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Laser ranging with analog all-optical coherent pulse compression using a frequency shifting loop

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In radar technology, the term *pulse compression* refers to a set of techniques that allows achieving the resolution of short and high peak-power pulses by transmitting long signals with relatively low peak powers [1]. This result is possible thanks to the use of modulated or coded waveforms with an enlarged time-bandwidth product, which can be easily amplified without the onset of nonlinearities. After these waveforms are sent to a remote target, the cross-correlation (CC) of the detected back-reflections with a reference signal (in a process called matched filtering) produces narrow pulses, enabling a range resolution set by the bandwidth of the transmitted signal. So far, the concept of pulse compression, when extended to the the optical counterpart of radar (lidar), has been mostly limited to incoherent optical waveforms coded in intensity. In this paper, we present a scheme for laser ranging by all-optical coherent pulse compression. It consists in a bidirectional frequency shifting loop (FSL), composed of a couple of acousto-optic frequency shifters (AOFS1 and AOFS2), an optical amplifier (EDFA) and a tunable bandpass filter (TBPF), see Fig.1a [2]. The system is configured so that the recirculation of the light inside the loop produces two optical frequency combs (OFCs) with quadratic spectral phases, and whose frequency spacings differ by a small quantity δf. By a precise adjustment, the FSL generates two trains of optical chirps with similar chirp rate but slightly different period. The interference of these quasi-continuous waveforms on a photodetector (PDcc), followed by a low-pass filter, produces the matched filtering in a purely analog manner. Simultaneously, the dual-comb interference enables to reduce by orders of magnitude the detection electronics bandwidth.

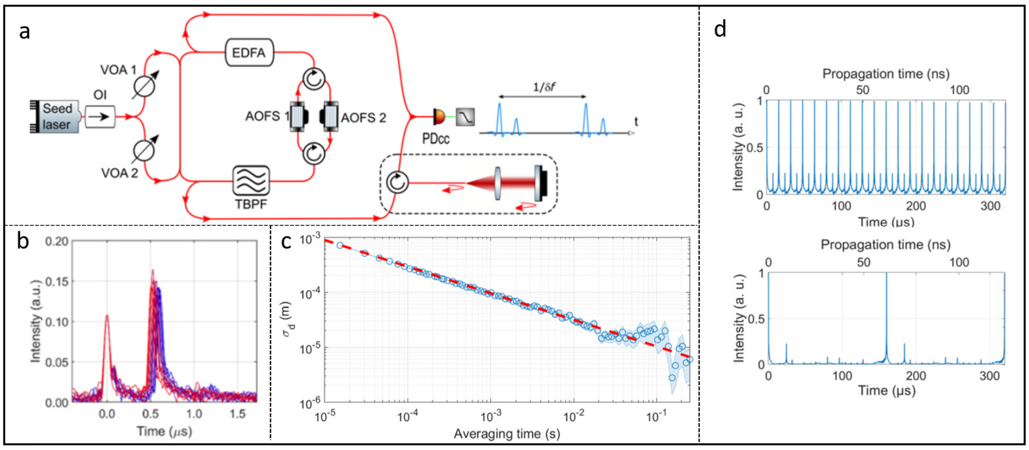

Fig. 1 a) Optical setup (VOA: variable optical attenuator; OI: optical isolator). b) Ranging experiment. c) Allan deviation. d) Ambiguity range extension.

A simple ranging experiment can be conducted by sending one of the OFCs to a remote target (dashed square in Fig. 1a). Fig.1b shows the processed CC traces for different positions of the target from a reference point (peak on the left). The line spacings of the OFCs are 80.770 MHz and 80.660 MHz. Their optical bandwidth is 24 GHz, coresponding to a range resolution < 5mm. The required detection bandwidth is as low as 33 MHz. To analyze the ranging precision, we evaluate the Allan deviation σ_d for a long CC trace corresponding to a fixed target position (with $\delta f = 65.79$ kHz). The ranging precision is about 20 µm for a 20 ms-integration time (Fig. 1c). Concerning the ambiguity range (AR), it is set by the comb line spacing at 1.85 m, as can be seen in Fig. 1d (upper plot), where the attenuated peak is the target reflection. However, AR can be easily extended by imprinting a perfect correlation phase code on the chirp trains by means of two phase modulators (not shown in Fig.1a) [3]. This AR extension can be observed in Fig. 1d (lower plot), where a suitable correlation sequence provides AR=18.5 m.

In summary, we have presented a ranging dual-comb architecture enabling analog pulse compression. This scheme is implementable with standard telecom equipment, does not require offline matched filtering nor fast electronics. The coherent nature of the pulse compression process opens up the door to phase-sensitive measurements and Doppler velocimetry.

References

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