from eq.26 and

$$V_{\max} = T_{\max}\exp\left[-(\frac{L(R)}{L_m} - 1)\int_{R_0}^{R_{\max}} a_m(r)dr\right]$$

$$T_{\max} = \exp\left[-\int_{R_0}^{R_{\max}} a(r)dr\right]$$ if we know the Optical Depth

$$OD = \int_{R_0}^{R_{\max}} a(r)dr$$

Then we can calculate T_{max} and V_{max}

B4 SIGNAL TO NOISE RATIO

Theory

The SNR of the echo Lidar signal is obtained by the following equation:

$$S/N = \frac{Ips}{\sqrt{2eFB(Ips + Ipb + Id)}}$$

Where Id is the PMT's anode dark current (with typical values of about 1nA), I_{pb} is the anode current due to background radiation signal, I_{ps} is the anode average output current of the echo Lidar signal, B is the bandwidth of the system, e is the electric charge and F is the noise component (noise figure) produced in the multiplication process in the PMT. F indicates how much the signal to noise ratio will degrade between the input and the output of the PMT.

Usually $F = \frac{\delta}{\delta + 1}$ where δ is the secondary emission ratio and is a function of the interstate voltage of dynodes. Typical values for δ are between 3 and 7.

The output current at the anode $I_p=\mu*I_c$ where μ is the gain and changes in relation to the supply voltage V to the PMT. Typical values are around $2x10^6$.

I_c is the photocurrent produced at the photocathode of the PMT and is calculated from the following equation.

$I_c = S_c P$ (A),

Where P is the incident radiant flux (W) and S_c is the cathode radiant sensitivity (A/W). Typical values for S_c are around 120 mA/W

The radiation power (W) arising from natural sources (background radiation) accepted by the receiver optics can be expressed in the form:

$$P_b = \chi A \Omega S_b(\lambda) K_0(\lambda)$$

χ is overall optical system efficiency, A is the area of primary receiver optics responsible for the collection of backscattering light (m^2), Ω is its acceptance solid angle, and $K_0(\lambda)$ is termed the filter function of the receiver system.

$$K_0(\lambda) \equiv \int_{\Delta\lambda} \xi(\lambda')d\lambda'$$

The S_b represents the spectral radiance of the sky background ($Wm^{-2}sr^{-1}nm^{-1}$).

At wavelengths within the visible range, a typical value for S_b is about 0.1 (Pratt, 1969) at sea level for a zenith angle of 45 degrees, with excellent visibility (for moonlight its value is approximately $1x10^{-12}$). For 355nm it is about $1x10^{-4}$.

The power of the echo Lidar signal corresponding to a distance R for a Raman channel can be written as:

$$P_{N2}(R) = \frac{\chi E_0 AQ(R)cN_{N2} \times \left.\frac{d\sigma}{d\Omega}\right|_{\mathrm{N2}}}{R^2} \exp\left[-\int_{R_0}^{R} \left[a_{aer}(x,\lambda_L) + a_{mol}(x,\lambda_L) + a_{aer}(x,\lambda_{N2}) + a_{mol}(x,\lambda_{N2})\right]dx\right]$$

E_0 is the energy of a single laser pulse (J), c is the velocity of light (m/s). The term Q(R) is the laser beam receiver field of view overlap function, describing the range-dependent measurement geometry, and can take values from 0 to 1. N is the atmospheric number density of Nitrogen (for simulation we use the USSA76 standard atmospheric model) and dσ/dΩ is the Raman backscatter cross section (1000 times smaller than elastic backscatter cross section).

$\alpha_{mol}(R,\lambda)$ is the extinction coefficient for laser and Raman wavelengths and is estimated from USS76 standard atmospheric models.

Extinction at the Raman wavelength is estimated from the following equation.

$$a_{aer}(R,\lambda_{\mathrm{N}_2}) = \frac{a_{aer}(R,\lambda_L)}{\left(\frac{\lambda_{\mathrm{N}_2}}{\lambda_L}\right)^{\gamma}}$$

For the simulation the following equation was used for calculating the backscatter coefficient:

$$\beta_{aer} = \left\{ 2.47\times10^{-6}\exp\left(\frac{-R}{2000}\right) + 5.13\times10^{-9}\exp\left(-\frac{\left(\frac{R}{1000}-20\right)^2}{36} \right) \right\} \left(\frac{532}{\lambda}\right)$$

(Horst Jager, et. al., Appl. Opt., 30(1), pp. 127-136, 1991)

In the next step we introduced the particle extinction to backscatter ratio (Lidar Ratio):

$$L_{aer}(\lambda, R) = \frac{\alpha_{aer}(\lambda, R)}{\beta_{aer}(\lambda, R)}$$ in analogy to molecular Lidar ratio

$$L_{mol}(\lambda) = \frac{\alpha_{mol}(\lambda)}{\beta_{mol}(\lambda)} = \frac{8\pi}{3} sr$$

In contrast to the molecular Lidar ratio, the particle Lidar ratio in general is range dependent because it depends on the size distribution, shape and chemical composition of the particles. For our simulation we used a constant value of 35 sr.

For horizontal measurement simulation we used the following equation:

$$a_{aer} = 2\times10^{-4}\left(\frac{532}{\lambda}\right)$$ for λ=355 nm

This gives a value of:

α_{aer}=3x10^{-4} (1/m) and β_{aer}=8.5x10^{-6} [1/(m*sr)]

B5 CALIBRATION METHODS

A Lidar system can be divided into two main functional units: the opto-mechanical transmitter-receiver unit, and the electronic data acquisition unit, each of which needs special tools for testing. The main problem of the transmitter-receiver unit is the a priori unknown range-dependent transmission, which enters as a factor into the Lidar equation. Usually only the incomplete overlap between the fields of view of the transmitter and the receiver is considered by the so-called overlap function, but in reality several other opto-mechanical features potentially have an influence, e.g. the incident angle dependence of the transmission of optical coatings of beam splitters and interference filters, vignetting of the light beam by mechanical apertures, and the spatial inhomogeneity of the sensitivity of the light detectors.

Methods that Raymetrics follows to calibrate and test its instruments:

Rayleigh Fit / Matching Method

The transmitter-receiver overlap has its main impact in the near range of the signal, but if the transmitter is not well aligned, the far range of the signal might also be affected. A well known check for the latter problem is a fit of the far range Lidar signal (assuming clear air in the upper troposphere) to the calculated clear air Rayleigh signal, the so called 'Rayleigh fit' or 'matching method'. Raymetrics provides software tools for easy Rayleigh fit calibration. This calibration procedure can be done in the field very easily and takes less than one minute.

Telecover Test

Before the shipment of any of our Lidar systems, extensive performance tests and calibration procedures are performed. One of the tools that Raymetrics uses for checking Lidar instrumentation is the newly developed 'Telecover Test', which is strongly suggested by EARLINET.

Raymetrics in addition provides all of the hardware and software required for such tests with all of our Lidar systems.

Electronic Data Acquisition

Light measurement is done in two ways in Lidar systems: in analogue mode, measuring the electron current from a detector after sufficient amplification with preamplifiers, and/or by means of counting amplified pulses of individual photons (photon counting method). Raymetrics uses special pulse generator techniques to calibrate and adjust analogue and photon counting measurements. It is well known, especially in analogue detection mode, that the main problem is various signals inducing signal distortions. If these distortions are neglected, errors of the Lidar signal inversion on the order of magnitude of 100% can result, although the distortion might be very small compared to the maximum signal. The Lidar signal should only be used over ranges where these errors are acceptable. This can be tested with a specially designed pulse generator.

Calibrating the 'Ranging'

In Lidar technologies two errors commonly occur if special attention is not paid:

There is always a delay between the emitted pulse and the data acquisition process, especially for analogue mode due to delays related to the pre-amplification process. But this is true as well in Photon Counting mode, although the phenomenon is not so pronounced. These delays reduce the accuracy of ranging of a Lidar.

Raymetrics uses special optical triggering that eliminates any delay in photon counting mode. In addition we use a near range target with a defined distance to the Lidar that produces a signal peak for Zero-bin calibration in analogue and photon counting modes. If such a target is not available we use a special procedure with an optical fibre to calibrate the 'ranging' of our systems.

Calibration Method for Depolarization Lidar

For calibration of the linear depolarization channels there are several methods, such as:

1. Rayleigh method (0^o)
2. 45^o method
3. +/- 45^o method
4. Multi-rotation-angle fit method
5. Three signal method
6. Unpolarized light source

1) Rayleigh method (0º)

This method is based on knowledge of the molecular linear depolarization ratio in an aerosol-free calibration range. However, since we can never be sure that the aerosol free region that we have assumed really is free, this method introduces many errors. It has been proved that this can give errors up to 260%. In addition this method cannot provide a range dependent calibration factor.

2) 45º method

With this method a 45º angle is produced between the laser polarization plane and the PBC. Rotation can be achieved mechanically, by using a half-wave plate or by the rotating of a polarizing sheet filter. This method is fast and has relatively few errors. However it gives large errors when there is a small angle difference between the laser polarization plane and the PBC at the default position (0º).

3) +/- 45º method

With this method the polarization plane of the PBC is turned +45 and -45 degrees from the default position (0 º). This method is fast accurate and it is 100 times less sensitive to errors produced by a small angle γ from the default position (0 º) compared to the 45º method.

4) Multi-rotation-angle fit method

With this method the PBC is rotated to several angles. It is a good method but it is time consuming and sensitive to atmospheric changes during the calibration procedure. In addition it exhibits low accuracy of the calibration constant.

5) Three signal method (detection of the total, cross and parallel signals separately)

With this method the Lidar detects a fraction of incoming light and the rest is beam-split by a Polarizing Beam Splitter. However such a set-up increases the cost of the instrument significantly (three deferred detected channels instead of two) and depends on large differences in $\delta(R)$.

6) Unpolarized light source

The beam path of rays from an unpolarized light source through the receiver optics is used. This method has many disadvantages and introduces errors.

Summary of theory for depolarization calibration

The total backscattering power P(r) is given by the Lidar equation:

$$P(R) = \frac{\chi \mathrm{E}_0 \mathrm{A} Q(R) c \beta(R,\lambda) \mathrm{T}(R,\lambda)}{2R^2}$$

For simplicity we form the equation in the following way:

$$P(r) = C \frac{\beta(r)\mathrm{T}(r)}{r^2}$$

The backscatter power **before the PBC** can be written as:

$$P(r) = C_{II} \frac{\left(\beta_{\mathrm{II}}^{aer} + \beta_{\mathrm{II}}^{mol}\right)\mathrm{T}(r)}{r^2} + C_{\perp} \frac{\left(\beta_{\perp}^{aer} + \beta_{\perp}^{mol}\right)\mathrm{T}(r)}{r^2}$$

The linear volume depolarization ratio δ^v is given by:

$$\delta^v(r) = \frac{\beta_{\perp}(r)}{\beta_{\mathrm{II}}(r)} = \frac{P_{\perp}(r)}{P_{\mathrm{II}}(r)}$$

However the measured signal ratio δ^* is given by:

$$\delta^*(r) = \frac{P_R(r)}{P_T(r)}$$

Where P_R and P_T are the reflected and transmitted signals from the PBC and are the ones which are recorded.

$$P_R(\phi) = \left[P_p(\phi)R_p + P_s(\phi)R_s\right]V_R \quad \text{and} \quad P_T(\phi) = \left[P_p(\phi)T_p + P_s(\phi)T_s\right]V_T$$

Where V_R and V_T include the optical transmittances of the receiver and the electronic amplification in each channel.

In addition the power components with respect to the incident plane of the PCB are:

$P_s(\phi) = P_{II}\sin^2(\phi) + P_{\perp}\cos^2(\phi)$ and $P_p(\phi) = P_{II}\cos^2(\phi) + P_{\perp}\sin^2(\phi)$

Φ is the angle between the plane of polarization of the laser and the incident plane of the PCB.

Combining the above equations we get:

$$\delta^*(\phi) = V^* \frac{\left[1+\delta^v \tan^2(\phi)\right]R_p + \left[\delta^v + \tan^2(\phi)\right]R_s}{\left[1+\delta^v \tan^2(\phi)\right]T_p + \left[\delta^v + \tan^2(\phi)\right]T_s}$$

Where $V^*=V_R/V_T$ and R, T are the transmittance and reflectance of the PBC.

In order to retrieve the total backscatter power P and δ^v from the measurements we need to know the V^* which is the calibration constant and we can get it through several methods.

For φ=0 we get:

$$V^* = \frac{T_p + \delta^v T_s}{(R_p + \delta^v R_s)}\delta*(0^0)$$

If we know δ^v for some range of the Lidar signal, we can determine V* (for example by using the linear depolarization ratio of air molecules). However a very low amount of strong depolarization aerosols, in the assumed clean range, causes very big errors on δ^v and thus of V*. So this method cannot be used for reliable data.

Another method is to turn 45 degrees (45-calibration method). φ=45 in that case:

$$V^* = \frac{T_p + T_s}{R_p + R_s}\delta*(45)$$

As can be seen, the calibration constant does not depend on δ^v. However it is very difficult and practically impossible to measure exactly the angle between the laser and the PBC. An error γ of the order of 1 degree causes a large error in V*.

With the proposed method we calculate V* from two subsequent measurements at exactly 90 degrees (φ=45+γ and φ=-45+γ) in that case:

$$V^* = \frac{T_p + T_s}{R_p + R_s}\sqrt{\delta^*(45) + \delta^*(-45)}$$

With this method (+/- 45 calibration method) it can be shown that the errors γ compensate each either over a large range of γ.

Retrieving of the linear depolarization ratio δ^v and linear aerosol depolarization ratio δ^p

If we know the calibration constant then:

$$\delta^v(r) = \frac{P_\perp(r)}{P_{II}(r)} = \frac{P_s(r)}{P_p(r)} = \frac{\frac{\delta^*(r)}{V^*(r)}T_p - R_p}{R_s - \frac{\delta^*(r)}{V^*(r)}T_s}$$

The total echo power is given by:

$P(r)=V^*(r)P_T(r)+P_R(r)$

$$\delta^{aer} = \frac{(1+\delta^m)\delta^v R - (1+\delta^v)\delta^m}{(1+\delta^m)R - (1+\delta^v)}$$

δ^m can be determined with high accuracy from radiosonde data (or by using a model).

$$R = \frac{\beta^m + \beta^{aer}}{\beta^m}$$

Where β^{aer} is retrieved from the total signal P using the Fernald/Klett inversion with a reference value $\beta^{aer}(r_{ref})$ at a reference range and known range dependent Lidar ratio L(r) (retrieved by an additional measurement with a Raman Channel).

Theory and the Inversion Problem of Lidar Technique

The power of the echo Lidar signal corresponding to a distance R can be written as

$$P(R) = \frac{\chi E_0 A Q(R) c \beta(R,\lambda) T(R,\lambda)}{2R^2} \qquad \text{eq. 1}$$

E_0 is the energy of a single laser pulse (J), c is the velocity of light, m/s. The term Q(R) is the laser beam receiver field of view overlap function, describing the range-dependent measurement geometry and can take values from 0 to 1. The β(R,λ) is the backscatter coefficient (1/(m*sr)) and it stands for the ability of the atmosphere to scatter light backwards. T(R) is the transmission term and describes how much light gets lost on the way from the Lidar to distance R and back.

$$T(R,\lambda) = \exp\left[-2\int_0^R \alpha(R',\lambda)\,dR'\right]$$ The factor 2 stands for the two-way transmission path.

$\beta(R,\lambda) = \beta_{mol}(R,\lambda)+\beta_{aer}(R,\lambda)$ and $\alpha(R,\lambda) = \alpha_{mol}(R,\lambda)+\alpha_{aer}(R,\lambda)$

α(R,λ) is the extinction coefficient.

Here we can rewrite the Lidar equation as

$$P(R) = C_0 \frac{\beta_\pi(R,\lambda)}{R^2} \exp\left[-2\int_0^R a(R,x)\,dx\right]$$

The factor C_0 is the Lidar system constant. One of the limitations of this equation is that includes more than one unknown. Therefore, it is considered to be mathematically ill posed and thus indeterminate. Such an equation cannot be solved without either a priori assumption about atmospheric properties along the Lidar range or the use of independent measurements of the unknown atmospheric parameters. Usually the use of a priori assumptions is the most common method.

Generally, the extinction coefficient. profile is the parameter of primary interest. A potential way to overcome this problem might be to make independent measurements of backscattering by the use of a combined Raman-elastic backscatter Lidar method (This method is used at our Raman Lidar Systems).

In order to extract a α(R) profile the calibration factor C_0 must be known and in addition, the relationship between backscatter and total extinction must in some way be established (Raman Lidar) or assumed (Klett solution)

$$P(R) = C_0 T_o^{\,2} \frac{\beta_\pi(R,\lambda)}{R^2} \exp\left[-2\int_{R_0}^{R} a(R,x)dx\right] \quad \text{eq. 2}$$

Where

$$T_o = \exp\left[-\int_{0}^{R_0} a(R,x)dx\right]$$

Methods-Solution for the Inversion of the Lidar Equation and Lidar Calibration

Intro

The simplest method is based on an absolute calibration of the Lidar system using only Co, whilst the other factors in the Lidar equation remain unknown (for example the two way atmospheric transmittance over the incomplete overlap zone). All self-sufficient elastic Lidar signal inversion methods developed to date require the use of one or more a priori assumptions that are chosen according to the particular optical situation. There are three basic inversion methods that Raymetrics uses depending on the Lidar type and the applications:

1. Slope method: This method is used for homogeneous atmospheres. In many of the cases, horizontal homogeneity is a reasonable assumption. With the slope method a mean value of α over the examined range in a homogeneous atmosphere is obtained.
2. The boundary point solution: This requires knowledge of or an a priori estimate of α at some point within the measurement range.
3. The optical depth solution: Here the total optical depth or transmittance over the Lidar measurement range should be known or assumed. In case of a clear and moderately turbid atmosphere the total α (or optical depth) is found be a solar radiometer.

In case of a two component atmosphere (with is the most usual case especially for vertical pointing systems)

The Lidar equation can be written as:

$$P(R)=C_0T_o{}^2\frac{\beta_{aer}(R)+\beta_{mol}(R)}{R^2}\exp\left[-2\int_{R_0}^{R}[a_{aer}(x)+a_{mol}(x)]dx\right]$$

In that case the backscatter coefficient can be found from the following equation:

$$\beta_{aer}(R)=-\beta_{mol}(R)+\frac{RCS(R)\exp\left\{2\int_{R}^{Rref}\left[L_{aer}(R)-\frac{8\pi}{3}\right]\beta_{mol}(x)dx\right\}}{C+2\int_{R}^{Rref}\left[L_{aer}(x)RCS(x)\exp\left(\int_{x}^{Rref}\left[L_{aer}(z)-\frac{8\pi}{3}\right]\beta_{mol}(z)dz\right)\right]dx}$$

This equation is solved iteratively downwards and gives the calibration constant of the instrument

$$C=\frac{RCS(R_{ref})}{\beta_{aer}(R_{ref})+\beta_{mol}(R_{ref})}$$

Calibration at height R_{ref} gives the system constant C.

Hardware Solution to the Inversion Problem

Use of Nitrogen Raman scattering for extinction measurements

Similar to an elastic Lidar, a Raman channel detects the inelastic backscatter Raman shifted radiation. Atmospheric gases like nitrogen and oxygen interact with the emitted radiation via the Raman Scattering process, causing light of longer wavelengths to be scattered. Thus in addition to elastically backscattered signal an extra backscattered wave-shifted component is detected. Because of the small value for the cross-sections of Raman scattering (so the small backscatter coefficient) the number of photons returning to the Lidar is small. **Because the probability of Raman scattering is proportional to λ^{-4} the use of short wavelengths increases the magnitude of signal.**

In addition the discrimination of Raman Photons from the background light is a problem. So operating at UV where the background radiation is smaller, it is strongly suggested. Since deep UV is strongly absorbed by Ozone and because the molecular scattering is reduced at longer wavelengths the optimum solution is around 350 nm. However discriminating Raman scattered photons from solar background is still an issue and requiring special measures. If the system is expected to operate during the day, the use of extremely narrow field of view in the receiving optics is required. For biaxial system this is almost impossible since the overlap is getting too high. In addition the system is getting susceptible to misalignments which are not good for an operational Lidar that have to be moved.

$$P_{N2}(R) = C_{N2}\frac{Q(R)N_{N2}\times\left.\frac{d\sigma}{d\Omega}\right|_{\mathrm{N2}}}{R^2}\exp\left[-2\int_{R_0}^{R}\left[a_{aer}(x,\lambda_L)+a_{mol}(x,\lambda_L)+a_{aer}(x,\lambda_{N2})+a_{mol}(x,\lambda_{N2})\right]dx\right]$$

Finally we can get

$$a_{aer}(R,\lambda_L) = \frac{\frac{d}{dR}\left[\ln\left(\frac{N_{N2}}{RCS_{N2}(R)}\right)\right]-a_{mol}(x,\lambda_L)-a_{mol}(x,\lambda_{N2})}{1+\left(\frac{\lambda_L}{\lambda_{N2}}\right)^{\gamma}}$$

α_{mol} are well known and can be found from Rayleigh scattering theory. The dominator corrects for the small difference in particulate attenuation between the laser and Raman scattered wavelengths. In horizontal direction for visibility from 3 to 20 km it is close to 1.3.

Finally when the Raman technique is used, the aerosol backscatter coefficient can be determined by reference to the signal at some height. The conventional assumption is made of the existence of a aerosol free area somewhere within Lidar measurements range $\beta_{aer}(R_{ref})=0$.

$$\beta_{aer}(R,\lambda_L) = -\beta_{mol}(R,\lambda_L)+\left[\beta_{aer}(R_{ref},\lambda_L)+\beta_{mol}(R_{ref},\lambda_L)\right]\frac{P(R_{ref},\lambda_{\mathrm{N2}})P(R,\lambda_L)N_{N2}(R)}{P(R_{ref},\lambda_L)P(R,\lambda_{N2})N_{N2}(R_{ref})}\exp\left[-\int_{R}^{R_{ref}}\left[a_{total}(x,\lambda_L)-a_{total}(x,\lambda_{N2})\right]dx\right]$$

Usually at R_{ref} $\beta_{aer}(R_{ref},\lambda_L)+\beta_{mol}(R_{ref},\lambda_L)\cong\beta_{mol}(R_{ref},\lambda_L)$

B6 POLARIZATION LIDAR BASICS

B6.1 Introduction

B6.1.1 Aerosols' Properties And Depolarization

Shape, size distribution and composition of aerosol particles influence their scattering characteristics and thus the radiative impact. ***The polarization Lidar technique*** (Sassen, 1991; Sassen, 2005) is a well-established method to distinguish ice clouds from water clouds and to identify layers with ice crystals in mixed–phase clouds. Freudenthaler et al. (1996) applied a scanning polarization Lidar to study the evolution of contrails. The technique has been used to identify the type of polar stratospheric clouds (Sassen, 2005) and volcanic ash in the troposphere and stratosphere (Sassen et al., 2007). The polarization Lidar is also well suited for aerosol profiling and allows us to unambiguously discriminate desert dust from other aerosols. Based on model calculations, it has been demonstrated that the spectral dependence of the dust linear depolarization ratio is sensitive to the size distribution of the nonspherical scatterers. Thus, observations of the linear depolarization ratio at several wavelengths may be used in retrieval schemes (Dubovik et al., 2006) to improve the estimation of the microphysical properties of dust from optical measurements (Wiegner et al., 2008). First dual-wavelength aerosol polarization Lidar measurements were presented by Sugimoto et al. (2002).

B6.1.2 Overview of Lidar Linear Depolarization

Lidar often uses polarized laser beams for sounding the atmosphere, and depolarization measurements have long been used in lidar investigation. ***The main application of depolarization measurements is the discrimination and the extent of liquid and solid phase clouds and aerosols***. Lidar signal is the superposition of scattering that is due to molecules and scattering that is due to particles that are greater than the typical dimensions of atmospheric molecules. Molecular backscattering follows Rayleigh theory, in which case changes in polarization are due only to the polarizability of molecules: The contribution to the orthogonal polarization is ;1%.2 Scattering processes on aerosols must be treated by means of Mie theory if particles are spherical or with Stokes matrix if particles are nonspherical. From Mie theory the polarization of incident light is conserved after backscattering, whereas backscattering on solid particles can change the polarization direction. If a laser beam is emitted with a definite polarization, the presence of polarized light in the perpendicular component denotes the presence of backscattering from nonspherical particles. Hence polarized backscattering, parallel to the laser polarization is considered, and depolarization is used to refer to the perpendicular component of polarized backscattered light. ***Three points*** must be taken into account during treatment with depolarization studies: 1. multiple scattering processes induce depolarized backscattering even in the presence of spherical scatterers, 2. particles with small dimensions compared with the lidar wavelength do not show depolarization even if they are not spherical and 3. emitted light polarization must remain stable throughout the measurement.

B6.1.3 Polarization Method Applied To Modern Lidar Systems: Theory and Methodology

Measurements of the ***linear depolarization ratio δ*** with lidars are often performed with the aim to just discern between the dry, the liquid and the ice phase of aerosols and clouds in the profiles of one lidar system, which requires only a relative measure of δ with a low accuracy of the absolute values. The total backscattered power $P(r)$ with their dependence on the distance r from the lidar is described by the lidar equation

$$P = \frac{\eta\beta(r)\tau^2(r)}{r^2} \qquad (1)$$

where η is the system constant, β the backscatter coefficient and the factor τ^2 accounts for the atmospheric transmittance on the way from the lidar to the scattering volume, and back. For the determination of δ the lidars used in this study measure the atmospheric backscatter signals in two receiver channels, parallel- and cross-polarized with respect to the plane of the linear polarized output of the laser beam. The two polarization components are separated in the receiver by means of ***polarizing beam splitter cubes (PBC).*** But this separation is not perfect. Furthermore the polarizing beam splitter might be misaligned with respect to the plane of polarization of the emitted laser beam, and additionally, a rotation of the polarization plane is used for the relative calibration of the two receiver channels. Therefore, we show the necessary equations of the angle ϕ between the plane of polarization of the laser and the incident plane of the polarizing beam splitter cube, according to Fig. B2.

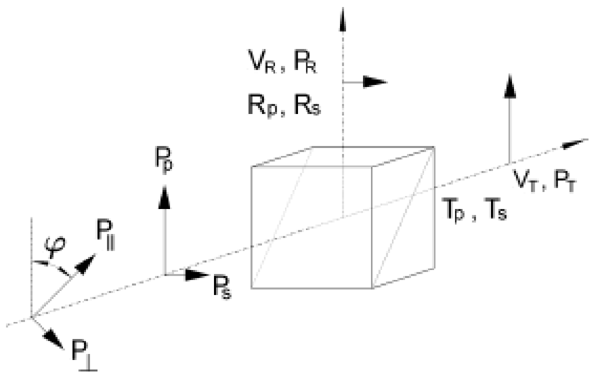


***Fig. B2*. Signal power components in a receiver of a depolarization lidar with a polarizing beam splitter cube with reflectivity R_p and R_s and transmittances T_p and T_s for linearly polarized light parallel (p) and perpendicular (s) to the incident plane of the polarizing beam splitter. P_R and P_T are the measured quantities in the reflected and transmitted path, respectively, and V_R and V_T are the corresponding amplification factors including the optical transmittances.**

The backscatter powers before the PBC are (skipping the range dependence in the following for convenience)

$$P_\perp = \frac{\eta_\perp \left(\beta_\perp^{p} + \beta_\perp^{m}\right) \tau^2}{r^2},$$
$$P_\parallel = \frac{\eta_\parallel \left(\beta_\parallel^{p} + \beta_\parallel^{m}\right) \tau^2}{r^2}, \qquad (2)$$

with the system constants $\eta_\parallel$ and $\eta_\perp$ including here only the laser power and the telescope aperture, assuming negligible diattenuation of the optics before the PBC, for example, a telescope or dichroic beam splitters. The backscatter coefficient β is split up in the parallel- (β_) and cross-polarized ($\beta_\perp$) components of the backscatter from particles (β^p) and from molecules (β^m). The total backscatter power P and the total backscatter coefficient β are the sum of both polarized components:

$$P = P_\parallel + P_\perp. \qquad (3)$$

The ratio of the total backscatter coefficient to the molecular component is called the backscatter ratio **R**

R = *βm* + *βp βm* , (4)

and the ratio of the total cross- to the total parallel-polarized backscatter coefficient is called the linear volume depolarization ratio δ^v:

$$\delta^v = \frac{\beta_\perp}{\beta_\|} = \frac{P_\perp}{P_\|}. \qquad (5)$$

The power components with respect to the incident plane of the PBC are

$$P_s(\varphi) = P_\| \sin^2(\varphi) + P_\perp \cos^2(\varphi),$$
$$P_p(\varphi) = P_\| \cos^2(\varphi) + P_\perp \sin^2(\varphi). \qquad (6)$$

The subscripts p and s denote the planes parallel and perpendicular to the incident plane of the PBC (see Fig. 1), respectively, and ϕ is the angle between the plane of polarization of the laser and the incident plane of the PBC. Depending on this angle, the cross polarized signal $P\perp$ can be measured in the reflected (for $\phi = 0^\circ$) or in the transmitted path ($\phi = 90^\circ$). Hence, we denote the power measured in the reflected and transmitted paths with the subscripts R and T, respectively. Behind the PBC the total reflected (P_R) and transmitted (P_T) power components are

$$P_R(\varphi) = [P_p(\varphi)R_p + P_s(\varphi)R_s]V_R,$$
$$P_T(\varphi) = [P_p(\varphi)T_p + P_s(\varphi)T_s]V_T. \qquad (7)$$

The amplification factors V_R and V_T include the optical transmittances of the receiver and the electronic amplification in each channel. PR and PT are the quantities we actually record with the data acquisition. For the following it is convenient to introduce a relative amplification factor $V*$ and the measured signal ratio $\delta*$

$$\delta^*(\varphi) = \frac{P_R(\varphi)}{P_T(\varphi)}, \quad V^* = \frac{V_R}{V_T}. \qquad (8)$$

With eqs. (6)–(8), we achieve

$$\delta^*(\varphi) = V^* \frac{[1 + \delta^v \tan^2(\varphi)]R_p + [\tan^2(\varphi) + \delta^v]R_s}{[1 + \delta^v \tan^2(\varphi)]T_p + [\tan^2(\varphi) + \delta^v]T_s}. \qquad (9)$$

B6.1.4 Retrieval of the Linear Volume Depolarization Ratio δ^v

Once $V*$ is known, we get δ^v with eqs. (5) and (6), for a regular measurements at $\phi = 0°$:

$$\delta^v = \frac{P_\perp}{P_\parallel} = \frac{P_s}{P_p}, \quad \varphi = 0°. \tag{10}$$

As for commercial PBCs, Rs is usually much closer to 1 than Tp, the noise and error caused by the cross-talk from the strong parallel-polarized signal to the weaker cross-polarized signal are reduced if the parallel polarized signal is detected in the reflected s-branch of the PBC. For this setup $\phi = 90°$, and we get

$$\delta^v = \frac{P_\perp}{P_\parallel} = \frac{P_p}{P_s}, \quad \varphi = 90°. \tag{11}$$

From eqs. (5)–(8) follows

$$\frac{P_s}{P_p} = \frac{\frac{\delta^*}{V^*}T_p - R_p}{R_s - \frac{\delta^*}{V^*}T_s} \tag{12}$$

And

$$P = P_p + P_s = \frac{V^*\left(R_s - R_p\right)P_T + \left(T_p - T_s\right)P_R}{V_R\left(T_pR_s - R_pT_s\right)}. \tag{13}$$

The knowledge of V_R is not necessary, as we only need a relative signal for the lidar signal inversion with the Fernald/Klett retrieval (Klett, 1985; Fernald, 1984), and thus we can set it to VR = 1. In case the parameters of the polarizing beamsplitter cube are

Ts = 1 − Rs, Rp = 1 − Tp, (14)

B6.1.5 Retrieval of the Linear Particle Depolarization Ratio δ^P

The δ^p can be calculated from eqs. (2)–(5) using

$$\delta^p = \frac{\beta_\perp^p}{\beta_\parallel^p} = \frac{(1+\delta^m)\,\delta^v \boldsymbol{R} - (1+\delta^v)\delta^m}{(1+\delta^m)\boldsymbol{R} - (1+\delta^v)} \qquad (15)$$

with the height in dependent linear depolarization ratio of air molecules:

$$\delta^p = \frac{\beta_\perp^p}{\beta_\parallel^p} = \frac{(1+\delta^m)\,\delta^v \boldsymbol{R} - (1+\delta^v)\delta^m}{(1+\delta^m)\boldsymbol{R} - (1+\delta^v)} \qquad (16)$$

which can be determined with high accuracy (Behrendt and Nakamura, 2002). The backscatter ratio **R** can be retrieved from the total signal *P* using, for example, the Fernald/Klett inversion with a reference value βp(r0) at a reference range r0 and known range-dependent lidar ratios *S*

$$S = \frac{\beta^P}{\alpha^P}, \qquad (17)$$

where α^p is the particle extinction coefficient. $S(r)$ must be retrieved by an additional measurement, for example, with a Raman channel. The values of δ^v and R are subject to systematic and statistical (noise) errors.

B6.2 Experiments And Results (From Samum Field Campaign) [11]

B6.2.1 Results and Comparison

During Saharan Mineral Dust Experiment (SAMUM), it was attempted to measure a possible wavelength dependence of the dust particle linear depolarization ratio δ^p, with four different lidar systems at four wavelengths as inputs for model calculations of δ^p regarding the particles shapes and size distribution. Thus, the uncertainty of the absolute values must be known and should be small compared with the expected natural variance. The paper presents linear particle depolarization ratio δ^p measurements at four wavelengths. However, MULIS (532 nm) and the airborne DLR-HSRL (532 and 1064 nm) provided the most accurate measurements of the linear depolarization ratio. These lidar measurements represent the backbone of the entire SAMUM polarization lidar activity. First, we compare the height resolved profiles of δ^p of all lidars at four dates with coincident measurements in Fig. B3. The lidar ratios *S* used for the depolarization retrieval of MULIS at 532 nm were adopted from the coincident DLR-HSRL measurements (displayed in Fig. 6 as broken lines) with errors in the range of ±5 sr. For non-coincident measurements *S* is assumed to be 50 sr ± 10 sr.

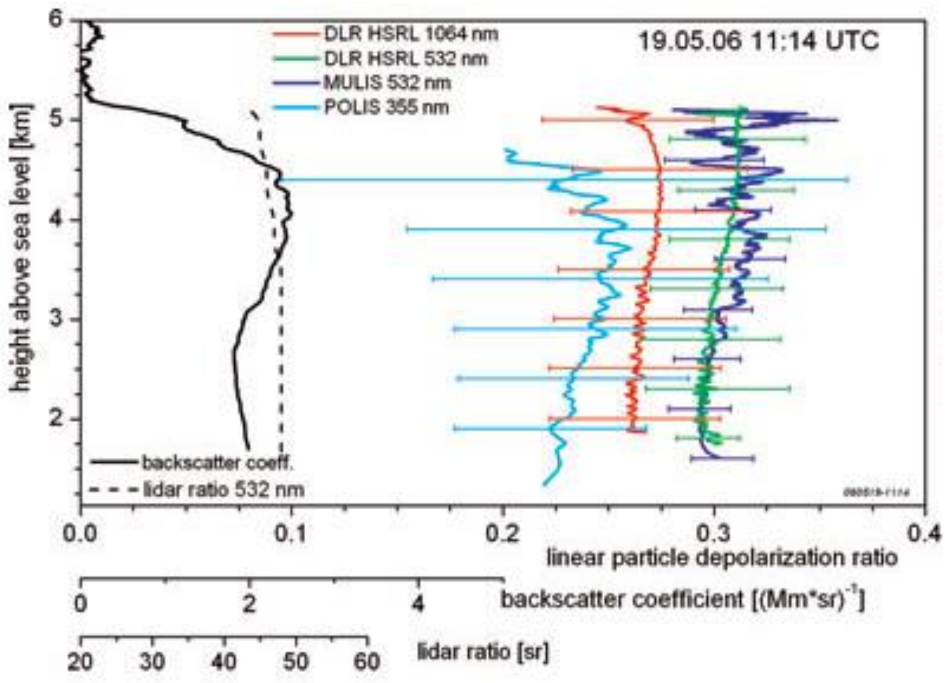


Fig. B3. Particle linear depolarization ratio profiles on 19 June 2006 at several wavelengths. The error bars indicate the systematic uncertainties

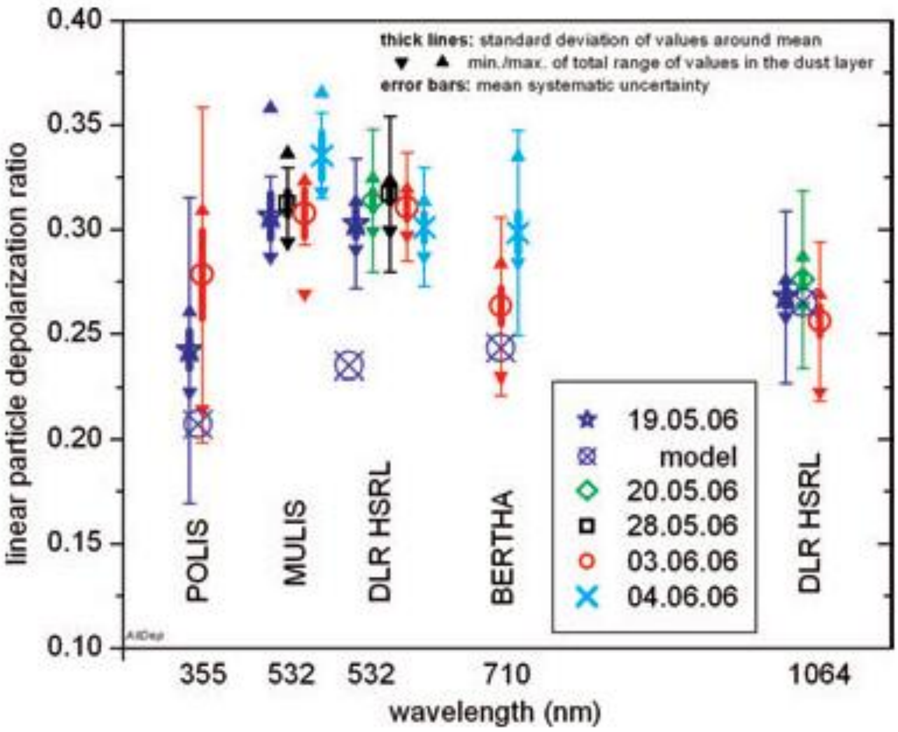


Fig. B4. Mean linear depolarization ratio of particles in the dust layer over the wavelength of the four lidar systems at four different dates during SAMUM 2006 and results of model calculations for the reference case 19 May 2006 (Wiegner et al., 2008).

The linear depolarization ratio was measured with MULIS continuously during SAMUM. Retrievals of the linear particle depolarization ratio δp at selected dates, together with error bars and statistical information are displayed in Fig. B5 and listed in Table 2, together with the measurements from the other lidars

from Fig. B4. The full ranges of the δp values are often asymmetric to the mean towards smaller δp. These smaller values mostly stem from the dust layer top caused by temporal averaging of the lidar measurements with changing dust layer top height.

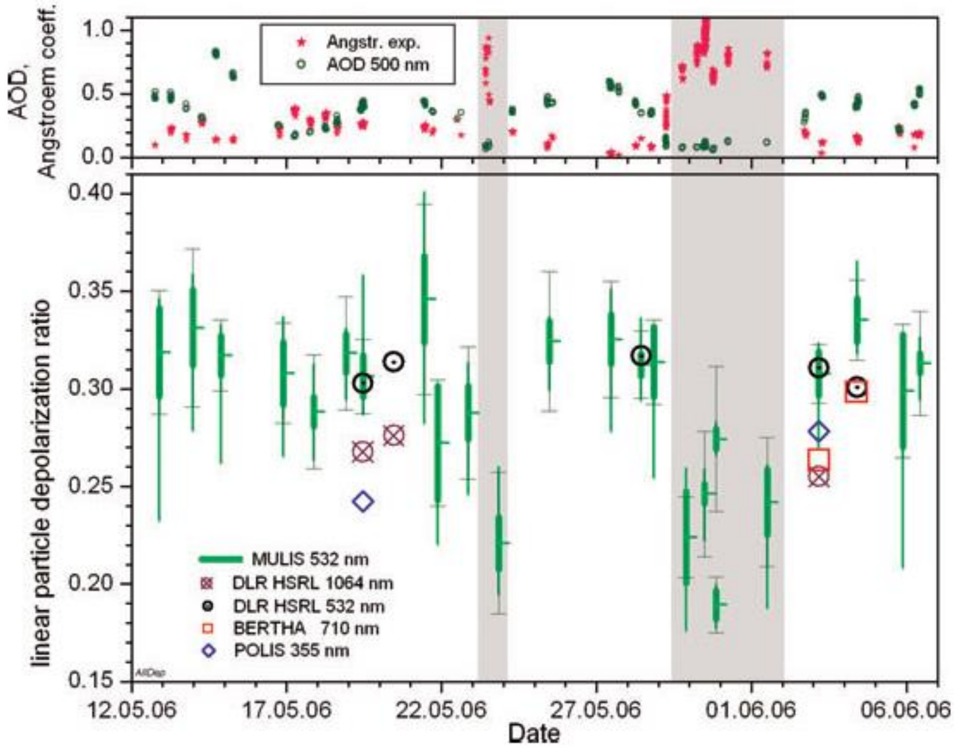


Fig. B5. Mean linear particle depolarization ratio δp in the dust layer over Quarzazate during the SAMUM 2006 period for selected dates (lower plot) and aerosol optical thickness at 500 nm and Ångstr¨om exponent (440–870 nm) from SSARA sun photometer at Quarzazate (upper plot).

The AOD at 500 nm and the AE (440–870 nm) derived from the SSARA measurements temporally closest to the MULIS measurements are displayed on top of Fig. B5. For night time, when no sun photometer data were available, the AE values were interpolated and the AE errors show the slope. Comparing the time-series in Fig. B5 we see low δp and high AE in the shaded time periods, and high δp and low AE else, whereas there is no evidence for a correlation between δp and AOD, as expected.

More details and information about this field campaign can be found at [11].

1. REFERENCES

[1] Sassen, K. 2005. Polarization in lidar. In: *Lidar* (ed. C. Weitkamp). Springer, New York, 19–42.

[2] Sassen, K. 1991. 'The polarization lidar technique for cloud research: a review and current assessments. *Bull. Am. Meteorol. Soc.* **72**, 1848– 1866.

[3] Freudenthaler V. et al, 'Depolarization ratio profiling at several wavelengths in pure Saharan dust during SAMUM 2006', *Tellus* (2009), 61B, 165–179.

[4] Cairo F., Donfrancesco G. Di, Adriani A., Lucio Pulvirenti, and F. Fierli, Comparison of various linear depolarization parameters measured by lidar, *APPLIED OPTICS,* 20 July 1999 y Vol. 38, No. 21, pp. 4425-4432.

[5] Sassen, K., Zhu, J., Webley, P., Dean, K. and Cobb, P. 2007. Volcanic ash plume identification using polarization lidar: Augustine eruption, Alaska. *Geophys. Res. Lett.* **34**, doi:10.1029/2006GL027237.

[6] Freudenthaler, V., Homburg, F. and J¨ager, H. 1996. Optical parameters of contrails from lidar measurements: linear depolarization. *Geophys. Res. Lett.* **23**, 3715–3718.

[7] Dubovik, O., Sinyuk, A., Lapyonok, T., Holben, B. N., Mishchenko, M. and co-authors. 2006. Application of spheroid models to account for aerosol particle nonsphericity in remote sensing of desert dust. *J. Geophys. Res.* **111**, doi:10.1029/2005JD006619.

[8] Wiegner, M., Gasteiger, J., Kandler, K.,Weinzierl, B., Rasp, K. and coauthors. 2008. Numerical simulations of optical properties of Saharan dust aerosols with special emphasis on the linear depolarization ratio. *Tellus* **61B**, doi:10.1111/j.1600-0889.2008.00381.x.

[9] R. Agishev, B. Gross, F. Moshary, A. Gilerson, **'Development of a SNR parameterization scheme for general lidar assessment,'** *Appl. Phys.* B 00, 1–12, 2005.

[10] QIU Zong-jia, CHEN Si-ying*, ZHANG Yin-chao, WANG Yu-zhao, NI Guo-qiang, '**Weak signal detection system and noise analysis for aerosol detection Lidar,'** *International Symposium on Photoelectronic Detection and Imaging 2009: Laser Sensing and Imaging,* SPIE 2009.

[11] R.M. Measures, *Laser Remote Sensing: Fundamentals and Applications,* Wiley, New York, 1994.

[12] Hamamatsu Photonics, *Photomultiplier Tubes*, Technical Manual.

Summary of equations for backscatter coefficient. calculation

Invert Klett Technique (Far – end solution)

$$\beta(r) = \frac{RCS(r) * \exp\left(2 * (LR - LR_{mol}) * \int_{r}^{r_{ref}} \beta_{mol}(r')dr'\right)}{\frac{RCS(r_{ref})}{C * \beta_{mol}(r_{ref})} + 2 * LR * \int_{r}^{r_{ref}} RCS(r') * \exp\left(2 * (LR - LR_{mol}) * \int_{r'}^{r_{ref}} \beta_{mol}(r'')dr''\right) r'}$$

$$\beta(r) = \beta_{mol}(r) + \beta_p(r)$$

Where

p is for particles (aerosols) and mol for molecular (Rayleigh)

$$LR_{mol}(r) = \frac{a_{mol}(r)}{\beta_{mol}(r)} = \frac{8\pi}{3}, \quad LR(r) = \frac{a_p(r)}{\beta_p(r)} = const = LR$$

$RCS(r) = P_c(r) * r^2$ This is the Range Corrected Signal.

$P_c(r)$ is the background corrected lidar signal.

$C = \frac{\beta_p(r_{ref}) + \beta_{mol}(r_{ref})}{\beta_{mol}(r_{ref})}$ Usually at r_{ref} we assume that $\beta_p(r_{ref}) = 0$ so C=1.

In any other case you can try different values for C.

How you can calculate the $\beta_{mol}(r)$

$$\alpha_{mol}(r)=\frac{8\pi^3}{3}\cdot\frac{\left(m_{air}{}^2-1\right)^2}{\lambda^4 N_S{}^2}\cdot\frac{6+3\delta}{6-7\delta}\cdot N_S(r)\cdot\frac{T_0}{p_0}\cdot\frac{p(r)}{T(r)}$$

$$\beta_{mol}(r)=\frac{\alpha_{mol}(r)}{LR_{mol}}=\frac{3}{8\pi}\cdot\alpha_{mol}(r)$$

T_0 = 288.15 K

p_0 = 1013 hPa

$$m_{air}{}^2-1=\left|\begin{array}{l}5.7148\cdot10^{-4}\rightarrow355\\5.5647\cdot10^{-4}\rightarrow532\\5.48\cdot10^{-4}\rightarrow1064\end{array}\right.$$

$$\delta=\left|\begin{array}{l}0.0301\rightarrow355\\0.0284\rightarrow532\\0.0273\rightarrow1064\end{array}\right.$$

$$N_S(r)=N_{S0}\cdot\frac{p_g}{T_g}\cdot\frac{T_0}{p_0}\cdot\exp\left(-\frac{r}{10200}\right)$$

N_{S0} = 2.547 10^{25} molecule/m^3

in troposfera (0 → 12000 m):

$T(r)=T_g-\gamma\cdot r$ γ= 0.0065 K/km

$$p(r) = p_g \cdot \left[1 - \frac{T(r)}{T_g}\right]^{\frac{M \cdot g}{\gamma \cdot R}}$$

unde: M = 0.0289644 kg/mol

g = 9.81 m/s^2

R = 8.31432 J/K

Tropopause (12000 → 15000 m)

$$T(r) = T(r = r_{troposhere} = const)$$

$$p(r) = p(r = r_{troposhere}) \cdot \exp\left\{-\frac{M \cdot g}{T(r = r_{troposhere}) \cdot R} \cdot (r - r_{troposhere})\right\}$$