Influence of birefringent fiber joints on the visibility drift in a Mach–Zehnder interferometer

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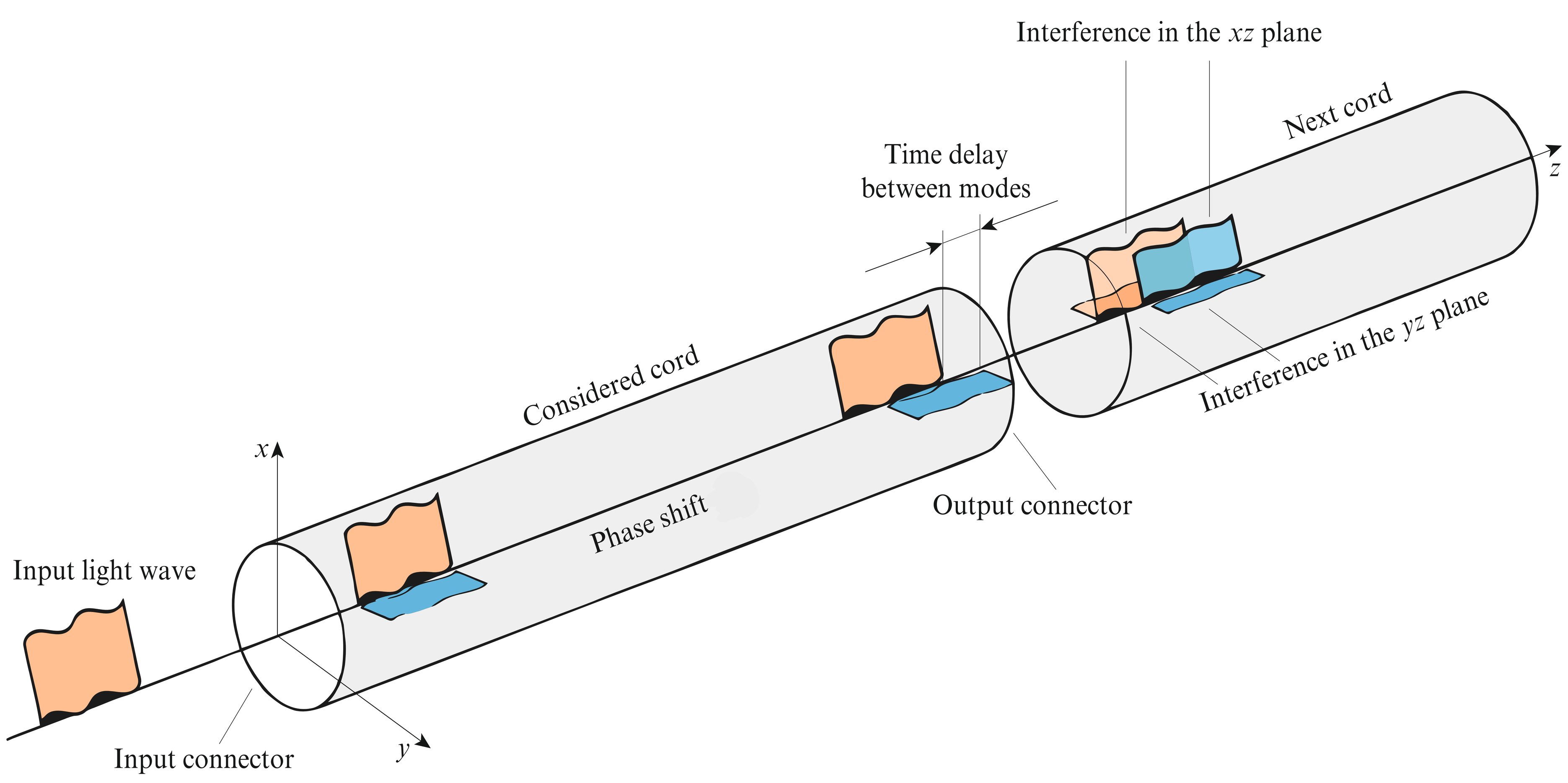
Interferometric devices used in QKD require matching the polarization states and phases of light beams in both arms. An accepted method for phase matching is altering the optical path length in one of the interferometer arms. In fiber devices, this may be realized in the form of a fiber stretcher. A widely used method for matching the polarization states is utilizing linear polarization maintaining fiber (PMF), which is intended for maintaining the linear polarization of radiation [1]. One could consider these aims to be comprehensive to provide stable visibility and, as a result, QBER. However, it is not unusual to obtain significant change of QBER during key sharing. In our work we show one of the possible causes of such drastic QBER changes [2]. It is shown that imperfect joints of linear PMF in a fiber interferometer may result in an uncontrolled visibility and QBER drift under varying environmental conditions even with a standard phase matching device.

Polarization state variation in a single PMF patch cord

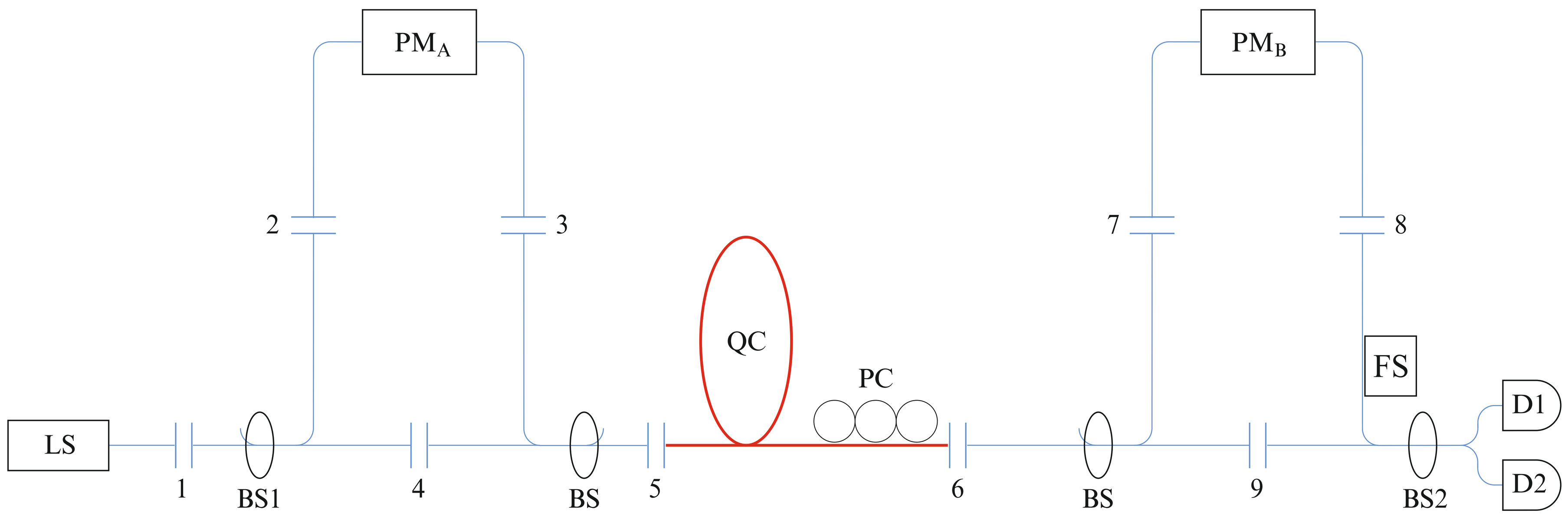
If a linearly polarized radiation with the polarization direction along any of PMF's axes is introduced into the fiber, then it will actually propagate without changing the polarization state. Nevertheless, when PMFs are connected, there is always a small misalignment angle. At the input connection, light wave is split into two waves polarized along the fiber axes. Due to a difference in the refractive indices in the fiber, the waves propagate at different velocities and acquire phase delay. Then at the output connector, each of them splits again into two waves. The waves polarized along similar directions interfere pairwise at the input to the next patch cord.



The resulting interference determines the patch cord's ability to maintain linear polarization and depends on the phase delay, which varies in time.

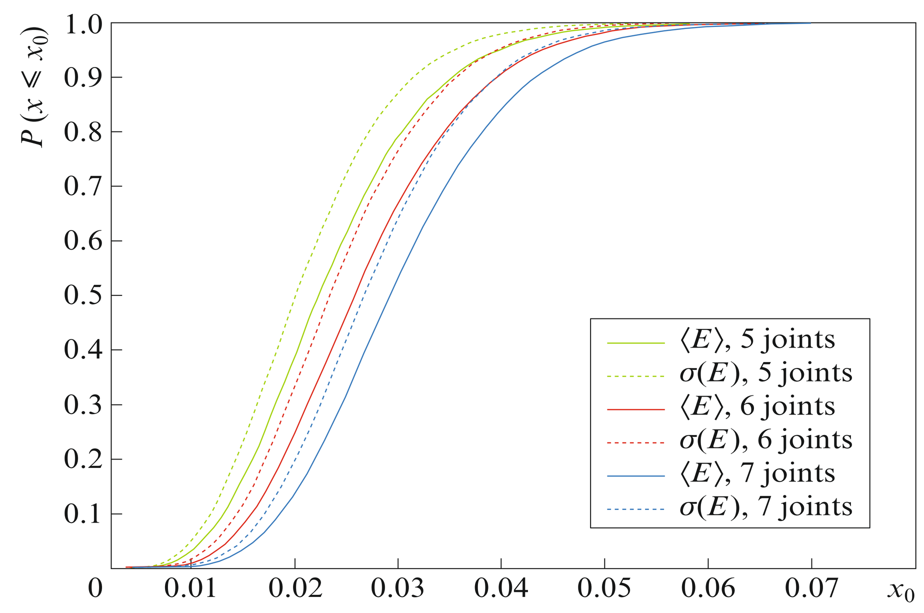
Results of numerical simulation

Consider propagation of optical radiation through a double Mach–Zehnder interferometer. While passing through the interferometer, light wave gradually goes to a polarization mode initially not intended for propagation.



Double Mach – Zehnder interferometer: (LS) laser source; (PM$_A$, PM$_B$) Alice and Bob phase modulators; (QC) quantum channel; (PC) polarization controller; (BS, BS1, BS2) polarization-maintaining fiber beam splitters; (FS) fiber stretcher; thin lines show PMF; bold lines indicate standard single-mode optical fiber; (D1, D2) detectors; digits enumerate fiber joints.

The fiber stretcher is aimed at affecting the fiber section so that the induced phase difference would provide the maximal visibility. A piezoelectric actuator which slightly varies the fiber length, almost identically changes the optical path length along both fast and slow axes. However, for reaching the maximal visibility, it is necessary to affect the fiber in such a way that the optical path lengths along both the axes will vary independently, because the phase differences in the interferometer arms corresponding to the fast and slow axes vary differently depending on external conditions. It follows that a standard piezoelectric actuator can only partially compensate for a variation of the interferometer visibility.



Data obtained by numerical simulation testify a substantial influence of the quality and number of joints in a BF fiber on the drift of the QBER under external conditions.

It is shown that imperfect joints of linear birefringent fibres in a fiber interferometer may result in an uncontrolled visibility drift under varying environmental conditions even with a standard phase matching device. As an example, a double Mach – Zehnder interferometer is considered, which is employed in schemes of quantum key distribution. Results of numerical simulation demonstrate the standard deviation of QBER, which is comparable to an average QBER.

1. *Tur M., Boger Y.S., Shaw H.J. J. Lightwave Technol., 13 (7), 1269 (1995).*
2. *G M Krylov, O V Fat'yanov, A V Duplinskii, "Influence of birefringent fibre joints on the visibility drift in a Mach–Zehnder interferometer", QUANTUM ELECTRON, 2020, 50 (5), 447–453.*