

## ENGLISH TRANSLATION FOR PCT/JP01/07698

## SPECIFICATION

OPTICAL SIGNAL TRANSMISSION DEVICE AND OPTICAL SIGNAL  
TRANSMISSION METHOD

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## Technical Field

The present invention relates to a transmission device for the use of, for instance, a quantum cryptography device of Faraday mirror system.

## 10 Background Art

Fig. 7 shows a configuration of a quantum cryptography device of a conventional Faraday mirror system shown in, for example, G. Ribordy, et.al. "Automated 'plug & play' quantum key distribution," ELECTRONICS LETTERS Vol. 34 No. 22 pp.2116-2117 (1998) or the International Patent  
15 Publication Gazette WO98/10560 "QUANTUM CRYPTOGRAPHY DEVICE AND METHOD." In Fig. 7, a quantum cryptography transmission device 100 includes: a coupler 1 connected to an optical fiber 10 for communication, an optical detector 2 for detecting a light pulse input to the coupler 1 from the optical fiber 10 for communication, a polarization controller 3 for  
20 adjusting a polarization mode of the input light pulse, an attenuator 4 for attenuating the strength of the light pulse and reducing the strength of the light pulse output from the quantum cryptography device to quantum level (0.1 photon per pulse), a Faraday mirror 7 which reflects the input pulse by rotating its polarization plate by 90 degrees, namely, reflects an input pulse  
25 of a TE polarization wave as the light pulse of a TM polarization wave and

an input pulse of the TM polarization wave as the light pulse of the TE polarization wave, a phase modulator 8 for phase modulating the pulse which passes through the phase modulator 8, and a control board 9. Here, the TE polarization wave (TRANSVERSE ELECTRIC POLARIZATION WAVE) is a lightwave of which vibration direction of electric vector is vertical to a plane of incidence and the vibration direction of magnetic vector is within the plane of incidence. The TM polarization wave (TRANSVERSE MAGNETIC POLARIZATION WAVE) is a lightwave of which vibration direction of magnetic vector is vertical to a plane of incidence and the vibration direction of electric vector is within the plane of incidence. A quantum cryptography reception device 200 includes a coupler 51, a photon detector 52, a photon detector 53, a polarization controller 54, a polarization controller 55, a polarization beam splitter 56, a circulator 57, a phase modulator 58, a control board 59, a laser 60, a short optical path 61, and a long optical path 62.

In the following, the operation will be explained referring to Fig. 8. The quantum cryptography reception device 200 in Fig. 7 generates a light pulse P by the laser 60. The light pulse P is split by the coupler 51 and carried into the short optical path 61 and the long optical path 62. After a polarized plane of the light pulse in the long optical path 62 is adjusted by the polarization controller 55, the light pulse is carried through the phase modulator 58, and output to the optical fiber 10 for communication by the polarization beam splitter 56. The light pulse in the short optical path 61 is also output to the optical fiber 10 for communication. Since the long optical path 62 is longer than the short optical path 61, two different pulses P1 and

P2 are output to the optical fiber 10 for communication. Namely, the light pulses P1 and P2 having two different polarization modes are output to the optical fiber 10 for communication.

The light pulses P1 and P2 having two different polarization modes are input to the quantum cryptography transmission device 100 through the optical fiber 10 for communication with staggered timings. The light pulses P1 and P2 input through the optical fiber 10 for communication are divided into two by the coupler 1, respectively, and ones of the divided light pulses P1 and P2 are detected by the optical detector 2. The phase modulator 8 modulates only the light pulse P2 out of the light pulses P1 and P2 according to the timing of detecting the light pulses by the optical detector 2.

Polarization planes of the others of the light pulses P1 and P2 divided by the coupler 1 are adjusted by the polarization controller 3 so that the phase modulator 8 works optimally. At this time, the first light pulse P1 out of the two light pulses P1 and P2 input to the quantum cryptography transmission device 100 with staggered timings is adjusted so as to have a polarization mode of the TE polarization wave. Accordingly, the second light pulse P2 becomes to have a polarization mode of a TM polarization wave. The light pulse which passes through the polarization controller 3 and the attenuator 4 to direct to the Faraday mirror 7 is carried through the phase modulator 8 and input to the Faraday mirror 7. The light pulse input to the Faraday mirror 7 having the polarization mode of the TE polarization wave is reflected as the light pulse of the TM polarization wave, and on the contrary, the light pulse of the TM polarization wave is reflected as the light pulse of the TE polarization wave. The reflected light pulse is carried through the

phase modulator 8 again. The phase modulator 8 is adjusted its timing by the control board 9 so that the phase modulator 8 phase modulates only the second light pulse P2 out of the two light pulses P1 and P2 which are reflected by the Faraday mirror 7 and carried through the phase modulator 8.

5 The phase modulated light pulse P2 is transmitted toward the optical fiber 10 for communication as if it flows backward through the optical path of the incidence. The two light pulses P1 and P2 which pass through the phase modulator 8 after reflected by the Faraday mirror 7 are directed to the attenuator 4. The attenuator 4 attenuates the strength of the light pulses  
10 which is phase modulated by the phase modulator 8 to the quantum level (0.1 photon per pulse). Thereafter, the light pulses pass serially through the polarization controller 3 and the coupler 1, and is transmitted to the optical fiber 10 for communication.

In the conventional quantum cryptography transmission device of  
15 the Faraday mirror system, the light pulse input to the device passes through the same optical path as an outgoing path and a returning path; namely, the light pulse passes through the phase modulator 8 twice. In addition, since the light pulses having two different modes: the polarization mode of the TE polarization wave in which loss of the light pulse is relatively  
20 small; and the polarization mode of the TM polarization wave in which loss is very large passes through the phase modulator 8, so that a loss L of the optical strength becomes extremely large. On adjusting the quantum cryptography device, the attenuator 4 is removed and each part is adjusted to increase an S/N ratio (signal/noise ratio), however, there is a problem that  
25 the S/N ratio at adjusting time of the quantum cryptography device becomes

extremely small when the loss  $L$  of the optical strength is large.

Hereinafter, the loss of the optical strength will be explained.

In Fig. 8,  $L_4$  shows a loss of the strength of each light pulse when the light pulses  $P_1$  and  $P_2$  pass through the attenuator 4, and  $L_8$  shows a loss of the strength of each light pulse when the light pulses  $P_1$  and  $P_2$  pass through the phase modulator 8. In Fig. 8, the loss which is received when the light pulses  $P_1$  and  $P_2$  pass through each element is shown as an arrow  $L$ .

For instance, the strength of the light pulse input from the optical fiber 10 for communication is supposed as  $S$ , the loss of the TE polarization wave of the phase modulator 8 as  $L_8$  (TE), the loss of the TM polarization wave of the phase modulator 8 as  $L_8$  (TM), the other losses as  $L_Z$ , and their concrete values are:

Here, the other losses include  $L_4$ .

$$S = 50\text{dB}$$

$$L_8 \text{ (TE)} = 6\text{dB}$$

$$L_8 \text{ (TM)} = 30\text{dB}$$

$$L_Z = 2\text{dB}$$

When the whole loss of the optical strength is supposed as  $L$ ,  $L$  can be obtained by the following equation:

$$\begin{aligned} L &= L_8 \text{ (TE)} + L_Z + L_8 \text{ (TM)} + L_Z \\ &= 6 + 2 + 30 + 2 \\ &= 40\text{dB} \end{aligned}$$

At this time, when the strength of the light pulse is supposed as  $M$  on adjusting the quantum cryptography device with removing the attenuator 4,

M is obtained by:

$$M = S - L = 50 - 40 = 10\text{dB}$$

As shown in the equation, the larger the loss L becomes, the less the strength M of the light pulse becomes, and the S/N ratio is degraded, which makes the adjustment difficult.

### Disclosure of the Invention

The invention provides a transmission device for an optical signal comprising:

- a first beam splitter for receiving the optical signal and for splitting the optical signal into a TE polarisation optical signal and a TM polarisation optical signal;

- a first optical path for receiving the TM polarisation optical signal from the first beam splitter;

- a second optical path for receiving the TE polarisation optical signal from the first beam splitter;

- a phase modulator located in the second optical path;

- a second beam splitter;

- a polarisation mode changer for receiving the TM and TE polarisation optical signals and changing the polarisation of the TE polarisation optical signal to a changed TM polarisation optical signal and the polarisation of the TM polarisation optical signal to a changed TE polarisation optical signal, and for returning the changed optical signals back to the second beam splitter so that the second beam splitter splits the changed TM polarisation optical signal and changed TE polarisation optical signal and supplies the changed TM polarisation optical signal to the first optical path and supplies the changed TE polarisation optical signal to the second optical path; and

- wherein the changed TM polarisation optical signal and the changed TE polarisation optical signal are recombined by the first beam splitter to provide a returning optical signal in which the phase of the TE polarisation optical signal and the changed TE polarisation optical signal have been modified by the phase modulator.

Preferably the polarisation mode changer comprises a Faraday mirror, and wherein the first optical path is an outgoing path and a return path for the TM polarisation optical signal and changed TM polarisation optical signal respectively, and the second optical path is an outgoing path and a return path for the TE polarisation optical signal and changed TE polarisation optical signal.

Preferably the transmission device further comprises a supply optical path for supplying the optical signal to the first beam splitter, the supply optical path having an attenuator and a polarisation controller.

Preferably the transmission device further comprises a coupler for splitting the optical signal and supplying the optical signal to the supply optical path and to an optical detector, and a control board for controlling the phase modulator in accordance with the timing of the signal received by the optical detector.

Preferably the second beam splitter is for receiving the TE polarisation optical signal and the TM polarisation optical signal from the first and second paths, and supplying the signals to the polarisation mode changer.

The invention also provides a transmission method for an optical signal comprising:

- splitting the optical signal into a TE polarisation optical signal and a TM polarisation optical signal with a first beam splitter;

- supplying the TM polarisation optical signal from the first beam splitter to a first optical path;

- supplying the TE polarisation optical signal from the first beam splitter to a second optical path;

- providing a phase modulator located in the second optical path;

- supplying the TE polarisation optical signal and the TM polarisation optical signal from the first and second optical paths to a polarisation mode

changer to change the polarisation of the TE polarisation optical signal to a TM polarisation optical signal and the polarisation of the TM polarisation optical signal to a TE polarisation optical signal;

5 supplying the changed optical signals to a second beam splitter to split the changed TM polarisation optical signal and changed TE polarisation optical signal and supplying the changed TM polarisation optical signal to the first optical path and supplying the changed TE polarisation optical signal to the second optical path; and

10 wherein the changed TM polarisation optical signal and the changed TE polarisation optical signal are recombined by the first beam splitter to provide a returning optical signal in which the phase of the TE polarisation optical signal and the changed TE polarisation optical signal have been modified by the phase modulator.

15 Preferably the polarisation mode changer comprises a Faraday mirror, and wherein the first optical path is an outgoing path and a return path for the TM polarisation optical signal and changed TM polarisation optical signal respectively, and the second optical path is an outgoing path and a return path for the TE polarisation optical signal and changed TE polarisation  
20 optical signal.

Preferably the transmission method further comprises providing a supply optical path for supplying the optical signal to the first beam splitter, the supply optical path having an attenuator and a polarisation controller.

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Preferably the transmission method further comprises a coupler for splitting the optical signal and supplying the optical signal to the supply optical path and to an optical detector, and a control board for controlling the phase modulator in accordance with the timing of the signal received by the optical  
30 detector.

According to another aspect, the invention provides a transmission device for an optical signal comprising:

- a beam splitter for splitting the optical signal into a TE polarisation optical signal and a TM polarisation optical signal;
- an optical transmitting/receiving path for supplying the optical signal to the beam splitter and receiving the optical signal from the beam splitter;
- an optical looping path connected to the beam splitter;
- a phase modulator in the optical looping path;
- a polarisation mode changer in the optical looping path and positioned relative to the phase modulator so that the TM polarisation optical signal is supplied from the beam splitter to the polarisation mode changer, and the TE polarisation optical signal is supplied from the beam splitter to the phase modulator; and

wherein the polarisation mode changer changes the TM polarisation optical signal to a changed TE polarisation optical signal so the changed TE polarisation optical signal can travel through the optical looping path to the phase modulator and then to the beam splitter, and wherein the TE polarisation optical signal is supplied by the beam splitter to the phase modulator and then travels around the optical looping path to the polarisation mode changer so that the TE polarisation optical signal is changed to a changed TM polarisation optical signal which is then received by the beam splitter; and

wherein the beam splitter supplies the changed TM polarisation optical signal and changed TE polarisation optical signal as the optical signal back to the optical transmitting/receiving path.

Preferably the polarisation mode changer comprises a fast/slow coupler for changing the polarisation mode by connecting a fast axis and a slow axis of a polarisation wave axis of an optical fibre, the optical transmitting/receiving path is used for an outgoing path and a return path for the optical signal, and the optical looping path is used for an outgoing path and a returning path for

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the TE polarisation optical signal and TM polarisation optical signal split by the beam splitter.

Preferably the optical transmitting/receiving path includes an attenuator and a polarisation controller.

The invention still further provides a transmission method for an optical signal comprising:

- splitting the optical signal into a TE polarisation optical signal and a TM polarisation optical signal by a beam splitter;

- providing an optical transmitting/receiving path for supplying the optical signal to the beam splitter and receiving the optical signal from the beam splitter;

- providing an optical looping path connected to the beam splitter;

- providing a phase modulator in the optical looping path;

- providing a polarisation mode changer in the optical looping path and positioned relative to the phase modulator so that the TM polarisation optical signal is supplied from the beam splitter to the polarisation mode changer, and the TE polarisation optical signal is supplied from the beam splitter to the phase modulator;

- wherein the polarisation mode changer changes the TM polarisation optical signal to a changed TE polarisation optical signal so the changed TE polarisation optical signal can travel through the optical looping path to the phase modulator and then back to the beam splitter, and wherein the TE polarisation optical signal is supplied by the beam splitter to the phase modulator and then travels around the optical looping path to the polarisation mode changer so that the TE polarisation optical signal is changed to a changed TM polarisation optical signal which is then received by the beam splitter; and

- wherein the beam splitter supplies the changed TM polarisation optical signal and changed TE polarisation optical signal as the optical signal back to the optical transmitting/receiving path.

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Preferably the polarisation mode changer comprises a fast/slow coupler for changing the polarisation mode by connecting a fast axis and a slow axis of a polarisation wave axis of an optical fibre, the optical transmitting/receiving path is used for an outgoing path and a return path for the optical signal, and  
5 the optical looping path is used for an outgoing path and a returning path for the TE polarisation optical signal and TM polarisation optical signal split by the beam splitter.

Preferably the optical transmitting/receiving path includes an attenuator and  
10 a polarisation controller.

#### Brief Explanation of the Drawings

Fig. 1 shows a configuration of an optical system of a quantum cryptography transmission device of Faraday mirror system according to the  
15 preferred embodiment of the present invention.

Fig. 2 is a flowchart showing the operation of Fig. 1.

Fig. 3 shows a status of light pulses.

Fig. 4 shows a time sequential status of the light pulse.

Fig. 5 shows a configuration of an optical system according to the second embodiment.

5 Fig. 6 shows a configuration of an optical system according to the second embodiment.

Fig. 7 shows a general configuration of a quantum cryptography device of a conventional Faraday mirror system.

10 Fig. 8 shows a status of light pulses in the quantum cryptography transmission device of a conventional Faraday mirror system.

Fig. 9 shows a configuration of an optical system according to the third embodiment.

Fig. 10 is a flowchart showing the operation of Fig. 9.

## 15 Preferred Embodiments for Carrying out the Invention

### Embodiment 1.

Fig. 1 shows a configuration of an optical system of a quantum cryptography transmission device 100 within a quantum cryptography device of a Faraday mirror system. In the quantum cryptography  
20 transmission device of the Faraday mirror system according to the present embodiment, the optical paths to go out and to return are made different within the transmission device by using two polarization beam splitters.

In the figure, the quantum cryptography transmission device 100 includes a coupler 1 connected to an optical fiber 10 for communication, an  
25 optical detector 2 for detecting a light pulse input from the optical fiber 10 for

communication, a polarization controller 3 for controlling the polarization mode of the input light pulse, an attenuator 4 for attenuating the strength of the light pulse and reducing the strength of the light pulse output from the quantum cryptography device to the quantum level (0.1 photon per pulse), polarization beam splitters 5 and 6 for automatically switching the light pulse according to the polarization mode; in case of the light pulse of the TE polarization wave, switching to an optical modulation path 13 which passes through a phase modulator 8, and in case of the light pulse of the TM polarization wave, switching to an optical bypass path 11 which bypasses the light pulse of the TM polarization wave, a Faraday mirror 7 which reflects the input pulse with rotating its polarization plate by 90 degrees; namely, reflects the input pulse of the TE polarization wave as the light pulse of the TM polarization wave, and reflects the input pulse of the TM polarization wave as the light pulse of the TE polarization wave, and the phase modulator 8 for phase modulating the pulse which passes through the phase modulator 8. A first optical path R1 connects the attenuator 4, the polarization beam splitter 5, the polarization beam splitter 6, and the Faraday mirror 7. A second optical path R2 connects the polarization beam splitter 5, the phase modulator 8, and the polarization beam splitter 6. The second optical path R2 is placed parallel to the first optical path R1. The phase modulator 8 is placed at the second optical path R2. Other configuration of the figure is the same as Fig. 7.

In the following, the operation will be explained referring to Figs. 2, 3, and 4.

Fig. 2 is a flowchart showing the operation of the quantum

cryptography transmission device 100. Fig. 3 shows status of the light pulses at each section. Fig. 4 shows time-sequential status of the light pulse which passes through the optical bypass path 11 and the optical modulation path 13. In Figs. 3 and 4, P, P1, and P2 show pulses. Arrows L4, L5, L6, and L8 above each pulse respectively show losses of the optical strength at the attenuator 4, the polarization beam splitter 5, the polarization beam splitter 6, and the phase modulator 8.

(1) Step S20 for an outgoing path

First, two light pulses P1 and P2 having two different polarization modes are input to the quantum cryptography transmission device 100 of Fig. 1 through the optical fiber 10 for communication with staggered timings (S1). The light pulses P1 and P2 input through the optical fiber 10 for communication are split into two by the coupler 1, and ones of the light pulses P1 and P2 split by the coupler 1 are detected by the optical detector 2. The phase modulator 8 modulates only the light pulse P2 out of the light pulses P1 and P2 according to the timings of detecting the light pulses by the optical detector 2. The others of the light pulses of P1 and P2 split by the coupler 1 are adjusted their polarization plates so that the phase modulator 8 works optimally (S2). At this time, the first light pulse P1 out of the two light pulses P1 and P2 input to the quantum cryptography transmission device 100 with the staggered timings is adjusted so as to become the polarization mode of the TE polarization wave. Accordingly, the second light pulse becomes the polarization mode of the TM polarization wave. Then, the attenuator 4 attenuates the strength of the light pulse (S3). The light pulse directing to the Faraday mirror 7 through the polarization

controller 3 is selected by the polarization beam splitter 5 to re-direct the light pulse P1 having the polarization mode of the TE polarization wave to the optical modulation path 13 which passes through the phase modulator 8, and the light pulse P2 having the polarization mode of the TM polarization wave to the optical bypass path 11 directing to the polarization beam splitter 6 (S4). The two light pulses P1 and P2 which pass through different optical paths are combined by the polarization beam splitter 6 and input to the Faraday mirror 7 (S5). The light pulse input to the Faraday mirror 7 is reflected; namely, the light pulse having the polarization mode of the TE polarization wave is reflected as the light pulse P1 having the polarization mode of the TM polarization wave, and the light pulse having the polarization mode of the TM polarization wave is reflected as the light pulse P2 having the polarization mode of the TE polarization wave (S6).

(2) Step S30 for a returning path

The reflected light pulses P1 and P2 are selected by the polarization beam splitter 6 to re-direct the light pulse P2 of the TE polarization wave to the optical modulation path 13 which passes through the phase modulator 8, and the light pulse P1 of the TM polarization wave to the optical bypass path 11 directing to the polarization beam splitter 5 (S7). The phase modulator 8 is adjusted its timing by the control board 9 to phase modulate only the light pulse P2 which is reflected by the Faraday mirror 7 and passes through the phase modulator 8 (S8). The light pulse P1 which is not phase modulated and the phase modulated light pulse P2 are transmitted toward the optical fiber 10 for communication as it returns through the optical path of incidence.

The two light pulses P1 and P2 which pass through the different optical

paths after reflected by the Faraday mirror 7 are combined by the polarization beam splitter 5 and directed to the attenuator 4 (S9). The attenuator 4 attenuates the strength of the light pulse phase modulated by the phase modulator 8 to the quantum level (0.1 photon per pulse) (S10).

5    Thereafter, the light pulse passes through the polarization controller 3 and the coupler 1, and is transmitted to the optical fiber 10 for communication (S11).

As shown in Fig. 4, only the light pulse of the TM polarization wave passes through the optical bypass path 11 which is a part of the first optical  
10    path R1. On the other hand, only the light pulse of the TE polarization wave passes through the optical modulation path 13 which is a part of the second optical path R2. The order of passing of the light pulses is shown by arrows A1, A2, and A3 of Fig. 4. And further, the light pulses pass in the order of arrows A4, A5, and A6.

15    Here, the loss of the optical strength will be explained.

For instance, the strength of the light pulse input from the optical fiber 10 for communication is supposed as  $S$ , the loss of the strength of the light pulse due to the polarization beam splitter 5 as  $L5$ , the loss of the strength of the light pulse due to the polarization beam splitter 6 as  $L6$ , the  
20    loss of the strength of the light pulse due to the phase modulator 8 as  $L8$ , other losses as  $LZ$ , and their concrete values are shown below.

The other losses  $LZ$  includes the loss  $L4$  of the strength of the light pulse due to the attenuator 4 of Fig. 4, and so forth. Further, in Fig. 4, the loss which is received during the light pulses  $P1$  and  $P2$  pass through each  
25    part is shown by an arrow  $L$ .

$$S = 50\text{dB}$$

$$L5 = 5\text{dB}$$

$$L6 = 5\text{dB}$$

$$L8 = 6\text{dB}$$

$$5 \quad LZ = 2\text{dB}$$

When the whole loss of the optical strength is supposed as  $L$ ,  $L$  can be obtained by the following expression:

$$L = (L5 + L6) + LZ + (L6 + L8 + L5) + LZ$$

$$= 5 + 5 + 2 + 5 + 6 + 5 + 2$$

$$10 \quad = 30\text{dB}$$

As described above, there are two light pulses to enter the transmission device; the light pulses of the TE polarization wave which pass through the phase modulator 8 and the TM polarization wave. These light pulses are reflected by the Faraday mirror 7, so that the TE polarization wave is reflected as the TM polarization wave, and the TM polarization wave is reflected as the TE polarization wave with rotating its polarization plate and are output from the transmission device. Conventionally, one light pulse passes through the phase modulator 8 in two different statuses; the TE polarization wave and the TM polarization wave. However, since the transmission factor of the phase modulator 8 for the TM polarization wave is low, the incident pulse is output with reduced by, for example, 40dB.

In the present embodiment, the phase modulator 8 is bypassed by the light pulse of the TM polarization wave using the two polarization beam splitters 5 and 6. Only the light pulse of the TE polarization wave is carried to the phase modulator 8. In this way, the reduction of the incident pulse

can be limited to 30dB, which improves the S/N ratio by 10dB.

As discussed above, according to the present embodiment, the optical path within the quantum cryptography transmission device 100 is separated for the outgoing and returning paths using the two polarization beam splitters 5 and 6, and the phase modulator 8 is placed at either path of the optical paths in the quantum cryptography transmission device of Faraday mirror system.

In this embodiment, however, the light pulse is split by the two polarization beam splitters 5 and 6 and passes through the quantum cryptography transmission device using different paths for outgoing and returning. Accordingly, the light pulse passes through the phase modulator 8 only once and by the form of only the light pulse having the polarization mode of the TE polarization wave, so that the loss of the incident pulse due to the quantum cryptography transmission device 100 becomes 30dB when the attenuator 4 is removed, which prevents the loss of 10dB compared with the loss due to the quantum cryptography transmission device 100 in the conventional art. This means, the S/N ratio is improved by 10dB at adjusting time, which enables to adjust the quantum cryptography device easily.

## Embodiment 2.

In Fig. 1, the polarization beam splitters 5 and 6 which reflect the TE polarization wave and pass the TM polarization wave are used. As shown in Fig. 5, another polarization beam splitter 5a which reflects the TM polarization wave and another polarization beam splitter 6a which passes

the TE polarization wave can be used.

In another way, as shown in Fig. 6, a combination of the polarization beam splitter 5 which passes the TM polarization wave and the polarization beam splitter 6a which passes the TE polarization wave can be used. Yet  
5 further, another combination of the polarization beam splitter 5a which passes the TE polarization wave and the polarization beam splitter 6 which passes the TM polarization wave can be used, which is not illustrated in the figure.

The Faraday mirror 7 is used in Fig. 1, however, another component  
10 can be used as long as it has the same function as the Faraday mirror 7.

### Embodiment 3.

Fig. 9 shows another configuration in which the Faraday mirror 7 is not included.

15 In Fig. 9, the transmission device is provided with an optical transmitting/receiving path R3 and an optical looping path R4.

The optical transmitting/receiving path R3 is provided with the polarization controller 3, the attenuator 4, and the polarization beam splitter 5. The polarization beam splitter 5 includes three ports A, B, and C. A  
20 port is connected to the optical transmitting/receiving path R3. B port is connected to one end of the optical looping path R4. C port is connected to the other end of the optical looping path R4. With this configuration, the optical signal output from B port is input to C port. The optical signal output from C port is input to B port.

25 Hereinafter, it is defined as "loop flow" to loop the optical signal

between B port and C port using the optical looping path R4.

The optical looping path R4 is provided with the phase modulator 8 and a fast/slow coupler 70. The fast/slow coupler 70 changes the TM polarization wave to the TE polarization wave by connecting a fast axis of polarization axis of the optical fiber to a slow axis, and changes the TE polarization wave to the TM polarization wave. The fast/slow coupler 70 is an example of a polarization mode changer.

The light pulse of the TM polarization wave and the light pulse of the TE polarization wave are separated by the polarization beam splitter 5, and the light pulse of the TE polarization wave is directly carried to the phase modulator 8. The light pulse of the TM polarization wave is carried to the other inlet of the phase modulator 8 through the fast/slow coupler 70.

Fig. 10 is a flowchart showing the operation of the quantum cryptography transmission device 100 of Fig. 9.

(1) Step S40 for an outgoing path

The operations of S1 through S4 of the step S40 for an outgoing path shown in Fig. 10 are the same as the operations of S1 through S4 shown in Fig. 2.

(2) Step S50 for a loop flow

The light pulse of the TE polarization wave which is split by the polarization beam splitter 5 is input to the phase modulator 8 and phase modulated (S8). Next, the phase modulated light pulse of the TE polarization wave is input to the fast/slow coupler 70, changed its polarization mode (S12), and output as the light pulse of the TM polarization wave.

On the other hand, the light pulse of the TM polarization wave split by the polarization beam splitter 5 is input to the fast/slow coupler 70, changed its mode to the TE polarization wave from the TM polarization wave (S12), and output. The light pulse of the TE polarization wave output from the fast/slow coupler 70 is input to the phase modulator 8, but is not phase modulated and output to the polarization beam splitter 5 without modulation.

(3) Step S60 for a returning path

The operations of S9 through S11 of the step S60 for a returning path shown in Fig. 10 are the same as the operations of S9 through S11 shown in Fig. 2.

The above-described the steps S40 and S60 for outgoing/returning paths are performed in the optical transmitting/receiving path R3. The step S50 for a loop flow is performed in the optical looping path R4.

Even when the configuration shown in Fig. 9 is used, the light pulse of the TE polarization wave output from B port is returned to C port after passing through the phase modulator 8 only once. Accordingly, the loss of the optical strength can be minimized, which enables the same effect as the foregoing embodiments.

The fast/slow coupler 70 is one example of a polarization mode changer, and another device can be used as long as it can change the polarization wave between TM and TE. For instance,  $1/2\lambda$  plate ( $\lambda$ : wave length) can be used. In another way, the optical communication cable can be used with twisting by 90 degrees. Further, the optical communication cable can be connected with crossing by 90 degrees.

### Industrial Applicability

As has been described, according to the quantum cryptography transmission device 100 of Faraday mirror system of preferred embodiment of the invention, the optical paths are provided for outgoing and returning separately within the device, so that the light pulse passes through the phase modulator 8 only once. Accordingly, the loss of the strength can be reduced, and the S/N ratio can be improved at adjusting time of the quantum cryptography transmission device 100, which enables to adjust the transmission device easily.

Further, according to another preferred embodiment of the invention, the optical looping path is used, which avoids using the Faraday mirror and facilitates the configuration of the device.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise", or variations such as "comprises" or "comprising", is used in an inclusive sense, ie. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

## CLAIMS:

1. A transmission device for an optical signal comprising:
  - a first beam splitter for receiving the optical signal and for splitting the optical signal into a TE polarisation optical signal and a TM polarisation optical signal;
  - a first optical path for receiving the TM polarisation optical signal from the first beam splitter;
  - a second optical path for receiving the TE polarisation optical signal from the first beam splitter;
  - a phase modulator located in the second optical path;
  - a second beam splitter;
  - a polarisation mode changer for receiving the TM and TE polarisation optical signals and changing the polarisation of the TE polarisation optical signal to a changed TM polarisation optical signal and the polarisation of the TM polarisation optical signal to a changed TE polarisation optical signal, and for returning the changed optical signals back to the second beam splitter so that the second beam splitter splits the changed TM polarisation optical signal and changed TE polarisation optical signal and supplies the changed TM polarisation optical signal to the first optical path and supplies the changed TE polarisation optical signal to the second optical path; and
  - wherein the changed TM polarisation optical signal and the changed TE polarisation optical signal are recombined by the first beam splitter to provide a returning optical signal in which the phase of the TE polarisation optical signal and the changed TE polarisation optical signal have been modified by the phase modulator.
2. The transmission device according to claim 1 wherein the polarisation mode changer comprises a Faraday mirror, and wherein the first optical path is an outgoing path and a return path for the TM polarisation optical signal and changed TM polarisation optical signal respectively, and the second optical path is an outgoing path and a return path for the TE polarisation optical signal and changed TE polarisation optical signal.

3. The transmission device according to claim 1 or claim 2 further comprising a supply optical path for supplying the optical signal to the first beam splitter, the supply optical path having an attenuator and a  
5 polarisation controller.

4. The transmission device according to any one of claims 1 to 3 further comprising a coupler for splitting the optical signal and supplying the optical signal to the supply optical path and to an optical detector, and a control  
10 board for controlling the phase modulator in accordance with the timing of the signal received by the optical detector.

5. A transmission device according to any one of claims 1 to 4 wherein the second beam splitter is for receiving the TE polarisation optical signal and  
15 the TM polarisation optical signal from the first and second paths, and supplying the signals to the polarisation mode changer.

6. A transmission method for an optical signal comprising:  
splitting the optical signal into a TE polarisation optical signal and a  
20 TM polarisation optical signal with a first beam splitter;  
supplying the TM polarisation optical signal from the first beam splitter to a first optical path;  
supplying the TE polarisation optical signal from the first beam splitter to a second optical path;  
25 providing a phase modulator located in the second optical path;  
supplying the TE polarisation optical signal and the TM polarisation optical signal from the first and second optical paths to a polarisation mode changer to change the polarisation of the TE polarisation optical signal to a TM polarisation optical signal and the polarisation of the TM polarisation  
30 optical signal to a TE polarisation optical signal;  
supplying the changed optical signals to a second beam splitter to split the changed TM polarisation optical signal and changed TE polarisation

optical signal and supplying the changed TM polarisation optical signal to the first optical path and supplying the changed TE polarisation optical signal to the second optical path; and

wherein the changed TM polarisation optical signal and the changed  
5 TE polarisation optical signal are recombined by the first beam splitter to provide a returning optical signal in which the phase of the TE polarisation optical signal and the changed TE polarisation optical signal have been modified by the phase modulator.

10 7. The transmission method according to claim 6 wherein the polarisation mode changer comprises a Faraday mirror, and wherein the first optical path is an outgoing path and a return path for the TM polarisation optical signal and changed TM polarisation optical signal respectively, and the second  
15 optical path is an outgoing path and a return path for the TE polarisation optical signal and changed TE polarisation optical signal.

8. The transmission method according to claim 6 or claim 7 further comprising providing a supply optical path for supplying the optical signal to the first beam splitter, the supply optical path having an attenuator and a  
20 polarisation controller.

9. The transmission method according to any one of claims 6 to 8 further comprising a coupler for splitting the optical signal and supplying the optical signal to the supply optical path and to an optical detector, and a control  
25 board for controlling the phase modulator in accordance with the timing of the signal received by the optical detector.

10. A transmission device for an optical signal comprising:  
a beam splitter for splitting the optical signal into a TE polarisation  
30 optical signal and a TM polarisation optical signal;  
an optical transmitting/receiving path for supplying the optical signal to the beam splitter and receiving the optical signal from the beam splitter;

an optical looping path connected to the beam splitter;

a phase modulator in the optical looping path;

a polarisation mode changer in the optical looping path and positioned relative to the phase modulator so that the TM polarisation optical signal is supplied from the beam splitter to the polarisation mode changer, and the TE polarisation optical signal is supplied from the beam splitter to the phase modulator; and

wherein the polarisation mode changer changes the TM polarisation optical signal to a changed TE polarisation optical signal so the changed TE polarisation optical signal can travel through the optical looping path to the phase modulator and then to the beam splitter, and wherein the TE polarisation optical signal is supplied by the beam splitter to the phase modulator and then travels around the optical looping path to the polarisation mode changer so that the TE polarisation optical signal is changed to a changed TM polarisation optical signal which is then received by the beam splitter; and

wherein the beam splitter supplies the changed TM polarisation optical signal and changed TE polarisation optical signal as the optical signal back to the optical transmitting/receiving path.

11. The device of claim 10 wherein the polarisation mode changer comprises a fast/slow coupler for changing the polarisation mode by connecting a fast axis and a slow axis of a polarisation wave axis of an optical fibre, the optical transmitting/receiving path is used for an outgoing path and a return path for the optical signal, and the optical looping path is used for an outgoing path and a returning path for the TE polarisation optical signal and TM polarisation optical signal split by the beam splitter.

12. The device of claim 10 or 11 wherein the optical transmitting/receiving path includes an attenuator and a polarisation controller.

13. A transmission method for an optical signal comprising:

splitting the optical signal into a TE polarisation optical signal and a TM polarisation optical signal by a beam splitter;

providing an optical transmitting/receiving path for supplying the optical signal to the beam splitter and receiving the optical signal from the beam splitter;

providing an optical looping path connected to the beam splitter;

providing a phase modulator in the optical looping path;

providing a polarisation mode changer in the optical looping path and positioned relative to the phase modulator so that the TM polarisation optical signal is supplied from the beam splitter to the polarisation mode changer, and the TE polarisation optical signal is supplied from the beam splitter to the phase modulator;

wherein the polarisation mode changer changes the TM polarisation optical signal to a changed TE polarisation optical signal so the changed TE polarisation optical signal can travel through the optical looping path to the phase modulator and then back to the beam splitter, and wherein the TE polarisation optical signal is supplied by the beam splitter to the phase modulator and then travels around the optical looping path to the polarisation mode changer so that the TE polarisation optical signal is changed to a changed TM polarisation optical signal which is then received by the beam splitter; and

wherein the beam splitter supplies the changed TM polarisation optical signal and changed TE polarisation optical signal as the optical signal back to the optical transmitting/receiving path.

14. The method of claim 13 wherein the polarisation mode changer comprises a fast/slow coupler for changing the polarisation mode by connecting a fast axis and a slow axis of a polarisation wave axis of an optical fibre, the optical transmitting/receiving path is used for an outgoing path and a return path for the optical signal, and the optical looping path is used for an outgoing path and a returning path for the TE polarisation optical signal and TM polarisation optical signal split by the beam splitter.

15. The method of claim 13 or 14 wherein the optical transmitting/receiving path includes an attenuator and a polarisation controller.

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16. A transmission device for an optical signal substantially as hereinbefore described with reference to any one of the embodiments of Figures 1 to 6 and 9 and 10 of the accompanying drawings.

10 17. A transmission method for an optical signal substantially as hereinbefore described with reference to any one of the embodiments of Figures 1 to 6 and 9 and 10 of the accompanying drawings.

### Abstract

An optical system of a transmission device for quantum cryptograph includes a Faraday mirror and a phase modulator. The phase modulator has multiple refractivity, and it is inevitable to lose an extreme amount of input due to the configuration of the optical path. As a result, the S/N ratio is reduced, which makes an adjustment at start time difficult. A light pulse incident to the transmission device includes two light pulses of the TE polarization wave and the TM polarization wave for a phase modulator 8. The light pulse of the TE polarization wave is changed to the TM polarization wave by a Faraday mirror 7, and the TM polarization wave is changed to the TE polarization wave by rotating the polarization plate and reflecting by the Faraday mirror 7, and output from the transmission device. Two polarization beam splitters 5 and 6 are used so that the light pulse of the TM polarization wave should bypass the phase modulator 8. Only light pulse of the TE polarization wave is carried to the phase modulator 8.