LIDAR for Atmospheric Measurement and Probing

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***Abstract*—This paper describes a LIDAR for atmospheric measurement and probing (LAMP). The LAMP system is a commercial LIDAR unit that uses the design of boundary layer LIDAR (BLL), an optical radar technology developed at the National Atmospheric Research Laboratory (NARL) for atmospheric applications. The LAMP technology is useful for remote monitoring of atmospheric particulate and clouds in the troposphere during nocturnal conditions.**

Keyword - LIDAR, Atmosphere, Remote monitoring, Atmospheric particulate, Clouds

I. INTRODUCTION

LIDAR, stands for Light Detection And Ranging, is an active optical remote sensing instrument. It is an innovative technique that uses laser for probing the planetary atmosphere [1, 2, and 3]. Atmospheric LIDARs use narrow pulsed lasers. Flash-lamp pumping is generally employed in the generation of Q-switched lasers. Flash-lamp pumped (FLP) systems produce lasers at low repetition rates with high pulse energies. Several problems such as limited lifetime of flash-lamp and requirement of pump motors for driving deionised (DI) water to cool the laser cavities limit the applications of FLP systems in strategic fields. Recent technologies employ semiconductor diodes as pump sources for solid-state lasing materials. These units built-in with accousto-optic modulator (AOM) produce pulse modulation in laser at high repetition rates. Diode pumped solid-state (DPSS) lasers offer several advantages over conventional FLP types. DPSS lasers generate radiations in Infrared (IR), visible and ultraviolet (UV) spectral bands. The commercially available DPSS lasers offer features like high pulse repetition rate, excellent beam profile, compact size, narrow pulsing, good spectral purity, long-life and stable output. Moreover, DPSS lasers operate with forced air cooling.

Recently LIDARs were employed with Q-switched DPSS lasers for atmospheric investigations. Micro pulse LIDAR [MPL] is a version of DPSS laser based new generation LIDAR technology. In recent years, MPLs have become increasingly popular owing to their unattended operation and more suitable for long-term measurement of atmospheric parameters [4]. The MPL uses high repetition rate, low pulse energy lasers for atmospheric investigations [5].

The MPL technology was successful globally in the studies of high altitude clouds [6], atmospheric aerosol [7], slow air motion [8], aerosol extinction [9], global monitoring of aerosols and clouds [10], boundary layer aerosol [11], internal boundary layer [12, 13], horizontal visibility [14], low humidity layer [15], multilayer clouds [16], aerosol studies in traffic [17] and in airborne studies [18].

In India, recently a portable LIDAR [19, 20] was successfully demonstrated at the National Atmospheric Research Laboratory (NARL) for atmospheric studies. The NARL is a Department of Space (DOS) unit operates several LIDAR instruments for atmospheric studies [21, 22, 23, and 24]. The portable LIDAR uses micro pulse operation and was developed under boundary layer LIDAR (BLL) project. The BLL was a popular LIDAR technology in India owing to "its" low-cost design and numerous applications in the scientific field. The BLL was constructed with several innovative features and was filed for intellectual property rights under ISRO in the year 2009 [25]. The BLL technology was successfully used by the Indian scientific community for studies on aerosol properties during low pressure [26] and foggy conditions [27], aerosol loading during cyclone [28], optical properties of aerosols and clouds [29], emissions from anthropogenic sources [30], aerosol mass concentrations associated with planetary boundary layer [31], long-range transport of aerosols from agriculture [32], Influence of vehicular traffic on urban air quality [33], Long-range transport of dust aerosols [34], Radiative effects of elevated aerosol layer [35], Influence of boundary layer dynamics on pollutant concentrations [36], and atmospheric aerosol properties during biomass-burning events [37], aerosol particles seasonal variation over an Urban polluted-site [38] and washout of airborne particles with rain [39].

(a) Boundary Layer Lidar (BLL) **(b) LAMP**

Figure 1 Pictures show (a) the NARL patent filed boundary layer LIDAR (BLL) and Industry fabricated LIDAR for Atmospheric Measurement and probing (LAMP). The LAMP system is being manufactured in the country by M/s General Optics (Asia) Ltd, Pondicherry under the technology transfer from NARL-DOS.

The BLL technology was successfully transferred to an Indian Opto-electronic industry for fabrication of commercial LIDAR in the country. The commercial LIDAR was named as LAMP. LAMP stands for LIDAR for atmospheric Measurement and Probing. The LAMP is the first commercial atmospheric LIDAR in India. The LAMP was realized in two phases. Several limitations of BLL unit have been corrected in the present LAMP version. The LAMP employs a compact single barrel construction that contains a laser transmitter and optical receiver units. This configuration makes the optical alignment simpler and easier to do at any observational site. The LAMP unit has equipped with a better version of laser source that can be controlled through RS-232 serial bus to set the laser source parameters. The entire LIDAR is possible to control through Ethernet interface using custom built software. Moreover, the LIDAR employs several features like tilting arrangement in the elevation (EL) plane, a provision of optical front window for environmental protection to the telescope optics and a silica gel pocket for desiccation (for transmit and receive assembly) and a provision of nitrogen purging to overcome the humidity effects. The receiver and transmitter units employed uses high quality indigenous optical parts. This paper briefly describes the engineering details of LAMP unit, the test results and the preliminary atmospheric observations obtained at “its” fabrication-site in Pondicherry.

II. LAMP SYSTEM ENGINEERING CONFIGURATION

LAMP uses an optical radar technique that employs narrow laser pulses for transmission. The radar uses a high repetition rate, low pulse energy laser for probing the atmosphere and generally operated in the vertical direction. The laser backscattered photon returns are collected using an optical collector known as a telescope. The collected photon returns are converted into electrical pulses using a photo-detector such as photomultiplier tube. The electrical pulses are level conditioned as per discriminator setting and counted using a photon counter such as Multichannel scalar (MCS). A trigger signal generated at regular intervals using the laser source is employed to time the photon counter to generate the photon count profile that constitutes the LIDAR signal profile. The typical block diagram of an optical radar is shown in figure 2. Figure 2 shows that the low energy laser pulse emitted from an optical radar illuminates the aerosol/cloud particles and get scattered. The scattered light is collected by the telescope, optically detected and electronically amplified to measure in photon counts. The laser backscatter photon counts measured up to an altitude of 20 km, at a specified spatial resolution. From the measured values, noise subtraction and range correction (noise subtracted data multiplied by square of the range) are done using a custom-developed software. Using this software, the observational data can be plotted with options such as Raw-photon count vs. Range, Noise-subtracted vs. Range and Range-Corrected vs. Range for immediate analysis on atmospheric aerosol and cloud scattering.

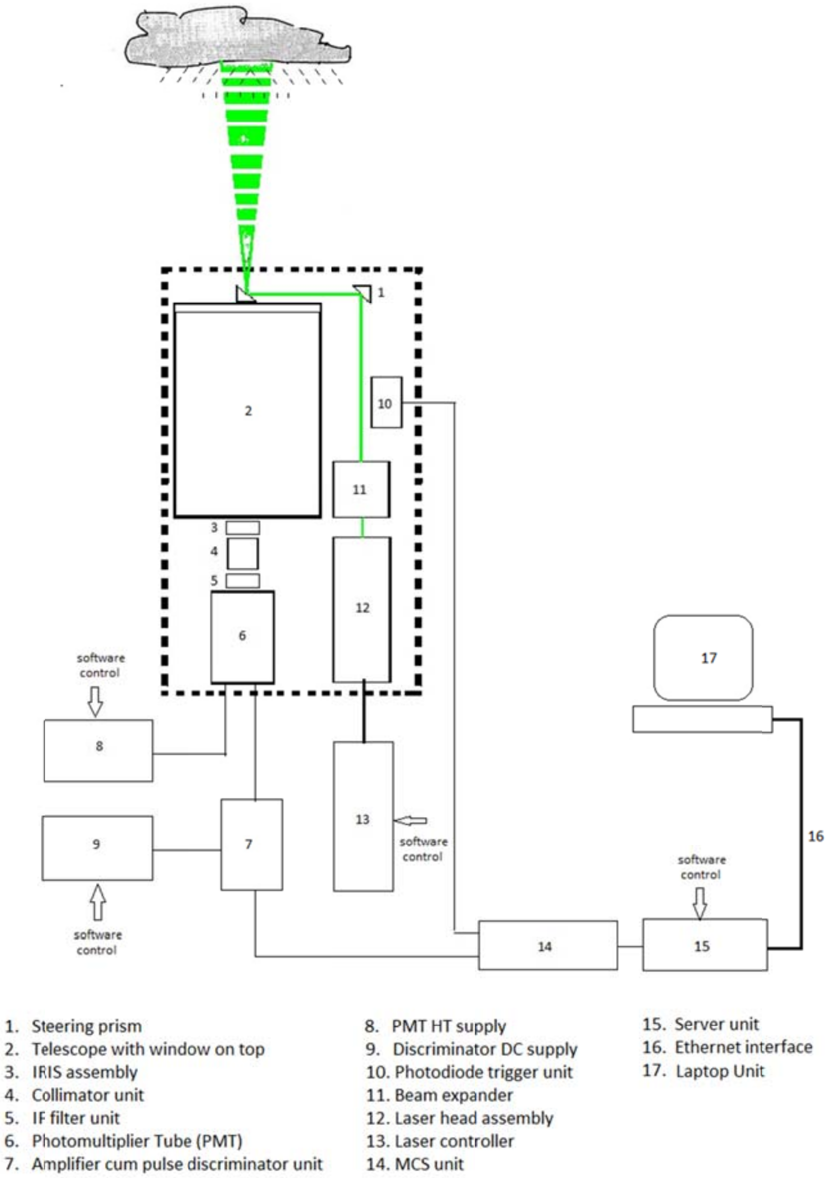

Figure 2. LAMP system block diagram

Figure 3(a) shows the photograph of laser source employed in the LAMP system. The LAMP uses a diode pumped Nd:YAG laser with built-in acousto-optic modulator (AOM) to do active Q-switching at narrow pulse operation. The active Q switching of AOM is possible using internal/External triggering methods and also possible through PC controlled RS-232 bus. The laser unit has equipped with feedback to correct the output and hence provides long-term consistent operation. Although the laser employed is capable of delivering 25 µJ energy per pulse over a wide range of frequencies, but the LAMP was designed to operate at 4 µJ energy with 2500 pulse repetition. Figure 3(b) illustrates the test output on the temporal variation of laser energy observed over a period of 9 hours of continuous operation that was recorded on 21 December 2010 at the factory site. The test results indicate that a variance of 0.01284 for a mean value of laser energy at 4.31507 µJ. The average pulse width of laser generated by the LAMP is about 7±3 nsec at a pulse stability of typically 6%. The laser beam profile confirms the Gaussian response at far-end with a maximum beam divergence of 1.5 mrad. The generated laser pulses are highly polarized and confines to horizontal mode. The maximum delay in the laser generation about Q-switching is less-than 50 nsec as per the manufacturer specifications. The laser operates in the temperature range of 15 to 35°C with maximum RH conditions less-than 80%. The line power conditions required for safe laser operations are in the range of 90 to 265 V AC. The laser head assembly is provided with an external fan cooling arrangement for controlling the temperature conditions of laser unit during operation. The laser unit requires a stabilization time period of 10 minute to conform to the manufacturer specifications. The laser output is made collimated using an external beam expander. The expanded laser beam divergence is specified as 0.2 mrad according to the LAMP design details. A photo-diode beam sampler is positioned in the collimated laser beam path to obtain the laser pulses for gating the receiver unit. The collimated laser beam is steered into the atmosphere using a set of prisms that are positioned at right angles to each other as indicated in Figure 2. Figure 4(a) illustrates the photograph of LAMP telescope front-end optics. One of the beam steering prisms is located at the central part of the telescope front-end optics to make the LAMP to function in the coaxial mode of operation.

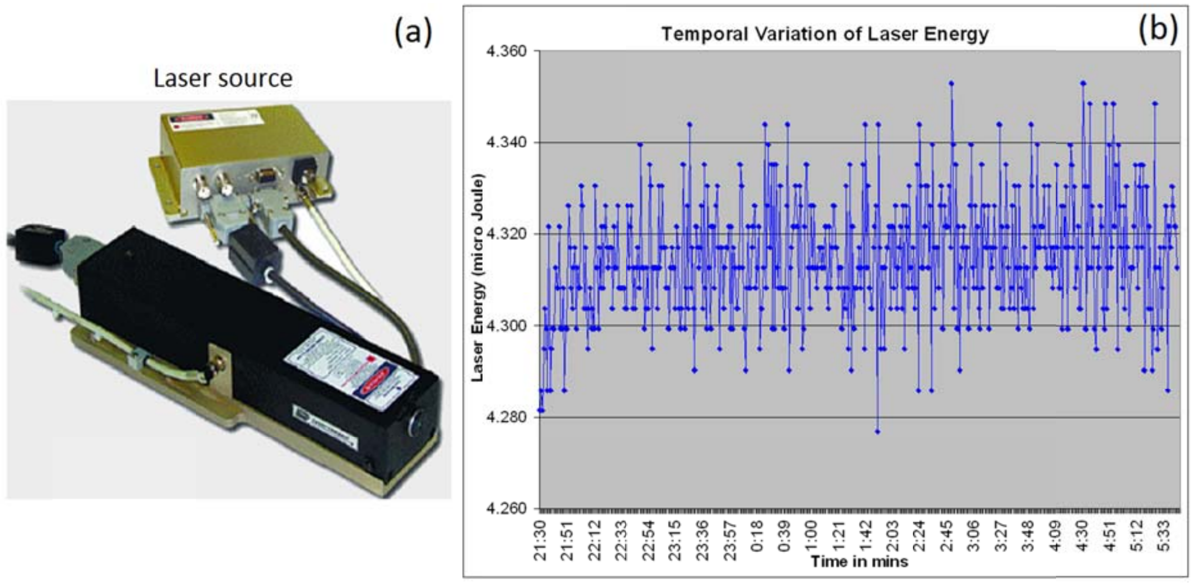

Figure 3 (a) The picture of diode pumped Nd:YAG laser source employed in the LAMP system (b) Temporal variation of laser energy recorded over a time period of 9 hours.

The optical collector of LAMP is a reflecting telescope having Cassegrain configuration. The telescope primary mirror design uses the parabolic surface. The design specification of primary mirror diameter is 150 mm. The primary mirror was fabricated using Pyrex material and the mirror has a central bore dia of 29 mm. As per the manufacturer specifications, primary mirror wavefront and reflectivity are given as $\lambda/20$ rms [@633 nm] and 98% respectively at the design wavelength. The design of secondary mirror employs a hyperbolic surface. The secondary mirror diameter was specified at 31 mm and has been fabricated using fused silica material. The effective focal length of the telescope unit is 1314 mm. The top of the Cassegrain telescope is covered by using a transparent window for prevention of dust entry into the telescope unit. Further, the telescope unit has been purged with Nitrogen gas to make the light collector as fog proof and humidity proof. A silica gel desiccant was attached to the light collector unit to absorb the trapped water vapour inside the telescope unit. When silica gel is fully saturated with moisture, it turns into pink colour from "its" original blue colour. When it turns pink, it has to be replaced with fresh (blue silica gel) or the silica gel has to be reactivated, to keep the instrument dry. The design specification of field of view (FOV) of LAMP telescope is about 400 mrad that is enough to collect the laser backscattered photons from the atmosphere with minimum background noise. For noise reduction, an interference filter with central wavelength (CWL) of 532nm is used. The filter is designed for use at 30 ± 1^0C. A heater was provided to ensure the filter temperature maintained at a specified value. The system must be operated in a cubicle to maintain a temperature between 16 and 23 ^{0}C for the heater to work properly. The filter is prone to degradation and has a limited lifetime. The LAMP manufacturer recommended the change IF filter once in 18 months for obtaining good signal strength. The transmission parameters of different optical units employed in LAMP are listed in Table 4(b). The measurement table contains parameters such as magnification of beam expander and transmission parameters of transmitter optics (laser with beam expander), telescope, collimator, and IF filter respectively. These parameter values are given for the 532 nm wavelength and are important for calculating the performance characteristics of LAMP system. The pulse signals from PMT pass through a discriminator unit and fed to a personal computer (PC) based multichannel analyser (EG&G Ortec model MCS-pci). The instrumental-bin width is normally set at 200 ns, which corresponds to a height resolution of 30 m. Usually 150000 shot-integrated photon count profile constitutes the raw data that correspond to a time resolution of 60 Sec.

(a)

Test Parameters for LAMP008 on 21/12/2010 (b)

	Parameter		Specification	Value
1	Beam Expander Magnification		8 ±0.1	8.0
2	Beam Expander Transmission @532nm	T%	>98.5	99.3
3	Tx Transmission	T%	>96	97.8
4	Telescope Transmission @532nm	T%	>99%	99.4
5	Collimator Transmission	T%	>98.5	98.9
6	Filter Transmission @532nm	T% @ 30℃	>30%	35.0
7	Nitrogen Purging / Pressure	atm	1.0 +0.1	1.0

Figure 4 (a) Photograph of LAMP telescope. Notice the position of steering prism located at central part of the telescope. (b) LAMP system transmitter and receiver unit test results.

A LIDAR system's overlap function is a geometrical parameter that depends on the laser beam divergence, telescope FOV and the configuration of transmitter and receiver optics [1, 2]. It is a height dependent parameter and provides information on useful range bins at lower altitudes possible from the LIDAR system. The LAMP system employs mono-axial arrangement between transmitter and receiver. The LAMP system transmitter beam divergence and receiver FOV are specified as 0.2 and 0.4 mrad respectively. Based on these specifications, the LAMP system's overlap occurs at 370 m above the surface level in the zenith direction. Figure 5 illustrates the overlap details of LAMP system. This overlap value changes if the system's transmitter and receiver optics alignment get disturbed.

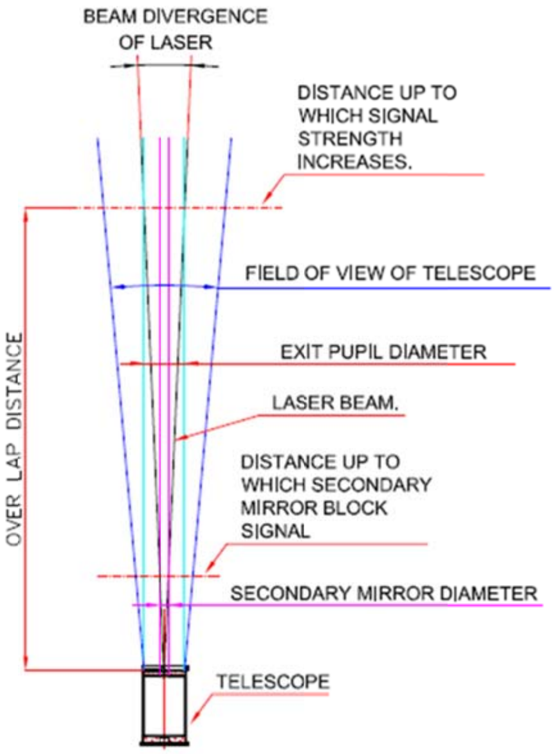

Figure 5. Illustration of overlap details of LAMP system. The overlap details are based on transmitter beam divergence and receiver FOV of LAMP system. These details provide the overlap height of LAMP system at a height of 370m above ground level in the vertical direction.

The LAMP is protected against operation at adverse cubicle temperature and humidity conditions. A set of temperature sensors is fitted to laser head, PMT, personal computer and electronic rack units. These sensors detect adverse operating conditions of laser source and switches OFF the laser source to protect the system.

Similarly it switches-off the PMT unit when the temperature is beyond the specified limits of operation. A humidity sensor is fitted to telescope body. The electronic sensing unit also monitors the adverse operating conditions (temperature above 35^0C and relative humidity above 70%) of the telescope, Electronic rack and personal computer units. If temperatures and humidity exceeds the specified limits, "warning messages" appear on the computer display and LCD unit. After the temperature stabilizes within the specified range (15^0C to 30^0C), the laser source and PMT can be switched "ON" manually by clicking the laser button and PMT button appearing on the computer display terminal, respectively. These sensors are connected to a controller that updates the status to the monitoring unit. Table 2.1 provides the environmental protection control arrangement made in LAMP during "its" operation. The arrangement of environmental protection control in LAMP monitors the system operation and informs the user with warning signs at abnormal conditions.

Table -2.1 Environmental protection control

Sl.Nr	Device	Condition	Action
1	Laser temperature	<15 or >30^0C	Switching OFF Laser
2	Interface unit temperature	<15 or >45^0C	Warning
3	Cabinet temperature	<15 or >35^0C	Warning
4	Telescope temperature	<15 or >35^0C	Warning
5	Telescope humidity	≥70%	Warning
6	Cabinet humidity	≥70^0%	Warning

Apart from the environmental protection control, the LAMP is provided with overload protection for the following sub-systems

1. Interface Unit-mains supply
2. Photomultiplier tube power supply.
3. Personal computer (PC)

An uninterrupted power supply (UPS) support is provided to the LAMP with a separate input and output protection. The UPS is connected to the computer for monitoring the power and battery backup status. If power fails, a set of warning messages is displayed on the liquid crystal display (LCD) in the client program. If the battery level falls to 10% of "its" capacity, then the system notifies the client program and immediately shutdowns the LAMP and "its" connected devices as a measure of safety.

III. LAMP SYSTEM SOFTWARE

The LAMP operates on custom built software that is user friendly in nature. The software has two parts.

a) Server software

b) Client software

a) Server software: The server software is loaded and runs on the main computer. This software automatically starts whenever the LAMP instrument is enabled. This software monitors the temperature, humidity and other parameters to ensure the LAMP instrument works properly.

b) Client software: The client software is used for control of LAMP for atmospheric observations. It provides a means to control various devices connected, viewing the status of each device, starting the signal acquisition, and viewing the acquired data etc.

The client software retrieves all the required information from the server software. For this, the client software is configured to automatically connect to the server on startup. The server name is designated as LSXXX, where XXX is the serial number of the equipment & is available on the name plate fixed on the rack. The user can also run the software without connecting to the server. When the client software is not connected, it works in offline mode. In the offline mode, the users can view the data that already acquired, process the data, view the log files, etc. However, users cannot acquire data or view the device values, when the client software is in offline mode.

Using the client software, various devices connected are controlled from the settings controls menu and then devices are selected for control from the sub menu. Device control allows turning ON or OFF the devices like Laser, Trigger, Discriminator, Heater and PMT. It also allows setting the laser energy value and frequency. When the device control form opens, it shows the current status of the devices. The green colour power symbol indicates that the device is turned ON and grey colour power symbol indicates the device is turned OFF. To turn ON or turn OFF a device, it requires a click on the concerned device button. To set the value of the laser energy, the required value of laser energy is needed to be entered in the box provided and then a click is required for confirmation of the same. The software menus and “its” radio buttons are shown in figure 6 to illustrate the user friendly operation of LAMP software.

Figure 6. LAMP client software control module for switching the LIDAR devices

The LIDAR signal acquisition is carried out using the acquisition module of client software. The acquisition window is opened by selecting the controls from the main menu. The acquisition menu allows the user to configure the parameters to start the signal acquisition. Figure 7 illustrates the LAMP client software acquisition module and various parameters required for entry into the module for LIDAR data acquisition. The details of the parameters required for entry into the acquisition module are described in table 3.1. The parameters indicated in brackets (<>) are default settings. An error message is displayed in the status bar of the acquisition window if the signal acquisition does not get activated. Suppose if acquisition starts, the status bar displays message likes ‘acquiring 1/500’ where 1 is the current measurement and 500 is the total number of measurements. During this process, the actual data acquired is plotted and displayed in the acquisition window.

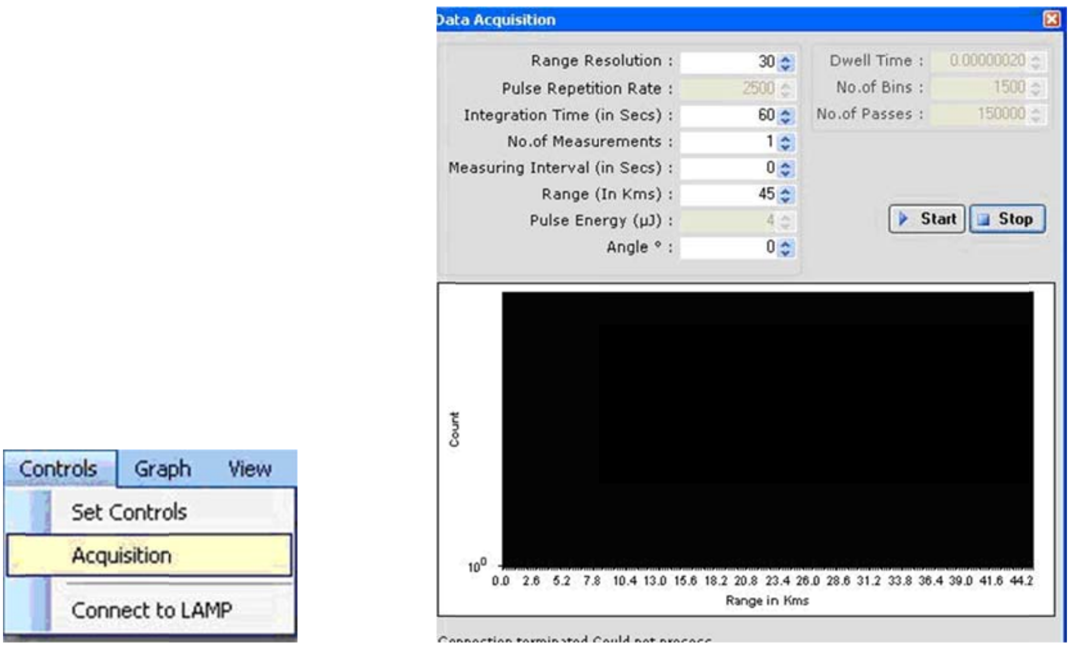

Figure 7 Data acquisition control using the LAMP client acquisition module.

The client software acquired signal profile is shown in figure 8 in the form of a graph. The profile graph presents the altitude distribution of signal counts collected from the atmosphere using LAMP system. The data were recorded on 28 October 2010 at 22:49 LT at the factory site. The graph provides altitude distribution of photon counts obtained from the atmosphere and was measured up to an altitude of 45 km range. The peaks in photon count data at 2, 10 and 12 km heights indicate the locations clouds in the atmosphere. The graph also provides details on energy transmitted per pulse, the number of pulses transmitted, integration time, and the direction of orientation of LIDAR system.

Table 3.1 LAMP system client software signal acquisition module

Sl.Nr	Parameter	Details of set value <Default value>
1	Range resolution	This set the height resolution. This is used to configure the bin width of the acquisition card,<30m>
2	Pulse repetition rate	Defines the number of laser shots fired per second. This value is obtained from the laser frequency set in the device control windows.<2500>
3	Integration time	The time for which the data is to be averaged into a single profile.<60secs>
4	Number of measurements	Number of measurements to be made <1>
5	Measuring interval	Interval between each measurement in minutes(use this control in order to specify a time gap between two profiles)<0>
6	Range	This specifies the number of bins for which data will be acquired<45Km>
7	Pulse Energy	The laser energy set in the device control window
8	Discriminator Voltage	Preset at 0.5V and cannot be modified

The LAMP client software also supports several real-time and offline analysis features like summation of acquired signal profiles as per the user definition, conversion of raw signal profiles into ASCIII format, display of selected signal graph, generation of range time intensity (RTI) maps for the selected signal profiles etc. The software also performs several analytical works such as background noise estimation and removal, range correction to backscatter to make quick atmospheric investigations, etc.

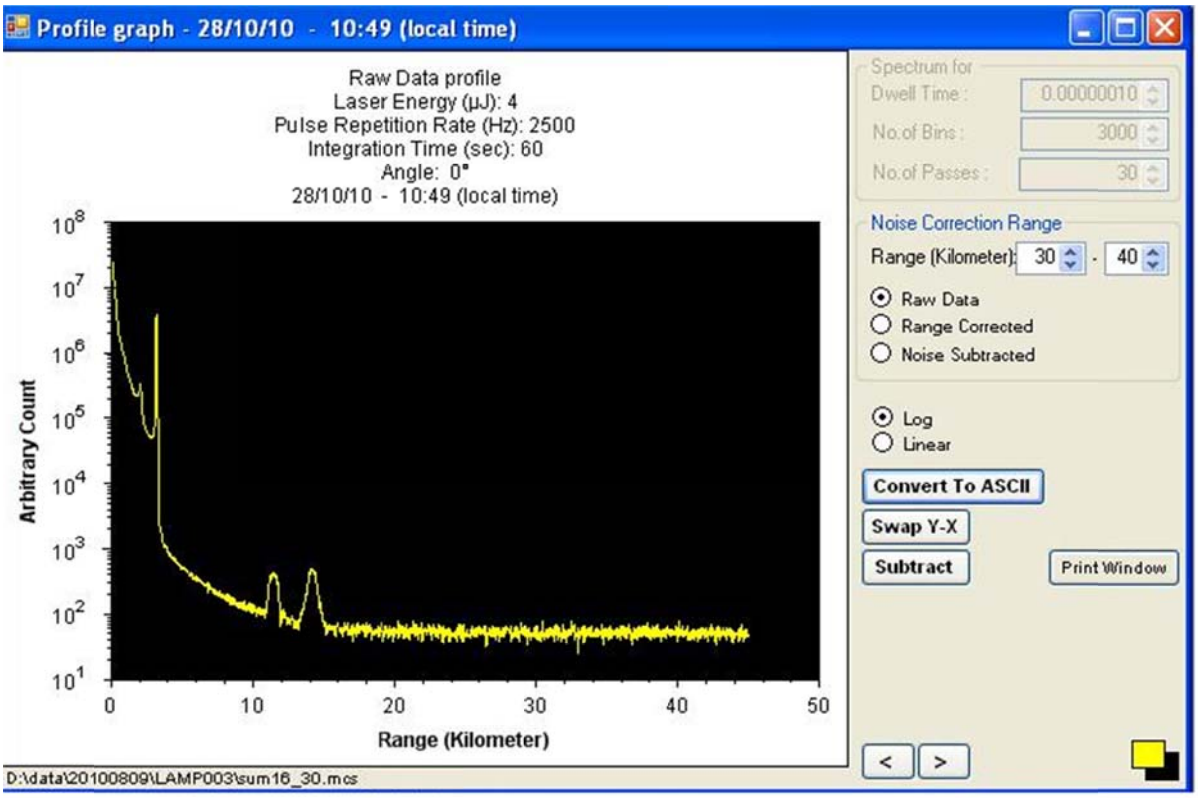

Figure 8. Signal profile generated by client software using LAMP system. The vertical axis of graph indicates the photon counts collected by the receiver during the integration period and the horizontal axis represents range in kilometres.

IV. LAMP SYSTEM OBSERVATION OF ATMOSPHERE

The LAMP was thoroughly calibrated using the portable LIDAR (BLL) of NARL during the period of testing. During testing, simultaneous backscatter measurements were collected using the two systems. The portable LIDAR [19, 20] used in the LAMP calibration process operates at 532 nm wavelength and uses high repetition rate low pulse energy laser. Panels (a), (b), (c) and (d) shown in Figure 9 indicate the atmospheric sounding results of LAMP conducted at the LAMP fabrication-site on 21 December 2010. On the night of 21 December 2010, the LAMP was operated in the zenith direction for about 10 hours from 1930 LT to 0514 LT of the next day. During this period, the LAMP was operated at 150000 laser shots-integration with 30m height resolution setting. The operational settings of the laser allow the LAMP to generate the atmospheric observation for every one-minute interval. Each atmospheric sounding constitutes one scan and provides an altitude profile laser backscatter in photon counts measured up to 45 km range. Panels (a), (b), and (c) of Figure 9 represent the laser backscattered intensity profile given in photon counts, background noise correction to basic signal, and range correction to backscatter respectively. The panel (d) illustrates the Rayleigh fitting to the path loss corrected LIDAR backscatter. The Rayleigh fitting to the LAMP backscattered signal indicates the fine alignment between LAMP transmitter and receiver units. A clear detection of thin high altitude cloud return at around 11 km above the local dust layer, shown as an enhanced spike, proves the detection of week target at long ranges. This illustrates the suitability of this instrument for atmospheric cloud and aerosol studies.

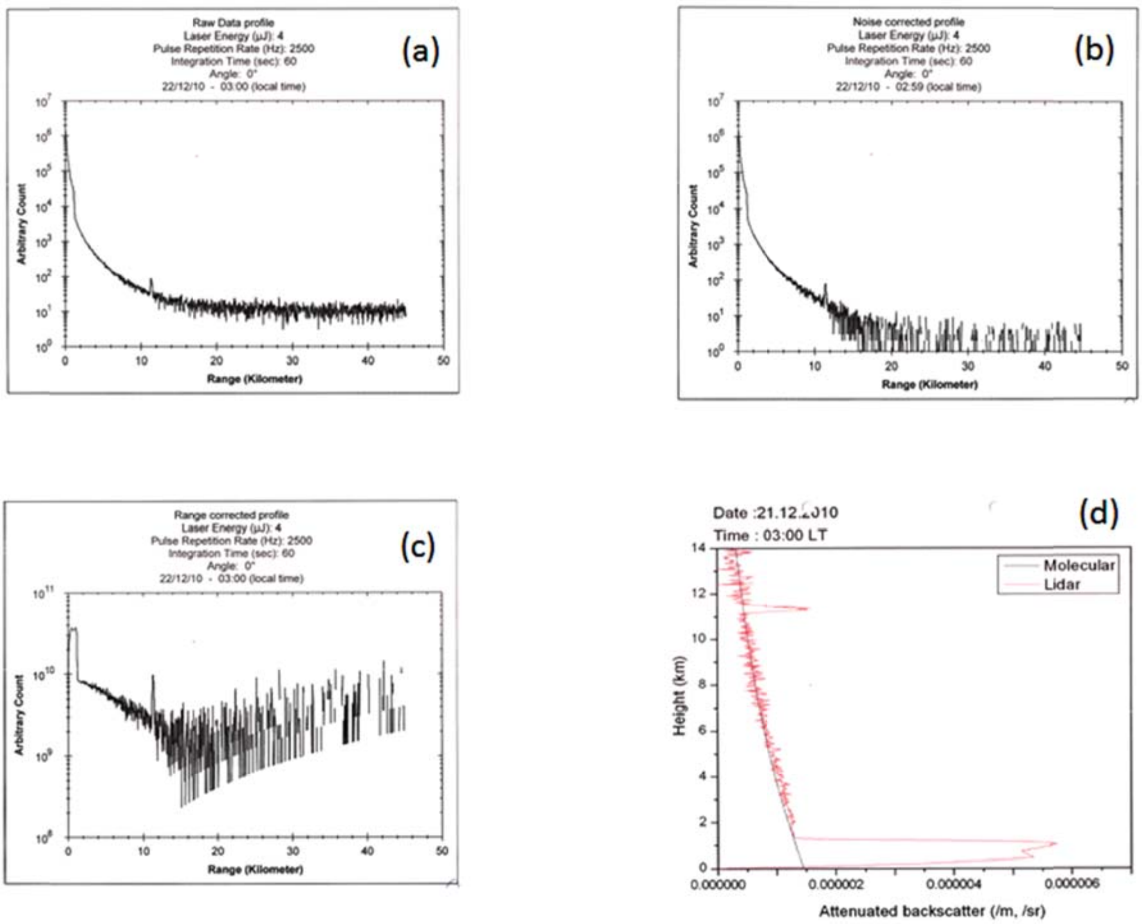

Figure 9 LAMP system atmospheric sounding generated signal and its various forms of analysis. Panels represent (a) Laser backscattered intensity profile given in photons for each range (b) Background noise correction to basic signal (c) Range correction to backscatter and (d) Rayleigh fitting to range corrected backscatter data respectively

V. CONCLUSION

This paper described the technology of an industry developed LIDAR system in India with the help of National Atmospheric Research Laboratory (NARL), Gadanki. The industry developed LIDAR was named as LAMP which stands for LIDAR for atmospheric measurement and probing. It is the first commercial LIDAR developed in the country for atmospheric applications. The LAMP technology contains several useful features and operates autonomously using state-of-the art software support.

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