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MULTICHANNEL PHOTON COUNTING LIDAR MEASUREMENTS USING USB-BASED DIGITAL STORAGE OSCILLOSCOPE

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Abstract. *We present a simple method of making multichannel photon counting measurements of weak lidar signal from large ranges, using commonly available USB-based digital storage oscilloscopes. The single photon pulses from compact photomultiplier tubes are amplified and stretched so that the pulses can be sampled efficiently by the USB oscilloscopes. A software interface written in Labview is then used to count the number of photon pulses in each of the prescribed time bins to form the histogram of LIDAR signal. This method presents a flexible alternative to the modular multichannel scalers and facilitate the development of sensitive lidar systems.*

Keywords: remote sensing; lidar; photomultipliers; electronic amplifiers.

Classification numbers: 07.07.Df; 42.68.Wt; 85.60.Ha; 84.30.Le.

I. INTRODUCTION

Light detection and ranging (LIDAR) has become the backbone technique for remote sensing and has been widely used for atmospheric research and environmental monitoring. LIDAR systems commonly use high power pulsed solid-state laser such as Nd:YAG laser, allowing the detection of backscattering signal from targets at relatively large distances [1, 2]. Because the LIDAR signal from the far ranges is usually very weak, thus requiring detection in photon counting mode to reach high enough signal to noise ratio to be useful in data analysis. Traditionally, the photon counting method is considered an expensive technique, requiring sophisticated electronic equipment [1, 2]. First of all, the technique requires the use of a detector that can response to single photons such as photomultiplier tubes or avalanche photodiode working in photon counting mode (Geiger mode). Secondly, fast electronics and digital signal processing are required to count the number of photons in each predetermined time bin to build up the histogram that form the intensity profile of the LIDAR signal. The commercially available electronics such as multichannel analyzers suitable for LIDAR measurement in photon counting mode are generally expensive. Thus building a multichannel LIDAR system would require significant investment, which would be an obstacle for small laboratories planning to setup a LIDAR system.

With the availability of Digital Storage Oscilloscope (DSO), photon counting technique has been shown to be adaptable to use with DSO at almost no additional cost, increasing the usefulness of DSO [3–6]. For example, the photon counting technique using DSO was used to perform fluorescence lifetime measurements [1, 2] or determine photon counting statistics [3]. More interestingly, this technique was also applied to LIDAR measurements with encouraging results [4]. In these works, the photomultiplier tubes (PMT) with broad single photon response of the order of 10 ns were used as detectors, allowing DSOs with sampling rate as low as 100 MSPS to sample adequately the photon pulses. The obvious drawback of this kind of setup is the limited data storage and data transfer capabilities from DSOs to computer. Schwarz [7] used a compact PMT head and a transient digitizer card for photon counting LIDAR measurements. The fast single photon response of about 1.5 ns of the PMT in this case necessitates the use of a preamplifier that can also broaden the single photon response allowing it to be adequately sampled by the digitizer at 8 ns sampling time. However, only test measurements are shown in Schwarz's thesis and did not provide the full potential of the setup [7].

Currently, low cost USB DSOs with multichannel, large buffer memory and adequate sampling rate (100 MSPS or better) are widely available. These USB DSOs are more versatile and much less expensive than the traditional digital oscilloscopes. In this paper we present the simple hardware and interface software to perform photon counting measurements using USB oscilloscopes and also present real photon counting LIDAR measurements up to distance of 30 km.

II. PHOTON COUNTING SETUP

The single photon response of the compact photomultiplier tube PMT such as R7400U series from Hamamatsu has a rise time of 0.7 ns and a pulse width of 1.5 ns [8]. Such fast response usually requires the use of high speed electronics (bandwidth of 300 MHz or more) for counting single photons. To use the photon counting technique with the low cost, lower bandwidth but widely available digital storage oscilloscope, we have designed an amplifier with a large gain and a moderate bandwidth based on the high speed current feedback op-amp LMH 6703 (Texas

Instrument). The electronic schematics of the amplifier is shown in Fig. 1. Normally the feedback resistor R2 is chosen so that the overall gain is 10. However, in our case we use a feedback resistor $R2 = 1$ kΩ, and $R1 = 10$ Ω allowing for a nominal gain of 100. At such a high gain, the bandwidth of the amplifier is significantly reduced. The fast single photon electrical pulses from the PMT are amplified and stretched by this amplifier to broad negative pulses having a FWHM slightly below 10 ns. These stretched photon pulses can then be adequately sampled with a DSO having a sampling rate of 100 MSPS or higher. The other resistors R3 and R4 are chosen to be 50 Ω for impedance matching with the coaxial connecting cables. The amplifier is designed using PCB design software CadSoft Eagle and fabricated using double-sided board with the lower side used as ground plane as recommended for high speed electronic design.

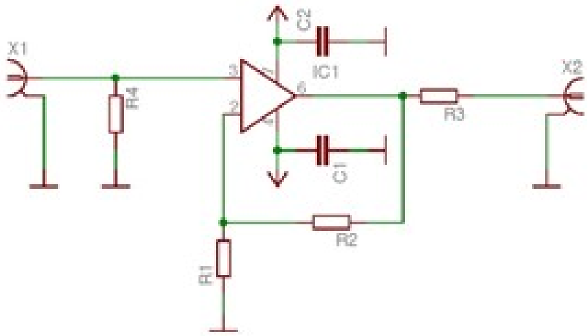

Fig. 1. Schematics of the amplifier. The op amp used is LMH 6703 from Texas Instrument.

The signal from the amplifier is then routed to the input of the USB digital oscilloscope equipped with a 50 Ω terminator at the input. In our setup we use either the low cost Picoscope model 3206A (Picotech, UK) with a bandwidth of 200 MHz and a sampling rate of 100 MSPS or the more advanced model 5304 with a bandwidth of 250 MHz and a sampling rate of 125 MSPS or higher, allowing for simultaneous photon counting measurements in two independent channels with time bin of 10 ns or 8 ns, respectively. A trigger signal from a fast photodiode marking the start of each laser pulse into the atmosphere is connected to the external trigger channel of the oscilloscope. Thanks to the large buffer memory size of these USB DSOs, the number of samples in each waveform, which corresponds to the LIDAR signal from the atmosphere for each laser shot, can reach 50 000, corresponding to a distance of up to 60 km. These waveforms are then transferred to a computer via the USB port for real-time processing. Photon pulses are discriminated against electronic noises by setting a suitable voltage threshold, which is user selectable. The photon pulses are then registered by their leading edge to the corresponding time bin. Accumulating photon pulses in the LIDAR return signal for a predetermined number of consecutive laser shots allows the reconstruction of the final LIDAR signal profile in each measurement channel.

In Fig. 2 we show the waveform of the LIDAR return signal at 532 nm collected for a particular laser pulse sent into the atmosphere. The individual photons are clearly seen. The discrimination voltage level is set at -10 mV, well above the noise level. The LIDAR signal profile is also shown in Fig. 2 after accumulating the photons in each 8 ns time bin for 1200 laser shots. Measurement results are then stored in text files for further off-line analysis.

The control of the photon counting operation is done through the GUI interface developed in Labview, integrating the drivers of the corresponding USB oscilloscopes provided by Picotech. One can conveniently select the sensitivity of each channel, the threshold voltage for photon pulse discrimination, the sampling rate of the oscilloscope etc...

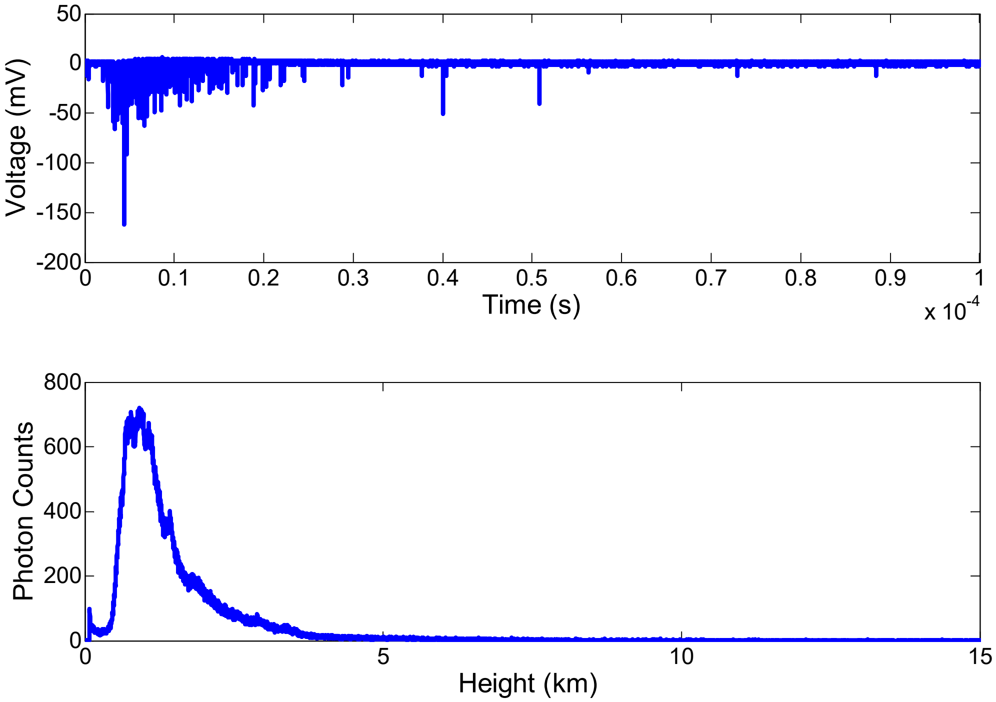

Fig. 2. The waveform for single laser pulse recorded by the DSO (upper frame) and the 5-minute average (1200 laser shots) LIDAR profile (lower frame).

III. LIDAR MEASUREMENT

Our LIDAR system developed at the Institute of Physics, which was described previously in more detail [8] has a compact and modular design that can be easily configured to measure simultaneously the elastic and Raman scattering at 532 nm and 607 nm. The transmitter is a high power pulsed Nd:YAG laser (Quantel Brilliant) providing 180 mJ – 5nspulse at 10 Hz repetition rate at the second harmonic wavelength of 532 nm. The backscattering lidar signal is collected by a 25-cm diameter Schmidt-Cassegrain telescope (Meade LX-90) with a field of view of 1.5 mrad. The detection consists of two separate channels the elastic channel at 532 nm and the nitrogen Raman scattering channel at 607 nm. Narrow band interference filters centered on the wavelength of each channel are used to blocked background light in both channels. A neutral density filter is used in the elastic channel to reduce the backscattering signal intensity to avoid saturation of the PMT working in photon counting mode. For detection we use the compact photomultiplier tubes PMTs made by Hamamatsu of the type R7400U and the compact photosensor H6780-20.

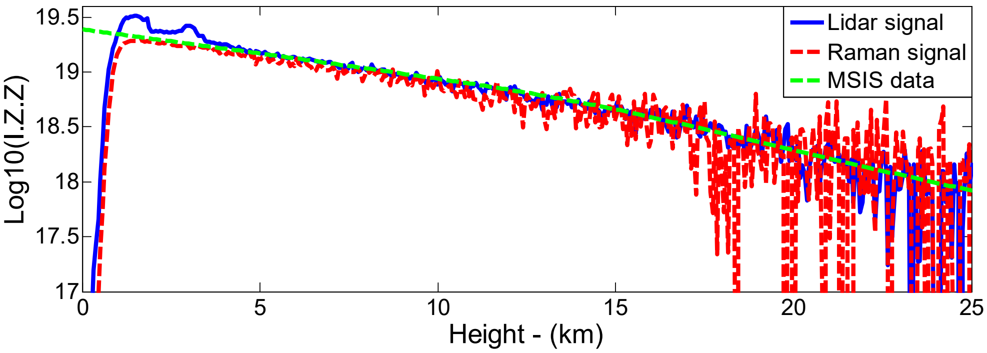

Fig. 3. Elastic (thin solid line) and Raman lidar (dotted line) signals in photon counting mode averaged over a period of 15 minutes. Atmospheric density from MSIS-E-90 model is over plotted (thick solid line) for comparison.

In Fig. 3 we show the range corrected LIDAR signals (Log10(I.Z.Z) is logarithm of LIDAR intensity times the distance squared) of the elastic and Raman channels, which are measured simultaneously. The data was collected after accumulating the return photons for 15 minutes corresponding to about 9000 laser shots. The data in both channels show very high dynamic range, allowing the detection of signal up to 25 km. The elastic channel shows strong backscattering for altitudes below 4 km due to the presence of atmospheric aerosols. Above this layer the atmosphere is practically aerosol-free and the elastic and lidar signals follow closely the atmospheric density obtained from the MSIS-E-90 model [9] for Hanoi area. These measurements demonstrate the good capability of the photon counting technique using USB digital oscilloscopes. Our photon counting system has been in regular use to make LIDAR measurement of the atmosphere above Hanoi, Vietnam.

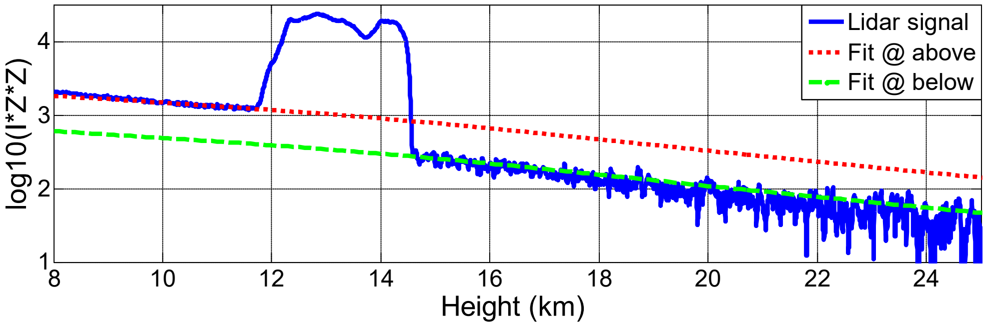

Fig. 4. Range corrected elastic lidar profile obtained on 11th January 2016 over an interval of 50 minutes corresponding to 30000 laser shots. Atmospheric density from MSIS-E-90 model is over plotted (dotted and broken line) for comparison on top and base of the cirrus cloud layer.

The lidar system using the USB – based digital storage oscilloscope has been used to monitor continuously the cirrus cloud layer distributed up to height of 20 km in Hanoi, Vietnam from

2011 to 2018. An example of data shown in Fig. 4, we can identify the basic characteristic parameters of cirrus clouds such as height distribution, optical depth, lidar ratio. We hope will soon be published these results in another article.

IV. CONCLUSION

We have developed a flexible and simple photon counting method for use with LIDAR measurements. The new method allows our LIDAR system to make sensitive measurements up to heights of 25 km. We believe that this photon counting method is very useful for setting up new LIDAR or extending the capability and measurement range of any existing LIDAR system.

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