Interference of Quantum Light subject to Dispersion in Long Telecom Fibers

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The interference of indistinguishable single photons on a balanced beamsplitter leads to bunched photons in the beamsplitter's output modes. This effect, known as Hong-Ou-Mandel interference, can be leveraged for various photonic quantum information tasks. In lieu of a true photon pair source, a similar classical interference effect is exhibited by attenuated laser pulses with identical spectra. Here, we examine the interference of attenuated femtosecond pulses originating from the same laser source, after traversing some distance in a telecom fiber (1 to 10 kilometers). We observe that the interference visibility of these pairs remains unaffected for the lengths of fiber under consideration. This is expected to be consistent with the interference of single-photon pairs in the same setup, which should be confirmed by further experiments.

Introduction

In an era where secure and authenticated communication is of utmost importance, the methods we use to protect our data face new and evolving challenges [1]. Traditional symmetric encryption relies on shared secrets, requiring a secure key exchange between parties in advance [2]. On the other hand, asymmetric encryption removes this requirement but fundamentally relies on the unproven existence of one-way functions [3], rendering it vulnerable to a quantum computer attack [4]. This has prompted the exploration of innovative solutions, for example through the use of physical unclonable functions (PUFs), which provide a means of secure authentication without the need for conventional cryptographic secrets [5]. PUFs generate unique challenge-response pairs that are practically impossible to replicate, ensuring the integrity of the authentication process. Among the various types of PUFs, optical PUFs present promising opportunities for secure authentication [6]. However, challenges in transporting spatial wavefronts over long distances have limited their practical applications. Spectral-temporal optical PUFs (tPUFs) address this limitation by modulating the challenge in the time domain, allowing for efficient signal transport through optical fibers. By integrating quantum-secure authentication protocols, tPUFs can provide authenticated communication [7]. Part of this protocol involves simultaneously sending two single photons, each through one of two orthogonal polarization modes of a single-mode (telecom) fiber, and performing a Hong-Ou-Mandel (HOM) measurement. To test the feasibility of such a setup, we used weak coherent pulses to measure the effect of polarization mode dispersion (PMD) on the HOM interference.

Polarization mode dispersion

Polarization mode dispersion arises from birefringence in optical fibers. Even in single-mode fibers, pairs of orthogonal polarization modes exist. Ideally, these modes are degenerate, but manufacturing imperfections, bending and external stresses break this

degeneracy, causing differing phase and group velocities between the two modes [8]. While first-order PMD separates the two pulses in time, higher-order PMD effects can alter the shape of the pulse itself, similar to chromatic dispersion [9]. For short fiber lengths, the birefringence can be treated as uniform, but as fiber length increases, the birefringence becomes stochastic [10], which limits the distance over which signals can be transmitted without distortion as compensation requires the use of active feedback [11].

Method

A femtosecond pulsed laser is used to create weak coherent pulses with an average photon number less than one. The pulses are then split in two paths. Using polarization-maintaining fiber combiners and half-wave plates, the polarization of each pulse is aligned to allow the pulses to travel in orthogonal modes. The pulses then pass through a fiber under test (FUT), where they undergo PMD and the same polarization drift, which is compensated for by a polarization controller. Upon exiting the FUT, the pulses enter a polarizing beamsplitter in preparation for a HOM measurement. Superconducting nanowire single-photon detectors (SNSPDs) are used in combination with a time tagger to capture the coincidence count rate. By adjusting the time delay using a piezo electric stage, the full HOM curve can be constructed.

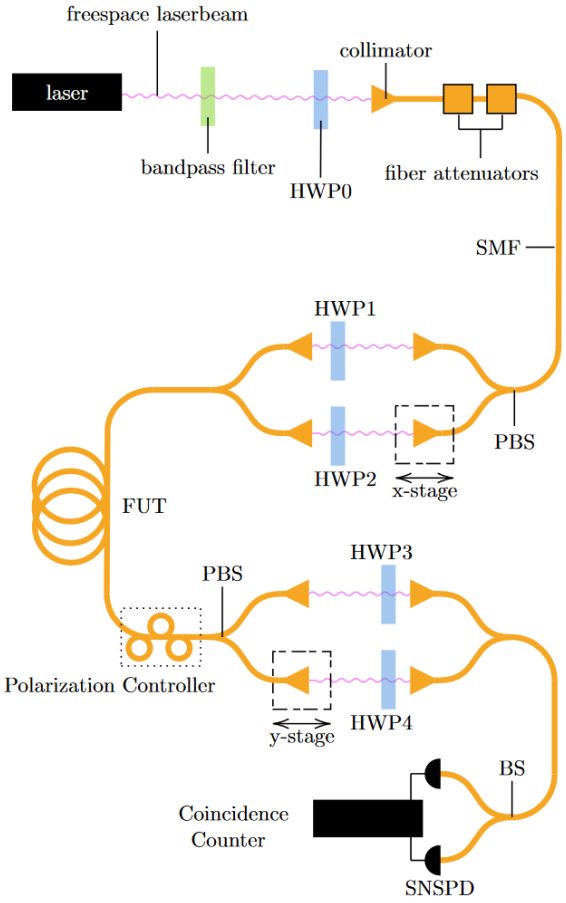

Figure 1. Schematic drawing of the setup. BS = Beam Splitter; HWP = Half Wave plate; PBS = Polarizing Beam Splitter; SMF = Single-Mode Fiber.

Conclusion

Preliminary results indicate that the HOM width shows a dependence on fiber length due to polarization mode dispersion, while HOM visibility remains stable over distances up to 10 km when using weak coherent pulses. Future work will extend these measurements to true single-photon sources and longer fibers to further characterize PMD's impact on HOM interference. These findings will support the potential implementation of tPUF-based schemes for quantum-secure authentication.

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