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Estimation of the Parameters of Free Space Quantum Key Distribution System Depending on the Insertion Losses

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Abstract

A telescopic system consisting of two modules is used to organize the quantum channel. The accuracy of the adjustment of these modules relative to each other ensures a reduction in losses in the channel, therefore, an important step before conducting the next experiments is the alignment of the system. Both modules of the system are mounted on movable supports that allow the modules to rotate around two axes. Using these supports, we managed to reduce the losses in the atmospheric channel with a length of 1 meter to 10 dB when the radiation is introduced into a single-mode fiber.

Keywords: Quantum key distribution; Quantum bit error rate; Sifted key; Telescopic system; Atmospheric quantum channel

1. INTRODUCTION

Quantum key distribution (QKD) systems using optical fiber have received a lot of attention recently. In the last few years, developments in this area have led to an increase in the key generation rate to 1 Gbit/s [1]. One of the approaches to the implementation of QKD is a generation of sidebands [2], based on the removal of single-photon radiation to the subcarrier of the spectrum using amplitude or phase modulation. This type of QKD system has its advantages which include absence of complicated interferometry schemes and simplification of matching the phase shift between transceiver and receiver modules. Contrast of two phase modulated signals' interference is called visibility. This parameter is valuable in QKD systems since the greater its value, the smaller the quantum bit error rate (QBER) and the greater the key rate.

Fiber communication lines demonstrate high loss values when operating at distances reaching several hundred kilometers. In order to increase the coverage of quantum communications to a global scale, the transmission of keys via an atmospheric channel is being actively studied. The transmission of keys over record-breaking long distances is feasible using satellites orbiting the Earth [3]. These satellites are equipped with reflectors that redirect the signal back to Earth. An aircraft simulating a low-orbit satellite can also act as a mobile object [4]. Establishing a secure connection with a moving object may be necessary on the surface of the Earth. The connection between the ground station and the car [5] can serve for the development of unmanned vehicles in the city, and the connection between drones [6] can serve for the development of mobile quantum networks.

It is also possible to integrate these channels into optical urban networks and provide higher bandwidth in congested places where there is a poor level of communication. Fiber laying can be hindered by buildings or objects with limited access in cities and specially protected natural areas between cities.

In this work, subcarrier wave QKD system was developed for wireless data transmission. A single-mode fiber is used for receiving and transmitting of key, data transmission occurs at a wavelength of 1310 nm. Given this, it will be possible to integrate this system into existing backbone fiber-optic communication lines without additional configuration.

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2. SUBCARRIER WAVE QKD

The laser installed in the transmitter unit (Alice) generates continuous radiation with a given wavelength. This radiation passes through modulation on a phase modulator. It selects the phase randomly according to the BB84 protocol [7]. After phase modulation, in addition to the carrier, sidebands appear in the signal, which are separated from the central frequency of the laser radiation by the magnitude of the frequency of the modulating signal [8]. Next, the modulated signal passes through the attenuator and enters the receiver unit (Bob). It also has a phase modulation unit, passing through which the signal is divided into two orthogonal components. This unit contains two phase modulators, each of which receives its own orthogonal component of the incoming signal. Similar to Alice's block, the state of the introduced phase is randomly selected here. If the selected phase coincides with the phase entered in the transmitter block, constructive interference occurs, due to which the signal at the side frequencies is amplified. Otherwise, destructive interference is observed, and the signal is extinguished. Next, a spectral filter is installed in the circuit, which reflects the signal at the central frequency and passes the side ones, which then arrive at the detector of single photons.

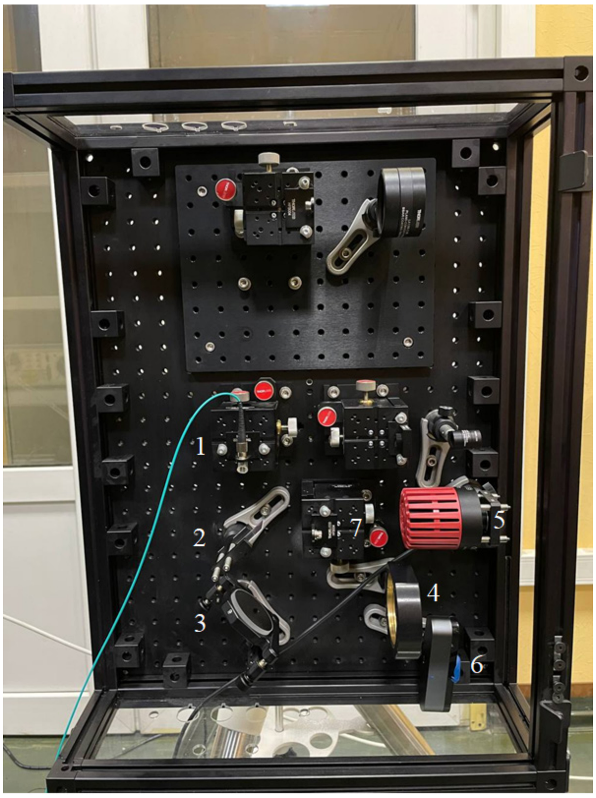

Fig. 1. Transmitter block. Quantum channel: 1 – fiber holder, 2 – dichroic mirror, 3 – mirror, 4 – lens. Rough guidance channel: 5 – infrared LED, 6 – camera. Precision guidance channel: 7 – fiber holder.

3. EXPERIMENT

The atmospheric communication channel was organized with the help of two telescopic devices connecting the fiber endings of the transmitter and receiver blocks of the quantum communication system. Transmitter and receiver blocks are shown in Figs.1 and 2, respectively.

These devices have an automatic guidance system. In addition to the quantum channel, there are channels for rough and precision guidance. At the top of the blocks there is a channel for rough guidance. Its job is to make blocks move in such a way that the label from the infrared LED (5) is always in the center of the camera lens (6). Below is the precision guidance channel. With the help of dichroic mirrors (2), the alignment beam enters the quantum channel in the sender block, and in the receiver block it separates from it, hits the camera matrix (7) and is directed to a given pixel. The precision guidance system provides guidance accuracy of up to 3.5 arc seconds. Sky watcher AZ-EQ6 with hybrid stepper motors (1.8°/step) were used as the movements of the rough guidance system.

This system was modeled in Zemax. Results are presented in Figs.4 and 5. In these images the presence of a parasitic beam and a distorted wavefront in the receiver plane can be observed. These aberrations were introduced by a dichroic mirror, so it was decided to remove it, which led to a reduction in losses. After the dichroic mirror was

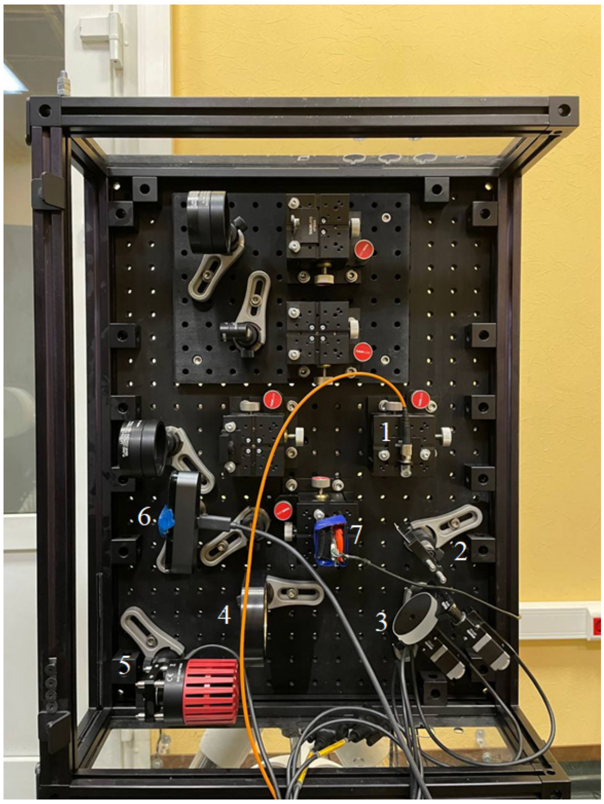

Fig. 2. Receiver block. Quantum channel: 1 – fiber holder, 2 – dichroic mirror, 3 – mirror, 4 – lens. Rough guidance channel: 5 – infrared LED, 6 – camera. Precision guidance channel:

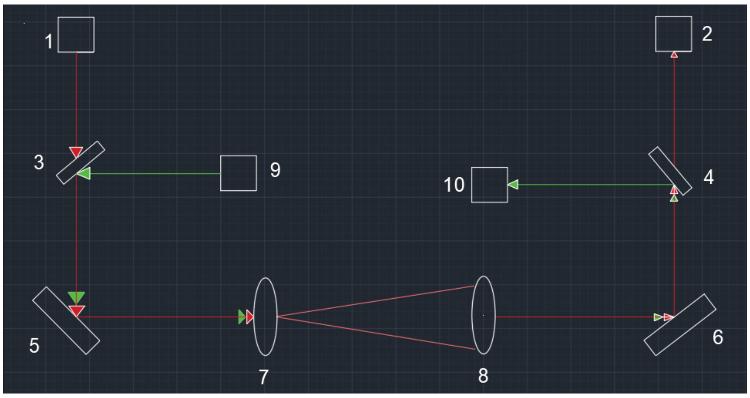

Fig. 3. Experiment scheme. Quantum channel: 1,2 – fiber holders, 3,4 – dichroic mirrors, 5,6 – mirrors, 7,8 – lenses. Rough guidance channel: 9 – infrared LED, 10 – camera.

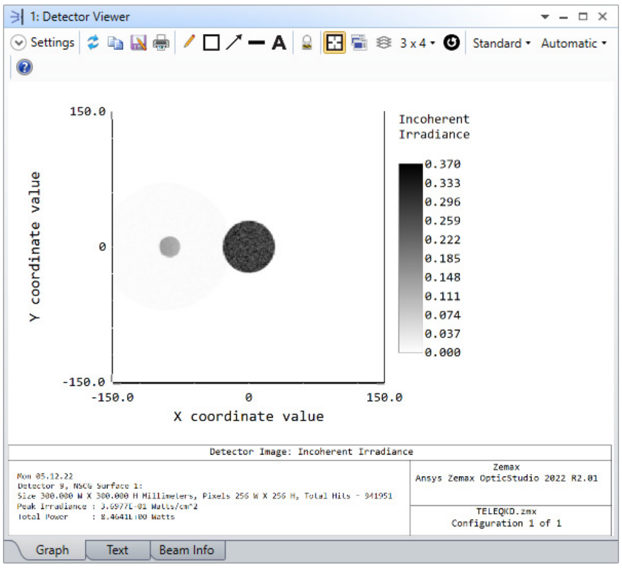

Fig. 4. The presence of a parasitic beam.

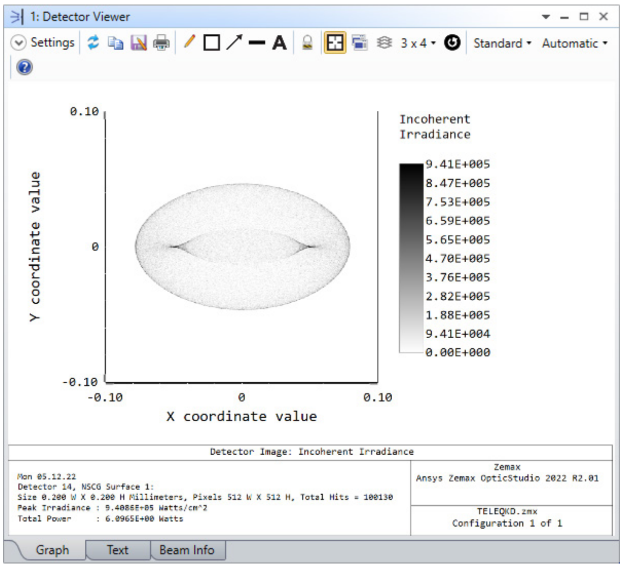

Fig. 5. Distorted wavefront at receiver plane.

removed from the system, new precision guidance is realized with the help of a power meter and motorized mirrors. We have developed and applied a specialized algorithm for controlling mirrors, which searches for the maximum value from the power meter and ensures the most efficient alignment of the modules relative to each other.

Before installing the telescopic devices on the Sky watcher, the internal optical elements of each device were configured. In the channel between two closely spaced telescopes, by adjusting the internal elements, the losses were reduced to 7 dB when radiation enters a single-mode fiber. After that devices were installed on the Sky watcher, taken outside in lack of precipitation and spaced at a distance of one meter. Under such conditions, the losses in the channel amounted to 10 dB.

4. RESULTS AND DISCUSSION

With channel losses of 10 dB, graphs of changes in the sifted key generation rate and QBER were obtained from the recorded data. The resulting graphs are shown in Figs.6 and 7, respectively. The average value of sifted key generation rate was approximately 5 kbit/s, which is several times less than that obtained one in the fiber channel. The average value of QBER was approximately 4%, which is less than the maximum allowable value at which secrecy is ensured. Practical limit set at approximately 6%, and if threshold is exceeded, it is assumed an adversary interferes in the key exchange.

5. CONCLUSION

In this paper, we demonstrated the operation of the telescope system we configured as devices for organizing an atmospheric channel for subcarrier wave QKD system. Obtained results indicate that with losses in the channel amounting to 10 dB, the necessary level of secrecy in the system was maintained. In the future, it can be used to transmit quantum bit sequences over long distances.

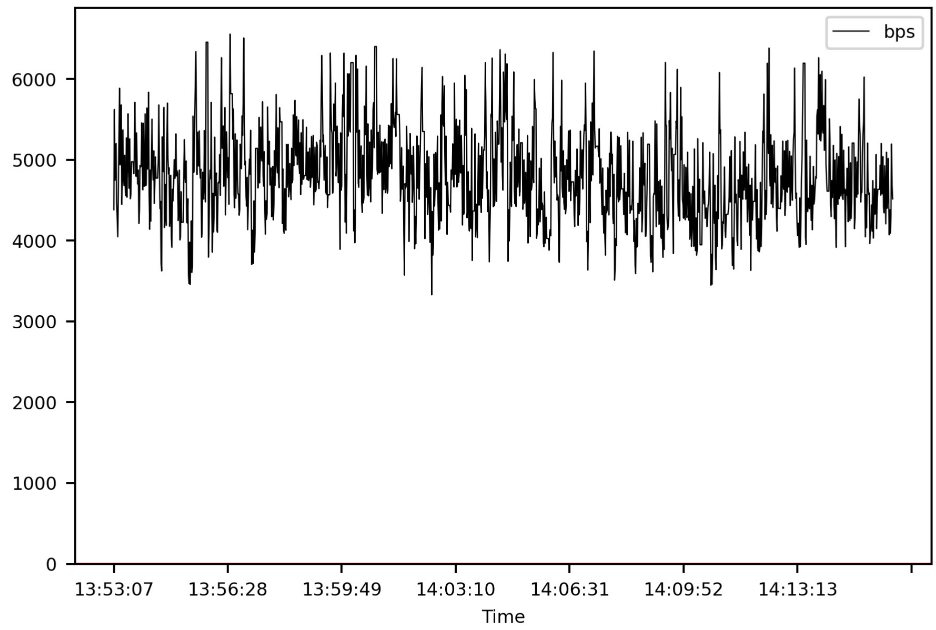

Fig. 6. The temporal fluctuations of sifted key rate in time monitored with a channel loss of 10 dB.

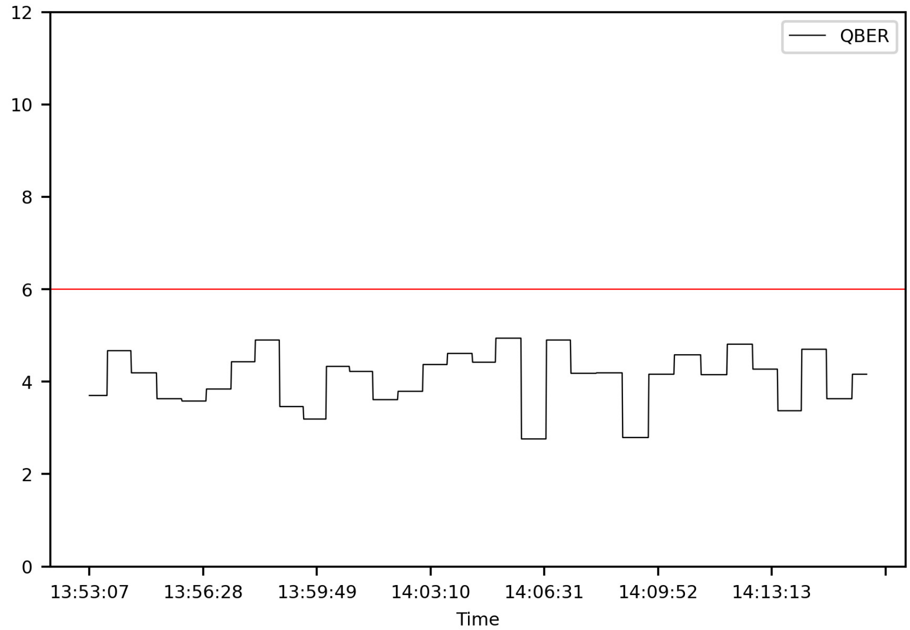

Fig. 7. The temporal fluctuations of QBER in time monitored with a channel loss of 10 dB.

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УДК 535.3

Оценка параметров системы квантового распределения ключей в открытом пространстве в зависимости от вносимых потерь

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Аннотация. Для организации квантового канала используется телескопическая система, состоящая из двух модулей. Точность регулировки этих модулей относительно друг друга обеспечивает снижение потерь в канале, поэтому важным этапом перед проведением следующих экспериментов является юстировка системы. Оба модуля системы установлены на подвижных опорах, которые позволяют модулям вращаться вокруг двух осей. Используя эти опоры, нам удалось снизить потери в атмосферном канале длиной 1 метр до 10 дБ при вводе излучения в одномодовое волокно.

Ключевые слова: квантовое распределение ключей; квантовый коэффициент ошибок; просеянный ключ; телескопическая система; атмосферный квантовый канал