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Ultra-short Multi Soliton Generation for Application in Long Distance Communication

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ABSTRACT

Generation of picometer optical soliton pulses is investigated using a nonlinear PANDA ring resonator system connecting to an add/drop filter system. The objectives of the research are to employ systems of microring resonator (MRR) to generate binary signals to be carried out along fiber optic communication. Effective parameters such as refractive indices of a silicon waveguide, coupling coefficients (κ), coupling loss, radius of the ring (R) and the input power can be selected properly to operate the nonlinear behavior. The input Gaussian laser pulses with power of 600 mW are inserted into the system. The central wavelength of the input power has been selected to λ_0=1.55 μm where the nonlinear refractive index of the medium is n_2=2.6×10^{-17} m^2 W^{-1}. Therefore binary signals generated by the add/drop filter system can be converted to secure codes where the decoding process of the transmitted codes can be obtained at the final step. Here, multi soliton pulses with full width at half maximum (FWHM) of 325 could be generated, converted to secure codes and finally detected over 70 km optical fiber communication link.

KEYWORDS:Nonlinear PANDA ring resonator; Add/drop filter system; Multi soliton generation; Binary codes; Coding and decoding.

1. INTRODUCTION

Fiber optic sensors and micro structured fibers hold great promise for integration of multiple sensing channels [1-2]. MRRs can be used with new applications in wide ranges of nano photonics integrated systems [3-6]. To generate a spectrum of light over a broad range [7], an optical soliton pulse [8-12] is recommended as a powerful laser pulse [13] that can be used to generate chaotic filter characteristics [14-16] when propagate within nonlinear MRRs [17]. Using this technique, the capacity of the transmission data [18] can be secured and increased when the chaotic packet switching is employed [19-20]. Nonlinear behavior of light inside a MRR system [21-24] takes place when a strong pulse of light [25-28] is inserted into the ring system [29-30]. Theoretical studies of such as systems have same conceptions with ring cavities [31], and Fabry–Perot system [32]. Another technique used the nonlinear behavior of light in microring resonator to generate secure coding [33-36]. A PANDA ring resonator [37-38] connecting to an add/drop filter system [39] can be used to generate binary signals which can be coded and decoded via a transmission link such as an optical fiber communication [40-41].

In this work, generation of chaotic signals in a PANDA ring resonator is presented where the easy controlling of the output chaotic signals is the benefit of using the proposed system due to the interferometric role of this system [42-43]. This paper presents the use of two properties of light, i.e. chaos behavior of the PANDA ring resonator system used to generate binary signals and the technique used for coding and decoding the transmitting signals.

2. THEORETICAL BACKGROUND

The proposed system of chaotic signal generation is known as a PANDA ring resonator (figure 1), where two input signals of Gaussian laser beam can be introduced into the system via the input and add ports [37].

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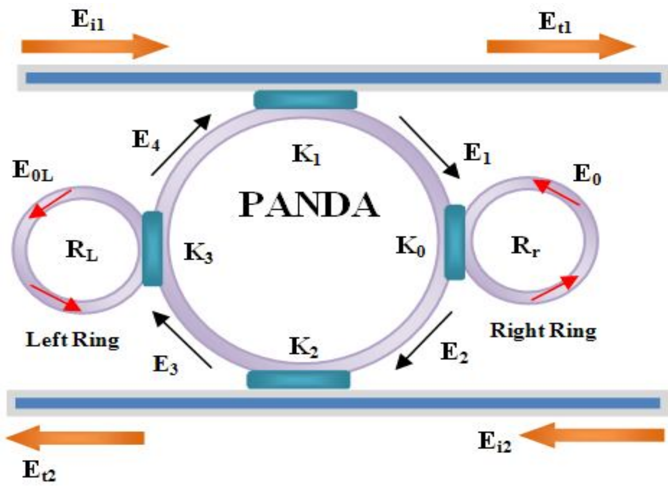

Fig. 1: Schematic diagram of a PANDA ring resonator system

The Kerr effect causes the refractive index (n) of the medium to be varied and it is given by [44]

$$n = n_0 + n_2 I = n_0 + \frac{n_2}{A_{eff}} P \tag{1}$$

with n_0 and n_2 as the linear and nonlinear refractive indexes, respectively [45-47]. I and P are the optical intensity and the power, respectively [48-50]. Here, n_0=3.34 and n_2=2.6×10^{-17} m^2 W^{-1}. The effective mode core area of the device (A_{eff}) ranges from 0.50 to 0.10 μm^2 [51-53]. Input optical fields of Gaussian pulses are given by [18]

$$E_{i1}(t) = E_{i2}(t) = E_0 \exp\left[(\frac{z}{2L_D}) - i\omega_0 t \right], \tag{2}$$

E_0 and z are the amplitude of optical field and propagation distance respectively [54-55]. L_D is the dispersion length where, frequency shift of the signal is ω_0 [56-58]. The electric field of the right ring of the PANDA system is given by [59]:

$$E_0 = (E_1\sqrt{1-\gamma}) \times \frac{\sqrt{1-\kappa_0} - \sqrt{1-\gamma}\, e^{-\frac{\alpha}{2}L_1 - jk_n L_1}}{1-\sqrt{(1-\gamma)(1-\kappa_0)}\, e^{-\frac{\alpha}{2}L_1 - jk_n L_1}}. \tag{3}$$

κ is the intensity coupling coefficient [60-61], k=2π/λ is the wave propagation [62-63], γ is the fractional coupler intensity loss [64-65], $L_1 = 2\pi R_r$, $R_r = 180nm$ is the radius of right ring. The electric field of the left ring of the PANDA system is given as [66-67]:

$$E_{0L} = (E_3\sqrt{1-\gamma_3}) \frac{\sqrt{1-\kappa_3} - \sqrt{1-\gamma_3}\, e^{-\frac{\alpha}{2}L_2 - jk_n L_2}}{1-\sqrt{1-\gamma_3}\sqrt{1-\kappa_3}\, e^{-\frac{\alpha}{2}L_2 - jk_n L_2}}, \tag{4}$$

Here, $L_2 = 2\pi R_L$ and $R_L = 200nm$ is the radius of left ring. We define the parameters of x_1, x_2, y_1 and y_2 as: $x_1 = (1-\gamma_1)^{\frac{1}{2}}$, $x_2 = (1-\gamma_2)^{\frac{1}{2}}$, $y_1 = (1-\kappa_1)^{\frac{1}{2}}$, and $y_2 = (1-\kappa_2)^{\frac{1}{2}}$, thus the interior signals can be expressed by [68-69],

$$E_1 = \frac{jx_1\left[\sqrt{\kappa_1}E_{i1} + x_2 y_1 \sqrt{\kappa_2} E_{0L} E_{i2} e^{-\frac{\alpha L}{4} - jk_n \frac{L}{2}} \right]}{1 - x_1 x_2 y_1 y_2 E_0 E_{0L} e^{-\frac{\alpha}{2}L - jk_n L}}, \tag{5}$$

$$E_2 = E_0 E_1 e^{-\frac{\alpha L}{4} - jk_n \frac{L}{2}},$$

$$E_3 = x_2\left[y_2 E_0 E_1 e^{-\frac{\alpha L}{4} - jk_n \frac{L}{2}} + j\sqrt{\kappa_2}E_{i2} \right], \tag{6}$$

$$E_4 = x_2 E_{0L} e^{-\frac{\alpha L}{4} - jk_n \frac{L}{2}} \left[y_2 E_0 E_1 e^{-\frac{\alpha L}{4} - jk_n \frac{L}{2}} + j\sqrt{\kappa_2}E_{i2} \right]. \tag{7}$$

L=100μm is the circumference of the centered ring resonator. Output electric fields of the PANDA system given by E_{t1} and E_{t2} are expressed as [70-71]:

$$E_{t1} = AE_{i1} - \frac{G^2 BE_{i2} e^{-\frac{\alpha L}{4} - jk_n \frac{L}{2}}}{1 - FG^2}\left[CE_{i1} + DE_{i2}G\right], \quad (8)$$

$$E_{t2} = \frac{G\, x_2 y_2 E_{i2}\sqrt{\kappa_1\kappa_2}}{1 - FG^2}\left[AE_0 E_{i1} + \frac{D}{x_1\kappa_1\sqrt{\kappa_2}E_{0L}} E_{i2}G\right], \quad (9)$$

where, $A = x_1 x_2$, $B = x_1 x_2 y_2 \sqrt{\kappa_1} E_{0L}$, $C = x_1^{\,2} x_2 \kappa_1 \sqrt{\kappa_2} E_0 E_{0L}$, $G = \left(e^{-\frac{\alpha L}{4} - jk_n \frac{L}{2}}\right)$, $D = (x_1 x_2)^2 y_1 y_2 \sqrt{\kappa_1\kappa_2} E_0 E_{0L}^{\ 2}$ and

$F = x_1 x_2 y_1 y_2 E_0 E_{0L}$.

Therefore, E_{t1} output signals from the PANDA system is inserted into the add-drop filter device [72-74] with proper parameters shown in figure 2.

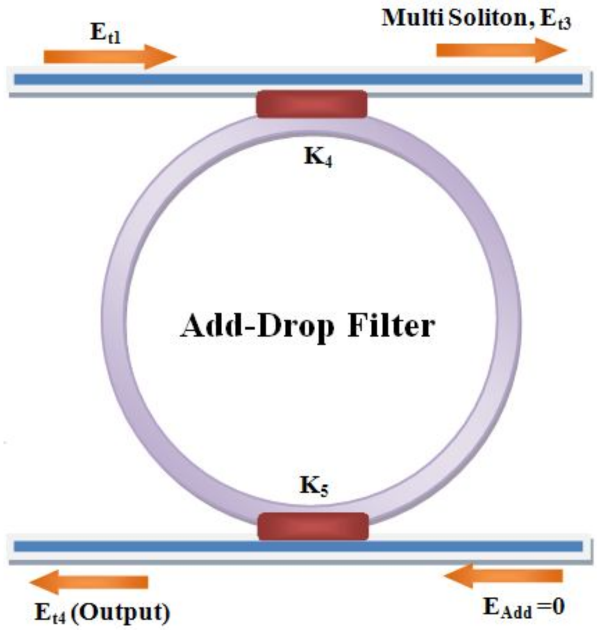

Fig (2): Add/drop filter system

The normalized output powers of the system can be expressed by [75]:

$$\frac{I_{t3}}{I_{t1}} = \left|\frac{E_{t3}}{E_{t1}}\right|^2 = \frac{1 - \kappa_4 - 2\sqrt{1-\kappa_4}\sqrt{1-\kappa_5}\, e^{\frac{-\alpha}{2}L_{ad}} \cos(k_n L_{ad}) + (1-\kappa_5)e^{-\alpha L_{ad}}}{1 + (1-\kappa_4)(1-\kappa_5)e^{-\alpha L_{ad}} - 2\sqrt{1-\kappa_4}\sqrt{1-\kappa_5}\, e^{\frac{-\alpha}{2}L_{ad}} \cos(k_n L_{ad})}, \quad (10)$$

$$\frac{I_{t4}}{I_{t1}} = \left|\frac{E_{t4}}{E_{t1}}\right|^2 = \frac{\kappa_4 . \kappa_5 e^{\frac{-\alpha}{2}L_{ad}}}{1 + (1-\kappa_4)(1-\kappa_5)e^{-\alpha L_{ad}} - 2\sqrt{1-\kappa_4}\sqrt{1-\kappa_5}\, e^{\frac{-\alpha}{2}L_{ad}} \cos(k_n L_{ad})}. \quad (11)$$

$L_{ad} = 2\pi R_{ad}$ and R_{ad} =130μm is the radius of the add/drop filter system. The nonlinear equations of the output powers can be simulated in which the multi soliton can be generated. The results of the multi soliton pulses are obtained by simulating the presented nonlinear equations into MATLAB codes applied for the PANDA and add/drop filter systems. Therefore the multi soliton pulses are inserted into the coding and decoding system where the simulated results of the system are obtained using the optical communication system design or optisystem software. We use the optisystem software to design the fiber optic communications system and the simulation results are presented, which can enhance the understanding of each component of the fiber optic communications system, where its function provides guidance in the real experimental design.

3. SIMULATION RESULTS

The coupling coefficients of the PANDA ring resonator are given as κ_0=0.2, κ_1=0.35, κ_2=0.1 and κ_3=0.95, where α=0.5 dB mm^{-1}, γ=0.1 and the input Gaussian beam has a power of 600 mW. Amplification of signals occurs during the propagation of light inside right and left rings shown in figure 3. Soliton are stable and seen within the system where the chaotic signals are generated at the through and drop ports of this system**.**

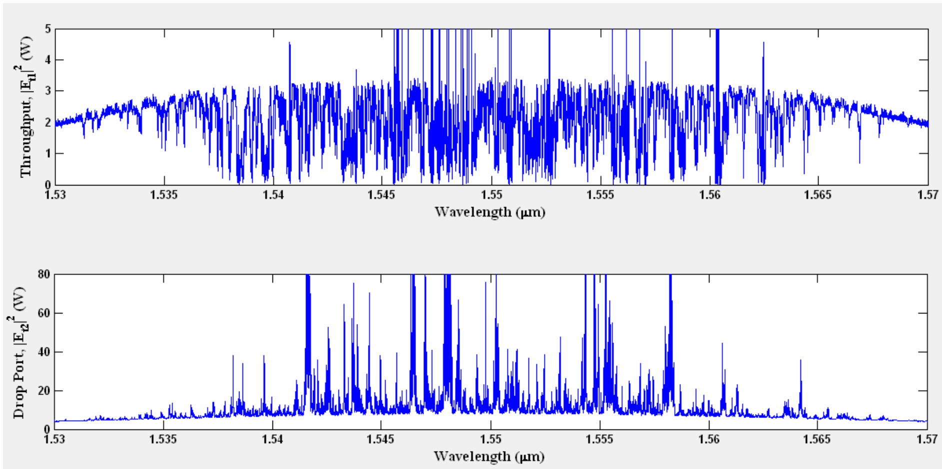

Fig. 3: Chaotic signal generation using the PANDA ring resonator system

The chaotic signals from the PANDA ring resonator are input into the add/drop filter system. The multi soliton signals are generated and can be used to produce binary signals while the improvement of the capacity of the system can be obtained and used for long distance fiber communication. Figure 4 shows generated multi soliton signals in the form of bright and dark soliton, where the radius of the add/drop filter system has been selected to 130 µm and κ_4=κ_5=0.5. Here, the ultra-short dark and bright soliton pulses with FWHM=325 pm are generated.

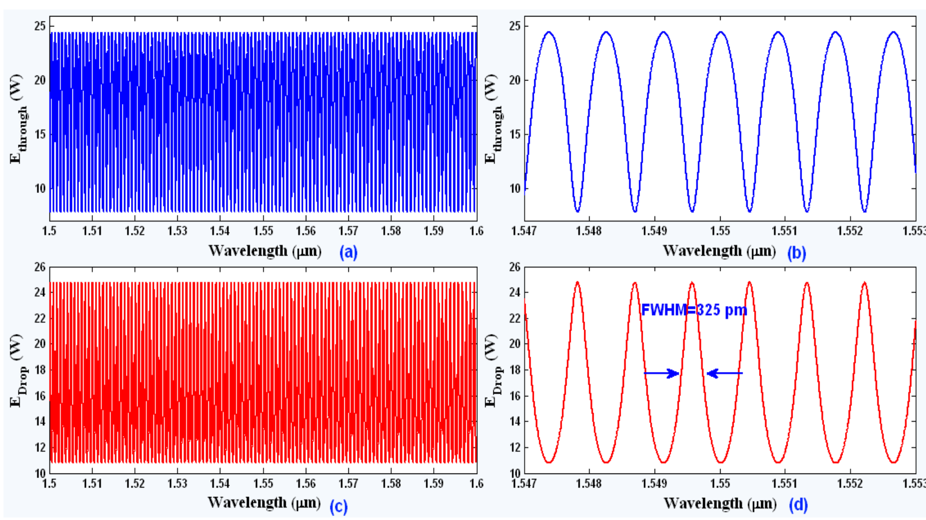

Fig. 4: Multi soliton generation using an Add/drop filter system, where (a): multi dark soliton, (b): expanded of the dark soliton pulses, (c): multi bright soliton, (d): expanded of the bright soliton pulses with FWHM=325 pm.

The potential of soliton bands [76-78] can be generated and used for many applications such as security transmission [79-81] and coding-decoding telecommunication [82-83]. Moreover, high capacity of data [84-85] can be performed by using more wavelength carriers, whereas the sensitivity of the microring resonator systems can be improved by decreasing of the FWHM applicable for laser sensing systems [86-88].The system of coding and decoding of the transmitting signals is shown in figure 5.

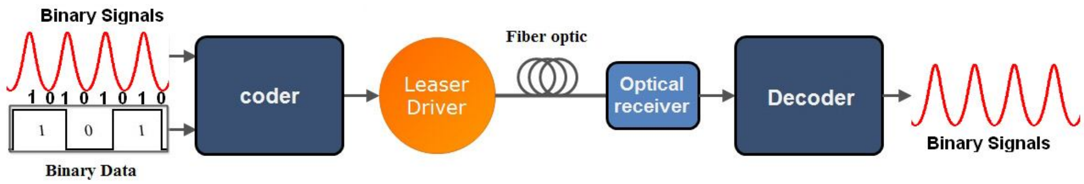

Fig. 5: System of coding and decoding of binary signals

Thus, generated binary signals from the add/drop filter system can be input into the coding and decoding system. Therefore, signals in the form of secured codes propagate inside the optical fiber communication and finally can be received, detected and decoded to original signals by the users. Figure 6 shows the forms of transmitting signals in the communication system.

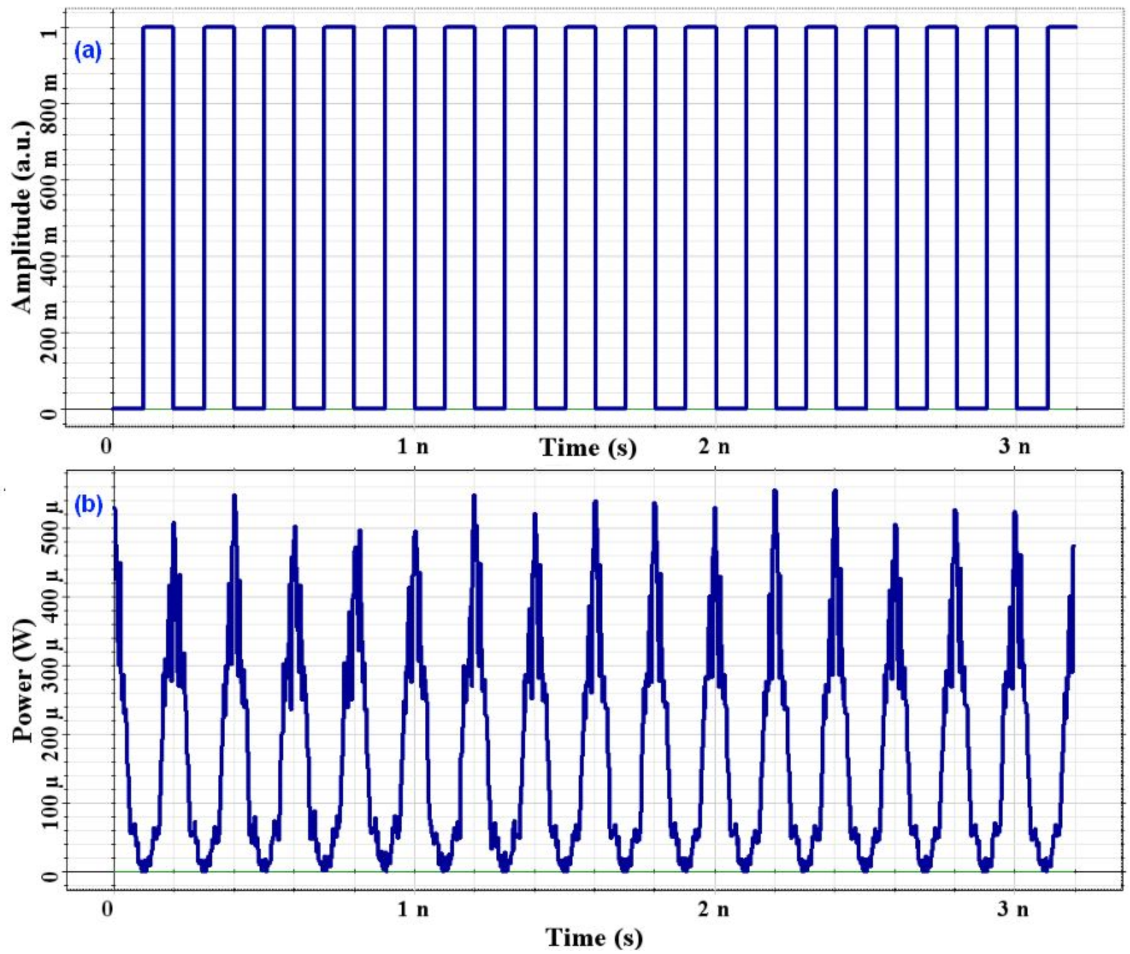

Fig. 6: Generation of transmitting signals where (a): Input binary codes, (b): Converted signals to transmit signals

The results of the transmitted and detected signals can be seen from figure 7 where the figure 7(a) shows the eye diagram of the detected signals. The decoding of the transmitted signals can be obtained after the signals were received using suitable optical receiver thus detection and decoding process can be performed via the coding and decoding system. The original signals can be recovered shown in figure 7(b).

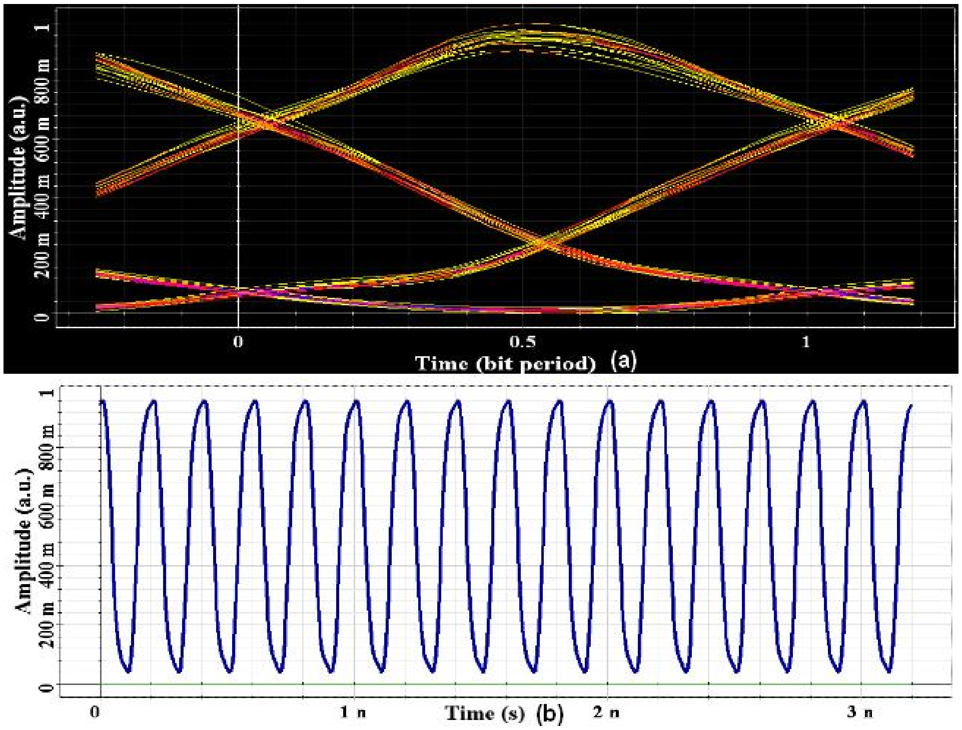

Fig. 7: Received and detected signals where (a): eye diagram, (b): decoded and recovered signals over 70 km fiber optics

Thus, localized wavelength can be used to generate variable codes. In this concept, we assume that the decoding of the transmitted signals can be performed by using the proposed arrangement. Optical codes via localized multi soliton can be connected into a fiber network communication system, therefore transmission of data along fiber optic is performed. The security scheme of the transmission can be obtained by coding and decoding of the optical soliton pulses.

4.0 CONCLUSION

In conclusion, the PANDA is presented as optical chaos. The Gaussian beams with center wavelength of 1.55 μm, are inserted into the PANDA system which are good to generate a high capacity of chaotic signals. Traveling of light inside the proposed ring system is analyzed using suitable parameters of the system. Transmission of signals can be implemented via a coding and decoding method where the coded signals of binary form can be converted to secure codes to be transmitted along long distance fiber optics. Here the binary signals of bright soliton pulses with FHWM=325 pm generated from the add/drop filter system are multiplexed with binary codes generating secured codes where the decoding of signals can be obtained at the end of the transmission link. Here the length of the transmission link has been selected for 70 km where the original signals could be retrieved.

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