Single Soliton Bandwidth Generation and Manipulation by Microring Resonator

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Abstract. In this paper, we propose a system for chaotic signal generation using a microring resonator (MRR) fiber optic system. This system uses a regular laserdiode as input power and can be incorporated with an optical add/drop filter system. When light from the laser diode feedbacks to the fiber ring resonator, the actual chaotic signal is produced by using the appropriate fiber ring resonator parameters and also the laser diode input power. The filtering process of the chaotic signals occurs during the round-trip of the pulse within the ring resonators. The single soliton pulses generation and bandwidth manipulation of the pulse can be performed using the add/drop system. Results obtained have established particular possibilities from the application. The obtained results show the effects of coupling coefficients on the bandwidth of the single soliton pulse, where the chaotic behaviors of the input pulses are presented.

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1. Introduction

Nonlinear behaviors associated with light traveling inside a fiber optic ring resonator can be caused by the effects such as the Kerr effects, four-wave mixing, as well as the external nonlinear pumping electrical power (Amiri and Ali 2013a; Shahidinejad *et al.* 2012; Amiri *et al.* 2011b). This sort of nonlinear behaviors usually are called chaos, bistability, in addition to bifurcation (S. E. Alavi *et al.* 2013a; Amiri *et al.* 2012c; Amiri and Ali 2014a). Additional information regarding these kinds of behaviors in a micro ring resonator evidently are defined by Amiri *et al* (Ridha *et al.* 2010a; Amiri *et al.* 2013e; I. S. Amiri and J. Ali 2014d; Suwanpayak *et al.* 2010) Nonetheless, aside from the penalties of the nonlinear behaviors of light traveling within the fiber ring resonator, there are several benefits that can be employed by the communication methods in order to examine the obtained result (Bahadoran *et al.* 2011; I. S. Amiri *et al.* ; Amiri *et al.* 2013d; I. S. Amiri *et al.* 2014b). One called chaotic behavior which has been employed to make the benefit within digital or optical communications (Amiri *et al.* 2012e; Shojaei and Amiri 2011a; I. S. Amiri *et al.* 2013e; Afroozeh *et al.* 2011a). The ability of chaotic carriers to synchronize in a communication system is valid (Amiri *et al.* 2012g; Amiri and Ali 2013b; Amiri *et al.* 2012n; Nikoukar *et al.* 2012). Recently, Amiri *et al.* have reported the successful experimental research based on generating and transmission of chaotic signals using an optical fiber communication link (I. S. Amiri *et al.* ; I. S. Amiri *et al.* 2013a; I. S. Amiri *et al.* 2013f; I. S. Amiri and J. Ali 2014c; I. S. Amiri *et al.* 2013g). In this paper, we propose a system for chaotic signal generation and cancellation using a microring resonator (MRR) fiber optic system, where the required signals of single bandwidth soliton pulse are recovered and manipulated using an add/drop system. Results show particular possibilities with this application. Also, effects of coupling coefficients on the bandwidth of the single soliton pulse are investigated here.

2. Chaotic Signal Generation

An add/drop ring resonator configuration connected to a single ring resonator depicted in Figure 1, is constructed by the fiber optic using optical couplers, where the circumference of the fiber ring is L . Here, the input pulse to the ring resonator is given by $E_{in}(t)$, where the output signal is expressed by $E_{out}(t)$.

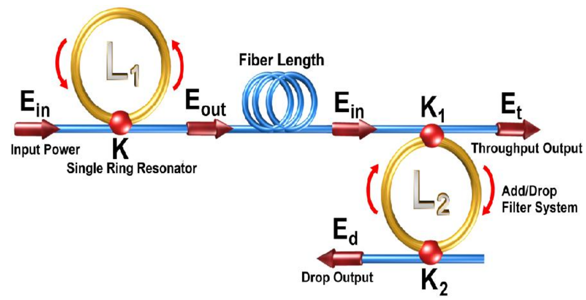

Fig. 1: A fiber optic ring resonator is constructed to an add/drop filter system by the couplers

The input light is monochromatic laser pulse with constant amplitude and random phase modulation, which results in temporal coherence degradation. It can be expressed as (Mohamad *et al.* 2010b; Amiri *et al.* 2011d; Amiri *et al.* 2012a; Afroozeh *et al.* 2010c)

$$E_{in}(t) = E_0 \exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t \right] \quad (1)$$

E_0 and z are the amplitude of optical field and propagation distance respectively (Amiri *et al.* 2012k; Nikoukar *et al.* 2013; Afroozeh *et al.* 2010b). L_D is the dispersion length of the soliton pulse where, frequency shift of the signal is ω_0 (I. S. Amiri and Ali 2013; Shojaei and Amiri 2011b; Amiri *et al.* 2012m). When a soliton pulse is input and propagated within a micro ring resonator as shown in Figure 1, the normalized output of the light field is defined as the ratio between the output and input fields $E_{out}(t)$ and $E_{in}(t)$ respectively in each round-trip and it can be expressed as (I. S. Amiri and J. Ali 2014b; Amiri *et al.* 2012j; Amiri *et al.* 2012l; Kouhnavard *et al.* 2010c; Kouhnavard *et al.* 2010b),

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

This system is very similar to a Fabry-Perot cavity (Tanaram *et al.* 2011; I. S. Amiri and J. Ali 2014a; Amiri *et al.* 2012p), which has an input and output mirror with a field reflectivity, (1-κ), and a fully reflecting mirror. κ is the coupling coefficient (Amiri *et al.* 2013a; Amiri *et al.* 2010-2011), and $x = \exp(-\alpha L/2)$ represents a round-trip loss coefficient (Amiri *et al.* 2012i; Amiri *et al.* 2012b; Amiri *et al.* 2012f; Amiri *et al.* 2010c), $\phi = \phi_0 + \phi_{NL}$, where $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2 |E_{in}|^2$ are the linear and nonlinear phase shifts (Amiri and Ali 2012; I. S. Amiri and J. Ali ; I. S. Amiri *et al.* 2013b; Afroozeh *et al.* 2012c), $k = 2\pi/\lambda$ is the wave propagation number in a vacuum (Sadegh Amiri *et al.* 2013; I. S. Amiri *et al.* 2014c; Nikoukar *et al.* 2010-2011; Ridha *et al.* 2010b). Here, L and α are a waveguide length and linear absorption coefficient, respectively (Gifany *et al.* 2013; Kouhnavard *et al.* 2010a; Amiri and Ali 2013e; Amiri *et al.* 2010b). The used parameters are shown in Table 1.

Table 1: Parameters of the system

Parameters	Value
R_1 = radius of the ring	15μm
κ = coupling coefficient of the ring	0.0225
R_{ad} = Add/drop MRR system, radius	15μm
κ_1 = coupling coefficient of the add/drop	0.01
κ_2 = coupling coefficient of the add/drop	0.01
λ_0 = central wavelengths of the Gaussian laser input	1.55μm
A_{eff} = effective mode core area	0.30μm^2
α=waveguide (ring resonator) loss	0.02 dB km^{-1}
γ=fractional coupler intensity loss	0.01
n_0=linear refractive index	3.34 (InGaAsP/InP)
n_2=nonlinear refractive index	3.8×10^{-20} m^2/W

The nonlinear behaviors of the fiber optic ring resonator in 20,000 round-trips inside the optical fiber ring resonator was described by Amiri *et al* (Amiri *et al.* 2012d; Amiri and Ali 2013c, 2014c; Afroozeh *et al.* 2012b). In Figure 2, the input power is maximized to1W, where the output power is varied directly with the input power. The output electrical power will be reduced as well as improved beyond the particular input electrical power abruptly, giving the particular output power having a couple values named the bistability characteristics, that is certainly switched-on and switched-off. The output powers at the round-trips 5750 times has shown the characteristics called "bifurcation". At this point, the abrupt change within the input electrical power provides output electrical power along with a pair of values. This is known as the optical bistability, the spot that the optical power switched-on/off happen. The bifurcation behavior occurs ahead of the chaotic signal. The chaotic signal can be generated and controlled by varying the coupling coefficients, where the required output power is obtained (Jalil *et al.* 2011; Ali Shahidinejad *et al.* 2014; P. Sanati *et al.* 2013; Jalil *et al.* 2010).

Figure 2 shows the chaotic signals generation for variety of coupling coefficients, where Figure 2(a-b) shows the output signals of the single ring resonator in terms of round-trips and input power. Figure 2(c-e) show the output signals for different coupling coefficients of κ =0.2, 0.6 and 0.9 respectively. Within practical applications, the input power is required to become lower as a result of available industrial laser diodes. As a result, a micro ring resonator could present the actual chaotic behavior using reduced input electric power, that's suited to assistant carry out to the communication system as well as device manufacture.

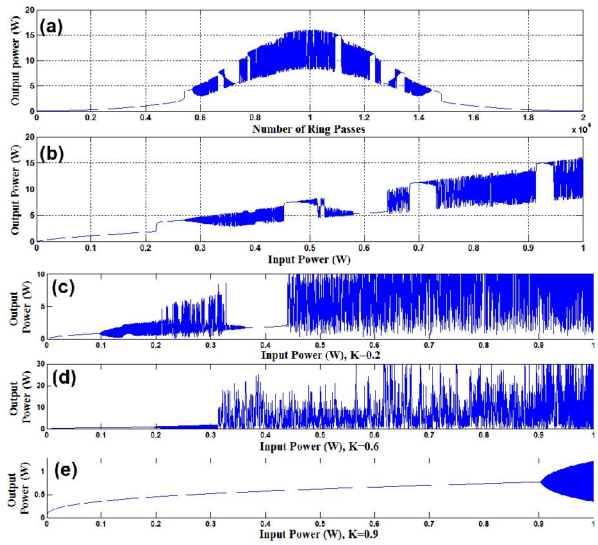

Fig. 2: The chaotic signal generation withinthe single ring resonator

3. Single Soliton Generation

To recover the pulses from the chaotic noises in the fiber ring resonator, the use of an add/drop filter system with the appropriate parameters is recommended (Teeka *et al.* 2011; Amiri *et al.* 2011c; I. S. Amiri *et al.* 2013c; I. S. Amiri *et al.* 2013d). The two optical output signals of the add/drop filter can be depicted by Equations (3) and (4) (Afroozeh *et al.* 2010a; Amiri *et al.* 2012o; S. E. Alavi *et al.* 2013b; Amiri *et al.* 2012h), where $k = 2\pi / \lambda$ is the vacuum wave number (Amiri and Ali 2014b; Mohamad *et al.* 2010a; Amiri *et al.* 2013b; Amiri *et al.* 2011a), and the circumference of the fiber ring is $L = 2\pi R_{ad}$, where R_{ad} is the radius of the ring (Afroozeh *et al.* 2012a; Afroozeh *et al.* 2012d; I. S. Amiri *et al.* 2014a; Amiri *et al.* 2013c).

$$\left|\frac{E_t}{E_{in}}\right|^2 = \frac{(1-\kappa_1) - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}\,e^{-\frac{\alpha}{2}L}\cos(k_n L) + (1-\kappa_2)e^{-\alpha L}}{1+(1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}\,e^{-\frac{\alpha}{2}L}\cos(k_n L)} \quad (3)$$

The drop port output signals can be given by (Afroozeh *et al.* 2010d; Afroozeh *et al.* 2011b; Amiri and Ali 2013d; A. Shahidinejad *et al.* 2014).

$$\left|\frac{E_d}{E_{in}}\right|^2 = \frac{\kappa_1\kappa_2 e^{-\frac{\alpha}{2}L}}{1+(1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}\,e^{-\frac{\alpha}{2}L}\cos(k_n L)} \quad (4)$$

Figure 3 shows the output signals of the add/drop filter system, where the single soliton pulses of dark and bright can be obtained. Here the temporal form of these signals are presented.

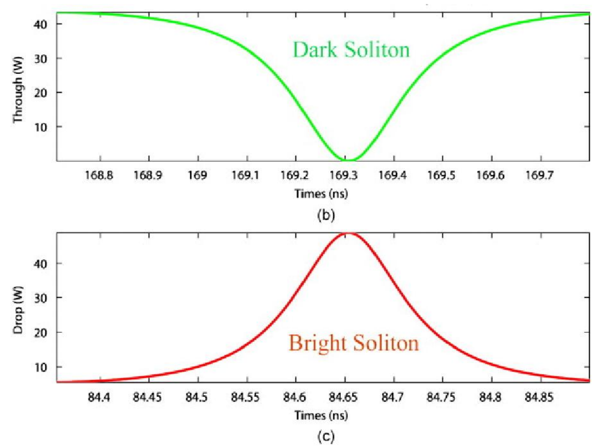

Fig. 3: Output temporal dark and bright signals using the add/drop filter system

The attenuation, or loss in signal power, resulting from the insertion of a component, such as a coupler or splice, in a circuit (Amiri *et al.* 2010a; Yupapin *et al.* 2010; Saktioto *et al.* 2010). Insertion loss is measured as a comparison of signal power at the point the incident energy strikes the component and the signal power at the point it exits the component. Insertion loss typically is measured in decibels (dB), although it also may be expressed as a coefficient or a fraction. The insertion loss of the add/drop filter system is show in Figure 4 which shows that how the bandwidth of the generated single pulse can be controlled via the system.

Therefore, the bandwidth varies respect to the variation of the coupling coefficients of the add/drop filter system. Here the increase of the coupling coefficient leads to increase the bandwidth as it can be seen from Figure 4.

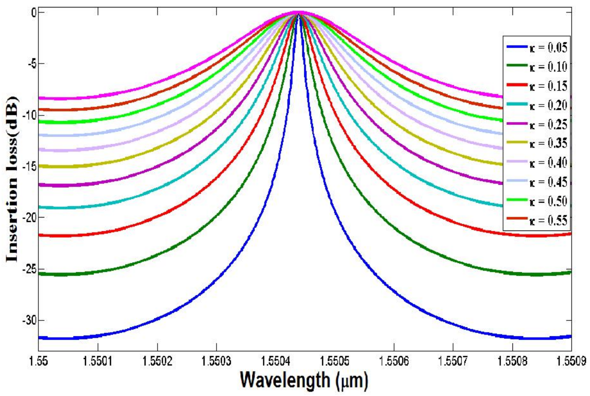

Fig. 4: The insertion loss, respect to variation of the coupling coefficient of the add/drop filter system

4. Conclusion

Chaotic signals can be generated using the input laser power propagating within a nonlinear ring resonator, where the required signals of single bandwidth soliton pulse can be recovered and manipulated by using an add/drop system. Results obtained have shown particular possibilities with this application. Also, effects of coupling coefficients on the bandwidth of the single soliton pulse have been presented here.

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