Nonlinear Chaotic Signals Generation and Transmission within an Optical Fiber Communication Link

I. S. Amiri 1*, A. Nikoukar 2, J. Ali 1

1Institute of Advanced Photonics Science, Nanotechnology Research Alliance, Universiti Teknologi Malaysia (UTM), 81300 Johor Bahru, Malaysia
2Faculty of Computer Science & Information Systems (FCSIS), Universiti Teknologi Malaysia (UTM), 81300 Johor Bahru, Malaysia

Abstract: The nonlinear behavior of light such as chaos traveling in an optical fiber ring resonator as a single ring resonator is presented. This phenomenon can be used to generate secret codes or arbitrary digital codes of “0” and “1” applicable in the communication system such as time division multiple access (TDMA) 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 $n_2=3.8\times10^{-20}$ m$^2$/W. The input power is selected at 1 W, where the coupling coefficient of the system varies as $0<\kappa<0.1$. As a result, train of logic codes could be generated and transmitted via a fiber communication link using the chaotic signals. To optimize the microring systems, Lower input power is recommended in many applications in optical optical communication systems.

Keywords: Chaotic communication; Logic Codes; TDMA system; Optical Soliton Transmission

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]. 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 [40-41], where the tapping of the signals from the optical communication link is extremely difficult [42-44]. The results obtained have shown that the device parameters used have good potentials for practical applications. The analogy of the chaotic signal generation using fiber ring resonator and the related behaviors is described. This research is supported by the Institute of Advanced Photonics Science, Nanotechnology Research Alliance, Universiti Teknologi Malaysia (UTM).

II. THEORY AND SYSTEM

A ring resonator configuration is shown in figure 1, where the circumference of the fiber ring is $L$ [45-48]. The input and output signals are given by $E_{in}$ and $E_{out}$ respectively.
Here, the input light of the monochromatic diode laser is inserted into the system [49-54]. The input light of Gaussian beams can be expressed as [55-59],

\[
E_{\text{in}}(t) = E_0 \exp \left( \frac{x}{2T_0} - i\omega_0 t \right)
\]  

(1)

\(E_0\) and \(x\) are the amplitude of optical field and propagation distance respectively [60-63]. \(L_0\) is the dispersion length of the soliton pulse [64-67] where, frequency shift of the signal is \(\omega_0\) [68-70]. When a soliton pulse is input and propagated within a microring resonator, the resonant output is formed, thus, optical circuits of the system can be given by [71-73],

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

(2)

\(\kappa\) is the coupling coefficient [74], and \(x = \exp(-\alpha L/2)\) represents a round-trip loss coefficient [75]. \(\Phi_0 = kL\beta\) [76] and \(\Phi_{\text{NL}} = kLn_2\beta_{\text{NL}}\) are the linear and nonlinear phase shifts [77-78] and \(k = 2\pi/\lambda\) is the wave propagation number in a vacuum [79]. \(L\) and \(\alpha\) are a waveguide length and linear absorption coefficient, respectively [80-82]. The parameters of the system were fixed to be \(\lambda_0 = 1.55\mu m, n_0 = 3.34\) [83-85], \(A_{\text{eff}}\) is the effective mode core area of the fiber [86-88], where \(A_{\text{eff}} = 30\mu m^2\), the fiber losses \(\alpha = 0.02 \text{dB/km}\) [89-90]. The fractional coupler intensity loss is \(\gamma = 0.01\) [91-92], and \(R = 12.5\mu m\). The coupling coefficient varies regarding to the input power [93-94]. The nonlinear refractive indices ranged from \(n_2 = 3.8 \times 10^{-20}m^2/W\), and the 20,000 iterations of round-trips inside the optical fiber is simulated [95].

III. 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. Here, the coupling coefficient ranges as \(0 < \kappa < 0.1\). 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 \(\kappa = 0.085\)](image-url)
The chaotic signals can be used to generate information of binary codes where the encoding and decoding of data can be performed via a TDMA system. This system will encode the binary logic codes of “0” and “1” and transmit them via fiber optic communication, where the decoding process is performed at the end of the transmission link. The schematic of the TDMA system is shown in figure 3, in which transmission of chaotic signals for communication networks can be obtained. Thus by using arbitrary digital coding, different signal information propagate in the network communication via a TDMA transmission system. This system uses data in the form of secured codes to be transferred to single users via different lengths of the fiber optic line to the TDMA transmitter.

![Fig. 3: Schematic of the TDMA system](image)

Therefore, digital code information can be shared between users in different time slots. The transmission unit is a part of the quantum processing system that can be used to transfer the high capacity packet of quantum codes. Moreover, a high capacity of data can be transferred by using more wavelength carriers. Here, transmission of arbitrary digital codes of "1111000001010001110000000000001" is performed. Figure 4 shows the forms of transmitting signals in the optical fiber communication system.

![Fig. 4: Transmitting of digital codes where (a): Binary codes, (b): Secured codes, (c), Transmitted codes over 125 km fiber optics, (d) decoded signals into original signals.](image)

Therefore, transmission of data along fiber network communication is performed using chaotic signals. The security scheme of the transmission can be obtained by encoding-decoding of data where the high capacity of transmission requires highly optical signals such as chaotic signal which is employed whether it is used as optical carrier or optical information.

IV. Conclusion

We have proposed 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 penalty in the fiber optic microring resonator is 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
The chaotic signals can be encoded and decoded within a communication network system such as a TDMA system. Therefore secret codes travel within the optical fiber communication, where the detection of the signals can be performed using the TDMA system. This technique is used to transfer the information along long distance fiber communication which is a promising application in nano digital communication especially when a soliton pulse is employed.

Acknowledgements

I. S. Amiri would like to thank the Institute of Advanced Photonics Science, Nanotechnology Research Alliance, Universiti Teknologi Malaysia (UTM).

REFERENCES


Nonlinear Chaotic Signals Generation and Transmission Within an Optical Fiber Communication


