Dual-Comb Ranging Using Soliton Microcombs with Tunable Repetition Rate

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Abstract: We propose a method of tuning the repetition rate of soliton microcombs by temperature. The tunable range reaches 12 MHz. The trade-off between acquisition rate and precision of ranging systems is overcome without additional barrier. © 2023 The Authors

1. Introduction

Optical ranging is extensively used in science and industry. Coherent laser ranging systems based on dual-frequency combs offers high accuracy and fast distance acquisition. Phase-based dual-comb ranging uses phase information of beat signals between multiple longitudinal modes. The maximum measuring distance is the ambiguity distance of $c/2\Delta f_{\mathrm{rep}}$ in one measurement by switching the combs according to vernier effect [1,2], where Δf_{rep} is the repetition rate difference. Meanwhile, it is proved that a quantified trade-off between precision and ambiguity distance can be tuned by adjusting the repetition rate [3]. However, the repetition rate of microcomb is almost immutable because it generated in a microresonator with certain cavity length and free spectral range (FSR). Consequently, the limitation of microcomb ranging systems need to be overcome. We propose a method to obtain soliton microcomb with a tunable repetition rate and the practicality is demonstrated in a dual-comb ranging system.

The generation and applications of single soliton microcomb is widely studied. In our soliton generating system, each microresonator chip is placed on a thermoelectric cooler (TEC) so that the FSR can be tuned by regulating the temperature. To analyze the tunable range, we use beat signals between two combs to measure their repetition rate variation. They consist of a series of equally spaced lines in RF segment. With one of the temperatures changed at a time, the move of the repetition rate is observed. Furthermore, microcombs with tunable FSRs reduce the demand for detector performance and expand the ambiguity distance in dual-comb distance measurements.

2. Soliton Microcomb with Tunable Repetition Rate

Thermo-optic effect shows that the refractive index of the medium increases with the rising of environment temperature. Thermal expansion and contraction effect also varies the length of the microcavity. Therefore, as the TEC temperature raised, the light range in the microresonator is lengthened and the repetition rate would be increased.

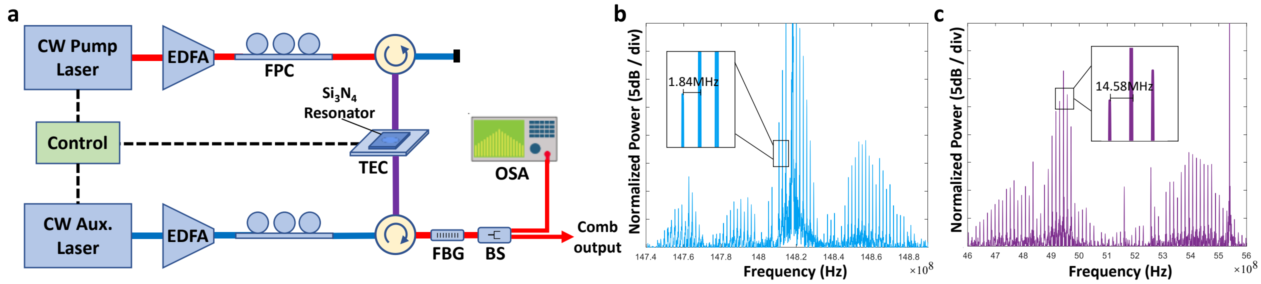

Fig. 1. (a) Soliton microcomb generating system with tunable repetition rate. The red and blue lines show the route of the pump and auxiliary laser, respectively. The purple lines are their mixture. FPC: Fiber polarization controller; FBG: Fiber Bragg grating; BS: beam-splitter; OSA: Optical spectrum analyzer. (b) The Fourier transform of beat signals with repetition rate at 1.84 MHz when TECs set at 25°C and 35°C. (c) The Fourier transform of beat signals with repetition rate at 14.58 MHz when TECs set at 30°C and 36.5°C.

Dual-pump method [4] is applied to a silicon nitride microresonator chip with a TEC in our microcomb generation system. The experimental setup for microcomb generation is presented in Fig.1(a). The beat signals between two combs are used to measure the current repetition rate. This method requires two microcombs with slightly different repetition rate. Two microresonators with almost the same repetition rate around 94 GHz are placed on two TECs. We tune the lasers and make the microcombs enter the single soliton state. For one microcomb, power and wavelength of the pump laser are set as 1557.84 nm and 27.5 dBm, and the auxiliary laser is set as 1550.08 nm and 30.5 dBm. For the other, the pump laser is set as 1553.05 nm and 29 dBm, and the auxiliary laser is set as 1557.13 nm and 32.5 dBm.

The TECs are both tuned within 25°C and 40°C. It is worth mentioning that each one of the single solitons possibly disappears when detuning changes with the temperature. The lasers must be tuned again after the stabilization of temperature. Fortunately, the automated soliton generation system [5] is available since the resonant wavelength changes within 0.1 nm. Consequently, the soliton would be generated with another repetition rate. In each step, we change the temperature one microresonator while the other one stays constant. In the experiments, it is found that the tunable range of the repetition rate can reach 12 MHz. The Fourier transform of recorded beat signals before and after tuning the TECs from 25°C and 35°C to 30°C and 36.5°C are shown in Fig.1(b) and Fig.1(c). The repetition rate difference between the two microcombs varies from 1.84 MHz to 14.58 MHz.

3. Dual-comb Ranging Using Tunable Solitons

The soliton microcombs and experimental setup for dual-comb ranging are presented in Fig.2(a) and Fig.2(b), respectively [5]. The generating process of two soliton microcombs is the same as the former ones. The ambiguity distance is about 1.6 mm. The signal comb and the local oscillator (LO) comb are amplified to ~6 mW by a pair of C+L-band Erbium-doped fiber amplifiers (EDFAs). The signal and LO combs are split by two fiber couplers. For the signal comb, one part is routed to the target and back, forwarded to a balanced photodetector (BPD) after interfering with the LO comb, while the other part directly interferes with the LO comb and sent to another BPD. The FPCs guarantee the premise of interference. In our experiment, both parts of the signal comb only transform via fibers with different lengths.

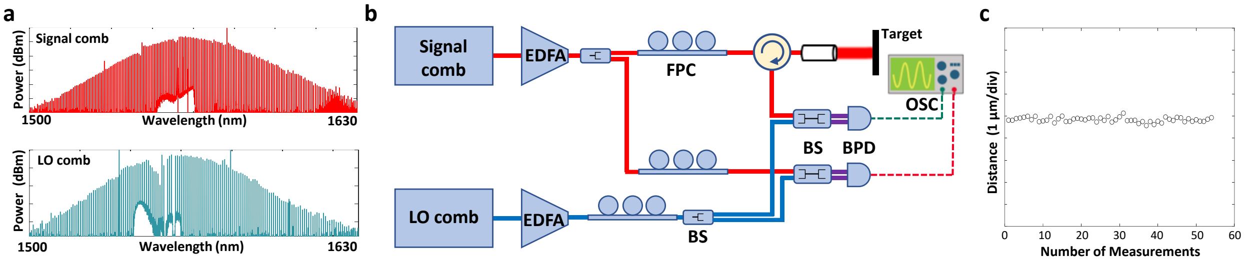

Fig. 2. (a) Signal and LO soliton microcombs used in the experiment. (b) The dual-comb ranging system. The red and blue lines show the route of two microcombs, respectively. The purple lines are their mixture. (c) Ranging results in 4μs measurement time.

The beat signal is recorded by a 50-GHz sampling-rate oscilloscope (OSC). It appears as a series of periodic pulse in the temporal domain. The total energy of the signal is proportional to the comb energy, and each pulse can be regarded as a measurement. Therefore, a high acquisition rate brings low signal-noise rate in one measurement, which cuts down the precision. To balance the acquisition rate and precision, the TECs are set as 30°C and 36°C, and the repetition rate of beat signals is tuned to 13.59 MHz, which means the acquisition time of an individual data point is about 73.5 ns. The average of 10 points is viewed as a result. Fig.2(c) shows the ranging results, and the precision reaches 32 nm for a measurement time of 4 μs.

4. Conclusion and Discussion

We propose a method of tuning the repetition rate of soliton microcombs and demonstrate the availability in a dual-comb ranging system. Tunable repetition rate breaks the limitation of a quantified trade-off between precision and ambiguity distance without introducing additional barrier to soliton generation. Since the performance of phase-based dual-comb systems are sensitive to the repetition rate difference, our method provides a route to higher adaptability and robustness. Considering these advantages, we believe soliton microcomb with tunable repetition rate can broaden the applications of dual-comb techniques.

References

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