Temporal Amplitude & Phase: Algorithmic Reconstruction via Time-domain Interferometry (TeAPARTI)

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Abstract: We introduce a novel pulse characterisation scheme–TeAPARTI–which facilitates single-shot amplitude and phase characterisation of nanosecond duration pulses. This regime has so far been inaccessible but is crucial for optimising quantum memories. We demonstrate the generation of shaped nanosecond pulses with an electro-optic modulator and their successive characterisation with TeAPARTI.

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Recently, temporal modes (TMs) of quantum light pulses have been identified as an appealing basis for quantum information processing applications [1]. Here, information is encoded onto the complex temporal amplitude of pulsed single photons. As of today, group-velocity matched nonlinear optics devices, so-called quantum pulse gates [2], are the only realised means that facilitate the harnessing of the potential of TMs. Raman-type quantum memories however, have the same capability. They can be described as special, time non-stationary quantum mechanical beam splitters, which address a single TM (determined by the control pulse) and store it, while transmitting all other modes [3]. In addition, they also facilitate a manipulation of the complex spectrum of the stored photon upon read out [4]. The latter has been demonstrated for simple operation like spectral shearing, but an operation on complex TMs is still outstanding.

In part, this is because most quantum memories operate with pulses that are longer than a nanosecond. As the stored and retrieved TM are defined by the complex spectrum of the pulses mediating the memory interaction, it is essential to have the means both to generate and to characterise these pulses in order to guarantee the desired operation. Existing pulse characterisation schemes (e.g. FROG [5], SPIDER [6], MICE [7]) operate in the spectral domain and are thus not applicable to longer pulses.

Here we demonstrate a single-shot, self-referenced pulse reconstruction protocol that operates in the temporal domain, namely Temporal Amplitude & Phase: Algorithmic Reconstruction via Time-domain Interferometry (TeA-PARTI). Using TeAPARTI, we demonstrate the complex characterisation of light pulses that are compatible with state-of-the-art Raman quantum memories [8]. We use an electro-optic modulator with two radio-frequency electrodes to carve nanosecond scale pulses with controlled intensity and phase from a continous wave laser. The pulses are then sent to the TeAPARTI setup, sketched in Figure 1(a).

The setup consists of an unbalanced Mach-Zehnder interferometer. An input pulse is split and the two parts travel along the two arms. Before recombination in a fibre beam-splitter, one arm undergoes a small temporal shift, whereas the other experiences a spectral shift that is a few times the pulse bandwidth. We detect the resulting temporal interference pattern with a fast photo diode and oscilloscope. The extraction of the phase and intensity of the pulses is analogous to the well-known SPIDER protocol.

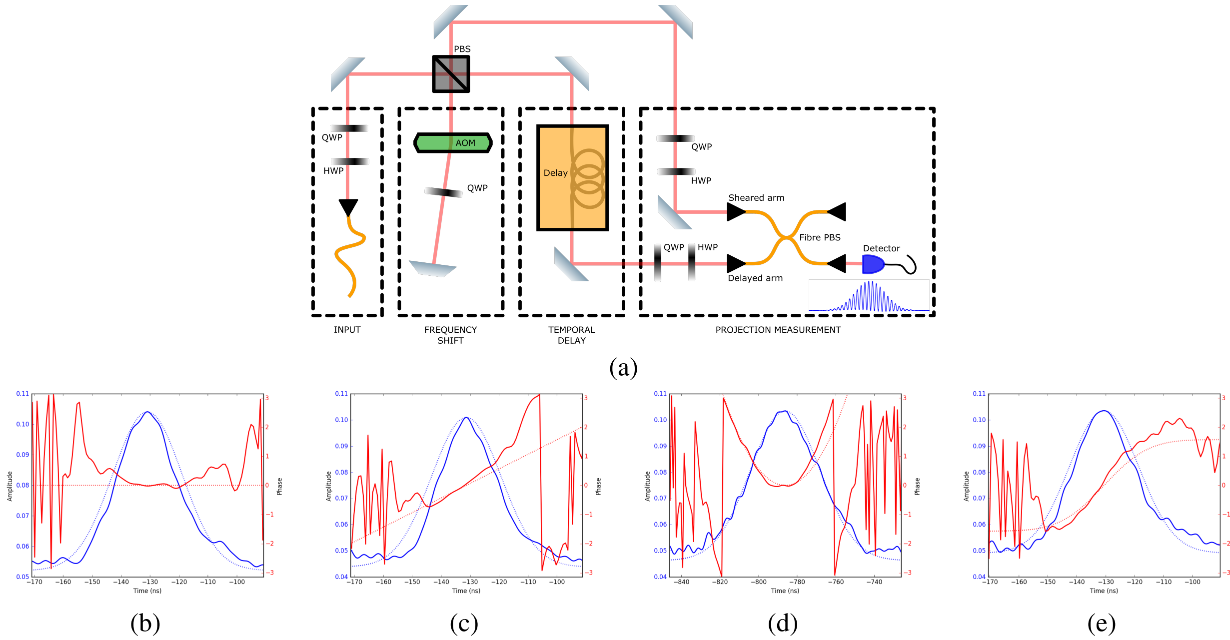

Fig. 1 (a) Schematic of the TeAPARTI setup, described in the main text. (b)-(d) Target (dashed) and reconstructed (solid) amplitude (blue) and phase (red) of four Gaussian pulses with similar intensities but different phase profiles.

In Figures 1(b)-(d) we plot the target (dashed lines) and reconstructed (solid lines) pulse amplitude (blue) and phase (red) for Gaussian pulses with (a) a flat phase profile, (b) a linear phase, (c) a quadratic phase and (d) an error-function shaped phase. For all cases we find excellent agreement between reconstructed and target pulse profiles.

In conclusion, we have introduced TeAPARTI, a novel protocol for the complex characterisation of nanosecond duration pulses. We applied it to different Gaussian pulses with similar intensities but different phase profiles and found excellent agreement between the target and reconstructed pulses. The full control over the intensity and phase of long pulses together with the ability to characterise them will enable both the optimisation of light-matter interaction for improved quantum-memory performance and the implementation of TM-selective operations with quantum memories. This will pave a way towards novel high-dimensional, scalable quantum information processing applications.

References

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