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Ultra-sensitive Dispersive Fourier-Transform Characterization Technique

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Abstract: We report on a novel approach of dispersive Fourier transform-based measurements. Using multiple single photon detectors, we demonstrate the characterization of nonlinear noise-driven dynamics with ultra-high sensibility, resolution, and a theoretically unlimited dynamic range.

Over the years, many optical characterization techniques have been experimentally demonstrated and refined to enable real-time measurements of fluctuating ultrashort optical pulses and gain insight into several complex, random or noise-driven dynamics such as Modulation Instability (MI), typically occurring as a result of nonlinear amplification of broadband noise during optical pulse propagation in fiber optics [1,2]. Among others, a well-known characterization approach is the Dispersive Fourier Transform technique (DFT), that maps the spectrum of an optical signal into an exact waveform replica in the time domain through dispersive effects: Using optoelectronic detection, one can then capture single-shot spectra and perform suitable statistical analysis of such fluctuations [3-4]. However, fast photodiodes (PD) are usually limited by their detection bandwidth (few tens of GHz at best), and thus limits the equivalent spectral resolution achieved by DFT. Furthermore, their low sensitivity paired with the limited dynamic range of high-speed oscilloscopes drastically hamper real-time spectra measurements at low intensity or with over 30 dB contrast (thus requiring mitigation scheme based on 2D detectors, loss compensation, etc.).

To overcome these limitations, we here propose a quantum-inspired variation of this technique using single photon detectors (SPD). Combined with DFT, SPDs time-tagged (i.e. time resolved) data collection of random individual photon detected on each event [5-6] brings about a sensitivity down to the photon-counting regime, along with a dynamic range that is intrinsically unlimited (only by the measurement time). Leveraging multiple SPDs thus allows a direct access to both inter- and intra-pulse MI dynamics by suitably processing the time stamps recorded from successive pulses. The SPD-DFT approach, allows the retrieval of spectral correlation maps by applying a joint statistical analysis method known as mutual information analysis [7], which can be readily compared to well-known Pearson's correlation analysis obtained via standard DFT measurements (i.e. PD-DFT) [4]. As seen in Fig. 1, both approaches show similar qualitative signatures, but with finer structures only visible with the SPD-based measurements being here associated with an excellent equivalent spectral resolution (40 GHz) provided by the low timing jitter of the SPDs (~25 ps).

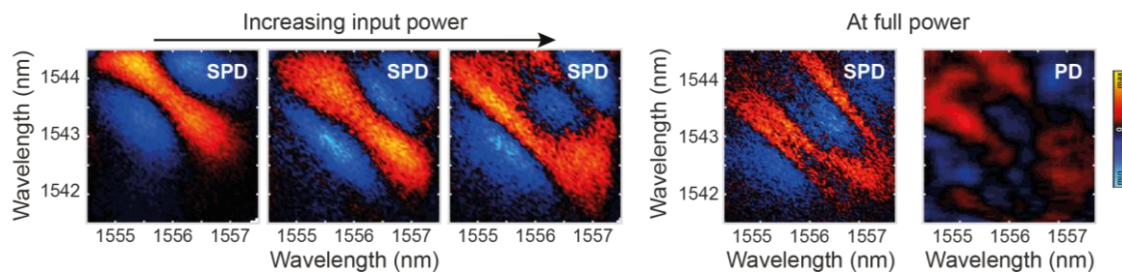


Figure 1: Spectral correlation maps of the first MI sidebands obtained via SPD-based DFT while increasing power (left), with a comparison of the correlation maps obtained via PD-based DFT measurements at full power (right).

With our scheme, we found that SPD-DFT allows for correlation measurements between weak spectral components at very low intensities (e.g., between MI cascading processes up to the third sidebands) without the impulse response of the photodiode nor the sensitivity cutoff associated with typical DFT dynamic range limitations. We further demonstrate the ability to finely adjust correlations between specific wavelengths by the addition of weak optical seeds to the initial pulse before propagation. We thus expect our results to pave the way towards the tailoring of nonlinear interactions in fiber optics, enabling the control of noise-driven processes at the boundary between quantum and nonlinear optics.

References

- [1] J.M. Dudley, et al. "Instabilities, breathers and rogue waves in optics," Nat. Photon. 8, 755 (2014).
- [2] M. Närhi, et al. "Real-time measurements of spontaneous breathers and rogue wave events in optical fibre modulation instability," Nat. Commun. 7, 13675 (2016).
- [3] A. Mahjoubfar, et al. "Time stretch and its applications," Nat. Photon. 11, 341 (2017).
- [4] T. Godin, et al. "Recent advances on time-stretch dispersive Fourier transform and its applications," Adv. Phys.: X 7, 2067487 (2022).
- [5] S.M. Kolenderska, et al. "Quantum-inspired detection for spectral domain optical coherence tomography," Opt. Lett. 45, 3443 (2020).
- [6] A. Khodadad Kashi, et al. "Frequency-to-Time Mapping Technique for Direct Spectral Characterization of Biphoton States From Pulsed Spontaneous Parametric Processes," Front. Photonics 3, 834065 (2022).
- [7] M. Touil, et al. "Spectral correlations in a fiber-optical parametric oscillator," Phys. Rev. A. 103, 043503 (2021).