



ENGLISH TRANSLATION FOR PCT/JP01/07770
SPECIFICATION
PHASE MODULATION APPARATUS AND PHASE MODULATION
METHOD

5

Technical Field

The present invention relates to a phase modulation apparatus and a phase modulation method for performing a phase modulation on an optical signal at a high speed. For example, the invention relates to a high-speed modulation apparatus and its method for quantum cryptography of phase modulation system.

Background Art

Figs. 14 and 15 show a method for phase modulation in the conventional quantum cryptography of phase modulation system disclosed in a document: Uchiyama, "Basic quantum mechanics and quantum cryptography" Mathematical Sciences No. 402, December 1996.

According to the cryptography of phase modulation system, a phase modulator (PM) is usually placed as shown in a configuration of Fig. 14. A transmitting apparatus and a receiving apparatus include phase modulators (PMA, PMB), respectively, and apply voltage corresponding to the phase modulation ($0, \pi/2, \pi, 3\pi/2$) to the phase modulators.

The quantum cryptography of phase modulation system physically creates the system utilizing interference of photons having different phases which flow through two kinds of optical paths having the same length in an



optical system using such as an optical fiber. In the modulation of the quantum cryptography of phase modulation system, each of the transmitting apparatus and the receiving apparatus usually includes one phase modulator and operate phase modulation between the two partners.

5 The following explains concretely the conventional method for phase modulation in the quantum cryptography of phase modulation system using one example.

For example, an embodiment of B92 protocol using a coupler at a joint where an optical fiber is used will be explained referring to Figs. 14 and
10 15.

A photon is oscillated from laser at a certain cyclic frequency, and transmits to a coupler 1 as an optical signal through the optical fiber, etc. Hereinafter, only two optical paths will be explained, which are critical to the quantum cryptography.

15 The first one is a first optical path in which, at a coupler 1, the laser goes upwards in Fig. 14, passes through the phase modulator PMA and a coupler 2, and at a coupler 3, the laser goes forward without passing through a phase modulator PMB and passes through a coupler 4 to reach a detector.

The second one is a second optical path in which at the coupler 1, the
20 laser goes forward without passing through the phase modulator PMA and passes through the coupler 2, and at the coupler 3, the laser goes upwards in Fig. 14, passes through the phase modulator PMB, passes through the coupler 4 to reach the detector.

The first optical path has the same length as the second optical path.

25 When it is assumed that one phase as Φ_a which modulated by the

phase modulator PMA, and the other as Φ_b which modulated by the phase modulator PMB, between the optical paths having the same length, an optical interference occurs according to a difference value of $(\Phi_a - \Phi_b)$. The quantum cryptography of the phase modulation system utilizes this

5 interference. As described, the conventional method for modulating the phase simply places one phase modulator in each of the transmitting device and the receiving device to perform desired phase modulation.

For example, in order to modulate phases of 0 , $\pi/2$, π , or $3\pi/2$, voltages of $0V$, $4V$, $8V$, or $12V$ are applied to the phase modulator. As shown
10 in Fig. 15, upon applying the voltage, there always exist a rise time LP and a fall time TP of the voltage. Further, when one phase modulator continuously modulates different random phases serially, a blank period BP ($BP > 0$) should be provided.

In the conventional phase modulation method, the modulation
15 requires to apply voltages in different values at a high speed, however, the rise time LP and the fall time TP of voltage prevents a high-speed operation. For example, when a photon is oscillated at a certain cyclic frequency using a pulse laser, the phase should be modulated synchronously with the timing of oscillating the photon, and therefore, various kinds of voltages corresponding
20 to the modulation amount should be applied synchronously with the above timing. A bit rate of the quantum cryptography is in proportion with the number of frequency of the pulse laser, so that the voltage should be switched to a high voltage and applied to the phase modulator to perform the high-speed operation. Because of this, generally, long LP and TP cause to
25 extend the time required for applying the voltage different from the previous

value. Ignoring this fact, if the cyclic frequency (of the pulse laser, for example) is raised, BP becomes hard to be taken ($BP \leq 0$), the next timing of the voltage to rise and the previous timing of the voltage to fall are overlapped, which causes malfunction of the modulator and, therefore,
5 prevents the high-speed operation.

The present invention aims to perform a high-speed processing of the phase modulation. The objectives of the invention are to improve a bit rate, namely, the high-speed operation in, for example, the quantum cryptography of the phase interference system.
10

Disclosure of the Invention

According to the present invention, a phase modulation apparatus includes:

N phase modulators (N: an integer equal to or greater than 2) for
15 performing a phase modulation on an optical signal which flows through an optical path;

a first optical switch and a second optical switch for selectively connecting one of the N phase modulators which are placed parallel to the optical path; and

20 a control unit for outputting a switching signal to the first optical switch and the second optical switch and making the one of the N phase modulators connect to the optical path.

The control unit includes:

a phase modulation data memory for storing phase modulation data;

25 N voltage generating units each of which generates a voltage

corresponding to each of the phase modulation to the N phase modulators;
and

a switching unit for serially reading the phase modulation data
stored in the phase modulation data memory and serially supplying the
5 phase modulation data read to the voltage generating unit for generating the
voltage to the phase modulator to be connected to the optical path by the first
optical switch and the second optical switch.

The control unit includes:

a phase modulation data memory for storing phase modulation data
10 having N values;

a voltage generating unit for generating N fixed voltages
corresponding to the N values of the phase modulation data, and for
supplying the N fixed voltages to the N phase modulators, respectively; and

a switching unit for reading the phase modulation data stored in the
15 phase modulation data memory, and outputting the switching signal for
selecting one of the N phase modulators, to which the voltage corresponding
to a value of the phase modulation data read is supplied, to the first optical
switch and the second optical switch.

According to the present invention, a phase modulation apparatus
20 includes:

N phase modulators (N: an integer equal to or greater than 2) which
are connected serially to an optical path; and

a control unit for generating N voltages to the N phase modulators so
that a sum of the N voltages applied to the N phase modulators becomes a
25 voltage corresponding to a phase modulation of an optical signal, and

supplying the N voltages to the N phase modulators.

The control unit includes:

a phase modulation data memory for storing phase modulation data;

and

5 a voltage generating unit for generating N equal voltages (V/N) by
equally dividing a voltage V, which corresponds to the phase modulation data
stored in the phase modulation data memory, by N, and supplying the N
equal voltages (V/N) generated to the N phase modulators, respectively.

According to the present invention, a phase modulation method for
10 serially performing a phase modulation on a first optical signal and a second
optical signal, the phase modulation method includes:

a first modulation step for phase modulating the first optical signal
by a first phase modulator; and

a second modulation step for phase modulating the second optical
15 signal by a second phase modulator before the first modulation step
terminates.

According to the present invention, a phase modulation method for
performing a phase modulation on an optical signal by a predetermined
amount includes:

20 a first modulation step for phase modulating the optical signal by a
first phase modulator; and

a second modulation step for phase modulating the optical signal,
which is phase modulated by the first modulation step, by a second phase
modulator, and

25 the phase modulation method performs the phase modulation on the

optical signal by the predetermined amount with performing both the first modulation step and the second modulation step.

Brief Explanation of the Drawings

5 Fig. 1 shows a phase modulation apparatus according to the first embodiment.

 Fig. 2 explains the operation of the phase modulation apparatus of the first embodiment.

 Fig. 3 shows an operational flowchart of a switching unit of the first
10 embodiment.

 Fig. 4 shows a phase modulation apparatus according to the second embodiment.

 Fig. 5 explains the operation of the phase modulation apparatus of the second embodiment.

15 Fig. 6 shows an operational flowchart of a switching unit of the second embodiment.

 Fig. 7 shows a phase modulation apparatus according to the third embodiment.

 Fig. 8 explains the operation of the phase modulation apparatus of
20 the third embodiment.

 Fig. 9 shows a wave diagram of an applied voltage.

 Fig. 10 shows an operational flowchart of a voltage generating unit of the third embodiment.

 Fig. 11 shows another configuration showing a location of the phase
25 modulation apparatus.

Fig. 12 shows another configuration showing a location of the phase modulation apparatus.

Fig. 13 shows another configuration showing a location of the phase modulation apparatus.

5 Fig. 14 shows a location of a conventional phase modulation apparatus.

Fig. 15 explains the operation of the conventional phase modulation.

Preferred Embodiments for Carrying out the Invention

10 Embodiment 1.

According to the first embodiment, in the quantum cryptography using the phase modulation method, a high-speed modulation method of the quantum cryptography of phase modulation system will be explained, in which multiple parallel phase modulators are provided and switched at a
15 high speed by an optical switch.

Fig. 1 shows a high-speed modulation system in the quantum cryptography of the phase modulation system.

This modulation system is configured by a transmitting apparatus 100, a transmission line 200, and a receiving apparatus 300. In the
20 transmitting apparatus 100, laser 91 oscillates optical signals with a cyclic frequency C to continuously generate the optical signals. A first coupler 94 and a second coupler 95 make the optical signal diverge and converge. A first phase modulator 71 and a second phase modulator 73 perform a phase modulation on the optical signal. A first optical switch 33 and a second
25 optical switch 35 switch the operations of the first phase modulator 71 and

the second phase modulator 73. A synchronous output signal 93 is output from the laser 91 to a switching unit 55.

A control unit 51 controls the phase modulation. The control unit 51 includes a phase modulation data memory 53, the switching unit 55, a first
5 voltage generating unit 57, and a second voltage generating unit 59. The phase modulation data memory 53 inputs and stores phase modulation data 31. When the synchronous output signal 93 is output from the laser 91, the switching unit 55 switches the first optical switch 33 and the second optical switch 35 alternately so as to switch to use the first phase modulator 71 and
10 the second phase modulator 73 in turn. And further, based on a value of the phase modulation data 31 stored in the phase modulation data memory 53, the switching unit 55 instructs the first voltage generating unit 57 and the second voltage generating unit 59 to generate voltage used for the phase modulation by the first phase modulator 71 and the second phase modulator
15 73. The first voltage generating unit 57 generates a phase voltage to the first phase modulator 71, and the second voltage generating unit 59 generates the voltage for the phase modulation to the second phase modulator 73.

The transmission line 200 is a transmission line made of optical fiber,
20 etc.

The receiving apparatus 300 is configured in the same manner with the transmitting apparatus 100. Different from the transmitting apparatus 100, the receiving apparatus 300 doesn't have the laser 91 like the transmitting apparatus 100, but includes a detector 98. The detector 98
25 detects an optical interference.

Fig. 2 shows the operation of the first phase modulator 71, the second phase modulator 73, the first phase modulator 81, and the second phase modulator 83.

In Fig. 2, (a) shows a voltage applied to the first optical signal, and
 5 (b) shows a voltage applied to the second optical signal.

As shown in Fig. 2, the operating time of the first phase modulator 71 overlaps with the operating time of the second phase modulator 73 by a period shown as OP. Namely, before a first modulation step in which the first phase modulator 71 performs the phase modulation on the first optical
 10 signal is finished, a second modulation step in which the second phase modulator 73 performs the phase modulation on the second optical signal is started. In this way, it is possible to have overlapped operating time OP between the first modulation step and the second modulation step, since the first phase modulator 71 and the second phase modulator 73 are connected
 15 in parallel.

Fig. 3 is a flowchart showing the operation of the switching unit 55 of the control unit 51.

First, the switching unit 55 obtains the phase modulation data 31 from the phase modulation data memory 53 serially at S11, and if there is no
 20 phase modulation data 31 at S12, the switching unit 55 finishes the phase modulation process. Next, at S 13, the switching unit 55 determines which of the first phase modulator 71 and the second phase modulator 73 is used for the phase modulation of the next optical signal. In this case, the first phase modulator 71 and the second phase modulator 73 is used alternately.
 25 And in case that the first phase modulator 71 is used at S14, the phase

modulation data 31 is transmitted to the first voltage generating unit 57.

On the other hand, in case that the second phase modulator 73 is used at S14, the phase modulation data 31 is transmitted to the second voltage

generating unit 59. Then, at S15, the synchronous output signal 93 from

5 the laser 91 is awaited. When the synchronous output signal 93 arrives from the laser 91, the switching unit 55 switches the first optical switch 33 and the second optical switch 35 to the first phase modulator 71 or the

second phase modulator 73 at S16. At S17, the switching unit 55 transmits an activation signal for generating the voltage based on the phase

10 modulation data 31 to the voltage generating unit which applies the voltage for the phase modulation to the phase modulator and connected by the first optical switch 33 and the second optical switch 35. As a result, the first voltage generating unit 57 or the second voltage generating unit 59 outputs the voltage based on the phase modulation data 31 to the first phase

15 modulator 71 or the second phase modulator 73.

In Fig. 2, at the time T1, the first voltage generating unit 57 is activated, and the second voltage generating unit 59 is activated at the time T2.

As described, the phase modulation at twice the speed at maximum
20 is enabled by connecting two phase modulators in parallel and switching the operations of the two phase modulators. And further, if N phase modulators are connected in parallel and their operations are switched, the phase modulation at N-time the speed at maximum is enabled.

25 Embodiment 2.

Fig. 4 shows another example of the transmitting apparatus 100 (or the receiving apparatus 300).

In Fig. 4, four phase modulators of the first phase modulator 71, the second phase modulator 73, a third phase modulator 75, and a fourth phase modulator 77 are connected in parallel, and the operations are switched by the first optical switch 33 and the second optical switch 35. The voltage generating unit 58 always generates 0V, 4V, 8V, and 12V for the use of the phase modulation of four kinds of amount; 0, $\pi/2$, π , and $3\pi/2$. 0V is supplied to the first phase modulator 71, 4V is to the second phase modulator 73, 8V is to the third phase modulator 75, and 12V is to the fourth phase modulator 77.

Fig. 5 explains the operations of the first phase modulator 71, the second phase modulator 73, the third phase modulator 75, and the fourth phase modulator 77 shown in Fig. 4.

The first phase modulator 71 always performs the phase modulation of 0V, the second phase modulator 73 always performs the one of 4V, the third phase modulator 75 always performs the one of 8V, and the fourth phase modulator 77 always performs the one of 12V. The switching unit 55 switches the first optical switch 33 and the second optical switch 35 based on the four values (0, $\pi/2$, π , and $3\pi/2$) of the phase modulation data 31 stored in the phase modulation data memory 53. For example, as shown in Fig. 5, when the phase modulation data 31 is $3\pi/2$, the switching unit 55 switches the first optical switch 33 and the second optical switch 35 to S4. Then, the first optical signal is phase modulated by the voltage of 12V. Next, when the phase modulation data 31 is π , the switching unit 55 switches the first

optical switch 33 and the second optical switch 35 to S3, and then, the second optical signal is phase modulated by 8V.

Fig. 6 is a flowchart showing the operation of the switching unit 55 of the control unit 51 shown in Fig. 4.

5 First, at S21, the switching unit 55 obtains the phase modulation data 31 stored in the phase modulation data memory 53 serially. Next, at S22, the switching unit 55 finishes the phase modulation process if there is no phase modulation data 31. When there exists the phase modulation data 31, the switching unit 55 awaits the synchronous output signal 93 from the
10 laser 91 at S23. When the synchronous output signal 93 is received from the laser 91, at S24, the switching unit 55 instructs to switch the first optical switch 33 and the second optical switch 35 based on the value of the phase modulation data 31.

In the present embodiment, each of the four phase modulators
15 always performs one phase modulation (0 , $\pi/2$, π , or $3\pi/2$), and the phase modulator is selected by the first optical switch 33 and the second optical switch 35. Accordingly, there is no need to consider the rise time and the fall time of the voltage, which enables a high-speed phase modulation.

In this embodiment, the time for switching the first optical switch 33
20 and the second optical switch 35 should be shorter by switching based on the cyclic frequency faster than the cyclic frequency C of the photon generated by the laser 91, which enables an extremely high-speed phase modulation.

Embodiment 3.

25 According to the third embodiment, in the quantum cryptography

employing the phase modulation system, another high-speed modulation system for the quantum cryptography of the phase modulation system will be explained, in which multiple series phase modulators are provided and the phase to be modulated is divided and modulated.

5 In this embodiment, another example of the transmitting apparatus 100 (or the receiving apparatus 300) will be discussed.

In this embodiment, a case in which the phase modulators are connected serially will be explained referring to Fig. 7.

10 In Fig. 7, the first phase modulator 71, the second phase modulator 73, the third phase modulator 75, and the fourth phase modulator 77 are serially connected. The voltage generating unit 56 generates the voltage of the same value to the four phase modulators and supplies the voltages to the phase modulators at the same time.

Fig. 8 shows applied voltages to the four phase modulators.

15 Fig. 9 shows the voltage V ($V = 8V$) in case of performing the phase modulation of π .

In order to generate the voltage of $8V$, it is assumed the rise time LP and the fall time TP are required. In case of the phase modulation, it is possible to apply the voltage of $8V$ at once to perform the phase modulation of π , and it is also possible to apply the voltage of $2V$ four times to perform the phase modulation of π . When it is assumed the rise time for generating the voltage of $2V$ as W and the fall time as U , $W = LP/4$ and $U = TP/4$, since the rise time and the fall time are in proportion with the voltage.

Accordingly, the present embodiment shortens the rise time and the fall time
25 required for generating the voltage to perform the phase modulation by

applying the voltage to perform the phase modulation dividedly. For example, as shown in Fig. 7, in order to apply the voltage to be essentially applied using four phase modulators, each of the four phase modulators applies 1/4 of the voltage. Therefore, the rise time and the fall time can be
 5 reduced to 1/4.

In Fig. 8, the voltages of 2V are supplied to the four phase modulators at the same time. This is because it is possible to regard the time required for carrying the optical signal from the first phase modulator 71 through the fourth phase modulator 77 as almost 0, since the distance
 10 between the locations of the first phase modulator 71 and the fourth phase modulator 77 is short. If the time required for carrying the optical signal from the first phase modulator 71 through the fourth phase modulator 77 is too long to be ignored, the timings to supply the applied voltage to each phase modulator should be staggered a little.

15 Fig. 10 is a flowchart showing the operation of the voltage generating unit 56 of the control unit 51.

The voltage generating unit 56 obtains the phase modulation data 31 from the phase modulation data memory 53 at S31. Next, if there is no phase modulation data 31, the voltage generating unit 56 finishes the phase
 20 modulation process at S32. Then, the voltage generating unit 56 awaits an input of the synchronous output signal 93 at S33. Further, at S34, the voltage generating unit 56 generates 1/4 of the voltage ($V/4$) of the voltage V which is originally indicated by the phase modulation data 31 and outputs to the four phase modulators at the same time.

25 In the foregoing example, the voltage of 8V is divided into four.

When the applied voltage is 4V, the voltage of 1V is applied to each of the four phase modulators, and when the applied voltage is 12V, the voltage of 3V is applied to each of the four phase modulators.

According to the present embodiment, N phase modulators are
5 connected serially, which can reduce the rise time and the fall time to $1/N$, respectively.

In this embodiment, the first modulating step in which the optical signal is phase modulated by the first phase modulator 71, the second modulating step in which the optical signal that is phase modulated at the
10 first modulating step is further phase modulated by the second phase modulator 73, and the third and the fourth modulating steps are provided. By executing these first through fourth modulating steps serially, a desired phase modulation of the predetermined amount can be performed. In this way, multiple phase modulators are connected serially and the modulated
15 phase is divided and applied, so that the rise time and the fall time of the voltage are reduced, which enables a high-speed operation.

Figs. 11 through 13 show examples of connecting the transmitting apparatus 100 and the receiving apparatus 300.

Fig. 11 shows a case in which N phase modulators are connected
20 serially.

Fig. 12 shows a case in which the phase modulators are connected in serial and partially in parallel.

Fig. 13 shows a case in which the phase modulators are connected in parallel, and further connected in serial.

25 Another combination of the phase modulators can be also embodied,

which is not illustrated here.

The above phase modulator can be used for the high-speed modulator in the quantum cryptography of the phase modulation system. And further, the application is not limited to the quantum cryptography, but the phase
5 modulator can be also used for the phase modulation of the optical signal. Yet further, the above-described configuration can be used in only one of the transmitting apparatus and the receiving apparatus.

Industrial Applicability

10 As has been described, according to the preferred embodiment of the invention, the value of the bit rate can be increased in the quantum cryptography employing the phase modulation system. Namely, the high-speed operation can be done without the influence of the rise time and the fall time of the voltage to be applied for the phase modulation, or the
15 influence of these time can be extremely reduced.

Further, according to the preferred embodiment of the invention, since the phase modulators are connected in parallel and switched, the phase modulation by another phase modulator can start the operation without awaiting until the voltage of the phase modulator in the process of the phase
20 modulation is fallen to 0V, which enables the high-speed phase modulation.

According to the preferred embodiment of the invention, since a predetermined level of voltage is always applied to the phase modulator, and the optical signal is supplied to the phase modulator by switching with the switch, the rise time and the fall time of the voltage can be reduced to 0.
25 Therefore, the high-speed phase modulation is enabled.

Yet further, according to the preferred embodiment of the invention, the phase modulators are connected serially, and the voltage is divided and applied. The rise time and the fall time of the voltage can be reduced, which enables the high-speed phase modulation.

Claims

1. A phase modulation apparatus comprising:

N phase modulators (N: an integer equal to or greater than 2) for performing a phase modulation on an optical signal which flows through an optical path;

a first optical switch and a second optical switch for selectively connecting one of the N phase modulators which are placed parallel to the optical path; and

a control unit for outputting a switching signal to the first optical switch and the second optical switch and making the one of the N phase modulators connect to the optical path.

2. The phase modulation apparatus of claim 1, wherein the control unit includes:

a phase modulation data memory for storing phase modulation data;

N voltage generating units each of which generates a voltage corresponding to each of the phase modulation to the N phase modulators; and

a switching unit for serially reading the phase modulation data stored in the phase modulation data memory and serially supplying the phase modulation data read to the voltage generating unit for generating the voltage to the phase modulator to be connected to the optical path by the first optical switch and the second optical switch.

3. The phase modulation apparatus of claim 1, wherein the control unit includes:

a phase modulation data memory for storing phase modulation data

having N values;

a voltage generating unit for generating N fixed voltages corresponding to the N values of the phase modulation data, and for supplying the N fixed voltages to the N phase modulators, respectively; and

5 a switching unit for reading the phase modulation data stored in the phase modulation data memory, and outputting the switching signal for selecting one of the N phase modulators, to which the voltage corresponding to a value of the phase modulation data read is supplied, to the first optical switch and the second optical switch.

10 4. A phase modulation apparatus comprising:

N phase modulators (N: an integer equal to or greater than 2) which are connected serially to an optical path; and

a control unit for generating N voltages to the N phase modulators so that a sum of the N voltages applied to the N phase modulators becomes a
15 voltage corresponding to a phase modulation of an optical signal, and supplying the N voltages to the N phase modulators.

5. The phase modulation apparatus of claim 4, wherein the control unit includes:

a phase modulation data memory for storing phase modulation data;
20 and

a voltage generating unit for generating N equal voltages (V/N) by equally dividing a voltage V, which corresponds to the phase modulation data stored in the phase modulation data memory, by N, and supplying the N equal voltages (V/N) generated to the N phase modulators, respectively.

25 6. A phase modulation method for serially performing a phase

modulation on a first optical signal and a second optical signal, the phase modulation method comprising:

a first modulation step for phase modulating the first optical signal by a first phase modulator; and

5 a second modulation step for phase modulating the second optical signal by a second phase modulator before the first modulation step terminates.

7. A phase modulation method for performing a phase modulation on an optical signal by a predetermined amount comprising:

10 a first modulation step for phase modulating the optical signal by a first phase modulator; and

a second modulation step for phase modulating the optical signal, which is phase modulated by the first modulation step, by a second phase modulator, and

15 wherein the phase modulation method performs the phase modulation on the optical signal by the predetermined amount with performing both the first modulation step and the second modulation step.