

Quantum entangle photon and applications in communication and measurement

Suebtarkul Suchat¹, Preecha P. Yupapin², and Surasak Chiangga³

Abstract

Suchat, S.¹ and Yupapin, P.² and Chiangga, S.³

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Songklanakarin J. Sci. Technol., 2004, 26(1) : 83-91

This paper presents the use of a single photon entangled state to secure the transmission data via a wireless communication link and a biological tissue study where the encrypted data/qubit is prepared and formed by using a simple optical system. The encrypted data can transmit securely i.e. without cloning to the intended recipient via a public wireless link. We have shown that the result of the entangled states has good visibility for the use of data quantum encryption. The generated entangled photon for up-link via wireless communication is proposed and the problem of quantum cloning described. The biological tissue characterizations using such a short pulse can be realize by using a simple optical arrangement and components. Such an implemented system has the advantage of that the ultra-short pulse of a single photon with its quantum state identification can be used to provide the required measured data.

Key words : Encryption, Cryptography, and Perfect Security

¹Ph.D. Student (Applied Physics KMITL), Department of Physics, Faculty of Science and Technology, Thammasat University, Rangsit Campus, Pathumtani 12121, ²Ph.D (Electrical Engineering), Prof., Lightwave Technology Research Center, Department of Applied Physics, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, ³Ph.D., Quantum Cryptography Group, Department of Physics, Faculty of Science, Kasetsart University, Bangkok 10900, Thailand.

Corresponding e-mail: sueb@alpha.tu.ac.th or Yupapin.Preecha@kmitl.ac.th

Received, 29 April 2003 Accept, 18 October 2003

บทคัดย่อ

สืบตระกูล สุชาติ¹ ปรีชา ยุพาริน² และ สุรศักดิ์ เชียงกาน³
ความตั้มเขอนแทงเกิลและการประยุกต์ใช้ทางด้านการวัดและการสื่อสาร

ว. สงขลานครินทร์ วทท. 2547 26(1) : 83-91

ในงานวิจัยนี้ใช้สถานะเขอนแทงเกิลของโฟตอนเดี่ยวในการส่งข้อมูลให้มีความปลอดภัยผ่านระบบการสื่อสารแบบไร้สายและใช้ในการศึกษาชีววิทยาของเนื้อเยื่อ ในการศึกษาทางด้านการสื่อสารนี้ใช้การเข้ารหัสข้อมูลทางความตั้มซึ่งในที่นี้จะเปรียบเทียบรูปแบบการใช้งานกับระบบทางแสง ในการเข้ารหัสของการส่งข้อมูลผ่านช่องทางสื่อสารไร้สาย สามารถรักษาข้อมูลให้มีความปลอดภัยอีกทั้งยังทำให้ไม่สามารถถอดรหัสได้โดยผู้อื่นได้ผลที่ได้ของสถานะเขอนแทงเกิลนั้นเป็นที่ความเป็นไปได้ที่มากกว่าการใช้ในการเข้ารหัสทางความตั้มในการสร้างเขอนแทงเกิลของโฟตอน สำหรับการอพลิงผ่านการสื่อสารระบบไร้สายนี้เป็นการเสนอความคิดและแสดงปัญหาทางด้านการป้องกันการลอกเลียนข้อมูลทางความตั้ม ส่วนในการศึกษาทางด้านชีววิทยาของลักษณะเนื้อเยื่อจะใช้พัลส์สั้น ๆ ในการศึกษา สามารถแสดงให้เห็นจริงได้โดยใช้พื้นฐานทางแสงและส่วนประกอบ ซึ่งการใช้ประโยชน์จากพัลส์ที่สั้นมาก ๆ ของโฟตอนเดี่ยวจะทำให้สามารถวัดข้อมูลตามที่ต้องการได้จากสถานะทางความตั้ม

¹ ภาควิชาฟิสิกส์ คณะวิทยาศาสตร์และเทคโนโลยี มหาวิทยาลัยธรรมศาสตร์ วิทยาเขตธانบุรี จังหวัดปทุมธานี 12121 ² ศูนย์วิจัยเทคโนโลยี Lightwave ภาควิชาฟิสิกส์ประยุกต์ คณะวิทยาศาสตร์ สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหาร ลาดกระบัง กรุงเทพฯ 10520
³ กลุ่ม Quantum Cryptography ภาควิชาฟิสิกส์ประยุกต์ คณะวิทยาศาสตร์ มหาวิทยาลัยเกษตรศาสตร์ กรุงเทพฯ 10900

Quantum entanglement is a physical resource, like energy, associated with the peculiar nonclassical correlations that are possible between separated quantum systems. In effect, the very possibility of considering a particle or system as possessing objective properties depends on its entanglement with another particle or system. Quantum entanglement has been widely studied and investigated during the 1990s. The Austrian-born Erwin Schrodinger, who in 1933 shared the Nobel Prize with Paul Dirac, introduced the conventional idea (Bennet, et al. 1993). Albert Einstein proposed a situation that came to known as the EPR (Einstein-Podolsky-Rosen) paradox, where he called attention to the fact that while it was impossible to know whether a single photon would pass or be absorbed by a filter paired photon. Would a subject to the same polarization test always being entangled. The experiment simply succeeded (Dehlinger, et al. 2002, Zeilinger, 1999, Vedral, 2002), where the entangle went of a single/two photons was observed and this has been used in some applications in quantum cloning, quantum teleportation, measurement

and cryptography (Mattle, et al. 1996, Bennet, et al. 1993, Suchat, et al. 2001).

In practice, we can implement a system by which scrambling and unscrambling digitized information is a task that either sender or intended recipients can easily perform but which is impossible for others to intercept for cloning or deciphering information in cyber space (Deachapunya, et al. 2001, Goldenberg, et al. 1995). In this paper, we propose the use of a single photon to encrypt the transmission data via a wireless link. A basic in quantum encryption is exchanging a secret message between two users, traditionally called Alice and Bob, in a way that no other party can read it. The only known method to do this in a proven secure way is to use a previously shared secret information called a key. The key, a sequence of random bits, is used for encrypting the message. The encrypted message is completely confidential, even if transmitted via a public communication channel. Thus the security of any key-based cryptographic method depends ultimately on the secrecy of the key. All existing classical key-distribution en-

cription are not proven to secure. Their secrecy is based on computational complexity assumptions, which sometimes turn out to be false. On the other hand, the fundamental laws of quantum mechanics guarantee the secrecy of quantum encryption. Any intervention of an eavesdropper, Eve, must leave some trace which can be detected by the legal users of the communication channel. The encoding in quantum cryptography was based on orthogonal states (Goldenberg, *et al.* 1995), since an eavesdropper cannot clone them. Even an imperfect cloning attempt (intended to gain partial information) induces errors in the transmission therefore, it is detectable. In general, any two orthogonal states can be used for quantum cryptography. In this paper, we present the quantum encryption via the transmission by using a classical channel via Mach-Zehnder Interferometer (MZI), in which data exchange between Alice and Bob is done using two orthogonal states and yet, any eavesdropping attempt is detectable. The two states are horizontal (H) and vertical (V) polarization a photon. In this application, the idea of an experiment of optical encryption technique can be realized to create perfect security, for mobile phone up-link converter and a biological tissue study using the entangled single photon pair (Yupapin, *et al.* 2003).

Theoretical background

An entangled state is a quantum superposition of a composite system whose subsystems are not probabilistically independent. An entangled state cannot be factorized as the direct product of the individual state function. Considering two two-state systems, an entangled state in a two-dimensional Hilbert space can always be written in the form:

$$|\psi\rangle = \alpha|a\rangle_1 \otimes |b\rangle_2 + \beta|a'\rangle_1 \otimes |b'\rangle_2 \quad (1)$$

where $|a\rangle_1$ and $|a'\rangle_1$, $|b\rangle_2$ and $|b'\rangle_2$ are orthogonal sets in the spaces of particle one and two respectively, where both of the scalars α and β are nonzero.

We prove that equation (1) can be factorized as:

$$|\psi\rangle = |x\rangle_1 \otimes |y\rangle_2 \quad (2)$$

where $|x\rangle_1$ and $|y\rangle_2$ are in the spaces of states of particle 1 and 2, respectively.

In general, the $|x\rangle_1$ and $|y\rangle_2$ can be expressed as a linear superposition of b and b':

$$\begin{aligned} |x\rangle_1 &= \gamma|a\rangle_1 + \gamma'|a'\rangle_1 \\ |y\rangle_2 &= \eta|b\rangle_2 + \eta'|b'\rangle_2 \end{aligned} \quad (3)$$

Then

$$\begin{aligned} |x\rangle_1 \otimes |y\rangle_2 &= \gamma|a\rangle_1 \otimes |b\rangle_2 + \gamma'|a'\rangle_1 \otimes |b'\rangle_2 \\ &+ \eta|a\rangle_1 \otimes |b'\rangle_2 + \eta'|a'\rangle_1 \otimes |b'\rangle_2 \end{aligned} \quad (4)$$

Comparing equation (1) and (4), we see that $\gamma\eta' = \gamma'\eta = 0$ which implies that either

$$\alpha = \gamma\eta = 0 \text{ or } \beta = \gamma'\eta' = 0 \quad (5)$$

Therefore, it is impossible to factorize the state in equation (1) i.e. it is entangled.

The measurement of each entangled photon state in one basis i.e. randomly quantum keys, according to the agreement between the sender and the receiver is unbreakable, unless the spy knows the key. The diagram of the quantum key distribution (QKD) and cloning is as shown in Figure 1.

From Figure 1, the pumping photon can thus follow the horizontal and vertical path or long path originating the superposition as

$$|\pm\rangle = \frac{1}{\sqrt{2}}(|H\rangle \pm e^{\pm i}|V\rangle) \quad (6)$$

Where $|H\rangle$ and $|V\rangle$ denote the photon which has followed the polarization Components respectively, and ϕ is the phase difference between the two paths.

The measurement system uses an entangled single photon in which one component is known as a reference photon. The other is going to interact with the required tissue sample and then the decay of emission light can be probed and measured such as is shown in Figure 2. The interaction

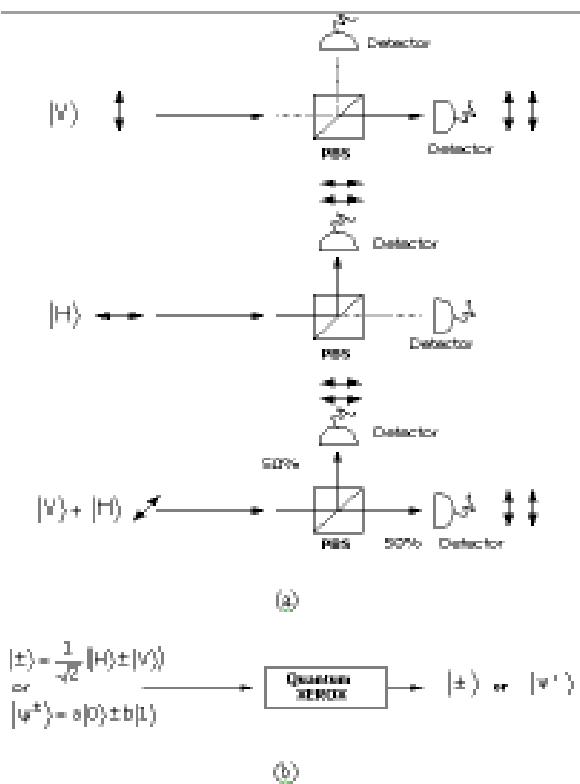


Figure 1. Schematic diagram of a single photon entangled state;
(a) Quantum entanglement,
(b) Quantum cloning.

between photon and sample may present some properties of light such as reflection, scattering or absorption, which can be observed. The tissue pigment can be performing to obtain the required measurement parameters. In general with a laser beam of wavelength λ , the photon energy is determined from the irradiant by the relationship,

$$I_{\text{photon}} = \frac{hc}{\lambda}$$

where I is defined in terms of the power (P), in watts, h is a Plank's constant, c is the speed of light. In this case, the decay time of the light emission is the range of ns.

In communication, the security of our scheme is based on two novel ingredients, firstly, the orthogonal states sent by Alice are a superposition of two localized wave packets. The wave packets are not sent simultaneously towards Bob, but one of them is delayed for a fixed time and sent after the other. Secondly, the transmission time of each particle is random (and therefore unknown to Eve). The interception of the data by a known user in the transmission system allows the detection of an eavesdropper. Let $|H\rangle$ and $|V\rangle$ be two polarization states of photon, which are sent from Alice to Bob

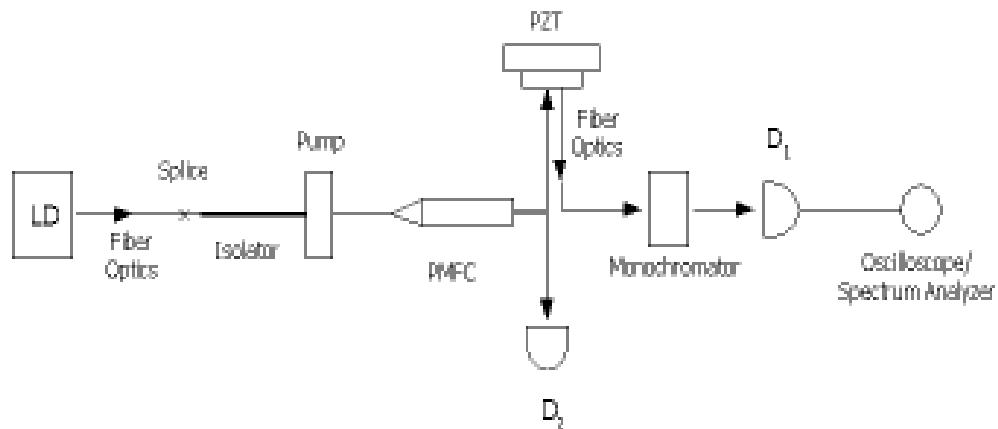


Figure 2. A schematic diagram of the proposed experimental set up: LD: Laser Diode, D: Avalanche Photodiode (APD), PBS: Polarizing Beam splitter, PZT: Piezoelectric Transducer, PMFC: Polarization Maintaining Fiber Coupler.

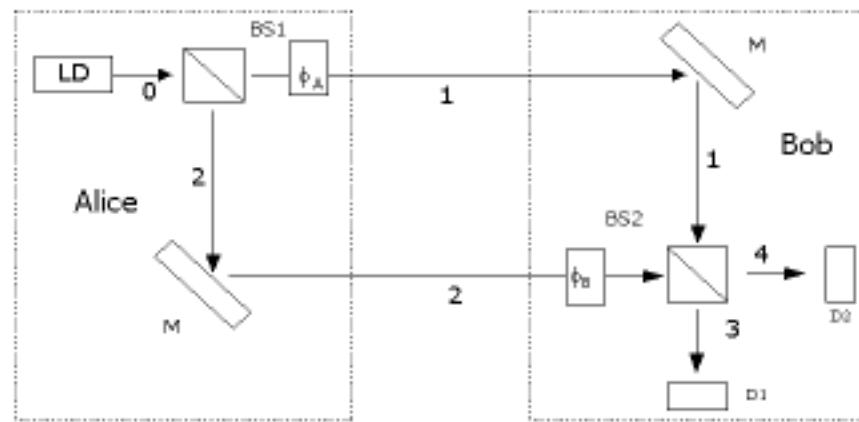


Figure 3. Encryption scheme bases on a Mach-Zehnder interferometer.
LD: Laser diode, BS1, 2: Beam splitter, M: Mirror, D1, 2: Detectors.

along two separated channels. We shall take two orthogonal states $|\Psi_+\rangle$ and $|\Psi_-\rangle$, linear combinations of $|H\rangle$ and $|V\rangle$, to represent bit value “0” and bit value “1,” respectively:

$$|\Psi_+\rangle = \frac{1}{\sqrt{2}}(|H\rangle + |V\rangle) \quad (7)$$

$$|\Psi_-\rangle = \frac{1}{\sqrt{2}}(|H\rangle - |V\rangle) \quad (8)$$

Alice sends to Bob either $|\Psi_+\rangle$ or $|\Psi_-\rangle$. The two localized states, $|H\rangle$ and $|V\rangle$, are not sent together, but $|V\rangle$ is delayed for some time τ . For simplicity, we choose τ to be larger than the traveling time of the particles from Alice to Bob, θ . Thus $|V\rangle$ starts traveling towards Bob only when $|H\rangle$ already has reached Bob, such that the two wave packets and never found together in the transmission channels.

We shall consider a particular implementation of our scheme. The setup (Figure 3) consists of a Mach-Zehnder interferometer, with ϕ_A and ϕ_B as phase delay which are equal to time delay. Alice can transmit an information bit by sending either from a single particle or from short pulse of laser source, where the sending time t is random and registered by Alice for later use. The particle passes

through the first beam splitter BS1 and evolves into a superposition of two localized wave packets. Finally, the two wave packets arrive simultaneously to the second beam splitter BS2 and interfere. A particle started in state $|\Psi_+\rangle$ emerges at the detector D1, and a particle started in state $|\Psi_-\rangle$ emerges at the detector D2. Bob. The detection of the arriving particle receives the bit sent by Alice: D1 was activated by mean of 0 and D2 mean 1, i.e. he registers the receiving time of the particle.

From Figure 3, consider a Mach-Zehnder interferometer when one mode of the input polarization states is traveling into the modulator i.e. external pumping power. The coupling mode occurs due to the change of the input orientation angle ($\Delta\phi$), which is caused by the change of the optical output power. When the interferometer is at a dark fringe position, this is different from the one used in a classical interferometer with intensity independent noise. The reason is that the signals and noises disappear at $\Delta\phi = 0$, while the quantum noise more rapidly disappears.

Given $I_1 = I_2$ is the output intensity of light in Mach-Zehnder interferometer, and $I_0 = I_1 + I_2 = I_3 + I_4$. Consider a perfect monochromatic light source from laser diode, the signal amplitude is expressed as in equation (9).

$$E_0 = \sqrt{2I_0} \cos(\omega t) \quad (9)$$

According to Figure 3, E_i , $i = 1, 2, 3, 4$ are the signal amplitudes of the transmitted light beams at the given positions in MZI, where l is coherence length and ω is an angular frequency. Consider that the first beam splitter (BS1), yields

$$E_0 = \sqrt{2I_0} \cos\left(\omega\left[t - \frac{l_0}{c}\right]\right) \quad (10)$$

$$E_1 = \sqrt{I_0} \cos\left(\omega\left[t - \frac{l_0}{c}\right]\right) \quad (11)$$

$$E_2 = \sqrt{I_0} \cos\left(\omega\left[t - \frac{l_0}{c}\right]\right) \quad (12)$$

and the second beam splitter (BS2)

$$E_1 = \sqrt{I_0} \cos\left(\omega\left[t - \frac{l_0}{c} - \frac{l_1}{c}\right]\right) \quad (13)$$

$$E_2 = \sqrt{I_0} \cos\left(\omega\left[t - \frac{l_0}{c} - \frac{l_2}{c}\right]\right) \quad (14)$$

We now consider E_3

$$E_3 = \sqrt{\frac{I_0}{2}} \left\{ \cos\left(\omega\left[t - \frac{l_0 + l_1}{c}\right]\right) + \cos\left(\omega\left[t - \frac{l_0 + l_2}{c}\right]\right) \right\} \quad (15)$$

$$E_3 = \sqrt{2I_0} \cos\left(\omega\left[t - \frac{2l_0 + l_1 + l_2}{2c}\right]\right) \cdot \cos\left(\omega\frac{l_1 - l_2}{2c}\right) \quad (16)$$

$$I_3 = \langle E_3^2 \rangle_t = I_0 \cos^2\left(\omega\frac{l_1 - l_2}{2c}\right) = I_0 \cos^2\left(\frac{\phi_A - \phi_B}{2}\right) \quad (17)$$

$$I_4 = I_0 \sin^2\left(\frac{\phi_A - \phi_B}{2}\right) \quad (18)$$

The normalized output is formed by substituting ϕ_A and ϕ_B into Eq. (17), (18), and yields.

ϕ_A	0	$\frac{\pi}{2}$	π	$\frac{3\pi}{2}$	2π
ϕ_B	0	0	0	0	0
$\frac{I_3}{I_0}$	1	$\frac{1}{2}$	0	$\frac{1}{2}$	1
$\frac{I_4}{I_0}$	0	$\frac{1}{2}$	1	$\frac{1}{2}$	0

This shows that Eve, who has access to the channels but not to the sites of Alice and Bob, cannot extract any information without introducing detectable distortions in the transmission. The data are encoded in the relative phase between the two polarization states $|H\rangle$ and $|V\rangle$. Therefore, the phase must be the same as time, which means the two-wave packet must arrive together at BS2 at the correct time.

Experiment and results

From Figure 2 a pair of the entangled photons are generated by a LiNbO₃ crystal and then linearly polarized launching into a biological tissue/sample via a polarizing beam splitter (PBS). The azimuth angle of the input beam I aligned 45 with the optical axis provides an equal intensity component, with orthogonal basis. One of a single photon detected and is identified by using an APD, the another component absorbed by a test sample. An optical polarizer is introduced to protect the optical feed back disturbing the original light source, along the optical line up. The interaction between photon and sample may present some properties of light such as reflection, scattering or absorption will be observed. The tissue pigment can be performed to obtain the required measurement parameters, which results in the fluorescence/ luminescence of light. The output light is collected by a fiber bundle probe, and then characterized by using an optical filter/monochromator, before entering a detector and then shown on the oscilloscope or spectrum analyzer. We expect that the decay time of the interaction between photon and sample molecule will be within the range of ns. One of the polarization states is split with equal intensity by a PBS, and detected by a reference detector (D1). The exchange of energy is transferred to the test sample,

and then the fluorescent/luminescent light is detected and observed using a second detector (D2). The expected result will be analyzed by a filter/monochromator before entering the detector and shown on the oscilloscope/spectrum analyzer. Finally, the relationship between the required information and the photon energy maybe characterized.

Figure 3 shows a CW laser diode emitter a laser with wavelength of 670 nm, which was linearly polarization right by a controlled polarizer (P1) and randomly launched into a classical MZI via a 50:50 percent beam splitter (BS1). One beam was propagated to mirror M2 then pass to a second beam splitter (BS2). Another beam was propagated through a pumping material i.e. LiNbO_3 modulator (LN phase modulator), where the output beam was attenuated and retarded before reflecting at a mirror M1 then combining at a beam splitter BS2. The randomly polarized detected signals and observed and recorded by the two identical detectors and shown on the oscilloscope. The system arrangement of the experiment is as shown in Figure 4. One mode of the input polarization states traveled into the modulator, where the coupling mode occurred due to the change of the input orientation angle ($\Delta\phi$), which was caused by the change of the optical output power. The largest value of phase ranged from $\Delta\phi = 0$ to 2π , as shown in Figure 4, where the output optical power is at a minimum when the interferometer is at a dark fringe position. This is different from the one used for a classical interferometer with intensity independent noise. The reason is that the signals and noises disappear at $\Delta\phi = 0$, while the quantum noise more rapidly disappears.

The results obtained are shown in Figure 5. The output signal characteristics with a linearly polarized light is split and propagated through two arms of the interferometer, one of beam being modulated by a lithium niobate crystal. The signals obtained from both channels are presented as in a phase oscillator with difference signal to noise ratio (S/N). These results are formed by the polarization characteristic of the modulated signals via

an external RF signal modulation. Where the reference detected signal shown in channel 1, relatively to the signal in channel 2, the small effects of the system noise can be neglected. At the detected phase of $(\Delta\phi / 2) = 90^\circ$, the detected signals at the detectors 1 and 2 are 0 and 1 respectively. Bob can be received the data bits as 0 and 1 from Alice via D1 and D2 respectively. Finally, the entanglement signals can be formed and realized before transmitting via a classical optical system. The quantum dense coding can also be performed by the technique of dense wavelength division multiplexing (DWDM) technique, where each of the transmitted wavelengths can be randomly a form entanglement pair, then the dense code/decode schemes can be employed and linked via cable or wireless transmission for mobile phone up-link converter.

Discussion and Conclusion

The experimental scheme as shown in Figure 2 provides a technique for using the entangled photon and the advantage of using the ultra-short pulse via a quantum channel. It can be used as the referencing data/information to fulfil the required measurement parameters. The interaction between the incident photon and sample will generate the light emission/absorption relationship of the interested physical parameter such as protein. The fluorescence/luminescence of light in the region of ns

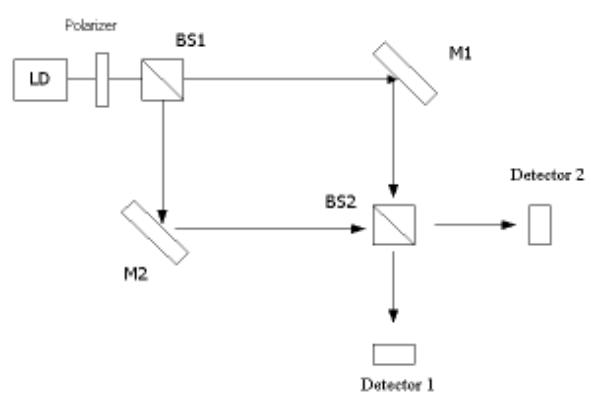


Figure 4. Schematic diagrams of the experiment based on a Mach-Zehnder interferometer.

LD: Laser diode, **BS:** Beam splitter, **M:** Mirror.

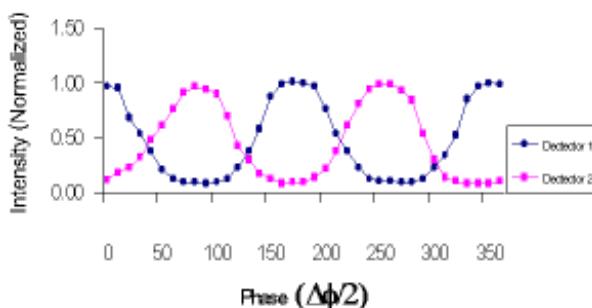


Figure 5. Output signal characteristics resulting from the experiment.

can be detected and observed with a high speed detector. The optical filter is required to reject the unwanted background noisy signal. The equivalence scheme using all fiber optics, the fluorescent/luminescent light will be probed and detected by using a detector one (D1) and detector two (D2) for measuring and referencing signals respectively.

We have assumed the idea of perfectly secured data transmission technique, which it is based on quantum entangled state encryption scheme. Strictly speaking, the set of all possible states sent by Alice to Bob is a set two states corresponding to identical bits, where the two states are horizontal (H) and vertical (V) polarization a single photon. In this application, the idea of an experiment of optical encryption technique can be realized to create top security, for mobile phone up-link converter and communication.

Further arrangement can be employed to make the possible up-link, where the message of the required information from the classical channel can be encrypted into quantum bit/qubit with the generated quantum channel using the single photon entangled property. Some protocol issues can be arranged by using the series of qubits. The encrypted data is then multiplexed with the classical message and transmitted to the required up-link destination, where the required data can be retrieved. In conclusion, the up-link transmission between optical and microwave communication can be realized with perfect security via quantum chan-

nel. The known polarization states can be modulated and amplified before transmitting to the required end users without any decryption/cloning of the secured data.

Acknowledgements

The authors would like to acknowledge King Mongkut's Institute of Technology Ladkrabang (KMITL), for some financial support of this work. One of the authors, Suchat would like to acknowledge to the National Science and Technology Development Agency (NSTDA) for financial support for his doctor degree study scholarship. He would also like to acknowledge the Department of Physics, Faculty of Science, Thammasat University (TU) for his doctor degree study allowance at KMITL.

The authors also would like to acknowledge for the financial support to attend the School/Workshop on "Entanglement at the Nanoscale" between 28 Oct.-8 Nov. 2002 from the Abdus Salam International Centre for Theoretical Physics, Trieste, Italy.

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