Optical besselon waves

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Ultrafast optics has provided extremely efficient means to generate various pulse waveforms with few-picosecond durations and very high-repetition rates. In principle, arbitrarily complex optical waveforms can be synthesised at high repetition rates by phase-intensity spectral shaping of frequency comb sources.

Here, we theoretically describe a new type of an optical waveform, the 'besselon', which is synthesised by the line-by-line application of $\pi/2$-spectral phase shifts to sinusoidally phase-modulated continuous-wave light. We provide accurate and simple analytical predictions of the main characteristics of the pulse wave, and emphasise its significant differences with the waveform that arises from quadratic spectral-phase compensation of the initial phase-modulated continuous wave. We introduce a simplified model in the limit of small amplitude of the initial phase modulation, in which the besselon is regarded as the result of the interference of three waves. For large phase-modulation depths, the individual pulses in the pattern develop into multi-peak structures and noticeable side-lobes develop in the pulse profiles. Imparting an additional π-phase shift to the central component of the frequency spectrum brings about substantial reduction of the temporal side-lobes, and concomitant increase/decrease of the pulse peak power/temporal duration. This makes the besselon waveform attractive for high-repetition-rate pulse sources and time multiplexing. By carefully choosing the initial phase-modulation depth, we show that efficient doubling of the pulse-repetition rate is achievable with residual-background-free pulse profiles. Proof-of-concept experiments demonstrate the generation of besselon pulse patterns at repetition rates of 14-GHz and 28-GHz with an excellent extinction ratio and low duty cycle.

Compared to existing solutions for high-repetition-rate and stable pulse train generation, which rely on the additional use of an intensity modulator tightly synchronised with the phase modulation or a nonlinear optical loop mirror, our method only requires a phase modulator. Our approach can also be of interest for noise-free amplification and optical sampling.