



- (51) **International Patent Classification:**
H04L 9/08 (2006.01) *H04B 10/70* (2013.01)
- (21) **International Application Number:**
PCT/MY2014/000159
- (22) **International Filing Date:**
4 June 2014 (04.06.2014)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
PI 2013004372 4 December 2013 (04.12.2013) MY
- (71) **Applicant:** MIMOS BERHAD [MY/MY]; Technology Park Malaysia, 57000 Kuala Lumpur (MY).
- (72) **Inventors:** ABDUL KHIR, Mohd Fared; c/o Mimos Berhad, Technology Park Malaysia, 57000 Kuala Lumpur (MY). WAH, Mohamed Ridza Bin; c/o Mimos Berhad, Technology Park Malaysia, 57000 Kuala Lumpur (MY). MOHD ZAIN, Mohd Norzaliman Bin; c/o Mimos Berhad, Technology Park Malaysia, 57000 Kuala Lumpur (MY).
- (74) **Agent:** MIRANDAH, Patrick; Mirandah Asia (Malaysia) sdn bhd, Suite 3B-19-3, Plaza Sentral, Jalan Stesen Sentral 5, 50470 Kuala Lumpur (MY).
- (81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) **Title:** AN APPARATUS AND METHOD FOR AUTOMATED FLIPPING OF SIX POLARIZATION STATES OF AN OPTICAL PULSE

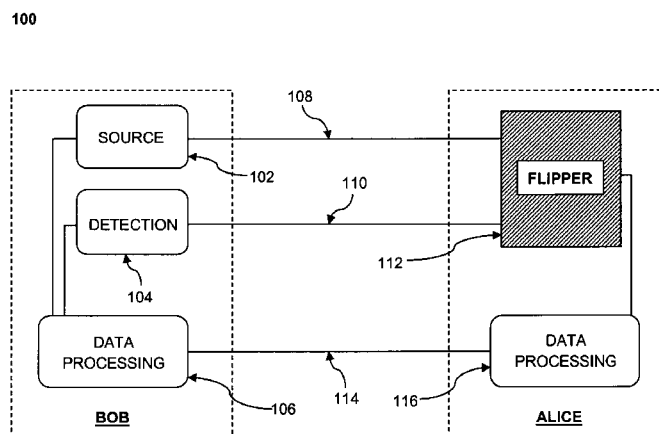


FIG. 1.0

(57) **Abstract:** The present invention provides an automated flipping apparatus and method to orthogonally rotate six degenerate polarization state (H, V, D, A, R, and L) in an automated manner by utilizing two active non-linear materials act as half wave plate (HWP) with different preset orientation (45 degree or 0 degree or vice versa) triggered by half wave voltage. The apparatus (100) for automated flipping of an optical pulse input (108) using six states out from three bases to obtain 6DP quantum key distribution protocol comprising at least one source (102) to prepare at least two non-orthogonal optical pulses; at least a detection module (104) to deterministically measure said pulse pair; at least one data processing module (106, 116) at each end to process said pulse pair; and at least one optical polarization flipper (112) to orthogonally rotate polarization states of received optical pulses. The at least one optical polarization flipper (112) to orthogonally rotate polarization states of received optical pulses further comprising at least two active non-linear materials (202, 204) utilized to act as half wave plates (HWP) positioned in series with optical path of input; the first non-linear material (202) is orientated at 45 degree from optical axis of an incoming optical pulse and the second non-linear material (204) is orientated at 0 degree from optical axis of the incoming optical pulse; and the polarization states are triggered by half wave voltage generated by the HWP to automatically flip said polarization state to horizontal (H), vertical (V), diagonal (D), anti-diagonal (A), circular right (R), and circular left (L).

**Declarations under Rule 4.17:**

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *of inventorship (Rule 4.17(iv))*

Published:

- *with international search report (Art. 21(3))*

- 1 -

AN APPARATUS AND METHOD FOR AUTOMATED FLIPPING OF SIX POLARIZATION STATES OF AN OPTICAL PULSE

FIELD OF INVENTION

5

The present invention relates to an apparatus and method for automated flipping of six polarization states of an optical pulse. In particular, the invention relates to an apparatus and method that provides for automated flipping of an optical pulse input using six states out from three bases to obtain 6DP quantum key distribution protocol.

10

BACKGROUND ART

15

The polarization state of light is known to be used in many technologies ranging from optical sensing to information security. In the field of information security, as in the case of quantum cryptography, the polarized state of light has been used for example in encoding logical bit for key exchange session between two distant parties. While the usage for four linear polarization states are common, having six polarization states gives more advantage in terms of security. An example of the application with respect to 6DP protocol is introduced by J.S. Shaari, M. Lucamarini, M.R.B. Wahiddin in the Physics Letters A Volume 358 (2): 85. The 6DP Protocol is a Quantum Key Distribution (QKD) protocol which belongs to the two way protocol variant. Among them also includes protocol such as LM05 and the PingPong protocol which utilizes four and two polarization states.

20

25

In general, the protocol can be realized using six polarization states of single photon pulses which are used to represent the six quantum states as provided in Europhysics Letter 87 (2009) 10008 entitled "Quantum state engineering with ququarts: Application for deterministic QKD protocol", by A.P. Shurupov, S.S. Straupe, S.P. Kulik, M. Gharib, M.R.B. Wahiddin and in International Patent Application No. PCT/MY2009/000087 entitled "Method of Preparation and Unitary transformation of Quantum States for Quantum Key Distribution" by Mohamed Ridza Wahiddin and Sergey Kulik. The six polarization states can be easily produced for example by using six different laser sources. Unlike other preparation and measurement scheme e.g. the BB84 protocol, the 6DP Protocol, being a two way protocol, for example the encoding operation at Alice

30

- 2 -

requires her to do a flipping operation against the polarization states of the optical pulses sent by Bob i.e. she has to orthogonally rotate the polarization states of the incoming optical pulse. While in a four states two way protocol e.g. the LM05 protocol, realization of the flipper is straight forward as disclosed in a paper entitled "Characterization of Four States Polarization Flipper for Single Photon Application" in Proceeding of the IEEE International Conference on Photonic (ICP2010), Langkawi by Abdul Khir MF, Mohd Zain M N, Suryadi, Saharudin S, Shaari S. and in Optical Engineering, 51, 045006 entitled "Implementation of Two Way Free Space Quantum Key Distribution", by Abdul Khir MF, Mohd Zain M N, Suryadi, Saharudin S, Shaari S.. However, being a six states protocol, one need to rely on a pair of non-orthogonal optical pulses and the number of flip bits to aid the information exchange.

An example of an experimental work on the 6DP protocol can be found in Europhysics Letter 87 (2009) 10008 entitled "Quantum state engineering with ququarts: Application for deterministic QKD protocol", by Wahiddin et al. and in International Patent Application No. PCT/MY2009/000087 entitled "Method of Preparation and Unitary transformation of Quantum States for Quantum Key Distribution" by Wahiddin and Kulik. While the 6DP protocol itself was successfully realized, one would immediately realize that the experiment was conducted in a manual fashion. For instance, the flipper at Alice which consists of two non-linear materials (half wave plates) had to be manually adjusted their rotation. Further, one needs to remove the non-linear materials (the half wave plates) from the optical path to apply the identity operation (I). While such implementation is enough for a proof of principle, it is certainly not for practical use. One needs an automated apparatus to benefit from the protocol. It is known that one can utilize an electro optic device such as the Pockels cell which can be turned into a half wave plate at certain preconfigured orientation by simply triggering with half wave voltage, thus enabling a fully automated operation. Such implementation can be seen in "Characterization of Four States Polarization Flipper for Single Photon Application" in Proceeding of the IEEE International Conference on Photonic (ICP2010), Langkawi by Abdul Khir MF et.al. and in Optical Engineering, 51, 045006 entitled "Implementation of Two Way Free Space Quantum Key Distribution", by Abdul Khir MF et.al..The implementation however realizes the flipping of only four linear polarization states (the vertical, horizontal, diagonal and anti-diagonal) which certainly is not for use with the 6DP protocol.

- 3 -

Due to the limitations of the existing mechanism, there is a need to develop an apparatus and method to be used as a flipper for six polarization states based on two way quantum key distribution protocol. The present invention provide a flipping apparatus and method to orthogonally rotate six degenerate polarization state (H, V, D, A, R, and L) in an automated manner by utilizing two active non-linear materials that act as a half wave plate (HWP) with different preset orientation (45 degree or 0 degree or vice versa) triggered by half wave voltage. The two active non-linear materials are positioned serially to the optical path of the input optical pulse such that the input optical path is made to pass through the said non-linear materials.

10

The subject matter claimed herein is not limited to embodiments that solve any disadvantages or that operate only in environments such as those described above. Rather, this background is only provided to illustrate one exemplary technology area where some embodiments described herein may be practice.

SUMMARY OF INVENTION

The present invention relates to an apparatus and method for automated flipping of six polarization states of an optical pulse. In particular, the invention relates to an apparatus and method that provides for automated flipping of an optical pulse input using six (6) states out from three (3) bases to obtain 6DP quantum key distribution protocol.

One aspect of the invention provides an apparatus (100) for automated flipping of an optical pulse input (108) using six (6) states out from three (3) bases to obtain 6DP quantum key distribution protocol. The apparatus comprising at least one source (102) to prepare at least two non-orthogonal optical pulses; at least a detection module (104) to deterministically measure said pulse pair; at least one data processing module (106, 116) at each end to process said pulse pair; and at least one optical polarization flipper (112) to orthogonally rotate polarization states of received optical pulses. The at least one optical polarization flipper (112) to orthogonally rotate polarization states of received optical pulses further comprising at least two active non-linear materials (202, 204) utilized to act as half wave plates (HWP) positioned in series with optical path of input; the first non-linear material (202) is orientated at 45 degree from optical axis of an incoming optical pulse and the second non-linear material (204) is orientated at 0 degree from optical axis of the incoming optical pulse; and the polarization states are triggered by half wave voltage generated by the HWP to automatically flip said polarization state to horizontal (H), vertical (V), diagonal (D), anti-diagonal (A), circular right (R), and circular left (L).

A further aspect of the invention provides that the input polarization state is flipped by applying either one of four unitary transformation (X, Y, Z and I) achieved with the at least one optical polarization flipper.

Yet another aspect of the invention provides that the unitary transformation is X which is when the half wave voltage triggers only the first non-linear material (202).

Still another aspect of the invention provides that the unitary transformation is iY which is when the half wave voltage triggers both the non-linear material (202, 204).

- 5 -

A further aspect of the invention provides that the unitary transformation is Z which is when the half wave voltage triggers only the second non- linear material (204).

5 Still another aspect of the invention provides that the unitary transformation is I which is when the half wave voltage does not trigger any of the two non-linear materials (202, 204).

10 Yet another aspect of the invention provides that the at least two active non-linear materials utilized to act as half wave plates (HWP) positioned in series with optical path of input; the position of the first (202) and the second non-linear material (204) can be swapped.

15 Another aspect of the invention provides a method (300) for automated flipping of an optical pulse input using six states out from three bases to obtain 6DP quantum key distribution protocol. The method comprising steps of initiating a Quantum Key Distribution (QKD) session by preparing at least two non-orthogonal optical pulses using a source (302); forwarding said non-orthogonal optical pulses through a forward quantum channel to at least one optical polarization flipper to flip logical bits by applying either one of the four unitary transformation (X, iY, Z and I) to at least two active non-
20 linear materials utilized to act as half wave plates (HWP) positioned in series with optical path of input (304); and returning pulse pair through a backward quantum channel to the at least one detection module which enables measurement of pulse pair (306). The step for forwarding said non-orthogonal optical pulses through a forward quantum channel to at least one optical polarization flipper to encode logical bits by applying either one of the
25 four unitary transformation (X, iY, Z and I) to at least two active non-linear materials utilized to act as half wave plates (HWP) positioned in series with optical path of input; the X unitary transformation is performed when only the first non-linear material is triggered and the second non-linear material is left as not triggered (406); the Z unitary operation is performed when only the second non-linear material is triggered and the first non-linear material is left not triggered (430); the iY unitary operation is performed
30 when both the first non-linear material is triggered and the second non-linear material is triggered (418); and the I unitary operation is performed when both the first non-linear material and the second non-linear material is left not triggered (432).

- 6 -

Yet another aspect of the invention provides that the X unitary transformation, the Z unitary transformation, the iY unitary transformation; and the I unitary transformation is randomly applied to a pair of two optical pulses with non-orthogonal polarization by randomly triggering either the first non-linear material or by triggering only the second non-linear material, or by triggering both the first and second non-linear material, or by
5 leaving both the first and second non-linear material as not triggered.

The present invention consists of features and a combination of parts hereinafter fully described and illustrated in the accompanying drawings, it being understood that various
10 changes in the details may be made without departing from the scope of the invention or sacrificing any of the advantages of the present invention.

- 7 -

BRIEF DESCRIPTION OF ACCOMPANYING DRAWINGS

To further clarify various aspects of some embodiments of the present invention, a more particular description of the invention will be rendered by references to specific
5 embodiments thereof, which are illustrated in the appended drawings. It is appreciated that these drawings depict only typical embodiments of the invention and are therefore not to be considered limiting of its scope. The invention will be described and explained with additional specificity and detail through the accompanying drawings in which:

10 FIG. 1.0 illustrates the example of interaction between Bob and Alice which includes flipping operation as provided for in the present invention.

FIG. 2.0 illustrates the general architecture of the apparatus for automated flipping of the 6DP protocol of the present invention.

15

FIG 3.0 is a flowchart illustrating the general methodology of the present invention.

FIG. 4.0 is a flowchart illustrating architecture of the four (4) conditions of the unitary transformation and the logical bit encoding of the present invention.

20

Table 1.0 illustrates the encoding of the logical bit and the corresponding triggering of the Pockels cell.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention relates to an apparatus and method for automated flipping of six polarization states of an optical pulse. In particular, the invention relates to an apparatus and method that provides for automated flipping of an optical pulse input using six (6) states out from three (3) bases to obtain 6DP quantum key distribution protocol.

Hereinafter, this specification will describe the present invention according to the preferred embodiments. It is to be understood that limiting the description to the preferred embodiments of the invention is merely to facilitate discussion of the present invention and it is envisioned without departing from the scope of the appended claims.

Referring to FIG. 1.0, the example of the setup (100) shows the interaction between Bob and Alice which includes flipping operation as provided for in the present invention. The apparatus (100) for automated flipping of an optical pulse input (108) using six states out from three bases to obtain 6DP quantum key distribution protocol comprising one source (102) to prepare at least two non-orthogonal optical pulses; a detection module (104) to deterministically measure said pulse pair; a data processing module (106, 116) at each end to process said pulse pair; and an optical polarization flipper (112) to orthogonally rotate polarization states of received optical pulses. Bob initiates the Quantum Key Distribution (QKD) session by preparing two non-orthogonal optical pulses using the source (102) and send it to Alice through the forward quantum channel (108). Alice upon receiving the optical pulse pair encode the logical bits (either 00, 01, 10, 11) by applying either one of the four unitary transformation (X, Y, Z and I) achieved with the optical polarization flipper (112) and return the pulse pair to Bob through the backward quantum channel (110). Bob uses the detection apparatus (104) to deterministically measure the pulse pair using the same basis he used during the preparation stage.

FIG. 2.0 illustrate the apparatus for automated flipping of the 6DP protocol as provided for in the present invention. The optical polarization flipper (112) to orthogonally rotate polarization states of received optical pulses further comprising two active non-linear materials (202, 204) which are normally the Pockels cells arranged serially inside the driver housings (206) and (208) utilized to act as half wave plates (HWP) positioned in series with optical path of input. The orientation of the first non-linear material (i.e. the

- 9 -

first Pockels cell) (202) and the second non-linear material (i.e. the second Pockels cell) (204) are set to be 45 degree and 0 degree respectively from the optical axis of the incoming optical pulse. The position of the two active non-linear materials (i.e. the Pockel cells) utilized to act as half wave plates (HWP) positioned in series with optical path of input; the position of the first (202) and the second non-linear material (204) can be swapped. If triggered with half wave voltage, both the Pockels cell (202) and (204) act as a half wave plate with their rotation from the optical axis according to the set orientation as the polarization states are triggered by half wave voltage generated by the HWP to automatically flip said polarization state to horizontal (H), vertical (V), diagonal (D), anti-diagonal (A), circular right (R), and circular left. The half wave plates are flipped by applying either one of four unitary transformation (X, Y, Z and I) achieved with the at least one optical polarization flipper. The unitary transformation, X which is when the half wave voltage triggers only the first non-linear material (202) while the unitary transformation, iY which is when the half wave voltage triggers both the non-linear material (202, 204). Further, the unitary transformation, Z which is when the half wave voltage triggers only the second non-linear material (204) and the unitary transformation, I which is when the half wave voltage does not trigger any of the two non-linear materials (202, 204). The optical pulse enter the optical polarization flipper through the forward channel (210), proceed through both the Pockels cells (202) and (204) and finally leaves the driver housing (208) and enter the backward quantum channel (212).

Referring to FIG. 3.0 and 4.0 respectively, a general method (300) of an embodiment of the invention is illustrated wherein the method (300) begins by initiating a Quantum Key Distribution (QKD) session by preparing at least two non-orthogonal optical pulses using a source (302). Thereafter, the said non-orthogonal optical pulses is forwarded through a forward quantum channel to an optical polarization flipper to flip logical bits by applying either one of the four unitary transformation (X, iY, Z and I) to the two active non-linear materials utilized to act as half wave plates (HWP) positioned in series with optical path of input (304). In forwarding the said non-orthogonal optical pulses through a forward quantum channel to the optical polarization flipper to flip logical bits by applying either one of the four unitary transformation (X, iY, Z and I) to two active non-linear materials utilized to act as half wave plates (HWP) positioned in series with optical path of input; the X unitary transformation is performed when only the first non-linear material is

- 10 -

triggered and the second non-linear material is left as not triggered (406); the Z unitary operation is performed when only the second non-linear material is triggered and the first non-linear material is left not triggered (430); the iY unitary operation is performed when both the first non-linear material is triggered and the second non-linear material is triggered (418); and the I unitary operation is performed when both the first non-linear material and the second non-linear material is left not triggered (432). Subsequently, the pulse pair is returned through a backward quantum channel to the at least one detection module which enables measurement of pulse pair (306). The X unitary transformation, the Z unitary transformation, the iY unitary transformation; and the I unitary transformation is randomly applied to a pair of two optical pulses with non-orthogonal polarization by randomly triggering either the first non-linear material or by triggering only the second non-linear material, or by triggering both the first and second non-linear material, or by leaving both the first and second non-linear material as not triggered. The pair of two optical pulses with non-orthogonal polarization is not necessary position as next to one another.

The configuration can be explained using Jones calculus which is often used in dealings with polarization transformation in a fully polarized optical setup as disclosed by E.Collett in the SPIE Press Book 2005 entitled "Field Guide to Polarization". Jones vector is first denoted for all six polarization states from the three mutually unbiased basis used in this protocol as:

Vertical, $|V\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$; Horizontal, $|H\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$;
 Diagonal, $|D\rangle = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$ Anti-diagonal, $|A\rangle = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$;
 Circular right, $|R\rangle = \begin{bmatrix} 1 \\ i \end{bmatrix}$, Circular left, $|L\rangle = \begin{bmatrix} 1 \\ -i \end{bmatrix}$.

Jones matrix for rotatable half wave plate (M) is given by:

$$M = \begin{bmatrix} \cos 2\theta & \sin 2\theta \\ \sin 2\theta & -\cos 2\theta \end{bmatrix}.$$

- 11 -

Pockels cell not in triggered state is equivalent to identity matrix (I)

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}.$$

- 5 Pockels cell at orientation θ to optical axis, triggered with half wave voltage is represented as half wave plate with the following Jones matrix $M(\theta)$.

$$M(\theta) = \begin{bmatrix} \cos 2\theta & \sin 2\theta \\ \sin 2\theta & -\cos 2\theta \end{bmatrix}.$$

- 10 By setting the orientation of the first Pockels cell 321 and the second Pockels cell 322 to $\theta = \frac{\pi}{4}$ and $\theta = 0$ respectively, their Jones matrix in triggered state are each given by

$$M1 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \text{ and } M2 = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}.$$

- 15 The M1 and M2 is the X and the Z operator. The two operations can further be combined by conducting matrix multiplication for M1 and M2 and further obtain M12.

$$M12 = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

- 20 which act as the iY operator in [1]. One may also swap the position of M1 and M2 such that the orientation of each Pockles cell is swapped. In this way, the combined Pockels cells becomes M21)

$$M21 = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

25

which still yields the same output polarization states as with the M12.

- Table 1.0 shows the four (4) conditions provided for in the invention where the said six (6) degenerate polarization states is being flipped. As indicated in Table 1.0, the four (4) conditions are:

30

- i) Not triggering any of the two non-linear materials is assigned as the (I) identity

- 12 -

operator;

ii) Triggering both non-linear materials is assigned as the (iY) operator.

iii) Triggering only the first non-linear material is assigned as the (X) unitary operator;
and

5 iv) Triggering only the second non-linear material is assigned as the (Z) unitary operator.

The requirement of utilizing the separate wavelength is avoided as the flipping operation of the six polarization states based on two way quantum key distribution protocol is met. The distinguishing features of the present invention lies in a flipping apparatus and the method to orthogonally rotate six degenerate polarization state (H, V, D, A, R, and L) in
10 an automated manner by utilizing two active non-linear materials act as half wave plate (HWP) with different preset orientation (45 degree or 0 degree or vice versa) triggered by half wave voltage.

Unless the context requires otherwise or specifically stated to the contrary, integers, steps or elements of the invention recited herein as singular integers, steps or elements
15 clearly encompass both singular and plural forms of the recited integers, steps or elements.

Throughout this specification, unless the context requires otherwise, the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply
20 the inclusion of a stated step or element or integer or group of steps or elements or integers, but not the exclusion of any other step or element or integer or group of steps, elements or integers. Thus, in the context of this specification, the term "comprising" is used in an inclusive sense and thus should be understood as meaning "including principally, but not necessarily solely".

25

It will be appreciated that the foregoing description has been given by way of illustrative example of the invention and that all such modifications and variations thereto as would be apparent to persons of skill in the art are deemed to fall within the broad scope and ambit of the invention as herein set forth.

CLAIMS

1. An apparatus (100) for automated flipping of an optical pulse input (108) using six states out from three bases to obtain 6DP quantum key distribution protocol comprising:
- 5 at least one source (102) to prepare at least two non-orthogonal optical pulses;
- at least a detection module (104) to deterministically measure said pulse pair;
- 10 at least one data processing module (106, 116) at each end to process said pulse pair; and
- at least one optical polarization flipper (112) to orthogonally rotate polarization states of received optical pulses characterized in that
- 15 the at least one optical polarization flipper (112) to orthogonally rotate polarization states of received optical pulses further comprising:
- at least two active non-linear materials (202, 204) utilized to act as half wave plates (HWP) positioned in series with optical path of input;
- 20 the first non-linear material (202) is orientated at 45 degree from optical axis of an incoming optical pulse and the second non-linear material (204) is orientated at 0 degree from optical axis of the incoming optical pulse; and
- the polarization states are triggered by half wave voltage generated by the HWP to automatically flip said
- 25 polarization state to horizontal (H), vertical (V), diagonal (D), anti-diagonal (A), circular right (R), and circular left (L).
- 30 2. An apparatus (100) as claimed in Claim 1, wherein the half wave plates are flipped by applying either one of four unitary transformation (X, Y, Z and I) achieved with the at least one optical polarization flipper.

- 14 -

3. An apparatus (100) as claimed in Claim 2, wherein the unitary transformation is X which is when the half wave voltage triggers only the first non-linear material (202).
- 5 4. An apparatus (100) as claimed in Claim 2, wherein the unitary transformation is iY which is when the half wave voltage triggers both the non-linear material (202, 204).
- 10 5. An apparatus (100) as claimed in Claim 2, wherein the unitary transformation is Z which is when the half wave voltage triggers only the second non-linear material (204).
- 15 6. An apparatus (100) as claimed in Claim 2, wherein the unitary transformation is I which is when the half wave voltage does not trigger any of the two non-linear materials (202, 204).
- 20 7. An apparatus (100) as claimed in Claim 1, wherein the at least two active non-linear materials utilized to act as half wave plates (HWP) positioned in series with optical path of input; the position of the first (202) and the second non-linear material (204) can be swapped.
- 25 8. A method (300) for automated flipping of an optical pulse input using six (6) states out from three bases to obtain 6DP quantum key distribution protocol comprising steps of:
 - 25 initiating a Quantum Key Distribution (QKD) session by preparing at least two non-orthogonal optical pulses using a source (302);
 - forwarding said non-orthogonal optical pulses through a forward quantum channel to at least one optical polarization flipper to encode logical bits by applying either one of the four unitary transformation (X, iY, Z and I) to at
 - 30 least two active non-linear materials utilized to act as half wave plates (HWP) positioned in series with optical path of input (304) ; and
 - returning pulse pair through a backward quantum channel to the at least one detection module which enables measurement of pulse pair (306) characterized in that

- 15 -

forwarding said non-orthogonal optical pulses through a forward quantum channel to at least one optical polarization flipper to encode logical bits by applying either one of the four unitary transformation (X, iY, Z and I) to at least two active non-linear materials utilized to act as half wave plates (HWP) positioned in series with optical path of input;

the X unitary transformation is performed when only the first non-linear material is triggered and the second non-linear material is left as not triggered (406);

the Z unitary operation is performed when only the second non-linear material is triggered and the first non-linear material is left not triggered (430);

the iY unitary operation is performed when both the first non-linear material is triggered and the second non-linear material is triggered (418); and

the I unitary operation is performed when both the first non-linear material and the second non-linear material is left not triggered (432).

9. A method according to Claim 8, wherein the X unitary transformation, the Z unitary transformation, the iY unitary transformation; and the I unitary transformation is randomly applied to a pair of two optical pulses with non-orthogonal polarization by randomly triggering either the first non-linear material or by triggering only the second non-linear material, or by triggering both the first and second non-linear material, or by leaving both the first and second non-linear material as not triggered.

10. A method according to Claim 8, wherein the pair of two optical pulses with non-orthogonal polarization are not necessary position as next to one another.

1/5

100

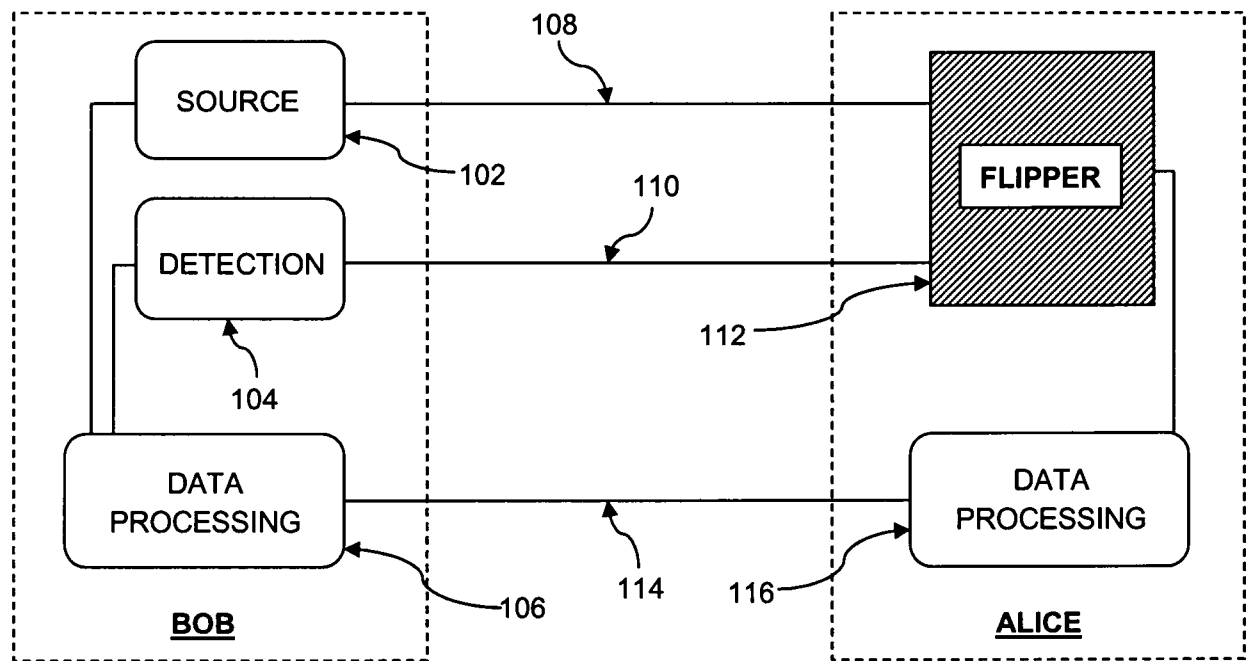


FIG. 1.0

200

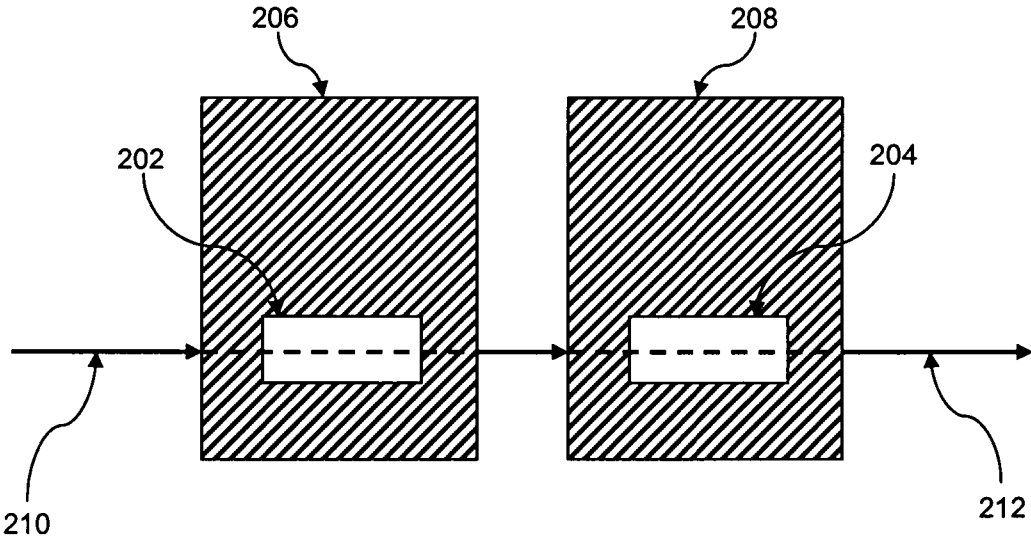


FIG. 2.0

300

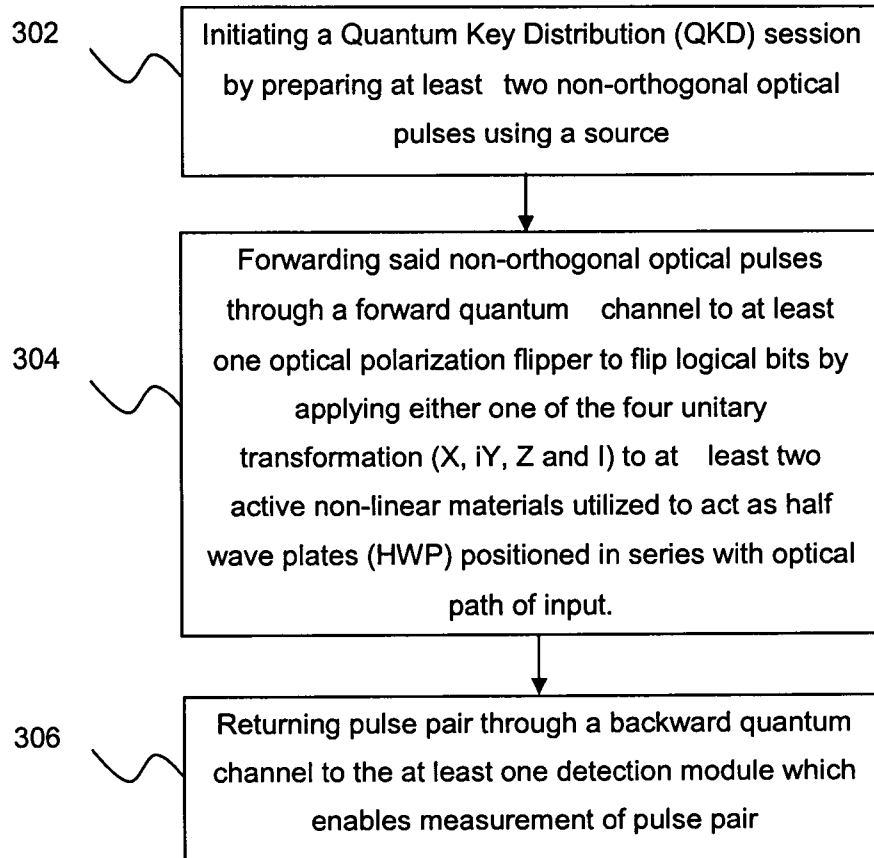
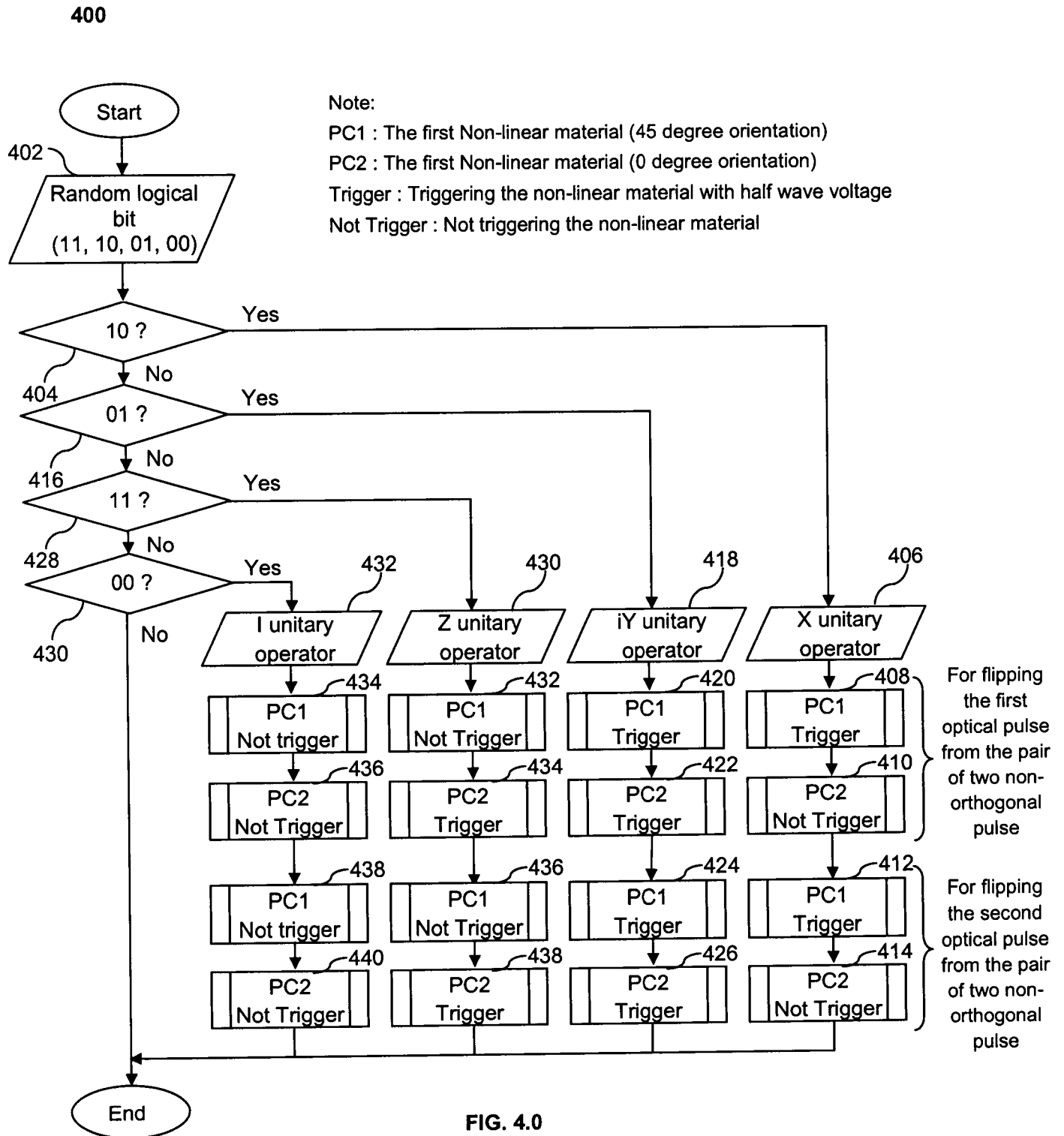


FIG. 3.0



Unitary Operator	First Pockels Cell	Second Pockel Cells	logical bit
X	Triggered	Not Triggered	10
iY	Triggered	Triggered	01
Z	Not Triggered	Triggered	11
I	Not Triggered	Not Triggered	00

Table 1.0

INTERNATIONAL SEARCH REPORT

International application No

PCT/MY2014/000159

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04L9/08 H04B10/70
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04L H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SHAARI J S ET AL: "Deterministic six states protocol for quantum communication", PHYSICS LETTERS A, NORTH-HOLLAND PUBLISHING CO., AMSTERDAM, NL, vol. 358, no. 2, 9 October 2006 (2006-10-09), pages 85-90, XP024929007, ISSN: 0375-9601, DOI: 10.1016/J.PHYSLETA.2006.05.007 [retrieved on 2006-10-09] cited in the application Sections 1 and 2 ----- -/-	1-10



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

2 December 2014

Date of mailing of the international search report

11/12/2014

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Wolters, Robert

INTERNATIONAL SEARCH REPORT

International application No

PCT/MY2014/000159

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ABDUL KHIR M F ET AL: "Characterization of four states polarization flipper for single photon application", PHOTONICS (ICP), 2010 INTERNATIONAL CONFERENCE ON, IEEE, PISCATAWAY, NJ, USA, 5 July 2010 (2010-07-05), pages 1-3, XP031777436, ISBN: 978-1-4244-7186-7 cited in the application the whole document -----	1-10
Y	SHURUPOV A P ET AL: "Quantum state engineering with ququarts: Application for deterministic QKD protocol", EUROPHYSICS LETTERS: A LETTERS JOURNAL EXPLORING THE FRONTIERS OF PHYSICS, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, FR, vol. 87, no. 1, 1 July 2009 (2009-07-01), page 10008, XP020159616, ISSN: 0295-5075 cited in the application Section "6DP PROTOCOL" and "EXPERIMENTAL REALIZATION" -----	1-10
A	WO 2009/157756 A2 (MIMOS BERHAD [MY]; WAHIDDIN MOHAMED RIDZA [MY]; KULIK SERGEY [MY]) 30 December 2009 (2009-12-30) cited in the application abstract; claims 1,7,8 -----	1-10
A	ABDUL KHIR1 M F ET AL: "Implementation of Two Way Free Space Quantum Key Distribution", 20110101 1 January 2011 (2011-01-01), pages 1-24, XP007922928, Retrieved from the Internet: URL:arxiv.org/pdf/1108.3411 [retrieved on 2014-12-01] cited in the application the whole document -----	1-10
A	WO 2012/018246 A1 (MIMOS BERHAD [MY]; ABDULLAH MUHAMMAD SYARGAWI [MY]; WITJAKSONO GUNAWAN) 9 February 2012 (2012-02-09) abstract page 1, line 12 - line 21 page 3, line 3 - line 24 -----	1-10
A	WO 2012/047087 A1 (MIMOS BERHAD [MY]; ABDUL KHIR MOHD FARED [MY]; MD YUSOF ZALHAN [MY]; S) 12 April 2012 (2012-04-12) abstract; claims 1-3 -----	1-10

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/MY2014/000159

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2009157756	A2	30-12-2009	NONE

WO 2012018246	A1	09-02-2012	MY 149261 A 15-08-2013
		WO 2012018246 A1	09-02-2012

WO 2012047087	A1	12-04-2012	NONE
