Pulsed serrodyning technique as applied to coherent laser transmitter for wind sensing

Eisuke HARAGUCHI(a), Hitomi ONO(a) and Toshiyuki ANDO
(a) Mitsubishi Electric Corporation, Information Technology R&D Center,
5-1-1 Ofuna, Kamakura, Kanagawa, Japan, 247-8501
Haraguchi.Eisuke@cw.MitsubishiElectric.co.jp

Abstract: We have developed a new pulsed-coherent light source for wind sensing, combining a semiconductor optical amplifier (SOA) with a phase modulator operated at serrodyning mode. The SOA-based light source has potential advantages of its small footprint, monolithic integration and gain properties, however, inevitably occurs frequency chirp, leading to the measurement error of wind velocities. We have demonstrated the correction of such frequency chirp by using phase modulation with sawtooth waveform, so called ‘optical serrodyning technique’.

Keywords: Coherent Laser Transmitter, Serrpdyne Modulation, Semiconductor Optical Amplifier.

1. Introduction

All-fiber coherent Doppler LIDAR system has many advantages such as its compactness, eye-safety and reliability thanks to using commercial off the shelf components from telecom products [1]. The Semiconductor Optical Amplifier (SOA) may be well used as a multifunctional device for the compensation of optical loss [2-4]. The SOA-based light source has potential advantages of its small footprint, monolithic integration and gain properties. However, directly modulated SOA is induced frequency chirp due to gain-induced variations of the refractive index [2], [3], leading to the measurement error of wind velocities. Several studies have reported that in ns time region the frequency chirp caused by direct modulation of the SOA is about a few GHz within optical pulses [3]. Earlier studies have suggested that the frequency chirp caused by SOA is proportional to amplitude modulation rate. Therefore, the frequency chirp in the long pulse region is estimated to a few 10 MHz. Furthermore, in all-fiber CDL system the frequency chirp caused by the self - phase modulation (SPM). We have already evaluated the frequency chirp caused by SPM [5]. As a result, we have been confirmed that the frequency chirp is about a few MHz [5]. However, as far as our knowledge, there is no report about the frequency chirp caused by direct modulation of the SOA and SPM for the long pulse of a few 100ns pulses.

In this paper, at first we estimated the SOA-induced frequency chirp in the long pulse. Next, we demonstrated the correction of such frequency chirp by using phase modulation with sawtooth waveform, so called ‘optical serrodyning technique’

2. EXPERIMENTAL ESTIMATION OF FREQUENCY CHIRP

At first, we have estimated the amount of frequency chirp caused by SOA in experimental. Fig. 1 shows the schematic diagrams of the loopback experimental setup for estimation of frequency chirp by using acousto optical modulator (AOM). Distributed Feed Back Laser Diode (DFB-LD) was used as a master laser with line width of 200 kHz and wavelength of 1550 nm. The output from DFB-LD was split into a local and a seed signal. The seed signal was coupled to the AOM and the SOA. The SOA was directly modulated to obtain the pulsed signal which pulses width was 500 ns and pulse repetition frequency was 4 kHz. The AOM was operated at constant frequency which is 162 MHz. This seed pulses ware amplified by an Erbium Doped Fiber Amplifier (EDFA) which output power was 20 W. The signal laser from EDFA was attenuated by the optical attenuator about 40 dB. Attenuated signal laser was propagated through the delay fiber which length is 100 m. The reflected light from fiber end were separated by the circulator and combined with a local laser. We estimated the frequency chirp caused by direct modulation of the SOA by analyzing the optical heterodyning signals between local and back – reflected light from fiber end.

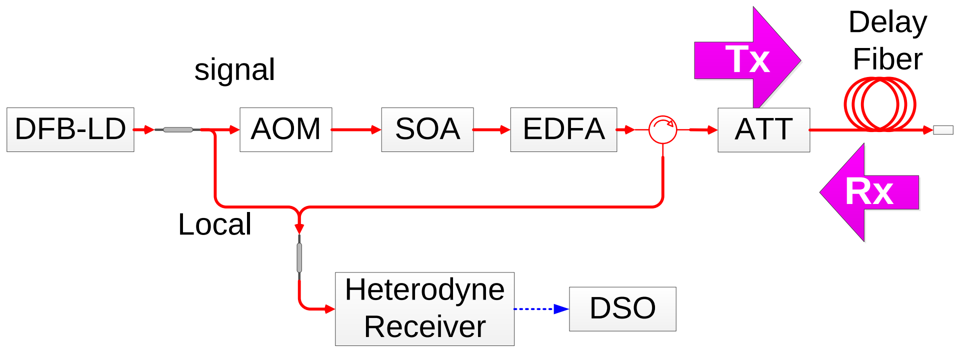

Figure 1 Scematic diagram of experimental setup

Fig. 2 shows the heterodyne signals around a signal pulse in time domain (a) and peak frequency variation of several spectral with respect to each time gate (b). As indicated in the figure, the peak frequency of spectrum in time gate of the rise time of the pulse has indicated positive deviation by 6 MHz, and in time gate of the fall time of the pulse has indicated by negative deviation by minus 4 MHz.

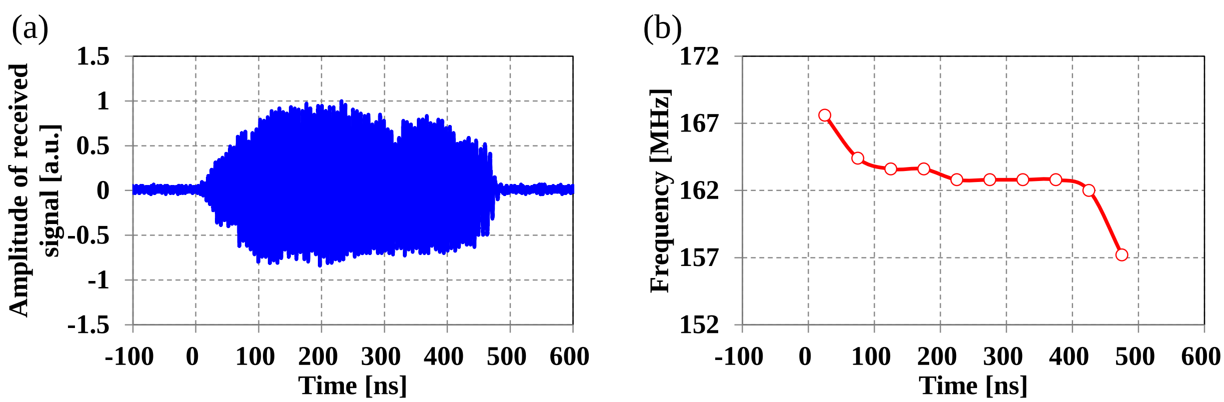

Figure 2 The heterodyne signals between local and back – reflected light
((a) : time domain data, (b) : frequency variation).

3. THE PRINCIPLE OF FREQUENCY CHIRP COMPENSATION

In the pulsed serrodyne phase modulation, a modulating signal with a pulsed sawtooth waveform is applied to the phase modulator. The optical signal of pulsed serrodyne phase modulation is shown in Eq. (1), where E_S, f_0 and Tm represent the field amplitude, the optical carrier frequency and the cycle of sawtooth waveform, respectively. From the Eq. (1), the amount of optical frequency shift depends on the cycle of the sawtooth waveform (T_m).

$$E_S(t) = E_S \exp\left[i2\pi\left(f_0 + 1/T_m\right)t\right] \tag{1}$$

Fig. 3 shows the image of the serrodyne phase modulation signal, optical pulse shape and the frequency of the heterodyne signals, respectively. Fig. 3 (a) is shown the constant frequency of serrodyne phase modulation. The frequency of heterodyne signal is chirping caused by SOA. Fig. 3 (b) shows the case of the corrected frequency chirp. Applying a serrodyne modulation signal of the inverse characteristics of the estimated frequency chirp caused by SOA, the frequency of heterodyne signal is constant.

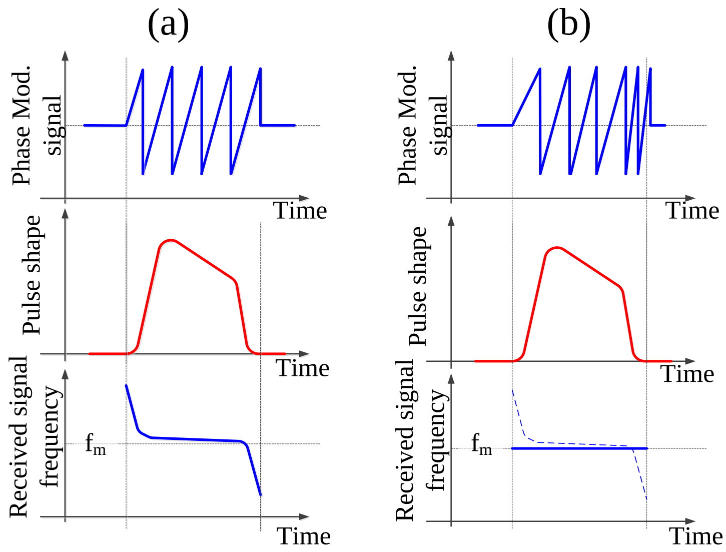

Figure 3 The image of the serrodyne modulation signal, optical pulse shape and the frequency of the heterodyne signals ((a) : no corrected frequency chirp, (b) : corrected frequency chirp).

4. CORRECTION OF FREQUENCY CHIRP

Fig. 4 shows the schematic diagrams of the experimental setup for correction of frequency chirp by using serrodyne phase modulation. The phase modulator (PM) was operated at serrodyne mode for correction of frequency chirp caused by direct modulation of the SOA. By applying a serrodyne phase modulation signal of the inverse characteristics of the estimated frequency chirp, the frequency chirp was corrected. This analysis was performed by using Digital Sampling Oscilloscope (DSO) with sampling rate of 2G samples/s. Offline Fast Fourier Transform (FFT) was executed to several data set with successive 256 sampling points around the gate time.

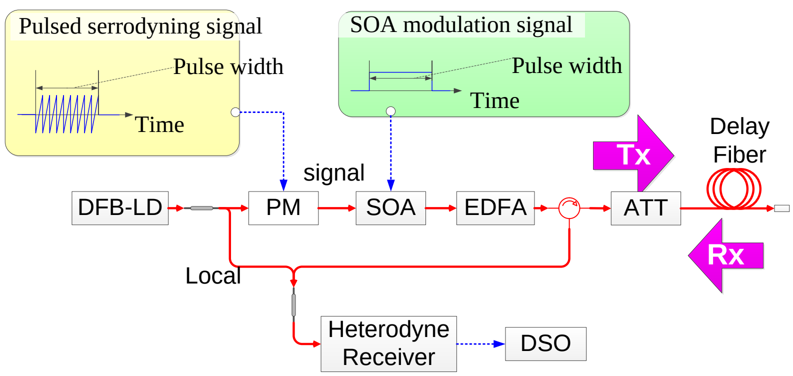

Figure 4 Scematic diagram of loopback experimental setup

Fig. 5 shows the heterodyne signals around a signal pulse in time domain (left) and peak frequency variation of several spectral with respect to each time gate (right). Fig. 5 (a) is in the case of without SOA and EDFA. It is found that the peak frequency of spectral in all time gate has indicated constant. Fig. 5 (c) shows the result in the case of a serrodyne phase modulation of the inverse characteristics of the estimated frequency chirp. It is clearly demonstrated that frequency deviation has been corrected less than 0.4 MHz compared to frequency deviation in the case of without SOA and EDFA. As for the measuring wind velocity, the frequency chirp cases the offset error. In the case of corrected frequency chirp, the average offset errors are evaluated as 0.03 MHz, which is corresponding to the offset velocity of 0.02 m/s.

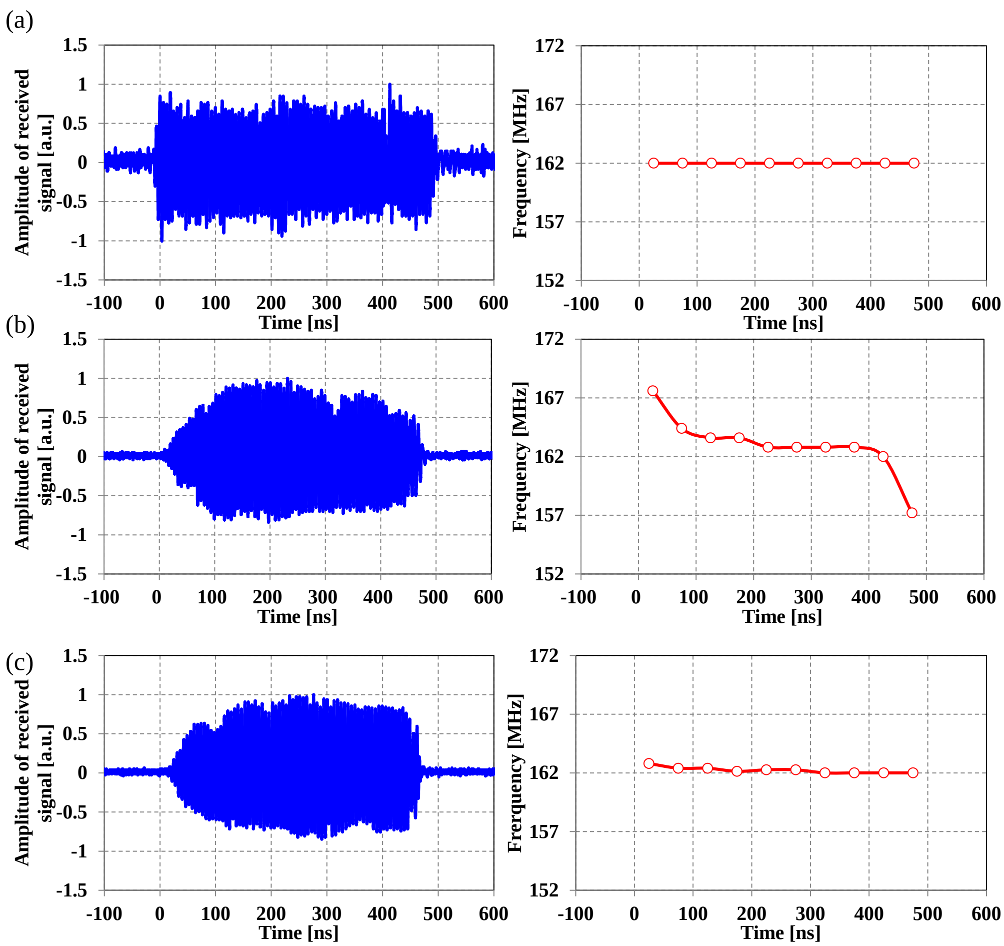

Figure 5 The heterodyne signals between local and back – reflected light (left : time domain data, right : frequency variation). (a) pulse output without SOA and EDFA, (b) pulse output with no corrected frequency chirp, and (c) pulse output with corrected frequency chirp

5. SUMMARY

We have developed a new pulsed-coherent light source for wind sensing, combining the SOA with a phase modulator operated at serrodyning mode. The SOA-based light source has potential advantages of its small footprint, monolithic integration and gain properties, however, inevitably occurs frequency chirp, leading to the measurement error of wind velocities. We have demonstrated the correction of such frequency chirp by using phase modulation with sawtooth waveform, so called ‘optical serrodyning technique’. It is clearly demonstrated tha residual frequency error has been decreased less than 0.4 MHz compared to the frequency error of 6 MHz where the no corrected frequency chirp. In the case of corrected frequency chirp, the average offset errors are evaluated as 0.03 MHz, which is corresponding to the offset velocity of 0.02 m/s.

6. References

[1] S. Kameyama et al, Applied Optics, vol. 46, 1953 (2007).
[2] F. Koyama et al, Journal of Lightwave Technology, vol. 6, No.1, 87 (1988).
[3] L. Gillner, IEE Proceedings-J, vol. 139, No.5, 331, (1992).
[4] G. P. Agrawal et al, IEEE Journal of quantum electronics, vol. 25, No. 11, 2297 (1989).
[5] T. Ando et al, 13 th Coherent Laser Radar Conference Proc. p.66 (2005).