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Near-Infrared Optical Transmitting Module for Service Channel of Atmospheric Quantum Communication Line

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Abstract

This work presents an optical transmitting module operating in the near-infrared wavelength range for the organization of a wireless service channel in an atmospheric optical quantum communication channel. The main characteristics were measured to demonstrate the functionality of the module and to assess the quality of the transmitted signal, such as the values of the error vector magnitude and the eye diagram opening level. It was determined that the transmitting module can operate at symbol rates up to 5 GBaud. In addition, the optimal signal modulation parameters were found and the possible bit rate of data transmission in the atmospheric optical communication channel was estimated: a QPSK-modulated signal with a carrier frequency of 80 MHz and a symbol rate of 50 MBaud allowed to get a bit rate of 100 Mbit/s with an EVM value of 14%.

Keywords: Atmospheric communication channel; Quantum communication; Signal modulation; Optical wireless communication

1. INTRODUCTION

One of the perspective optical communication channels is atmospheric channel, which has several advantages, for example, high noise immunity, since the emission of the optical range is practically not affected by radio disturbances. In addition, atmospheric optical communication lines relieve the radio frequency band, thereby solving the problem of saving radio frequency resources [1]. Moreover, one of the important advantages of atmospheric optical communication lines is the security of data transmission, as it is difficult to read or intercept the signal unnoticed [2]. Therefore, such communication lines are used to solve specific problems where it is not always possible to apply fiber-optic communication lines, for example, in quantum communications [3].

Quantum communication is a technology that allows to encode and transmit data in quantum states of photons. Quantum communication systems contain three channels: quantum channel, synchronization channel, and service channel [4,5]. The quantum channel transmits the encrypted key, the synchronization channel synchronizes the transmitting and receiving modules of the quantum communication system, and the service channel transmits data.

Atmospheric quantum communication lines are the object of several research. For example, in 2014, the transmission of quantum bit sequences in urban environments over distances of up to 210 m via an atmospheric communication channel was studied inside the model hall of the Venetian Lagoon, which is in the Padua region [6]. And in 2017, quantum key distribution was demonstrated over 53 km for satellite communications. The experiment was executed with an operating wavelength of 1550 nm and single-photon detectors with an ultra-low noise level, which made it possible to overcome the noise from sunlight [7]. However, in all of the above experiments service channel was implemented using wired fiber-optic networks, which are not available everywhere. Therefore, the task of a service channel implementation in quantum communication systems using atmospheric optical communication lines is relevant.

This paper presents an optical transmitting module operating in the near-infrared wavelength range for the organization of a wireless service channel in an atmospheric optical quantum communication system. The module was developed for the XI All-Russian scientific and technical conference "Electronics and microwave microelectronics" [8]. The following tasks were set to show the functionality of the module:

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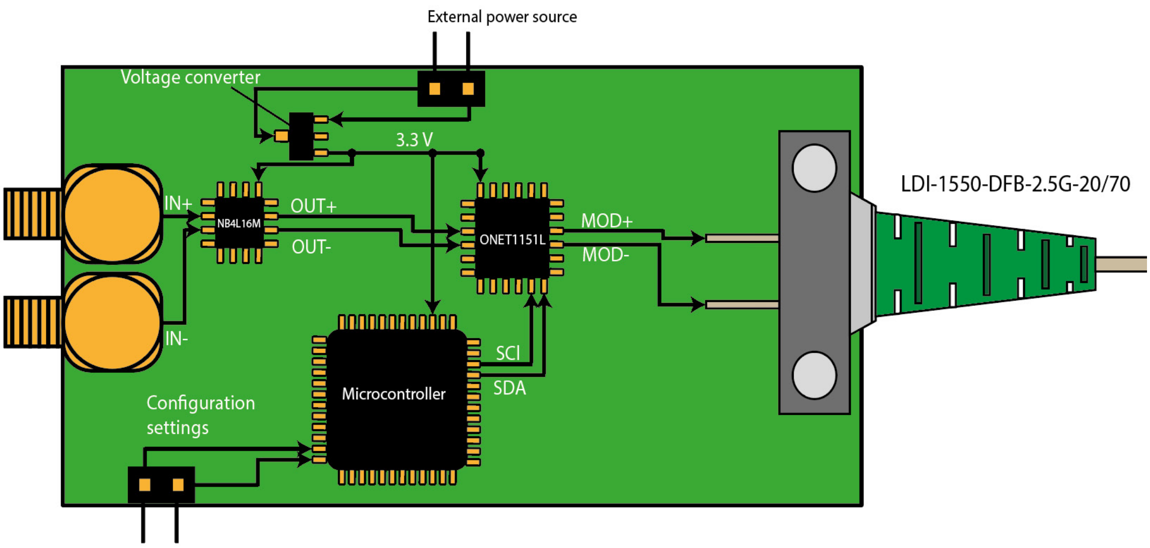

Fig. 1. Functional diagram of the transmitting module for the near infrared range.

1. Determination of the maximum symbol rate at which the transmitting module can operate;

2. Organization of an optical wireless communication channel to measure the characteristics of the information path, such as the eye diagram opening level and error vector magnitude (EVM);

3. Evaluation of the communication channel quality and determination of the optimal parameters of the modulated signal, such as symbol rate, carrier frequency and modulation type.

2. METHODS

The functional diagram of the transmitting module is shown in Fig. 1. The operating principle of the presented module is as follows: first, the input of the NB4L16M interface converter receives a differential signal from an arbitrary waveform generator or other source. Then, the signal received by the interface converter is converted into an output CML (current mode logic) signal, which is fed through a differential pair to the ONET1151L laser driver. The laser driver is used to transmit the CML signal to the laser LDI-1550-DFB. It is carried out by controlling the current flow through the driver. After that, the laser transmits the signal via the atmospheric communication channel to the receiving module for further analysis of the received data. To configure the laser driver, a microcontroller is used that transmits configuration settings from a personal computer via the I^2C (Inter-Integrated Circuit) interface, using the SDA (Serial Data) and the SCK (Serial Clock) buses. To supply power from a voltage source to the main elements of the module, a step-down voltage converter is used, designed to reduce the voltage in the circuit to 3.3 V.

To organize an optical wireless communication channel for the characteristics of the information path measurement, in addition to the transmitting module, a receiving module is used. The functional diagram of the receiving module is shown in Fig. 2. The receiving module is based on FDGA05 photodiodes from Thorlabs. The operating wavelength range of this photodiode is in the range from 800 to 1700 nm. The central wavelength is 1550 nm, which corresponds to the wavelength of the laser used. To increase the sensitivity of the receiving module, a transimpedance amplifier is used in the electrical circuit. It amplifies the output information signal from the photodiodes. To combine signals from all photodiodes after transimpedance amplifiers, an adder based on an operational amplifier is used in the electrical circuit of the module. A band-pass filter is installed at the output of the adder, which limits the receiving module in bandwidth at a frequency of about 120 MHz. This filter is necessary to reduce the

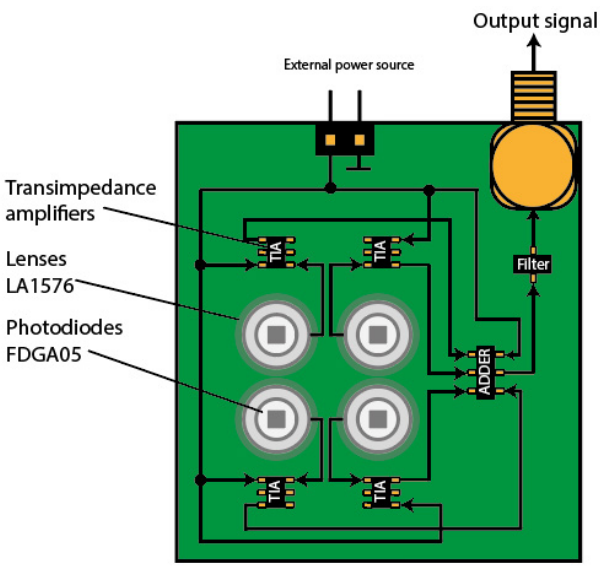

Fig. 2. Functional diagram of the receiving module.

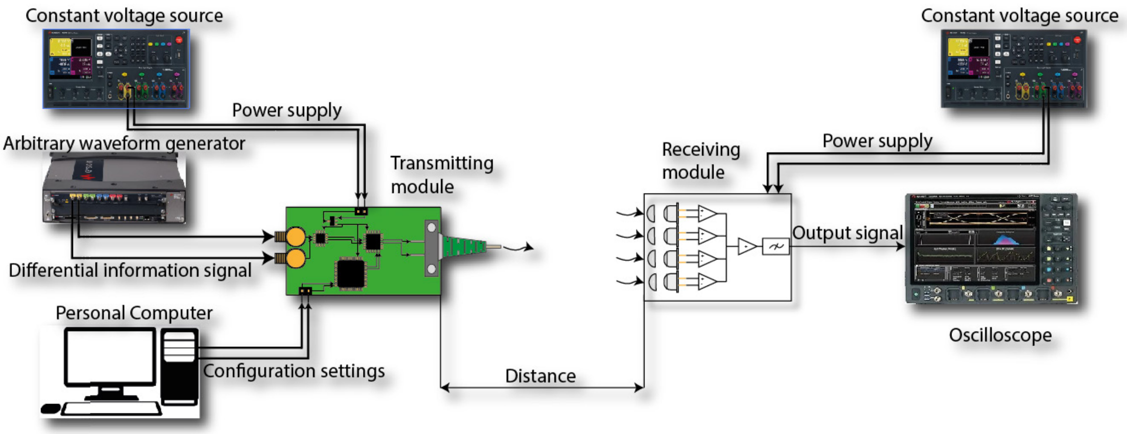

Fig. 3. Measurement setup.

influence of external noise on the signal coming to the receiving module. To increase the power density of the emission coming to the photodiodes, LA1576 converging lenses by Thorlabs are used. The operating bandwidth of photodiodes can be estimated using the following expression:

$$f_{BW} = \frac{1}{2\pi R_L C_j},$$

where R_L is the load resistance equal to 50 Ohm, C_j is the photodiode capacitance equal to 10 pF. After the calculations, the value of the photodiode's operating bandwidth is about 300 MHz.

This receiving module reduces the transmission speed due to a bandpass filter in it, however, the lack of alternative receivers and element base for their production leads us to the choice of the considered receiving module. In further studies it is planned to develop a receiving module based on avalanche photodiodes with a bandpass filter of higher bandwidth.

Before measuring the main parameters to assess the quality of the transmitted signal over the atmospheric communication channel, the performance of the transmitting module was checked. For this purpose, the module was connected directly to an oscilloscope to measure eye diagrams at various symbol rates. The modulation amplitude was 35 mA. The obtained data are presented in the Results section.

Measurements of the main parameters for assessing the quality of the transmitted signal over the atmospheric communication channel were carried out using the experimental measurement scheme shown in Fig. 3. The differential information signal with a given modulation and pseudorandom binary sequence (PRBS) is sent to the transmitting module from an arbitrary waveform generator Keysight M8195A. Configuration settings are transmitted to the microcontroller of the transmitting module from a personal computer. After that, the signal is transmitted via the atmospheric channel to the receiving module, from where it enters the oscilloscope Keysight UXR0204A. The transmitting and receiving modules are powered from constant voltage sources Keysight N6715C. The eye diagrams were measured at distances of 7, 45, and 85.5 cm from the source. The EVM values were measured at 45 cm between source and receiver. The choice of these distances is due to the fact that under laboratory conditions it was not possible to carry out measurements at large distances.

3. RESULTS

The eye diagram opening level was measured using the transmitting module connected directly to the oscilloscope. The step of symbol rate change in the measurement of the eye diagram was 0.1 GBaud. The resulting eye diagrams are shown in Fig. 4. It was determined that the transmitting module can operate at symbol rates up to 5 GBaud. After that, an optical wireless communication channel was organized using both transmitting and receiving modules for further research.

Fig. 5 shows the results of measuring the eye diagram opening level depending on the symbol rate at various

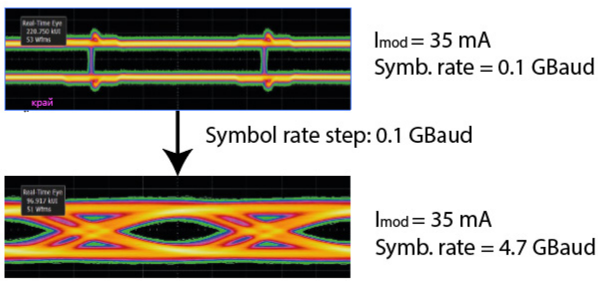

Fig. 4. The result of measuring the eye diagrams when checking the performance of the transmitting module.

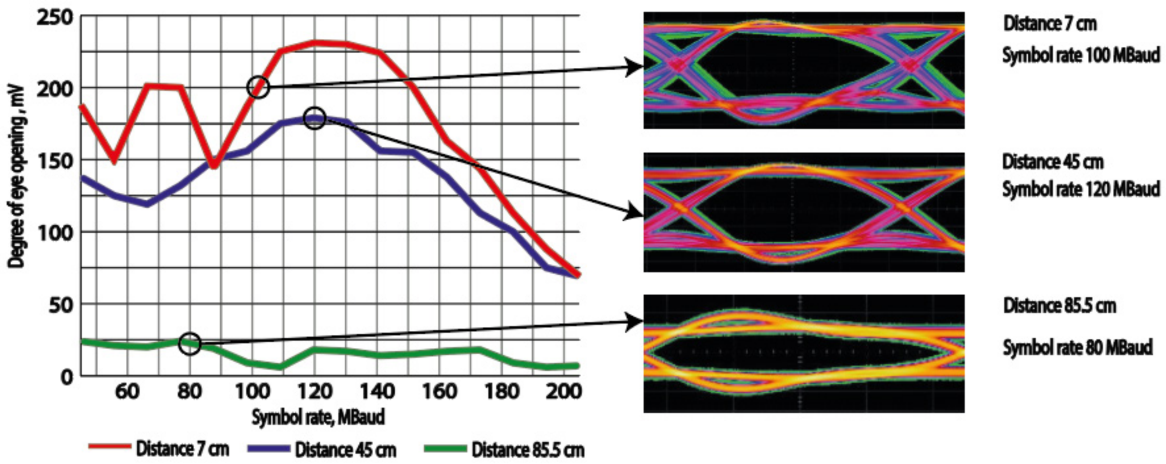

Fig. 5. Dependence of the eye diagram opening level on the symbol rate of signal at different distances and eye diagrams at certain values of symbolic speed.

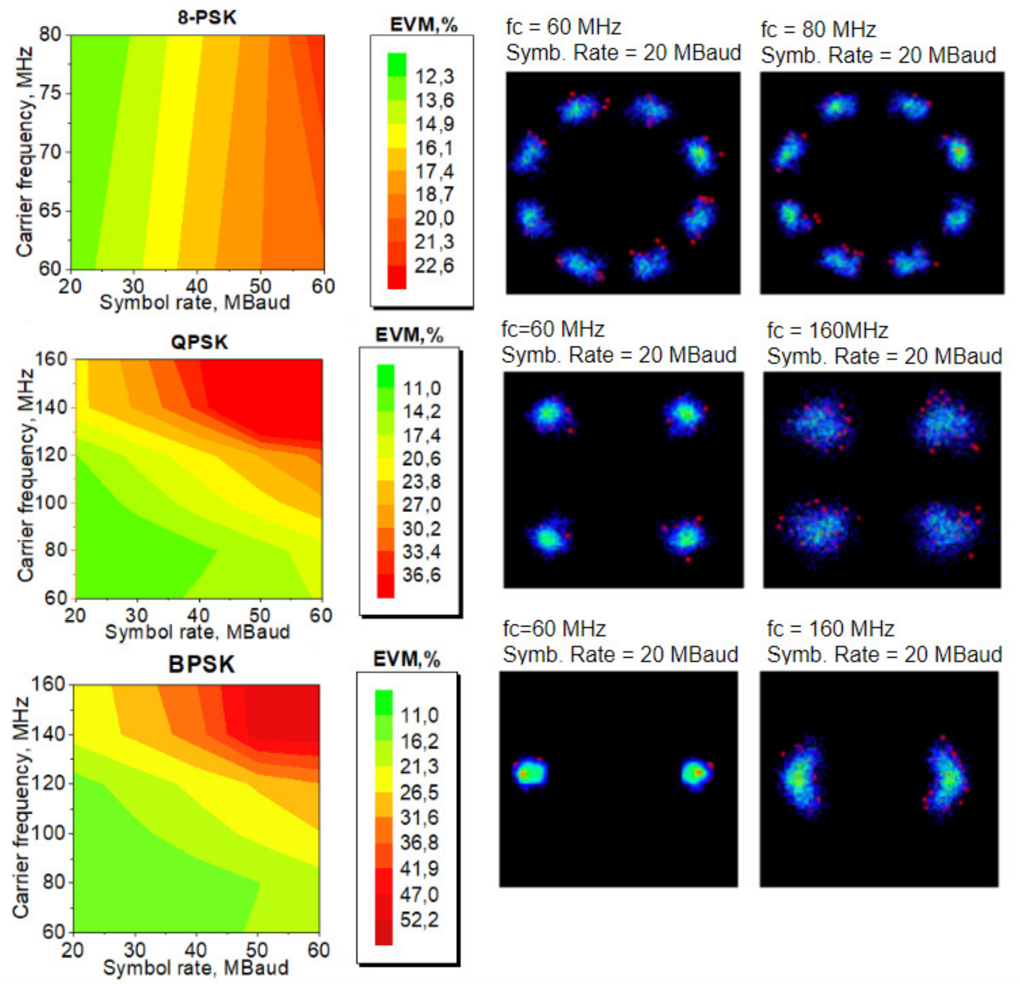

Fig. 6. EVM dependences on the symbol rate and carrier frequency of the signal.

distances between the transmitting and the receiving modules using the measurement scheme shown in Fig. 3. It was found that the maximum eye diagram opening level occurs at a symbol rate of 120 MBaud. The eye diagram closing in the high frequency region can be caused by the fact that the receiving module is limited in the bandwidth.

Fig. 6 shows the obtained results for the dependence of the error vector magnitude (EVM) on the symbol rate for various types of modulations and the signal constellations for each modulation at minimum and maximum carrier frequencies.

The measurements were carried out for the following carrier frequency ranges:

- 60 MHz to 100 MHz for 8-PSK modulation;
- 60 MHz to 160 MHz for QPSK and BPSK modulations.

The range of symbol rates was from 20 to 60 MBaud for all modulations.

From the obtained results, it follows that with an increase in the symbol rate and carrier frequency, the quality of the signal constellations deteriorates, which leads to an increase in the EVM values. The increase in EVM values at high carrier frequencies is explained by the receiving module limitation in bandwidth at a frequency of about 120 MHz as a bandpass filter is used in it. In addition, the obtained results can be affected by external noises. The main noise effect on the service communication channel is “white noise”, which causes a scatter of points on the signal constellation diagram around the true signal values. However, from the obtained results, it is possible to determine the optimal zones with a minimum number of errors in the channel, which can be implemented using these transmitting and receiving modules. For example, a QPSK-modulated signal with a carrier frequency of 80 MHz and a symbol rate of 50 MBaud allows to get a bit rate of 100 Mbit/s with an EVM value of 14%. This bit rate is sufficient to organize a service channel in a quantum communications system.

4. CONCLUSION

In this work, near-infrared optical transmitting module for service channel of atmospheric quantum communication line was presented. The values of the error vector magnitude and the eye diagram opening level were measured to assess the quality of the transmitted signal. It has been found that the transmitting module is capable of operating at symbol rates up to 5 GBaud. In addition, it was determined that in laboratory conditions with the use of the described receiving module, the optimal distance for data transmission was approximately 0.5 meters, and the optimal modulation parameters were QPSK modulation with a carrier frequency of 80 MHz and a symbol rate of 50 MBaud. An increase in working distances can be achieved by using avalanche photodiodes in the receiving module, which is planned in further studies. Increase in transmission rates can be achieved by using a bandpass filter of higher frequency in the receiving module.

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Оптический передающий модуль ближнего инфракрасного диапазона для служебного канала атмосферной квантовой линии связи

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Аннотация. В данной работе представлен оптический передающий модуль, работающий в ближнем инфракрасном диапазоне длин волн, для организации беспроводного служебного канала в атмосферном оптическом квантовом канале связи. Для демонстрации работоспособности модуля и оценки качества передаваемого сигнала были измерены основные характеристики, такие как значения амплитуды вектора ошибки и степень открытия глазковой диаграммы. Было определено, что передающий модуль может работать с символьными скоростями до 5 ГБод. Кроме этого, были определены оптимальные параметры модуляции и оценена возможная скорость передачи данных по атмосферному оптическому каналу связи: QPSK-модулированный сигнал с несущей частотой 80 МГц и символьной скоростью 50 МБод позволяет получить скорость передачи данных 100 Мбит/с с значением амплитуды вектора ошибки EVM 14%.

Ключевые слова: атмосферный канал связи; квантовая коммуникация; модуляция сигнала; оптическая беспроводная связь