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Multi-heterodyne Differential Phase Measurement of Microcombs

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Microcombs have been an intense area of research in frequency synthesis and metrology over the past decade. The measurement of amplitude and phase of microcombs provides unique insight into the nonlinear cavity dynamics. Different techniques have been reported to this aim, including iterative pulse shaping [1], dual-comb interferometry [2] and lately stepped-laser interferometry [3], resulting in unprecedented sensitivity and bandwidth. Here, we report a dramatic simplification of the latter setup by using another microcomb instead of a stepped tunable laser. This results into the acquisition of complex spectra in a single-scan without requiring additional optical components and high-end detection units.

Fig. 1a shows a schematic of the setup, which uses two power-efficient microcombs [4] with slightly different repetition rate $\Delta\upsilon = f_{rep2} - f_{rep1} = \sim 4$ MHz. The comb under test is intensity modulated (IM), that gives access to the pair of comb lines with low bandwidth photodetectors and enables generation of a reference signal for the multi-heterodyne phase difference calculation. The harmonics of comb lines retain the phase information with a trivial constant phase offset [5]. The two combs are driven by separate free running lasers of frequency f_{p1} (blue) and f_{p2} (red). The pump frequency of the reference comb (f_{p2}) is set to $f_{p1} \pm (f_{rep1}/2 \pm \Omega/4)$ to ensure the RF combs fit into the bandwidth limit of the detector (Ω) and avoid the RF spectrum aliasing. Thermal tuning of the cavities simplifies precise adjustment of the reference pump location. The static phase of combs lines is labelled in Fig. 1b. The phase noise of pump sources and phase behaviour of the reference comb (α_μ) cancel out in the differential phase as these terms are common to corresponding beating signals.

The IM comb and reference comb are mixed on a detector and recorded by a real-time scope (RTS). In the spectral domain, this in turn generates RF combs. The RTS trace consists of an interferogram of period $1/\Delta\upsilon$ and carries the information of the complex spectrum of the comb under test. Figure 1c is the Fourier transform of an interferogram recorded over a period of 12.5 µs. It has two RF combs of $\Delta\upsilon$ (4 MHz) repetition rate and a RF reference at the frequency $\Omega = 1.6$ GHz (not shown in Figure). The RF spectra linked to each reference comb line are paired up and combined in the temporal domain. Comparing this signal with the RF reference enables extracting the phase difference $\Delta\phi$ (Fig. 1d) with a certain offset ϕ_{net}. The phase jump at the pump location is governed by the comb dynamics in the microcavity coupled with a waveguide. The constant phase offset consists of contribution from the RF source and phase of the reference signal. Integration of $\Delta\phi$ results in the relative phase of the comb lines upon an otherwise irrelevant linear phase. The spectrally-truncated soliton pulse (Fig. 1d inset) was inferred from the spectral power and phase of the comb lines (μ). In conclusion, this technique enables broadband spectral and temporal characterization of microcombs from a single-shot interference trace.

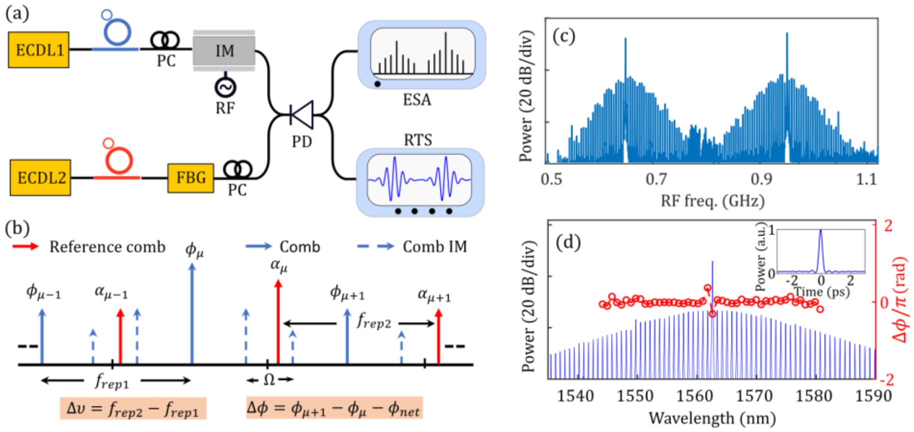

Fig. 1 Multi-heterodyne differential phase measurement of microcombs. (a) Schematic experimental setup. (b) Schematic spectra of reference comb (red), comb (solid blue lines), and intensity modulated comb (broken blue lines). (c) RF comb spectra obtained from Fourier transform of the interferogram. (d) Comb spectrum and differential phase of comb lines. Inset: Recovered temporal profile of soliton comb.

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