Frequency-bin entanglement based quantum key distribution

Massimo Borghi[1], Noemi Tagliavacche[1], Giulia Guarda[2,3], Domenico Ribezzo[3,4], Marco Liscidini[1], Davide Bacco[5,6], Matteo Galli[1] and Daniele Bajoni[7]

1. University of Pavia, Department of Physics, via Bassi 6, 27100 Pavia, Italy

2. European Laboratory for Non-Linear Spectroscopy (LENS), 50019 Sesto Fiorentino, Italy

3. CNR-National Institute of Optics (CNR-INO), 50125 Florence, Italy

4. University of L' Aquila, Department of Physical and Chemical Sciences, 67100 L' Aquila, Italy

5-QTI S.r.l., 50125 Firenze, Italy

6. University of Florence, Department of Physics and Astronomy, 50019 Sesto Fiorentino, Italy

7. University of Pavia, Department of Industrial and Information Engineering, Via Adolfo Ferrata 5, 27100, Pavia, Italy

Abstract: We demonstrate the BBM92 quantum key distribution protocol using frequency-bin entangled photon pairs generated by two independent, high-finesse, ring resonators on a silicon photonic chip.

Entanglement-based quantum key distribution allows one to share unconditionally secure keys between two remote parties exploiting non-local correlations between entangled photons. So far, integrated sources of entangled photon pairs have been used to exchange secure keys using either time-energy or polarization encoding. Less explored is frequency-bin encoding, in which quantum information is encoded in discrete set of frequency intervals. Here we report a demonstration of the BBM92 quantum key distribution protocol using frequency-bin entangled photon pairs generated on a silicon photonic chip [1].

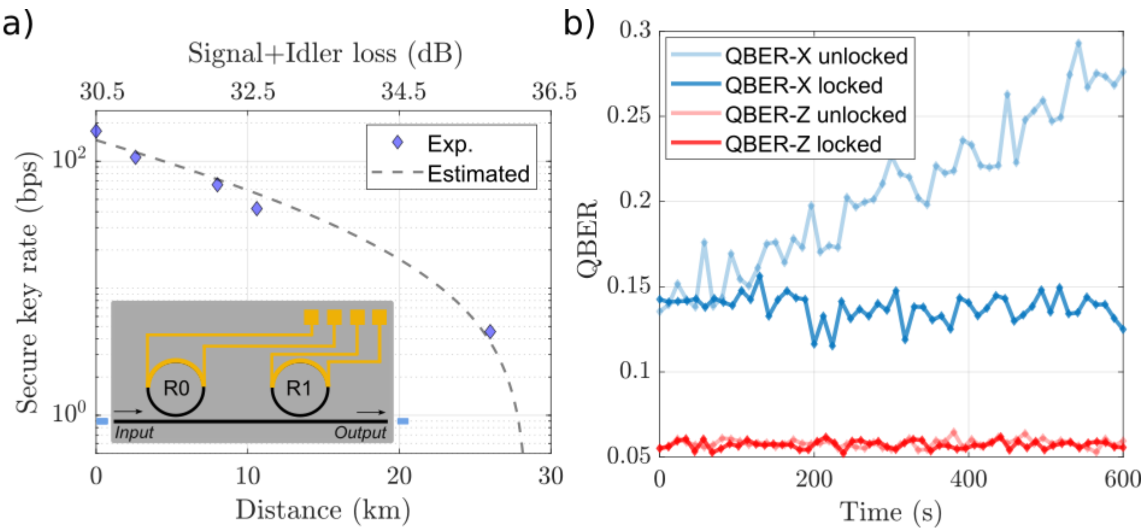

Fig. 1 Secure key rate as a function of the transmission distance. The upper axis shows the aggregated loss from photon pair generation on the chip to the detection. The inset shows a sketch of the silicon photonic circuit. (b) Quantum bit error rate variations on the X and Z basis as a function of time with (locked) and without (unlocked) active phase compensation.

A sketch is shown in Fig.1(a). Two identical microring resonators of radius 22µm are excited by a continuous pump laser at 1550 nm to trigger pair generation by spontaneous four wave mixing. By simultaneously exciting both rings with two mutually coherent pumps and by offsetting their resonances by 15 GHz, signal and idler photons are generated in frequency-bin encoded maximally entangled Bell state [1]. The BBM92 protocol is implemented by sending the idler photon sent to the Alice measurement stage, and the signal photon to Bob. Fiber spools of different length are introduced into Bob's path up to a maximum length of 26 Km. We used 50/50 beamsplitters to implement passive random basis selection among the Z and X basis. Figure 1(a) shows the extracted secure key rate as a function of the spool length. The rate is mainly limited by the high loss from pair generation to detection. For fiber lengths longer than 2.6 km, it was necessary to introduce an adaptive phase rotation of the measurement basis to compensate for the random relative phase fluctuation between the two frequency bins travelling through the Bob's fiber spool, which is induced by temperature fluctuations of the environment. Phase compensation allows one to achieve a low quantum bit error rate over time, as shown in Fig.1(b). Our work demonstrates that frequency-bin encoding is suitable for the realization of entangled based QKD protocols in telecom networks.

References

[1] N. Tagliavacche et al., "Frequency-bin entanglement-based quantum key distribution", *arXiv preprint arXiv:2411.07884* (2024).