Chaotic Signal Generation and Trapping Using an Optical Transmission Link

S. E. Alavi [1], I. S. Amiri [*2], S. M. Idrus [1], ASM. Supa'at [1], J. Ali [2]

[1] Lightwave Communication Research Group, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia

[2] Institute of Advanced Photonics Science, Nanotechnology Research Alliance, Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Malaysia

*isafiz@yahoo.com

Abstract: Chaotic soliton can be generated using a nonlinear PANDA system. The research uses microring resonator (MRR) to generate and trap chaotic signals along fiber optic communication. The 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 0.45 W 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 $n_2=1.3\times10^{-17}$ m^2 W^{-1}. The generated chaotic signals with Full at Half Maximum of 24 pm can be transmitted along the fiber optic with length of 195 km. The trapping of chaotic signals can be obtained at the end of the transmission link. Here signals with 600 fm bandwidth could be trapped within the system.

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1. Introduction

The concepts and techniques on chaotic signal trapping (Afroozeh *et al.* 2010a; Ali *et al.* 2010o) within a fiber optic system is presented. Amiri *et al.* demonstrates optically trapping of microparticles on silicon (MRRs (Ali *et al.* 2010p; Amiri *et al.* 2010c; Ali *et al.* 2010j). The techniques of light trapping is reported in both theory and experiment, respectively (Amiri *et al.* 2012d; Amiri *et al.* 2013e; Amiri and Ali 2013g; Afroozeh *et al.* 2012c; Suwanpayak *et al.* 2010). A PANDA system can be used to generate chaotic signals (Gifany *et al.* 2013; Kouhnavard *et al.* 2010c; Amiri *et al.* 2011a). These resonators hold great promise for use as optical switching systems (Amiri and Ali 2013b; Kouhnavard *et al.* 2010a; I. S. Amiri *et al.* 2013c; Ali *et al.* 2010r). To generate a spectrum of light over a broad range , an optical Gaussian pulse is recommended (Afroozeh *et al.* 2012a; Jalil *et al.* 2010; Amiri *et al.* 2012a). Using this technique, the transmission data can be secured using chaotic signals (Afroozeh *et al.* 2010d; Amiri *et al.* 2012i; Nikoukar *et al.* 2010-2011). Recently, the use of a chaotic signals within a MRR system for the trapping application has been studied (Bahadoran *et al.* 2011; Amiri *et al.* 2012k; Nikoukar *et al.* 2013; Shahidinejad *et al.* 2012). Exciting new technological progress in the field of tunable narrow band laser systems (Ali *et al.* 2010m; Ali *et al.* 2010f; Ali *et al.* 2010a), optical trapping and storing (I. S. Amiri *et al.* 2013a; Afroozeh *et al.* 2010b; Amiri *et al.* 2010b) and the MRR interferometers (I. S. Amiri *et al.* ; I. S. Amiri and J. Ali ; A. Nikoukar *et al.* 2013), provide the new transmission techniques. The multi-soliton generation is the advantage for the MRRs (Ali *et al.* 2010h; Ali *et al.* 2010l; I. S. Amiri *et al.* 2014). The soliton pulses are so stable that its shape and velocity is preserved while travelling along the medium (Ali *et al.* 2010c; I. S. Amiri *et al.* ; Ali *et al.* 2010q). The quantum memory generation, quantum theory is necessary for the description of the light trapping behaviours (Jalil *et al.* 2011; Teeka *et al.* 2011; Amiri *et al.* 2012l; Imran *et al.* 2010).

2. Theoretical Background

The proposed system of chaotic signal generation is known as a PANDA system (Figure 1), where two input signals of Gaussian laser beam can be introduced into the system via the input and add ports (Amiri *et al.* 2013b; Amiri *et al.* 2013c; Amiri *et al.* 2012f; Amiri *et al.* 2012m).

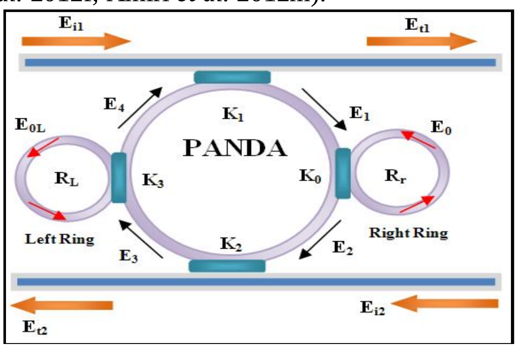

Fig. 1: Schematic diagram of a PANDA system

The refractive index (n) of the medium is given by (Tanaram *et al.* 2011; Amiri *et al.* 2012e; Shojaei and Amiri 2011a; Afroozeh *et al.* 2012b)

$$n = n_0 + n_2 I = n_0 + \frac{n_2}{A_{eff}} P \quad (1)$$

with n_0 and n_2 as the linear and nonlinear refractive indexes, respectively (Amiri *et al.* 2012n; Yupapin *et al.* 2010). I and P are the optical intensity and the power, respectively (Afroozeh *et al.* 2011b; Kouhnavard *et al.* 2010b). Here, n_0=3.34 and n_2=1.3×10^{-17} m^2 W^{-1}. The effective mode core area of the device (A_{eff}) ranges from 0.50 to 0.10 μm^2. Input optical fields of Gaussian pulses are given by (Amiri *et al.* 2011d; Afroozeh *et al.* 2011a; Shojaei and Amiri 2011b)

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

E_0 and z are the amplitude of optical field and propagation distance respectively (Amiri and Ali 2013a; I. S. Amiri and J. Ali 2013a; Amiri *et al.* 2012b). L_D is the dispersion length (Amiri *et al.* 2012h; Amiri *et al.* 2011b) where, frequency shift of the signal is ω_0 (Amiri *et al.* 2013a; Ali Shahidinejad *et al.* 2013; I. S. Amiri and J. Ali 2013b; Amiri and Ali 2013e). The electric field of the right ring of the PANDA system is given by (Amiri *et al.* 2012o; Amiri *et al.* 2012p):

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

κ is the intensity coupling coefficient (Amiri and Ali 2012; Amiri *et al.* 2013f; Amiri and Ali 2013d, f), k=2π/λ is the wave propagation (Amiri *et al.* 2010a; Nikoukar *et al.* 2012; A. Shahidinejad *et al.* 2013), γ is the fractional coupler intensity loss (Sadegh Amiri *et al.* 2013; Amiri *et al.* 2013d; Amiri and Ali 2013c), $L_1 = 2\pi R_r$, R_r is the radius of right ring (Amiri *et al.* 2012c; Amiri *et al.* 2011c; Afroozeh *et al.* 2012d; Afroozeh *et al.* 2010c). The electric field of the left ring of the PANDA system is given as (Amiri *et al.* 2012j):

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

Here, $L_2 = 2\pi R_L$ and R_L 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 (Ali *et al.* 2010n; I. S. Amiri *et al.* 2013b; Ali *et al.* 2010i; I. S. Amiri and J. Ali 2014; Ali *et al.* 2010e; Ali *et al.* 2010g; I. S. Amiri and J. Ali ; Ali *et al.* 2010k),

$$E_1 = \frac{jx_1\left[\sqrt{\kappa_1}E_{i1} + x_2 y_1\sqrt{\kappa_2}E_{0L}E_{i2}e^{-\frac{\alpha L}{4} - jk_n\frac{L}{2}}\right]}{1 - x_1x_2y_1y_2E_0E_{0L}e^{-\frac{\alpha}{2}L - jk_n L}}, \quad (5)$$

$$E_2 = E_0 E_1 e^{-\frac{\alpha L}{4} - jk_n\frac{L}{2}}, \quad (6)$$

$$E_3 = x_2\left[y_2 E_0 E_1 e^{-\frac{\alpha L}{4} - jk_n\frac{L}{2}} + j\sqrt{\kappa_2}E_{i2}\right], \quad (7)$$

$$E_4 = x_2 E_{0L} e^{-\frac{\alpha L}{4} - jk_n\frac{L}{2}}\left[y_2 E_0 E_1 e^{-\frac{\alpha L}{4} - jk_n\frac{L}{2}} + j\sqrt{\kappa_2}E_{i2}\right]. \quad (8)$$

L 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 (Amiri *et al.* 2012g; I. S. Amiri and Ali 2013; Amiri *et al.* 2010-2011):

$$E_{t1} = AE_{i1} - \frac{G^2 BE_{i2}e^{-\frac{\alpha L}{4} - jk_n\frac{L}{2}}}{1-FG^2}[CE_{i1} + DE_{i2}G], \quad (9)$$

$$E_{t2} = \frac{G\, x_2 y_2 E_{i2}\sqrt{\kappa_1\kappa_2}}{1-FG^2}\left[AE_0E_{i1} + \frac{D}{x_1\kappa_1\sqrt{\kappa_2}E_{0L}}E_{i2}G\right], \quad (10)$$

where, $A = x_1x_2$, $B = x_1x_2y_2\sqrt{\kappa_1}E_{0L}$, $C = x_1^2 x_2\kappa_1\sqrt{\kappa_2}E_0E_{0L}$, $G = e^{(-\frac{\alpha L}{4} - jk_n\frac{L}{2})}$, $D = (x_1x_2)^2 y_1y_2\sqrt{\kappa_1\kappa_2}E_0E_{0L}^2$ and $F = x_1x_2y_1y_2E_0E_{0L}$.

3. Result And Discussion

The input pulses of the Gaussian pulse with power of 0.45 W are inserted into the PANDA system. The results of the chaotic signal are shown in Figure 2. The centered ring of the PANDA system has a radius of 100 μm, where the radii of the rings on the right and left sides are the same as 7 μm. The coupling coefficients are selected to, $K_1 = 0.7$, $K_2 = 0.2$, $K_0 = 0.01$ and $K_3 = 0.85$. The nonlinear refractive index is $n_2 = 1.3\times10^{-17} m^2 W^{-1}$. The signals on the right side of the PANDA system are shown in Figure 2(a-b) where the Figure 2(c-d) shows the signals on the left side of the system.

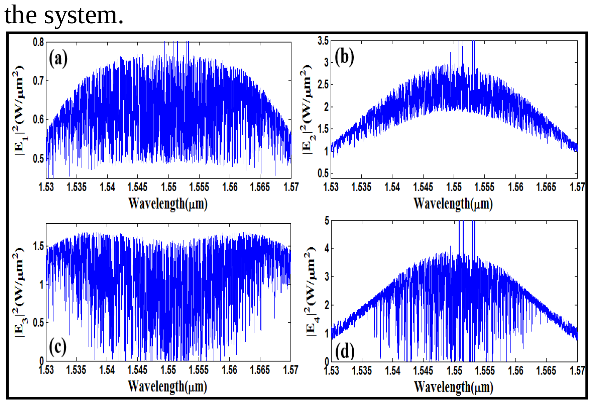

Fig. 2: Chaotic signals generated by the PANDA system, where (a): $|E_1|^2$(b): $|E_2|^2$, (c): $|E_3|^2$ and (d): $|E_4|^2$

More channel capacity can be The stable signals of the chaotic signals can be seen within the through port of the system shown in Figure 3.

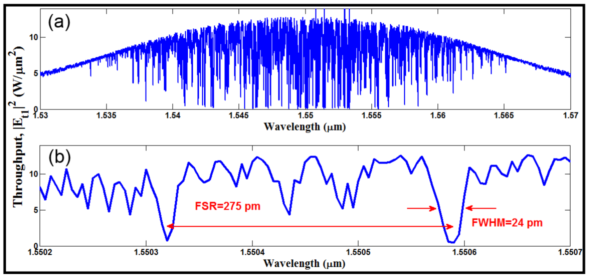

Fig. 3: Chaotic signal generation using the system where (a): Throughput chaotic signals and (b): Expansion of the Throughput chaotic signals

The potential of chaotic bands can be used for many applications such as optical trapping and coding-decoding telecommunication (Ali *et al.* 2010b; Ali *et al.* 2010d; I. S. Amiri and J. Ali ; Saktioto *et al.* 2010). The chaotic signals pass into the transmission link to perform the optical trapping using the transmission link shown in Figure 4.

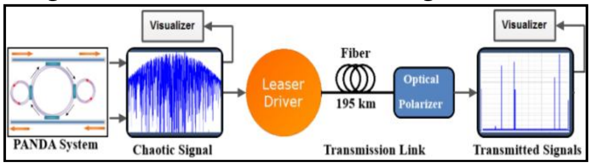

Fig. 4: System of fiber optic transmission link

In Figure 4, the fiber optic has a length of 195 km, attenuation of 0.4 dB/km, dispersion of 1.67 ps/nm/km, the differential group delay of 0.2 ps/km, the nonlinear refractive index of 2.6 $\times 10^{-20}$ m^2/W, effective area of 62.8 μm^2 and the nonlinear phase shift of 3 *mrad*. Figure 5 shows the trapping of chaotic signals in the communication system.

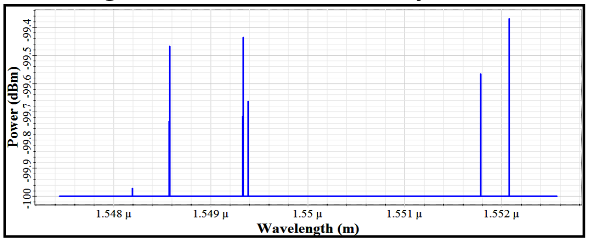

Fig. 5: Trapping of chaotic signals

The trapping of signals can be obtained after the signals were transmitted along the fiber optic and finally received by suitable optical receiver. The FWHM and FSR of the trapped signals are as 600 fm and 45 pm shown in Figure 6.

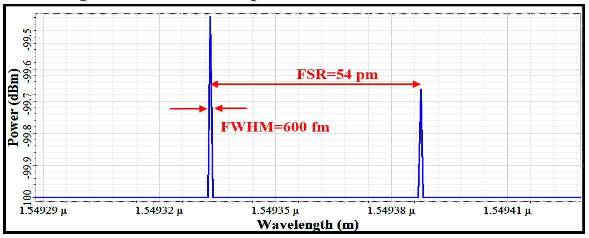

Fig. 6: Transmitted chaotic signals with FWHM and FSR of 600 fm and 54 pm respectively

Therefore, trapping of chaotic signals along the fiber optic is performed.

4. Conclusion

In conclusion, the PANDA system is used as optical chaos. The Gaussian beams with center wavelength of 1.55 μm, are inserted into the system to generate a high capacity of chaotic signals. Transmission of chaotic signals can be obtained via a fiber optic communication link with the length of 195 km, where trapping of the signals is performed. Here the trapped signals with FHWM=600 fm is generated.

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CORRESPONDING AUTHOR:
DR. I. S. AMIRI
DEPARTMENT OF PHYSICS
INSTITUTE OF ADVANCED PHOTONICS SCIENCE,
NANOTECHNOLOGY RESEARCH ALLIANCE,
UNIVERSITI TEKNOLOGI MALAYSIA (UTM), 81310
JOHOR BAHRU, MALAYSIA
E-MAIL: ISAFIZ@YAHOO.COM

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