Mobile coherent doppler lidar prototype v2 for wind sensing

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Abstract: We have developed ultra-compact coherent doppler lidar prototype version 2 for wind sensing. This new mobile lidar has its dimension of 39x29x16 cm, its weight of 2.9kg, and power consumption of 31.4W. The new mobile lidar can be operated by a lithium battery and can be continuously measured wind profile over 2.5 hours, thanks to the low consumption optical transceiver / signal processor sub system, called coherent doppler lidar engine. Preliminary experiments have been performed by this mobile lidar prototype 2 for line of sight wind velocities with the maximum horizontal range more than 1km.

Keywords: Coherent Doppler Lidar, Serrodyne Modulation, Pulsed Modulation.

1. Introduction

Coherent Doppler lidar (CDL) systems are attractive sensors for wind sensing because they offer a method of remote wind speed measurements in clear atmospheric conditions. An all-fiber CDL system using a 1.5-micron wavelength has many advantages, such as compactness, eye-safety, and reliability, due to using commercial-off-the-shelf components from telecom products [1]. The deployment of this CDL is expanding steeply for many applications of wind energy [2]. Mitsubishi Electric released 1st generation commercial all-fiber CDL system in 2006[3], and 2nd generation CDL, DIABREZZA™ compact’ for wind resource assessment in 2014. While the CDL deployments at a steep mountain, small islands, or disaster areas, it needed not only transportable but also battery drivable. The mobile CDL proto type 1 has also demonstrated two-hour successive operation without exchanging batteries [4]. This CDL, however, was not enough small to be transported by one person. This paper presents a new ultra-compact CDL updated by newly developed sub-systems [4].

2. System Configuration

Figure 1 shows a schematic block diagram and outer view of the mobile coherent Doppler Lidar prototype V2. This new lidar has an all-in-one design consisting of an optical transceiver board directly connected with a signal processor, an optical high power amplifier(OHPA), an optical antenna via a fiber circulator, and a lithium polymer battery. The dimension is 39(W)x29 (H)x16(D)cm, and its weight is 2.9kg.

Fig.1 Schematic block diagram and outer view of the mobile Doppler lidar prototype type V2.
The optical transceiver is combined a conventional fiber-optic heterodyning receiver with a newly developed coherent optical pulse seeder based on pulsed-serrodyning modulation. In the signal processing board a system-on-a-chip (SoC) solutions have been adopted by using a large Field Programmable Gate Array (FPGA) with an internal processor core. Measured wind data can be displayed on a tablet PC via the WiFi after on-board signal processing for wind speed estimation.

3. Optical Transceiver Unit

Fig.2 shows the block diagram and outer view of the optical transceiver unit as a coherent pulse seeder combined with a heterodyne receiver. All fiber-optic components are commercial off the shelf components in the optical communication which have enough high reliability with Telcodia GR468-core compliant. An Integrable Tunable Laser Assembly (ITLA) was used as a master laser with line width of 200 kHz and wavelength of 1550 nm. Then its output was split into a local oscillator (LO) and a seed light to a pulsed serrodyning modulator which is consisting of a semiconductor optical amplifier (SOA), a lithium niobate optical phase modulator (LNM) and their drivers with digital-to-analog converters (DAC). The pulsed serrodyning modulation is our newly developed technique to realize both pulse modulation and frequency shift without a double-pass AO (Acousto optic) modulator currently used in our CDL system [3]. In a receiver section optical return signals (RX) are phonically mixed with a LO signal, then detected as intermediate frequency (IF) signals at balanced two photo diodes (PD). In order to accommodate a bandwidth of 100MHz corresponding to a range of Doppler frequency of +/- 35m/s, the heterodyning signal is sampled at rate of 216MSps with analog-to-digital converter (ADC) and transferred to the signal processing board.

4. Pulsed Serrodyning Modulation

Serrodyne frequency shifting is realized by applying a saw-tooth phase modulation to the optical signals. Recently frequency shift of a few hundred megahertz as required in CDL can be obtained with a good quality by technological advances in high speed driver electronics. While, SOA is the promising to optical pulse modulator with small foot print if the issue s of frequency chirp is solved. We have newly developed a pulsed serrodyning modulation which realizes both frequency shift and compensation of frequency chirp in SOA[5].

Figure 3 shows the temporal signals of pulsed serrodyning modulation for an optical intensity of a SOA and a optical phase of a LNM. The saw-tooth phase modulation is applied within only the pulse-on period, T1 over pulse repetition interval (PRI). If the complete saw-tooth phase modulation with cycle of Tm is applied, the output optical frequency is shifted with an offset frequency of 1/Tm.
Fig.3 Temporal signals of pulsed serrodyning modulation for an optical intensity of a SOA and a optical phase of a LNM.

It is worthy to note that no frequency shift is occurred within pulse-off periods because of not applying the saw-tooth signal. This leads effective rejection performance of unwanted beat noise between optically internal reflections within pulse-off periods and the LO signal in the heterodyne receiver without such a special pulsed modulator as a double-pass AOM with a high extinction ratio.

5. Experimental Results

In order to confirm whether the pulsed-serrodyning modulation does correctly perform, line of sight (LOS) wind Doppler spectra have been evaluated in the case of pulsed-serrodyne modulation and that of single-pass AO modulation as a reference. The measuring condition as follows: the pulse-on period, T1 of 500ns corresponding to range resolution of 75m, a PRI of 250 μs, the saw-tooth cycle, Tm of 6.17 ns corresponding to IF of 162MHz as shown in fig.3. Figure 4 shows the LOS wind Doppler spectra at distance of 500m. In the case of single-path AO modulation the spectrum has a strong peak around zero Doppler velocity which may be caused by beat noise between a LO signal and internally reflection of leaky lights within pulse-off periods. This unwanted beat noise makes it difficult to measure wind signals near the zero-Doppler velocity. Meanwhile, the spectrum of pulsed-serrodyne modulation has a peak around -1m/s without any noise peak at zero-Doppler velocity.
Figure 5 shows the measurement data of the LOS wind velocity with respect to distance and that of their detectability. Theoretical calculation for detectability is also shown as a function of distance. The setting parameters are as follows: the optical peak power of 30W at a fiber end of an OHPA, the aperture diameter of 50mm, the focusing distance of 500m and the integration number of 4000. The back scattered coefficient is assumed of $8.3 \times 10^{-8} \text{ m}^{-1} \text{sr}^{-1}$ taking into account of measured number of aerosol using a particle counter. The measured detectability has considerably agreed with theoretical curve, which indicated the LOS wind velocities are measured up to 900m because of larger detectability than the detection limit of 7dB.

Figure 6 shows that the temporal variation of supplying power from fully charged batteries for continuously wind sensing under the same measurement condition as in fig. 6. In this figure the present mobile CDL ran the wind measurement over 5 hour 20 minutes without exchanging battery. The average supplying power was 31.4W.

![Graph showing battery supplying power over time](image)

**Fig.6 Battery supplying power under continuously wind sensing**

### 6. Summary

We have developed a new mobile coherent Doppler lidar prototype for wind sensing with its dimension of 39x29x16 cm. The pulsed-serrodyning modulation makes it possible to realize both frequency shift and compensation of frequency chirp within pulse-on period of the SOA as pulse modulator. The new mobile lidar can be operated by a lithium battery and can be continuously measured wind profile over 5 hours, thanks to the low consumption optical transceiver / signal processor sub system. Preliminary experiments have been performed by this mobile lidar prototype 2 for line of sight wind velocities with the maximum horizontal range more than 1km.

### 7. References


