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Demonstration of a photonic time-frequency Fourier transform and temporal double slit

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We present a novel demonstration of an optical memory-based time-frequency Fourier transform (TFFT) using an ensemble of cold 87Rb atoms. Our approach combines two widely studied light-matter interaction protocols, Gradient Echo Memory (GEM) for storage and Electromagnetically Induced Transparency (EIT) for recall, to perform a Fourier transform directly within the atomic medium. Optical pulses are first mapped into a spin-wave using GEM, and subsequently retrieved under EIT conditions, producing an output that corresponds to the Fourier transform of the input temporal profile. This in-memory processing is experimentally characterised through the observation of temporal double-slit interference: two time-separated input pulses yield a modulated output (and vice-versa) with modulation frequencies that scale linearly with the input temporal separation, while relative phase controls the interference phase (Fig.1). The experimental results are supported by numerical simulations based on optical Bloch equations, which account for effects such as finite optical depth, decoherence, and the limited transparency bandwidth of the EIT process. Additionally, simulations show similar behavior when storage is performed with EIT and recall with GEM.

These results demonstrate how atomic quantum memories can be used not only for storage but also as functional devices for manipulating time-frequency structure. While the present demonstration is limited by technical factors such as decoherence and bandwidth constraints, the approach provides a flexible route to studying dispersion and interference phenomena in light-matter systems. Although this work is a proof-of-principle demonstration, the behavior can be tuned through storage gradients, retrieval conditions, and input pulse parameters. We believe this method can support applications such as temporal mode characterization, basic signal reshaping in communication channels, and controlled studies of quantum interference in stored optical fields, contributing to the gradual expansion of memory-based optical processing capabilities.

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