

Conference materials

UDC 53

DOI: <https://doi.org/10.18721/JPM.153.338>

## Novel method for preparing high-indistinguishable coherent states

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**Abstract.** The preparation of indistinguishable quantum states by remote users is one of the crucial tasks in MDI-QKD. To solve this problem, laser injection techniques or modulation of the CW laser on the transceiver side are used. These techniques require a complex setup or a pair of modulators. Here we present a different setup for generating coherent states, using one modulator and one gain-switched laser per transceiver, to find a balance between the complexity of the setup and its cost. The level of indistinguishability achieved allows our scheme to be used in high-speed MDI-QKD protocols.

**Keywords:** MDI-QKD, Hong-Ou-Mandel interference, Weak Coherent Pulses with Randomized Phase, Indistinguishable quantum states

**Funding:** The study was commissioned by JSCo "RZD".

**Citation:** Gerasin I. S., Mekhtiev E. E., Maksimova E. I., Rudavin N. V., Duplinsky A. V., Kurochkin Yu. V., Novel method for preparing high-indistinguishable coherent states. St. Petersburg State Polytechnical University Journal. Physics and Mathematics, 15 (3.3) (2022) 198–201. DOI: <https://doi.org/10.18721/JPM.153.338>

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Материалы конференции

УДК 53

DOI: <https://doi.org/10.18721/JPM.153.338>

## Новый способ получения слаборазличимых когерентных состояний

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**Аннотация.** Подготовка неразличимых квантовых состояний различными пользователями является одной из важнейших задач в КРК с НЦУ. Для решения этой проблемы используются методы лазерной инжекции или модуляции непрерывного лазера на стороне передатчика. Эти методы требуют сложной настройки или нескольких оптических модуляторов. В данной работе мы представляем новую установку для генерации когерентных состояний, использующую один модулятор и один лазер на стороне каждого из отправителей, чтобы найти баланс между сложностью установки и ее стоимостью. Достигнутый уровень неразличимости позволяет использовать нашу схему приготовления состояний в высокоскоростных протоколах КРК с НЦУ.



**Ключевые слова:** КРК с НЦУ, интерференция Хонга-У-Манделя, слабые когерентные импульсы с рандомизированной фазой (СКИРФ), неразличимые квантовые состояния.

**Финансирование:** Исследовательская работа выполнена по заказу ОАО «РЖД».

**Ссылка при цитировании:** Герасин И. С., Мехтиев Э. Э., Максимова Е. И., Рудавин Н. В., Дуплинский А. В., Курочкин Ю. В. Новый способ получения слаборазличимых когерентных состояний // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2022. Т. 15. № 3.3. С. 198–201. DOI: <https://doi.org/10.18721/JPM.153.338>

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## Introduction

Quantum interference is one of the key experiments in quantum information technologies. It is useful for quantum teleportation, quantum computing, and quantum cryptography. Usually, the visibility of interference at the beamsplitter (Hong-Ou-Mandel interference) serves as a measure of indistinguishability of quantum states. Measurement device independent quantum key distribution (MDI-QKD) protocols require the interference at the central untrusted node of two weak coherent pulses with random phase (WCPRP) prepared by two remote users [1, 2]. There are two main approaches to generate such indistinguishable states by remote users: (a) modulating a CW laser with an intensity modulator (IM) and a phase modulator, (b) using a gain-switched semiconductor laser. The first approach allows to easily prepare almost indistinguishable states by two remote users in cost of additional optical devices and lasers with high stability [3]. The second approach implies only semiconductor lasers, however the states produced by two users are more distinguishable due to the temporal and spectral properties of two different laser diodes [4]. To increase mode match, in recent work the laser injection technique was adopted to prepare WCPRP by two remote users [5]. On the one hand, laser injection allows to achieve better mode overlap between independent gain switch laser sources, but on the other hand, it increases the complexity of the setup, and one needs to drive laser with high stability current. In our work, we propose a novel method to prepare WCPRP using gain-switched lasers without injection and only one modulator.

## Materials and Methods

While building MDI-QKD system high visibility of Hong-Ou-Mandel interference [6] (Fig. 1.) must be achieved. For pure Fock single photon states best visibility  $V = 1$ . In case of WCPRP maximal visibility  $V = 0.5$  [7]. To push experimental results close to theoretical limits interfering states, must be indistinguishable in each degree of freedom.

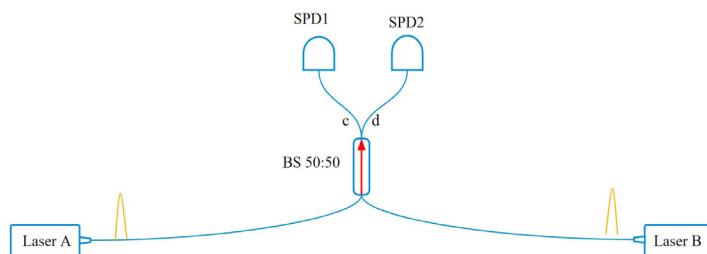


Fig.1. Basic two single photons interference scheme

Using single-mode optical fiber guarantees indistinguishability of transversal special modes, synchronization system and optical delay line should provide simultaneity of two WCPRP arrival time to the beam splitter, beam splitter with polarizer eliminates distinguishability over polarization. However, one also should adjust spectral and temporal shapes of the pulses itself, for which we use variable optical filter and intensity modulator.

To characterize the quality of preparation of indistinguishable states we calculate second order correlation function  $g^2$  which has simple relation with visibility:

$$V = 1 - g^2 \quad (1)$$

The definition of  $g^2$  is

$$g^2 = \frac{\langle I_c I_d \rangle}{\langle I_c \rangle \langle I_d \rangle} \quad (2)$$

where  $I_c$ ,  $I_d$  are intensities of WCPRP at reseaving detectors SPD1 and SPD2 in Fig. 1. The expression for  $g^2$  can be transformed to the more convinient form if we consider conservation of energy and the symmetry of the setup:

$$\begin{aligned} I_d(t) + I_c(t) &= 2I \\ \langle I_c \rangle &= \langle I_d \rangle = I \end{aligned} \quad (3)$$

Thus, we have for  $g^2$ :

$$g^2 = 2 - \frac{\langle I_c^2 \rangle}{\langle I_c \rangle^2} = 1 - \left( \frac{\sigma_{I_c}}{\langle I_c \rangle} \right)^2 \quad (4)$$

which proves that measuring a distribution of only one of intensities is sufficient for calculating  $g^2$ .

The goal of our experiment is to find filtration setup which minimizes  $g^2$  preparing the ground for building full-fledged MDI-QKD system.

### Results and Discussion

By configuring our experimental setup, we can observe the interference of different preparation schemes. We compare 4 preparation setups: **GS-laser** (Gain Switched); **GS-laser + filter**; **GS-laser + IM**; **GS-laser + filter + IM** (Fig. 2.). First, we consider the **GS-laser** scheme, where IM is turned off and the filter bandwidth is opened to its maximum value (3 nm) around the central peak of the lasers.

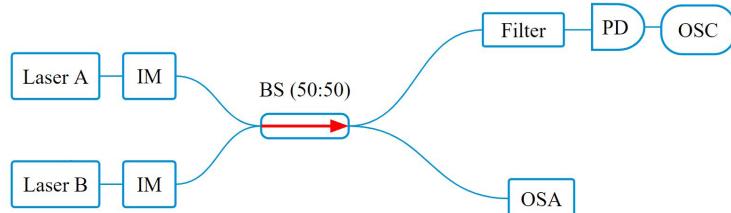


Fig. 2. Different preparation setups compared in our work

In this mode, we calculate the indistinguishability of two directly modulating semiconductor lasers. The second setup is **GS-laser + filter**. Also, in this case IM is not driven, however the filter bandwidth has its narrowest value (0.05 nm). Another setup **GS-laser + IM** is to drive IM with opened filter. The last scheme **GS-laser + filter + IM** includes the driving of IM and the filter with its narrowest bandwidth. The results of the measured second order correlation function are presented in Table 1. The results show that the proposed scheme with proper time and frequency filtering achieves values close to the theoretical minimum  $g^2 = 0.5$  and can be used to prepare states in high-speed MDI-QKD setups. Moreover, the same intensity modulator can be used to prepare decoy states in MDI-QKD.

Table 1

Values of  $g^2$  obtained for different setups of optical shemes for WCPRP preparation

Setup	$g^2$
GS-Laser	0.728
GS-Laser + Filter	0.588
GS-Laser + IM	0.534
GS-Laser + Filter + IM	0.508



## Conclusion

Our time and spectral filtering scheme provide highly indistinguishable WCPRP states. In order to prove that we provide a Hong-Ou-Mandel experiment. Results of the experiment show the visibility close to theoretical value 0.5. Such results allow to reduce complexity of high-speed MDI QKD device and thus reduce the device cost making MDI QKD closer to commercial use.

## REFERENCES

1. Hoi-Kwong L., Curty M., Qi B., Measurement-device-independent quantum key distribution, Physical review letters. 108 (13) (2012) 130503.
2. Tang Z., Wei K., Bedroya O., Qian L., Lo H. K., Experimental measurement-device-independent quantum key distribution with imperfect sources, Physical Review A. 93 (4) (2016) 042308.
3. Tang Zhiyuan, et al., Experimental demonstration of polarization encoding measurement-device-independent quantum key distribution, Physical review letters. 112 (19) (2014) 190503.
4. Yuan Z. L., et al., Interference of short optical pulses from independent gain-switched laser diodes for quantum secure communications, Physical Review A. 2 (6) (2014) 064006.
5. Comandar L. C., et al., Near perfect mode overlap between independently seeded, gain-switched lasers, Optics express. 24 (16) (2016) 17849–17859.
6. Hong Chong-Ki, Zhe-Yu Ou, Mandel L., Measurement of subpicosecond time intervals between two photons by interference, Physical review letters. 59 18 (1987) 2044.
7. Hoi-Kwong L., Curty M., Qi B., Measurement-device-independent quantum key distribution. Physical review letters. 108 13 (2012) 130503.

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*Received 12.08.2022. Approved after reviewing 05.09.2022. Accepted 05.09.2022.*