NEW SYSTEM OF CHAOTIC SIGNAL GENERATION BASED ON COUPLING COEFFICIENTS APPLIED TO AN ADD/DROP SYSTEM

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ABSTRACT
The nonlinear behavior (chaotic) of light traveling in an optical fiber ring resonator such as an add/drop system is presented. The chaotic behavior is considered to be a beneficial effect that can be used in the communication system. Such a system can be used to secure the information signals, therefore, the ability of chaotic carriers to synchronize in a communication system is performed. The used optical material is InGaAsP/InP regarding to suitable parameters of the system. The nonlinear refractive index is fixed to $n_2 = 3.8 \times 10^{-20}$ *m*^{2}*/W, and the 20,000 iterations of round-trip within the system is simulated. The input powers are selected at 1 W, where the coupling coefficient of the system varies according to two critical cases, where* $0 < \kappa < 0.1$ *and* $0.1 < \kappa < 1$*. As a results, larger coupler coefficient corresponds to lower input power for the case of* $0 < \kappa < 0.1$ *and smaller coupling coefficient of the system is corresponds to lower input power when* $0.1 < \kappa < 1$*. To optimize the microring systems, Lower input power is recommended in many applications in optical optical communication systems*

KEYWORDS: *Chaotic communication; chaotic control; Nonlinear optical.*

I. INTRODUCTION

Nonlinear behaviors of light traveling in a fiber optic ring resonator are commonly induced by the effects such as Kerr effects [1-4], four-wave mixing, and the external nonlinear pumping power [5]. Such nonlinear behaviors are named as chaos, bistability, and bifurcation [6]. More details of such behaviors in a microring resonator are clearly described by Amiri *et al* [7]. However, apart from the penalties of the nonlinear behaviors of light traveling in the fiber ring resonator [8-9], there are some benefits that can be used in the communication system [10]. One of them known as chaotic behavior that has been used to make the benefit of communication system in either electronic or optical communications [11-13]. Fortunately, most of the previous investigations are shown in mathematical ways, where the practical applications could be implemented [14-16]. For instance, the chaotic control input power [17-20] into the system is equal to the standard communication light source used in the system, and the implemented fiber optic devices are in the fabrication scales [21-23]. This means the ability of chaotic carriers to synchronize in a communication system is valid [24-26]. Recently, Amiri *et al*. have reported the successful characterization of the microring resonator with a radius of micron meters [27-28] using the optical materials called InGaAsP/InP [29-31], which are suitable for use in the practical devices and systems [32-33].
Amiri *et al* have also shown that an add/drop device could be constructed using a microring resonator, where the device characteristics have shown that they are suitable to implement in the practical

communication system [34-35]. In practical applications, the microring resonator and add/drop device parameters are required to make them within the ranges of the usual fabrication parameters [36-39]. Sumetsky *et al* showed that a high quality factor of the microfiber loop resonator (MLR) can be obtained by using suitable coupling coefficient of the system. Here, the high coupling efficiency of an MLR is achieved through an adiabatically slow variation of the microfiber diameter in the coupling region [40]. Yunchu *et al* demonstrated that the coupling coefficient between the two ring resonators plays a critical role in optimizing the performance of the coupled-ring modulator. One can consider the coupled-ring structure as a single compound resonator, where the coupling coefficient can be varied to adjust the energy distribution between the inner and outer rings [41].
This paper presents the design of the system of the chaotic signal generation that uses the practical device parameters. Such a system can be used to secure the information signals [42-43], where the tapping of the signals from the optical communication link is extremely difficult [44-46]. The analogy of the chaotic signal generation using fiber ring resonator and the related behaviors is described. The sections of the research work are organized by the comprehensive literature of the soliton pulse propagating within a microring system using critical parameter of the system (Section I); theory of the research which is based on the solving the nonlinear equations of the pulse propagating within a nonlinear fiber optics (Section II); method of the simulation results which is implemented using an iterative method (Section III); results which show that the device parameters used have good potentials for practical applications (Section IV); future works and further research studies, which can be done based on the micro and nanoring resonators (Section V), and conclusion section which provides a thoughtful end to a piece of writing and will lead the reader to the main motive of the whole research paper (Section VI).

II. THEORY AND SYSTEM

An add/drop microring resonator configuration is shown in figure 1. It is constructed by a single ring resonator which is coupled to two optical couplers on the top and bottom sides, where the circumference of the fiber ring is L [47-50]. The input signals at the input and add ports are given by E_i and E_{add} respectively. We assume the composite electric fields at each port as shown in figure 1 and are given by E_t and E_d. The rest of the fields E_r is the circulated fields inside the fiber ring resonator.

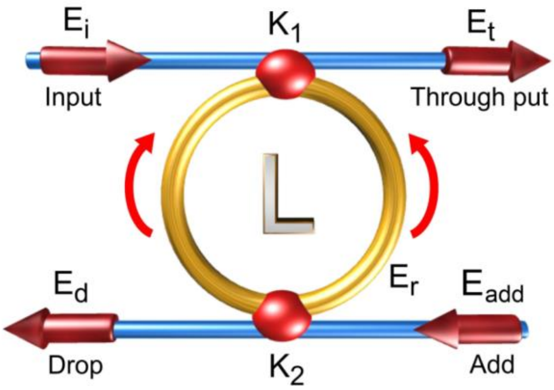

Fig. 1: A diagram of a fiber optic ring resonator

Here, the input light is monochromatic diode laser with constant amplitude and random phase modulation, thus producing a temporal coherence degradation [51-56]. The input light fields which are Gaussian beams can be expressed as [57-61]

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

E_0 and x are the amplitude of optical field and propagation distance respectively [62-65]. L_D is the dispersion length of the soliton pulse [66-69] where, frequency shift of the signal is ω_0 [70-72]. When a soliton pulse is input and propagated within a microring resonator, the resonant output is formed, thus, two complementary optical circuits of the add/drop system can be given by [73-75]

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

and

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

κ is the coupling coefficient [76], and $x=\exp(-\alpha L/2)$ represents a round-trip loss coefficient [77], $\Phi_0=kLn_0$ [78] and $\Phi_{NL}=kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts [79-80] and $k=2\pi/\lambda$ is the wave propagation number in a vacuum [81]. L and α are a waveguide length and linear absorption coefficient, respectively [82-84]. The parameters of the system were fixed to be $\lambda_0=1.55\mu m$, $n_0=3.34$ [85-87], A_{eff} is the effective mode core area of the fiber [88-90], where $A_{eff}=30\mu m^2$, the fiber losses $\alpha=0.02$dB/km [91-92]. The fractional coupler intensity loss is $\gamma=0.01$ [93-94], and $R=12.5\mu m$. The coupling coefficient varies regarding to the input power. The nonlinear refractive indices ranged from $n_2=3.8\times10^{-20}m^2/W$, and the 20,000 iterations of round-trips inside the optical fiber is simulated.

III. METHOD OF SIMULATION

To simulate the results based on the optical soliton propagating within microring resonator, MATLAB software is used. Here, an iterative method is used for calculating the output power of each round-trip of the input pulse within the ring system. Programming codes were written in regard to the ring resonator parameters, namely, the coupling coefficient, ring radius, central wavelength, linear and nonlinear refractive indices, linear and nonlinear phase, round-trips, internal loss, and so forth. Actual data from practical experiments were implemented for simulation programming codes for different input pulses propagating inside the nonlinear Kerr type fiber ring resonators.

IV. RESULTS AND DISCUSSION

The input power is maximized at 1 W, where the output power is varied directly with the coupling coefficient. Thus, the chaotic signal can be generated and controlled by varying the coupling coefficients, where the required output power is obtained. In real experimental works, the input power of the laser diode is needed to be lower due to the available commercial laser diodes. There are two cases which should be taken into account as follows: First where the coupling coefficient ranges as $0<\kappa<0.1$ and second where it ranges as $0.1<\kappa<1$.

Figure 2 shows the output chaotic signals generated for a variety of coupling coefficients, where the coupling coefficients vary from $\kappa=0.02$ to $\kappa=0.085$. The figure 2 (a) shows the output signal in terms of round-trip, where the figure 2(b-e) show the output signals reverence to different coupling coefficients. Therefore, larger coupler coefficient corresponds to lower input power which is required in many applications in optical switching and optical communication systems.

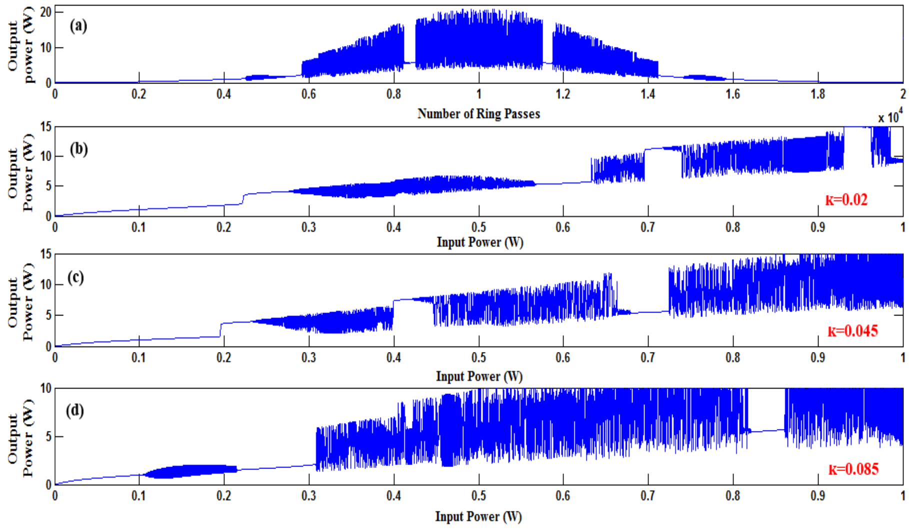

Fig. 2: Generation of chaotic signals when $0 < \kappa < 0.1$, (a): output signal versus number of round-trips, (b): Output chaotic signal where $\kappa = 0.02$, (c): Output chaotic signal where $\kappa = 0.045$, (d): Output chaotic signal where $\kappa = 0.085$

For the second case, where the coupling coefficient is $0.1 < \kappa < 1$, the larger coupling coefficient corresponds to higher input power as shown in figure 3.

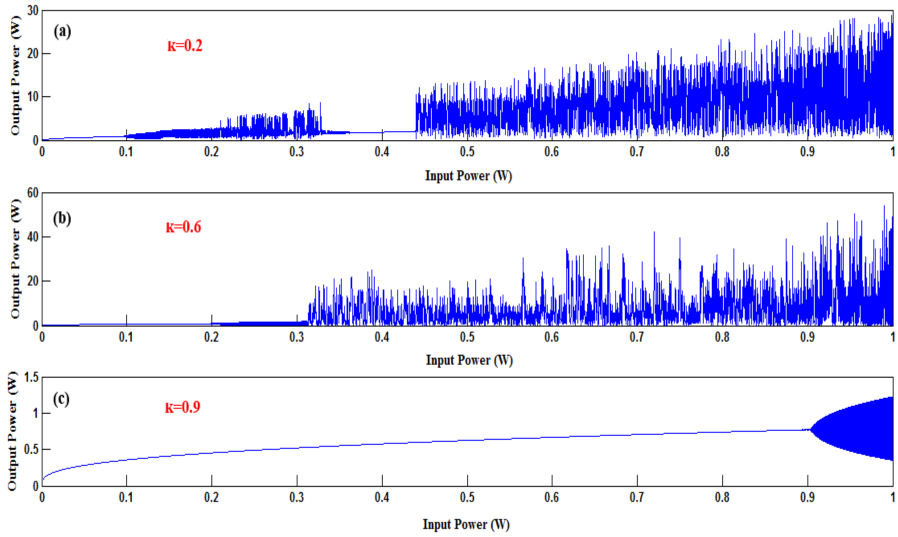

Fig. 3: Generation of chaotic signals where $0.1 < \kappa < 1$, (a): Output chaotic signal where $\kappa = 0.2$, (b): Output chaotic signal where $\kappa = 0.6$, (c): Output chaotic signal where $\kappa = 0.9$

Therefore smaller coupling coefficient of the system is recommended in order to optimize the microring system and the output signal which is in the form of chaotic signals.

V. Future Work

The quantum key system based on the entangled photon can be applied by using system of chaotic generation. A microring resonator system can be used to switch signals in the form of chaotic which can be applied to improve the quantum key systems working on the same principle. The technique of quantum entanglement photon switching is called a quantum repeater which uses entangled states stored in quantum memories. Quantum communication involves encoding information in quantum states, or quabits, as opposed to classical communication's use of bits. Quantum key distribution exploits certain properties of these quantum states to ensure its security. Another technique is cryptography based on synchronized chaos. There, the encrypted signal is simply added to some chaotic noise. The security lies in the fact that the noise has a larger amplitude than the signal for the entire spectrum.

VI. CONCLUSION

We have proposed the new design of the optical microring resonator system that uses critical parameters such as coupling coefficient to generate and control the output signals in the form of chaotic signals. Here, the common nonlinear penalties in fiber optic microring resonator are presented. By using the chaotic signal generation system, the information or data, in an optical communication and transmission link can be secured and used for a public network. Thus an add/drop system can be used to generate chaotic signal and operate as an optical switching system in which then requires output signals can be obtained and used in optical communication systems. The simulation results show that specific parameters such as the input power and coupling coefficients are used to control the output signals. To optimize the microring system, lower input power is recommended which can be obtained by using a larger coupling coefficient where it is less than 1 and by using smaller coupling coefficients where $0.1<\kappa<1$.

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