26B1 MICRO PULSE LIDAR SYSTEMS AND APPLICATIONS

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1. INTRODUCTION

A problem with lidar observations in the past has been that systems are large, complex, lack eye safety and require the presence of a specialized group for operation. Systems based on a technology concept we have called Micro Pulse Lidar (MPL) eliminate these disadvantages. Recent developments in solid state lasers and detectors permit small, eye safe MPL systems that can profile all significant cloud and aerosol scattering layers. Eye safety is the key requirement met by MPL. It has been demonstrated that the systems allow full time autonomous use by non lidar-specialized investigators. For cloud and aerosol measurements, the conventional large lidar systems as have been used previously are now obsolete. A discussion of the technology concept has been given by Spinhirne (1993). In this paper we describe MPL field instruments and results from atmospheric experiments. . The initial MPL field instrument began full time operation at the Atmospheric Radiation Measurement (ARM) project Cloud and Radiation Test (CART) site in 1993. Aircraft systems and other advanced applications are under development.

2. CURRENT INSTRUMENTS

The basic idea of MPL is that present highly efficient solid state lasers and detectors permit the design of small, eye safe lidar systems of high sensitivity and practicality. Individually, the primary components and design factors for MPL are not new. They may be found as elements of previous lidar systems. Realization of the system design with advanced technology provides the unique operational capability.

MPL is a conventional time gated, incoherent detection lidar approach. Beyond that there are three basic differences between the micro pulse lidar and most previous lidar systems. First the laser pulse repetition rate (PRF) is much higher, kilohertz rather than Hertz, and the pulse energies are much lower, micro-Joules rather than milli-Joules or greater. The low pulse energy is the factor that permits the systems to be eye safe. The second difference is that the laser is diode pumped rather than flashlamp pumped. The solid state lasers are much more efficient and smaller. The third difference is that the signal detector is a solid state photon counting module rather than a photo multiplier tube or avalanche photo diode (APD). The Geiger mode APD detectors are quantum noise limited and highly efficient with quantum efficiencies approaching 70%. Photon counting is generally a more accurate and problem free means of signal acquisition for low level signals than analog detection. Calculations of system performance for differing system parameters is discussed by Spinhirne (1993). The per pulse received signals are on the order of a photon per microsecond or less. Accuracy is obtained by pulse summation.

A bread board MPL system was first completed in 1991 and in 1992 a ruggedized field instrument was completed. A picture of the MPL field instrument is shown in Fig. 1 and the basic system parameters are listed in Table 1. The design factors for the system are to obtain eye safety, maintain a stable optical alignment and to minimize noise induce by daytime background radiation. For micro Joule pulse energies, eye safety may be realized by expansion of the laser beam. Beam expansion and collimation by a telescope is thus required in the transmitter design. Elimination of background photon noise is a significant problem for a low pulse power, high PRF lidar system. The smallest possible receiver field of view (FOV) and optical filter bandwidth is necessary. A small FOV introduces the problem of alignment stability between the transmitter and receiver. In order to avoid alignment problems and also to minimize the system size, a single transmitter-receiver design is dictated.

The transmitter-receiver is based on a 20 cm cassegrain telescope. For the initial field instrument the laser pulse energy is 2 uJ but after optical losses approximately 1 uJ is transmitted to the atmosphere. The laser beam is expanded to the full telescope diameter . The transmitter and receiver beam paths are combined and separated through the telescope by passive polarization optics. The greatest technical challenge of the system design proved to be eliminating a large pulse of internally scattered photons to the detector. A large initial pulse has the effect of saturating and shutting off the detector if uncorrected.

The signal is received as photo-electron counts per range bin. One advantage of MPL is a simple data system design. A single PC card multi-channel scalar sums signals. The averaging time may be selected, but one minute averages have typically been used. Data are recorded and displayed on a PC screen in real time.

3. RESULTS

The MPL development was directed toward atmospheric radiation field experiments. For cloud and aerosol radiation measurements the laser observation allow radiometric measurements to be interpreted. Lidar measurements have been especially important for observations of the emittance of cirrus and in defining atmospheric aerosol layers. Commercial ceilometer system can detect the height of low clouds, but lack the sensitivity to reliably detect high clouds and aerosol layers.

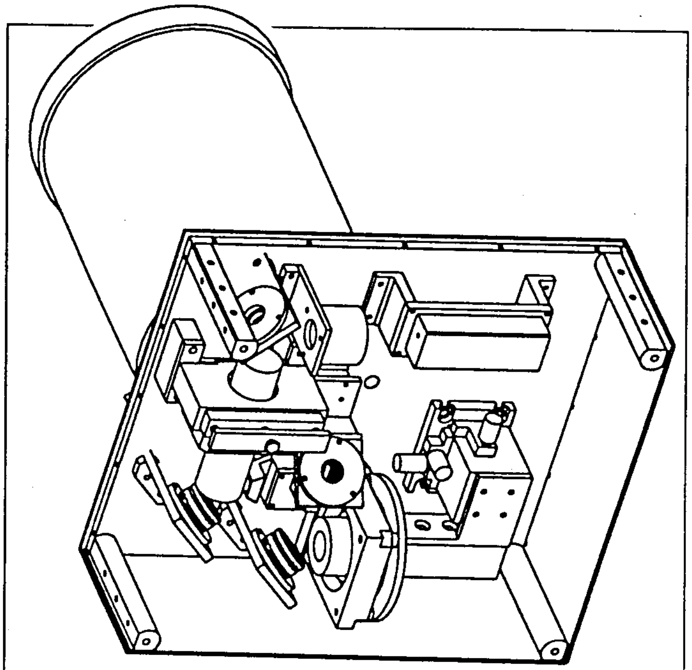

Fig. 1 Micro pulse lidar instrument

A signal example from the MPL system is shown in Fig. 2. The most difficult of the cloud and aerosol lidar measurements that are important for atmospheric radiation measurements is possibly monitoring the stratospheric aerosol layer. The return signal profile shown in Fig. 2 clearly indicates the increased signal from 15 to 20 km that is the result of scattering from stratospheric aerosols, at this time the Pinaturbo aerosol layer. The layer at 12 km is probably sub visual cirrus. The data is a 30 minute signal average.

TABLE 1

MPL System Parameters	
Laser	Nd:YLF (Spectra-Physics 7300)
Wavelength	523 nm
Pulse Energy	2 uJ
PRF	2500 Hz
Transmitter FOV	50 uradians
Telescope Diam.	20 cm
Receiver FOV	100 uradians
Receiver Opt. BW	0.1 nm
Detector	EG&G SPCM-100-PQ GAPD
Quantum Eff.	40%
System Opt. Trans.	8%
Data Acquisition Card	Santa Fe ERN MCS-II
Data Computer	Portable 386 PC

There are two signal corrections that must be applied to MPL data. One is a correction for multiple photon coincidence at higher count rates. The second is a correction for the near range overlap function for the transmitter-receiver system. The photon coincidence correction has been applied to the data in Fig. 2 but not the overlap correction. A simulated signal for a model atmosphere is shown to compare to the observation.

As discussed by Spinhirne(1993) there is a significant difference in the performance of an MPL system in the night and in the day. Measurements of the stratospheric aerosol layer is only possible at night. However day time results indicate that all cirrus and tropospheric aerosol layers can be readily detected. A greater signal averaging time is required for the same accuracy as at night.

The first field deployment of the MPL system was for the South Western Pacific Pilot Radiation Observation Experiment site in Kavieng, Papua New Guinea., in association with the TOGA/COARE field experiment of 1993. The MPL system successfully monitored high cirrus and all other tropical clouds as well as aerosol structure and was set up and operated by non specialized personnel. Since then operation has been in progress at the ARM CART site. Full time detection and profiling of all significant cloud and aerosol structure has been demonstrated.

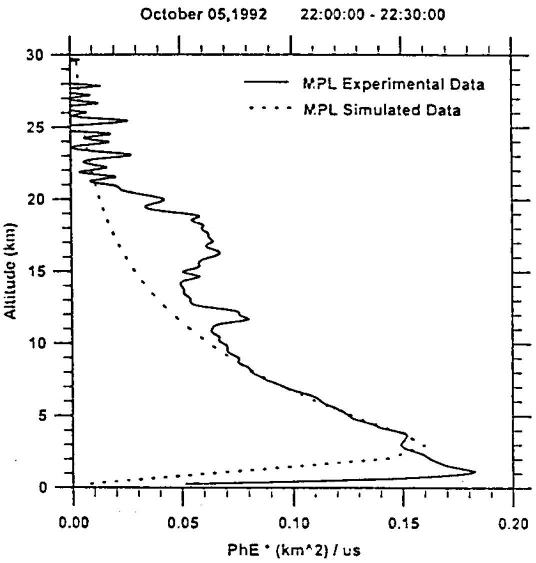

Fig. 2 A signal example from MPL .

4. DEVELOPMENT POTENTIAL

The MPL basic technology has considerable potential for future development. The pulse energy of our current system can be significantly increased from 2 uJ and still maintain eye safety. The necessary lasers are available. A problem for operations at higher pulse energies is the count rate limitation, 1 to 2 Mc/sec, of the passive quenched mode GAPD detector that has been used in the initial system (Daulet et al., 1993). A new GAPD detector module is now available that employs active quenching with counts rates to 10 Mc/sec and above. Another recent improvement in GAPD detectors is a larger active area of 500 um diameter rather than 50 um of the initial units. Optical system design is thus simplified.

A very compact instrument with 25 uJ per pulse, which is at the eye safe limit for a 20 cm aperture, and with sufficient performance for airborne applications is in development. The signal performance should be approximately an order of magnitude above the system described above. Another MPL approach that is being developed is to operate the Nd:YLF laser at the fundamental 1.046 um wavelength rather than 0.523 um as in the system described above. The quoted GAPD detector quantum efficiencies are only 1 to 2 %, but the eye safe transmitted energies can be an order of magnitude greater. Considerations of the background photon flux and saturation of signals from large dynamic ranges is greatly reduced and the beam will be invisible. A larger and more inefficient system is required for the same performance as for a 0.523 um instrument however.

Lidar applications other than cloud and aerosol monitoring can be made eye safe and practical by technology similar to what is described here as MPL. A wind sensing system using an incoherent detection technique and a uJ pulse energy Nd laser has been demonstrated. In this case a narrow frequency, stabilized laser was used. Differential absorption lidar applications for MPL water vapor sensing have been modeled with success and other applications should be possible. An appropriate laser source for the differential absorption applications is not now commercially available, but it is a development to be expected.

5. INSTRUMENT COMPARISON

The goal of MPL technology is eye safe, practical lidar systems. That goal may possibly be realized by other lidar approaches that are under rapid development. In particular systems with direct transmission of the output of AlGaAs diode lasers using CW pseudonoise (PN) code modulation for range resolution are possible. These systems have the advantage of a relatively simple wavelength tunable source. Some initial night time water vapor differential absorption measurements have been made Rall (1993). The AlGaAs PN code lidar however has major disadvantages from daytime background noise and for dynamic range. The effective RMS shot noise for PN code lidar is from a sum over the entire repeat signal length rather than for a single range bin as is the case of MPL and other standard incoherent lidar. Extremely narrow optical filtering will be required for full time AlGaAs PN code lidar.

Another approach for eye safe lidar is large pulse systems that operate at fundamentally eye safe wavelengths such as 1.54 um. Detector performance at these wavelengths is currently too poor for these systems to be competitive to MPL without going to the complexity of coherent detection.

6. SUMMARY

The MPL approach provides small, reliable, autonomous instruments that can profile all cloud and aerosol structure. With such technology lidar can enter an era of practical, routine applications such as long been the case with radar and other highly developed systems.

Reference

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