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Testing of influence of polarization perturbation on dark channel in the system of entangled photons QKD (EPR Quelle, AIT)

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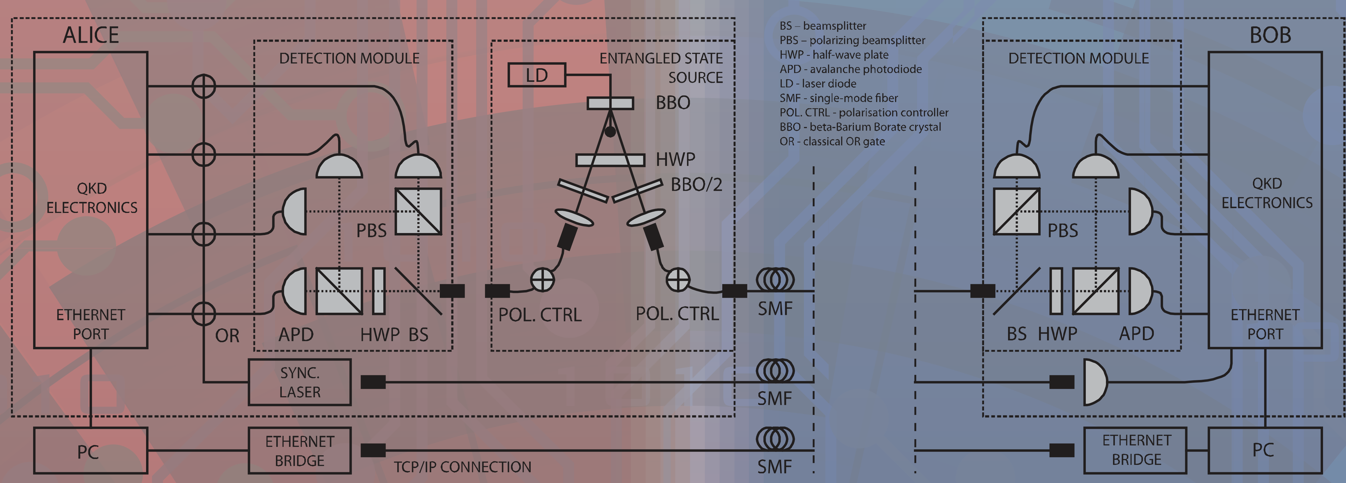
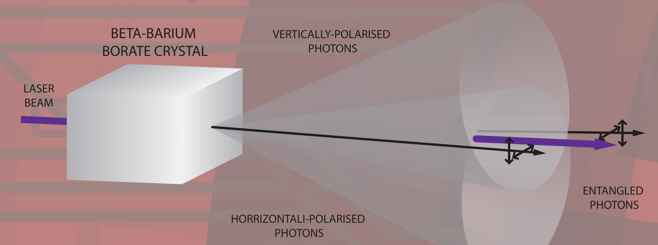
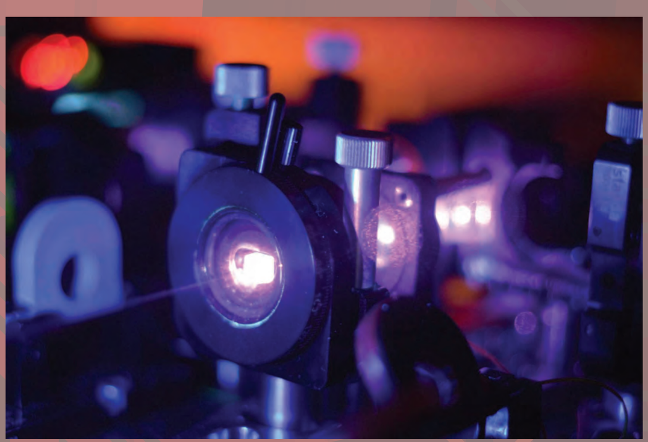
Two customized setups producing, detecting and synchronizing EPR photon pairs (AIT system) available to the research team in the National Quantum Technologies Laboratory NLTK and Compsecur laboratories (advanced laboratory infrastructure under supervision of the national network of the several leading Polish public universities and an academic spin-off R&D security information technologies company recently equipped in current state-of-the-art quantum communications and entanglement technologies)

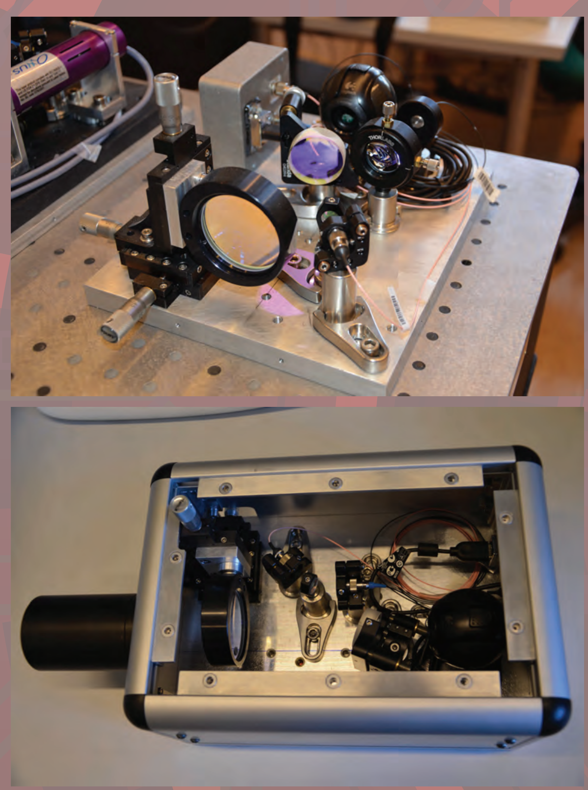


The entangled pairs of photons are provided by parametric down conversion II (PDC) in BBO crystal - EPR S405 Quelle (Austrian Institute of Technology - AIT). Mutually orthogonal, V and H polarized states of photons are entangled on intersection of two cones of transmission of PDC pair produced in birefringent BBO crystal.





The AIT EPR Quelle systems are equipped with telescope setups design for allowing long distance QKD (up to 5 km) in open air dark channel, where the satisfactory level of conservation of polarization of flying qubits is provided



Usage of commercial fiber connections for dark channel encounters, however, a problem with polarization mish-mash produced by accidental birefringence of fiber due to strain in welding and fiber flexion regions.

Tests of the system using different probe optical fibers for a dark quantum channel and compare QBER to short (2-m) polarization fiber connection. Testing include also a commercial 5 km long patchcord of fibers to assess possibility of practical implementation of entangled QKD system in metropolitan real network.

The objective of the present report is to summarize the results of stability testing of QKD system on entangled photons, EPR S405 Quelle System (Austrian Institute of Technology), with respect to various types of optical fibers for dark quantum channel, in order to assess feasibility of practical utilization of this system in commercial communication networks.

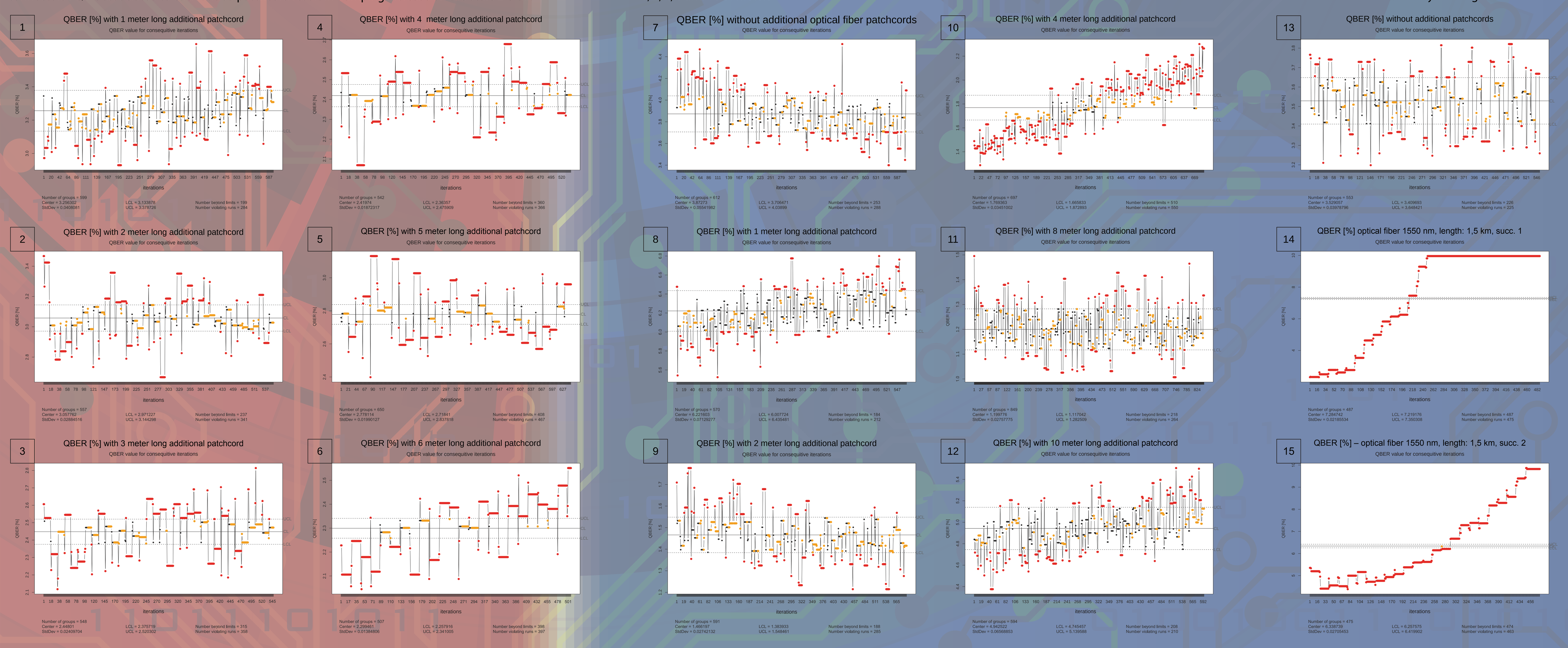
As the test indicator testing cards generated by packet qcc in application GNU R in the Quelle system have been used, allowing for quick estimation of stability of system functionality. The quantitative measure is quantum bit error, QBER, which displays the summarized level of communication perturbations. QBER is an effective resultant parameter summarizing all imperfections of the system including detector errors, optical elements mish-mash and optical fiber decoherence. Comparison of QBER for various configurations of optical fibers for dark channel allows, however, to distillate the net factor caused by polarization decoherence of photons in the quantum communication line.

In the system EPR S405 Quelle (AIT) for QKD on entangled photons employing protocol E91 the polarization of photons is treated as flying qubit, which is connected with manufactoring of entanglement by parametric down conversion II in BBO crystal applied in this setup. Nevertheless, it is obvious that any perturbation in the optical fiber link between Alice and Bob would modify polarization of transferred entangled photon state and effectively blur the key distribution. Especially exposed to polarization mish-mash are commercial telecom network lines with many weldings and connectors in patchcords as well as with some accidental stress of fibers e.g., due to their flexion. All these produce uncontrolled birefringence in glass of fibers resulting in uncontrolled drift of polarization of transmitted photons. Except of polarization drift one can encounter also the damping effects of the fragile quantum signal especially inconvenient for longer connections and for fibers not exactly accommodated to transmitted wave-length requirements. Estimation of the influence rate of these perturbations onto functionality of the system is crucial from point of view of feasibility of practical usage of entangled systems even for short distance quantum cryptographic communication in standard commercial optical patchcord metropolitan networks.

Comparison of dark channel efficiency for different connections by adding fiber patchcords with the same length (additional test optical fiber fragments with standard 1 meter length and using also typical standard connectors). Patchcords with the 1 meter lenght would not enhance strongly decoherence rate of the quantum channel, but connectors FC/PC associated to each added patchcord result in dumping increase on the scale 2-3 dB.

Measurements of dark channel efficiency for patchcords with different length - optical fibers SX 780H with lengths 1, 2, 4, 8 and 16 of meters

Measurement of system efficiency with application of third telecom window commercial optical fibers (1530-1565 nm). The cryptographic key has been obtained, but only of the system efficiency edge, because ca. 20% of trials of key sending has been failed.



Data

The data were gathered immediately from the protocol responsible for communication between particular modules of the system software. Each value of QBER was repeated twice and only every second its vale was collected in the final data file.

The test card consists of the plot with three type points indicated and of estimated parameters on the base of the collected data. The types of points are differentiated by distinct colors. The points within 'three sigma' region and satisfying the test requirements are indicated in black. The points which do not satisfy configuration tests but are located inside the region of 'three sigma', are indicated in orange.

The most inconveniently located points, outside the 'three sigma' region are shown in red. In figures are also plotted lines: (1) the line CL corresponding to average of all values of data, (2) the lines UCL and LCL located on positions CL_3 sigma, respectively. In figure descriptions the calculated parameter values are listed.

Conclusions:

Quelle system works efficiently for quantum communication using ca. 800 nm wave length photons. Application of optical fiber with ca. 1550 nm transmission window considerably diminishes efficiency to the level of almost preclusion the key distribution. Moreover, one can observe that the process of key generation is not stable, i.e., the corresponding QBER does not has a normal distribution. The good example is presented in the figure 13. The points in this figure are accidentally distributed (between 290 to 320) with extremally high amplitude. The figures 14 and 15 show that the considered perturbations strongly influence the system and change its functionality in a qualitative manner. Two adjustment procedures were necessary to restore the system functionality. The first one corresponds to mechanical adjustments of fixing of optical elements preserving alignment of pumping beam collinear with respect to the base, resulting then in proper alignment of entangled photons. Using the special system with photo-diode one can adjust the pumping beam to optimal position – this procedure had to be, repeated more frequently than without dark channel modification (ca. at every 5 min in comparison to ca. 30 min for net system) for the system with dark channel with higher level of polarization mish-mash. Application of automatic piezo-electric control of the correction mirror would be thus recommended. The second adjustment procedure concerns the direct correction of polarization in order to repair its drift. Each modification of the quantum channel results in some polarization drift which requires the by-hand polarization correction. This adjustment must be performed up to achievement the optimal value of observed data. With this regard one can recommend development of the system towards automatic self-adjustment of polarization. Both mentioned here improvements would enhance the feasibility level of usage of Quelle system for QKD in real commercial metropolitan telecom webs.

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