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Entangled Photon Encoding Using Trapping of Picoseconds Soliton pulse

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ABSTRACT: *The microring resonator (MRR) system can be used to trap optical solitons. These types of pulses are used to generate entangled photon required for quantum keys. The required information can be provided via the quantum keys. We simulate localized spatial and temporal soliton pulses to form an optical communication used in wireless systems. The input soliton pulses with peak power of 500 and 550 mW are used to generate a spectrum of chaotic signals within the nonlinear medium, where the nonlinear refractive index is selected to* $n_2=2.2 \times 10^{-17} m^2/W$. *The ultra-short soliton pulse can be trapped within the 3.52 GHz frequency, where the temporal soliton pulse with FWHM of 25 ps could be simulated and used to generate entangled photon pair. The generated entangled photons are input into a wireless router system which is used to transfer them within a network communication system. The router system is used to receive the information and convert it to analog signals at the end of the transmission link, thus data can be sent to the users via a secured optical communication system using MRRs.*

Keywords: *Microring Resonator (MRR), Spatial and Temporal Soliton, Quantum Keys*

I. INTRODUCTION

Optical communication is an interesting area in Photonics for two decades [1]. It is very attractive especially when it uses quantum cryptography in a network system where it was reported by Amiri *et al* [2-3]. Quantum keys can form requires information which provides the perfect communication security [4]. Amiri *et al*. showed that quantum security could be performed via the optical-wired and wireless link [5]. Some research works have shown that some techniques of quantum cryptography are proposed, where the systems of MRR are still complicated [6-8]. Amiri et al proposed a new quantum key distribution rule in which carrier information is encoded on continuous variables of a single photon [9]. In such a way, Alice randomly encodes information on either the central frequency of a narrow band single-photon pulse or the time delay of a broadband single-photon pulse [10]. Liu and Goan studied the entanglement evolution under the influence of non-Markovian thermal environments. The continuous variable systems could be two modes of electromagnetic fields or two nano-mechanical oscillators in the quantum domain, where there is no process that can be performed within a single system [11].

To generate a spectrum of light over a broad range [12-13], an optical soliton pulse is recommended as a powerful laser pulse that can be used to generate chaotic filter characteristics when propagating within MRRs [14-19]. Therefore, the capacity of the transmission data can be secured and increased when the chaotic packet switching is employed [20]. In this research, we simulate localized spatial and temporal soliton pulses to form the high capacity and security communication [21-23]. The MRR system is used to trap optical solitons in order to generate entangled photon pair required for quantum keys [24]. Here, generation of the localized ultra-short soliton pulses for continuous variable application is demonstrated [25-27]. The system of quantum key generation can be implemented within the wireless networks [28]. Thus, the links can be set up using the optical soliton, generated by the technique called chaotic filtering scheme in which required signals can be selected and used [29-35]. The device parameters are simulated according to the practical device parameters [36-40], where the results obtained have shown that the entangled photon pair can be performed within the MRR device [41].

II. THEORETICAL MODELING

The schematic diagram of the proposed system is as shown in Fig. 1. This system is associated with the practical device.

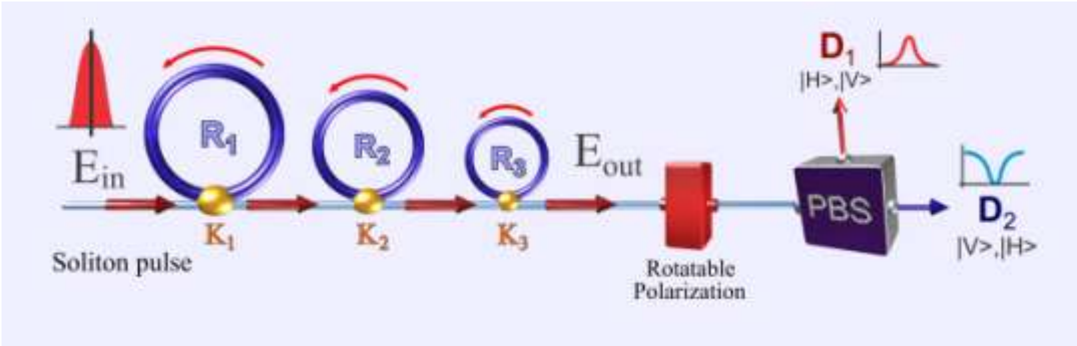

Fig.1: Schematic diagram of a continuous variable quantum key distribution with the different time slot entangled photon encoding. PBS, polarizing beam splitter, Ds, detectors, Rs, ring radii and κs, coupling coefficients.

The soliton pulse is introduced into the proposed system. The input optical field (E_{in}) of the bright soliton pulse can be expressed as [42-44],

$$E_{in} = A\operatorname{sech}\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \tag{1}$$

A and z are the optical field amplitude and propagation distance, respectively [45-47]. T is a soliton pulse propagation time in a frame moving at the group velocity [48], $T = t\text{-}\beta_1 \times z$ [49], where β_1 and β_2 are the coefficients of the linear and second order terms of the Taylor expansion of the propagation constant [50-53]. $L_D = T_0^2 / |\beta_2|$ is the dispersion length of the soliton pulse [54-57]. The frequency shift of the soliton is ω_0 [58]. This solution describes a pulse that keeps its temporal width invariance as it propagates [59], and thus is called a temporal soliton [60]. When a soliton peak intensity $\left(|\beta_2 / \Gamma T_0^2|\right)$ is given [61], then T_o is known [62]. For the soliton pulse in the micro ring device, a balance should be achieved between the dispersion length (L_D) [63-65] and the nonlinear length (L_{NL}= (1/ $\Gamma\phi_{NL}$) [66-68] , where $\Gamma = n_2 \times k_0$ [69], is the length scale over which disperse or nonlinear effects makes the beam becomes wider or narrower [70-71]. For a soliton pulse, there is a balance between dispersion and nonlinear lengths, hence $L_D = L_{NL}$ [72-75]. When light propagates within the nonlinear medium, the refractive index (n) of light within the medium is given by [76-77]

$$n = n_0 + n_2 I = n_0 + \left(\frac{n_2}{A_{eff}}\right)P, \tag{2}$$

where n_0 and n_2 are the linear and nonlinear refractive indexes, respectively. I and P are the optical intensity and optical power, respectively [78]. The effective mode core area of the device is given by A_{eff} [79]. For the MRR, the effective mode core areas range from 0.50 to 0.12 μm^2. The resonant output is can be formed, thus the normalized output of the light field is given by [80-81],

$$\left|\frac{E_{out}(t)}{E_{in}(t)}\right|^2 = (1-\gamma)\left[1 - \frac{(1-(1-\gamma)x^2)\kappa}{(1 - x\sqrt{1-\gamma}\sqrt{1-\kappa})^2 + 4x\sqrt{1-\gamma}\sqrt{1-\kappa}\sin^2\left(\frac{\phi}{2}\right)}\right] \tag{3}$$

where, the output and input fields in each round-trip are presented by E_{out} (t) and E_{in} (t) [82]. Equation (3) indicates that a ring resonator in the particular case is very similar to a Fabry-Perot cavity [83], which has an input and an output mirror with a field reflectivity, (1- κ), and a fully reflecting mirror [84]. κ is the coupling coefficient [85-87], and x=exp (-αL/2) represents a round-trip loss coefficient [88], $\Phi_0 = kLn_0$ [89] and $\Phi_{NL} = kLn_2|E_{in}|^2$ [90] are the linear and nonlinear phase shifts, $k=2\pi/\lambda$ is the wave propagation number in a vacuum [91]. L and α are a waveguide length and linear absorption coefficient, respectively [13]. In this work, the iterative method is introduced to obtain the results as shown in equation (3).

III. RESULT AND DISCUSSION

A soliton pulse with a peak power of 550 mW is input into the system. The suitable ring parameters are used, for instance, ring radii R_1=10 µm, R_2=10µm, and R_3=12µm. The selected parameters of the system are fixed to λ_0=87.5 mm, n_0=3.34 (InGaAsP/InP), A_{eff1}=0.50, A_{eff2}=0.50 and A_{eff3}=0.25µm^2 for three microring resonators respectively, α=0.5dBmm^{-1}, γ=0.1. The coupling coefficient (κ) of the MRR ranged from 0.97 to 0.998.

The large bandwidth within the micro ring device can be generated by using a soliton pulse input into the nonlinear MRR shown in Fig. 1, where the required signals perform the secure communication network. The nonlinear refractive index is n_2=2.2 x 10^{-17}m^2/W. In this case, the wave guided loss used is 0.5dBmm^{-1}. From Fig. 2, the signal is sliced into a smaller signals spreading over the spectrum. The compress bandwidth is obtained within the ring R_2. The amplified gain is obtained within a MRR (R_3). Frequency soliton pulse is formed and trapped by using the constant gain condition. The attenuation of the optical power within a MRR is required in order to keep the constant output gain, where the next round input power is attenuated and kept the same level with the R_2 output.

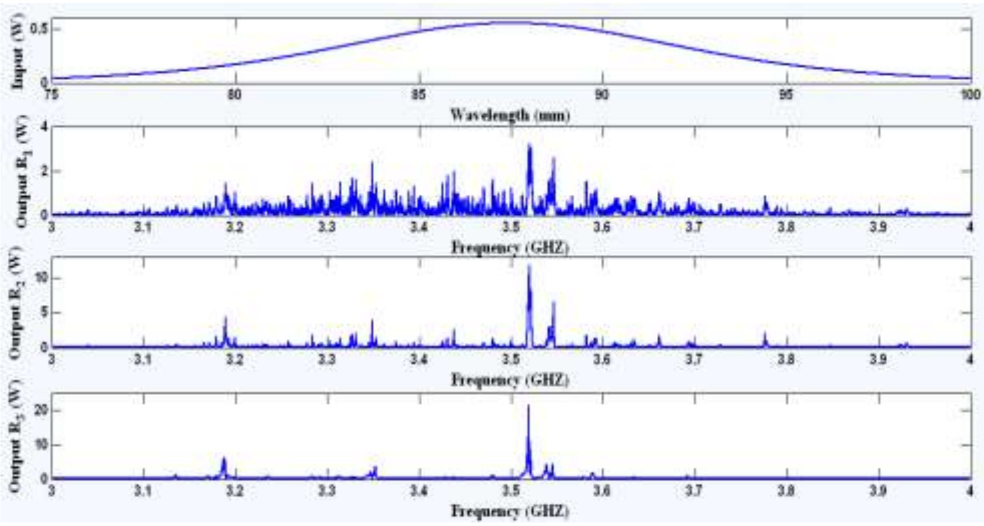

Fig. 2: Results obtained when frequency soliton pulse is localized within a microring device with 20,000 roundtrips, the ring radii are R_1= 10 µm , R_2= 10 µm , R_3= 12 µm

Therefore ultra-short of soliton pulse can be trapped within 3.52 GHz frequency as shown in Fig. 2. Similarly, the temporal soliton is obtained as shown in Fig. 3, where a soliton pulse with peak power of 500 mW is input into the MRRs system. The ring radii R_1=10 µm, R_2=5µm, and R_3=4rµm. The selected parameters of the system are fixed to λ_0=1.55 µm, n_0=3.34 (InGaAsP/InP), A_{eff1}=0.50µm^2, A_{eff2}=0.25µm^2 and A_{eff3}=0.12µm^2 for three microring resonators respectively, α=0.5dBmm^{-1}, γ=0.1. The coupling coefficient of the MRR is fixed to 0.975. Here, a soliton pulse with FWHM of 25 ps is simulated.

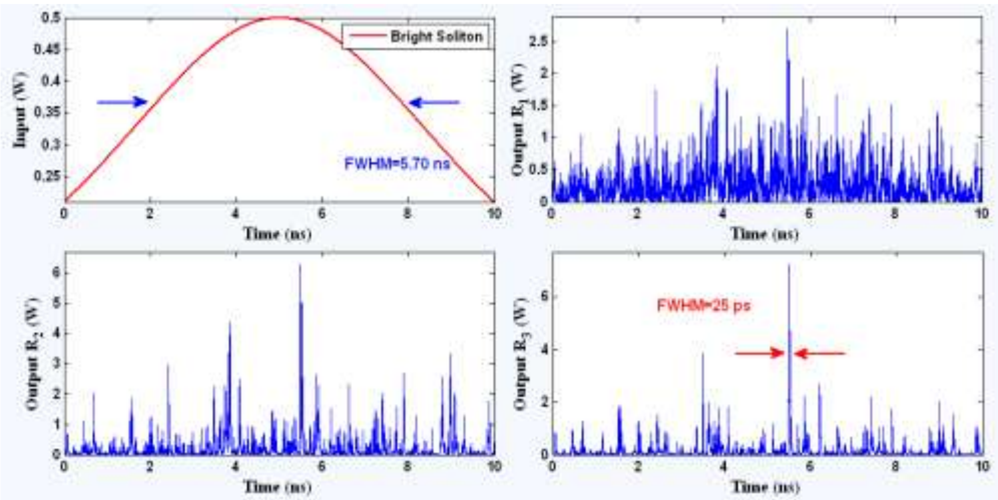

Fig. 3: Results obtained when temporal soliton with FWHM=25 ps is localized within a microring device

Each pair of the possible polarization entangled photons is formed within different time frames by using the polarization control unit as shown in Fig. 1, which they can be represented by two polarization orientation angles as [0°, 90°]. They can be formed by using the optical component called the polarization rotatable device and PBS. Here we introduce the technique that is used to generate the qubits. A polarization coupler separates the basic vertical and horizontal polarization states according to an optical switch between the short and long pulses. The following state at time t_1 is created by Eq. (4).

$$|\Phi\rangle_p = |1, H\rangle_s |1, H\rangle_i + |2, H\rangle_s |2, H\rangle_i \quad (4)$$

In the expression |k, H>, k is defined as the number of time slots, where it denotes the state of polarization. The subscripts, *s* and *i* present the signal and idler states. The two-photon state with |H> polarization shown by equation (4) is input into the orthogonal polarization-delay circuit. The delay circuit consists of a coupler and the difference between the round-trip times of the MRR is equal to Δt. The round trip of the ring can be converted into |V> at the delay circuit output. That is the delay circuits convert

$$r|k, H\rangle + t_2 \exp(i\Phi) |k+1, V\rangle + rt_2 \exp(i_2\Phi) |k+2, H\rangle + r_2t_2 \exp(i_3\Phi) |k+3, V\rangle \quad (5)$$

Where t and r is the amplitude transmittances to cross and bar ports in a coupler. Then, the polarized state is given by [92]

$$\begin{aligned} |\Phi\rangle = &[|1, H\rangle_s + \exp(i\Phi_s) |2, V\rangle_s] \times [|1, H\rangle_i + \exp(i\Phi_i) |2, V\rangle_i] \\ &+ [|2, H\rangle_s + \exp(i\Phi_s) |3, V\rangle_s \times [|2, H\rangle_i + \exp(i\Phi_i) |2, V\rangle_i] = \\ &[|1, H\rangle_s |1, H\rangle_i + \exp(i\Phi_i) |1, H\rangle_s |2, V\rangle_i] + \exp(i\Phi_s) |2, V\rangle_s |1, H\rangle_i + \\ &\exp[i(\Phi_s+\Phi_i)] |2, V\rangle_s |2, V\rangle_i + |2, H\rangle_s |2, H\rangle_i + \exp(i\Phi_i) |2, H\rangle_s |3, V\rangle_i + \\ &\exp(i\Phi_s) |3, V\rangle_s |2, H\rangle_i + \exp[i(\Phi_s+\Phi_i)] |3, V\rangle_s |3, V\rangle_i \end{aligned} \quad (6)$$

As a result, we can obtain the following polarization entangled state as

$$|\Phi\rangle = |2, H\rangle_s |2, H\rangle_i + \exp [i(\Phi_s+\Phi_i)] |2, V\rangle_s |2, V\rangle_i \quad (7)$$

A wireless router system can be used to transfer generated entangled photons via a wireless access point, and network communication system shown in Fig. 4.

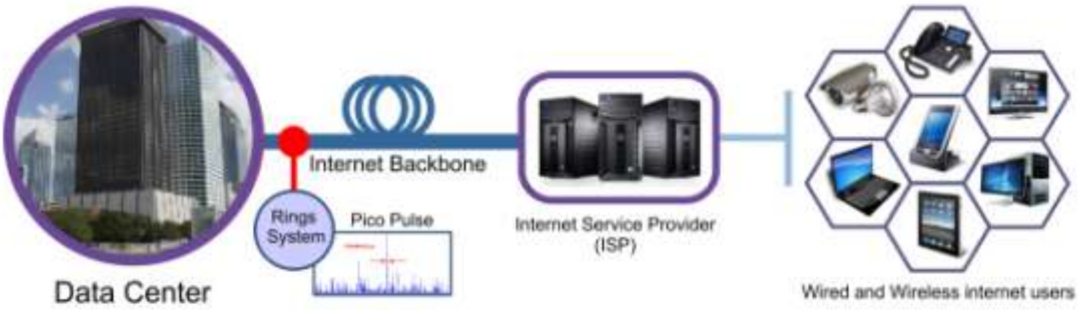

Fig.4: System of entangled photons transmission using a wireless access point system

A wireless access system transmits data to different users via wireless connection [93]. The transmission of information can be sent to the Internet using a physical, wired Ethernet connection. This method also works in reverse, when the router system used to receive information from the Internet, translating it into an analog signal and sending it to the computer's wireless adapter.

IV. CONCLUSION

An interesting concept can be presented, in which the quantum key is generated by using a remarkably simple system. Proposed system consists of a series of MRRs. Balance between dispersion and nonlinear lengths of the soliton pulse exhibit the self-phase modulation effect. Therefore, light pulse can be trapped, localized coherently within the waveguide. We have shown that a large bandwidth of the arbitrary soliton pulses can be generated and compressed within a micro waveguide. The chaotic signal generation using a soliton pulse propagating within the nonlinear MRR has been presented. A selected light pulse can be localized and used to perform the secure communication network. Localized spatial and temporal soliton pulse can used to generate entangled photon pair that provides quantum keys, applicable for communication networks. We have analyzed the entangled photon generated by chaotic signals in the series MRR devices. The classical information and security code can be formed by using the temporal and spatial soliton pulses, respectively, where the transmission of secured data can be implemented via wireless access point system used in optical communication networks.

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