Bridging sub-GHz and telecom spectral bandwidths of single-photon pulses

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Abstract

We experimentally realized spectral bandwidth compression of single-phpton-level pulses via direct electro-optic temporal phase modulation driven by high-amplitude arbitrary radio-frequency signals. Using complex temporal phase waveforms, analogous to spatial Fresnel lens profiles, we modified the spectral bandwidth of optical pulses by more than two orders of magnitude, reaching single GHz bandwidths for single-photon level light, and sub-GHz bandwidths for bright optical signals. Our work will enable efficient conversion of single-photon pulses generated by solid-state emitters to photons matching standard telecommunication channel bandwidths.

Recent years have seen increased interest in processing quantum information by using hybrid networks consisting of quantum devices in nodes interconnected via photonic links e.g. optical fibers. The range of possible devices occupying nodes is extensive, ranging from single-photon sources based on quantum dots or defects in diamond, entangled photon pairs sources based on spontaneous parameteric processes to atom- and ion-based quantum gates and memories. Optically interfacing this wide variety of quantum devices requires matching the spectral-temporal characteristics of photons compatible with the devices. In particular it requires bringing the spectral bandwidth to a common standard, such as the standard 100 GHz bandwidth of a wavelength division multiplexed telecom channel.

Time-frequency transformations of light pulses can be explained on the basis of the optical space-time duality (OSTD), which relates spectro-temporal optics concepts with their spatial analogues [1]. Using OSTD one can postulate a time lens, which consists of applying time-varying quadratic phase, to an optical pulse. For example bandwidth conversion can be obtained by propagating a light pulse through a dispersive element followed by a temporal lens implemented by direct electro-optic phase modulation allowing for a deterministic, optical-noise-free spectro-temporal manipulation [2]. Here we use complex Fresnel-lens-like quadratic phase patterns (parabolic phase modulo 2π) generated by high power rf waveforms driving an electroptic phase modulator.

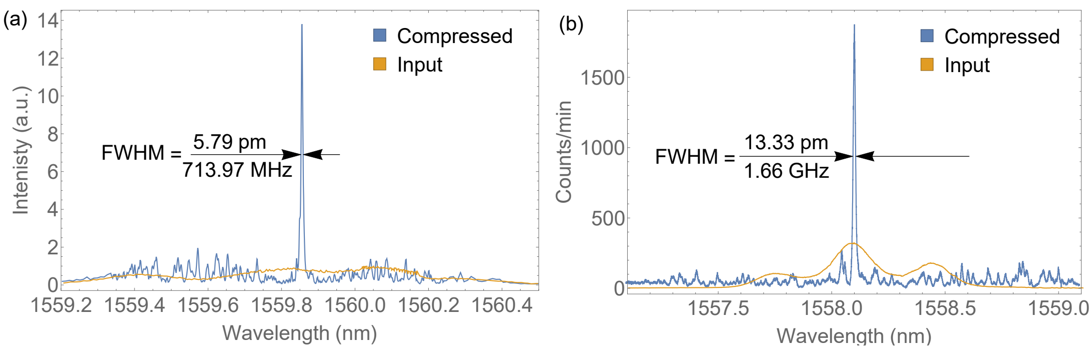

Figure 1: Spectra of (orange) input and (blue) compressed (a) classical and (b) weak coherent light. The spectrum in (a) was measured scanning a 250-MHz Fabry-Perot filter. Single-photon level spectrum was acquired by a single-photon-counting high resolution dispersive spectrometer. The input bandwidth was in the order of 125 GHz in both cases.

We experimentally implement a time lens employing complex, Fresnel-lens-like phase profiles. We used the setup to demonstrate a bandwidth conversion of approximately 100-GHz bandwidth weak coherent light pulses by a factor exceeding 100 reaching sub-GHz bandwidths with bright coherent light, and 2 GHz bandwidth for single-photon level pulses. Our results indicate that electro-optic bandwidth convereters employing complex phase profiles may become an enabling tool for the development of photonic interlinked hybrid quantum networks.

[1] B. H. Kolner, *Space-Time Duality and the Theory of Temporal Imaging*, IEEE J. Quant. Electron. **30**, 1951–1963 (1994).

[2] M. Karpiński, M. Jachura, L. J. Wright and, B. J. Smith, *Bandwidth manipulation of quantum light by an electro-optic time lens*, Nat. Photon. **11**, 53–57 (2017).