Optik 165 (2018) 275–287

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Generation & control of chaos in a single loop optoelectronic oscillator

Dia Ghosh [a,*], Arindum Mukherjee [b], Nikhil Ranjan Das [c], Baidya Nath Biswas [d]

[a] Department of Electronics & Communication Engineering, Siliguri Institute of Technology, Siliguri, 734009, West Bengal, India
[b] Department of Electronics & Communication Engineering, Central Institute of Technology, Kokrajhar, 783370, Assam, India
[c] Institute of Radio Physics and Electronics, Calcutta University, 92 A.P.C. Road, Kolkata 700009, West Bengal, India
[d] Education Division, SKF Group of Institutions, Mankundu, Hooghly 712139, West Bengal, India

ARTICLE INFO

Article history:
Received 25 October 2017
Accepted 4 February 2018

Keywords:
Delay dynamical system
Optoelectronic oscillator (OEO)
Chaos
Injection synchronization

ABSTRACT

We present a detailed study on the dynamics of a single Loop optoelectronic Oscillator (SLOEO), with the variation of feedback loop delay. The feedback delay can be varied by changing the length of the optical fiber delay line. From the numerical study it is observed that with the variation of the delay the oscillator produces chaotic oscillation following the sequence of Hopf bifurcation, stable periodic and period doubling oscillation. In OEO, incrementing the feedback loop delay increases the number of neighboring modes. The effect of these modes on the dynamics of the OEO is reported through simulation study. It has been seen that due to the generation of additional modes, instability grows in the system and the oscillator changes its state from periodic to chaotic oscillation. Consequently the effect of periodic external synchronizing signal is studied in the chaotic OEO. It is observed that application of an external periodic signal with suitably chosen amplitude and frequency can destroy the chaotic oscillation and produce single frequency oscillation. This mechanism has an additional advantage in the reduction of phase noise with regard to the use of larger delay in the loop. Moreover, the sync. signal increases the effective quality factor (Q) of the circuit thereby reducing the deleterious effect of phase noise.

1. Introduction

The ubiquity of chaos relies on its broadband frequency spectrum, noise-like complex aperiodic pattern, its unpredictability etc. These characteristic features make it effectual in cryptographic communication, ultra wide band sensor network, high speed random number generation, modern communication system. The broadband continuous frequency spectrum of chaotic signals implies that they are orthogonal signal because the signals with wide spectral width can be rapidly decorrelated. Thus, broadband chaotic information carrier has a potential application in interference free communication [1]. In recent past, a developing trend has been noticed in producing chaos from delay dynamical system [2–8]. A nonlinear system with delay becomes infinite dimensional and can show various complex phenomenon like bifurcation, chaos, hyper chaos, multi stability, amplitude death etc. It is well rendered in several articles that chaos produced by a time delayed system has higher dimensionality and communication with higher dimensional chaos is more secure compared to low dimensional chaos [9,10].

* Corresponding author.

https://doi.org/10.1016/j.ijleo.2018.02.010
0030-4026/

In the present literature we report a study on the complex dynamics of an OEO. Over the last few years OEO has seen wide spread application in the field of RADAR, fiber optic communication system, long distance digital communication system, in view of the fact that it has the ability to produce high frequency signal with ultra high spectral purity. This oscillator was first introduced by Neyer and Voges [11]. Posterior to their pioneering work, Yao and Maleki introduced this oscillator as a high quality microwave oscillator [12]. The OEO contains a continuous wave laser source. The optical signal generated from the laser is fed to a Mach-Zehnder modulator (MZM), which is acting as intensity modulator. The intensity modulated optical signal is passed through an optical fiber delay line and applied to the photo detector. The detected RF signal is then filtered by a band pass filter (BPF). The output of the BPF is fed to the electrical port of the MZM. Generation of high spectrally pure signal is possible due to the long low loss optical fiber delay line in its feedback loop. The long delay line results in a high quality factor and spectral purity. However, increasing the length of the fiber delay produces a great number of closely spaced oscillation modes, out of which only one mode is unleashed by the BPF. Conversely it becomes quite difficult to design a BPF which can select a single mode oscillation. To circumvent this problem Dual Loop Optoelectronic oscillator was proposed [13,14], also Zhou and Blasche reported a new injection locked dual OEO [15]. Other techniques have also been reported to operate OEO without electrical BPF [16,17]. Furthermore, the present authors have reported a new OEO where the BPF has been replaced by a conventional oscillator using injection locking technique [18,19]. In addition to these studies, research on the dynamics of an OEO too is endeavored. The presence of optical fiber delay line facilitates OEO as a candidate of electro-optical system with delayed feedback. Therefore the study on the complex dynamics of OEO is an important aspect, both from academic and engineering application point of view. Considering the feedback gain as a control parameter Chembo et al described the generation of chaotic breathers in an OEO [20].Other schemes for chaotic signal generation and stability analysis in an OEO was also being contemplated [21–26]. By controlling both feedback delay and loop gain the complex dynamics and synchronization property of an OEO was reported [27,28] but the OEO in this report was implemented using discrete time DSP technology. The oscillator was designed with a laser, electro-optic modulator and a photo-detector but for delay and filtering purpose the DSP board was used. In contrast to the above-mentioned works, the present work uses the time delay, produced by an optical delay line in the feedback loop, as control parameter. The variation of the delay generated additional cavity modes, whose effect on the dynamics of the oscillator is demonstrated. The frequency of these spurious signals is very close to the fundamental oscillation frequency, which leads to frequency entrainment process. Due to this entrainment process the system loses its stability and following a period doubling route it produces chaotic oscillation. As far as the knowledge of the authors is concerned, the effect of these modes on the dynamics of the OEO is addressed nowhere. Here we have considered the fundamental architecture of the OEO, by fundamental we mean the basic circuit configuration proposed by Yao and Maleki. Recently the complex dynamical behavior of some low frequency electronic oscillators has been reported [29,30]. The method adopted for the stability analysis in our study is similar to these works. The present work differs from these articles in the sense that here the oscillator under consideration is an SLOEO, which can generate signal ranging from GHz to KHz. whereas in the aforementioned studies the oscillator being different creates a varying dynamical behavior. After studying the complex dynamics with variation of loop delay, we applied a periodic signal into the free running chaotic OEO. It is being seen that by controlling amplitude of the external signal the chaotic oscillation at the output of the free running oscillator can be destroyed and period -1 oscillation can be produced. This method has multitude benefits; such as a large feedback loop delay can be used which in turn helps to reduce the phase noise, as well as the unwanted cavity modes are prohibited to appear in the pass band of the filter. Furthermore sync signal improves the effective quality factor of the circuit. Although the method of chaos quenching is not new [34–37], as far as the knowledge of the authors is concerned, the effect of sync signal to control the chaotic dynamics of the OEO has never been approached before.

The paper is organized in the following way: Section 2 describes the basic configuration of the oscillator and derivation of the system equation. In Section 3 the stability and bifurcation analysis is presented. System equation of the synchronized OEO is discussed in Section 4. Section 5 reports the detailed numerical study of free running and synchronized OEO. The simulation study is described in Section 6. Finally the paper concludes in Section 7.

2. System equation of free running OEO

Fig. 1 shows the basic configuration of an SLOEO. It consists of a continuous wave laser source which is fed in to a Mach-Zehnder modulator (MZM), the MZM acts as an intensity modulator of the optical signal. The optical output of the modulator is detected by a photo detector after passing through a long optical delay line. This signal is then passed through an electrical band pass filter (BPF). The output from the BPF is fed back to the electrical port of the MZM. The BPF implemented here using a single tuned circuit.

Let us consider the RF input to the MZM is $V_{in}(t) = V(t)e^{j(\omega_0 t+\theta(t))}$, where $V(t)$ is the amplitude of the signal with free-running frequency ω_0 and the initial phase of $\theta(t)$. The output power of the MZM can be expressed as [32]

$$P(t) = \frac{1}{2}\alpha P_0 \left[1 - \eta \mathrm{Sin}\pi \left(\frac{V_{in}(t) + V_B}{V_\pi}\right)\right] \tag{1}$$

Where P_0 is the input optical power, $\alpha$is the insertion loss of the modulator and fiber's transmission loss, $\eta$is the extinction ratio of the modulator,$V_B$is the bias voltage of the modulator, and $V_\pi$is the half wave voltage of the modulator. Therefore the photo-detector output can be expressed as $V_0(t) = \rho R P(t-\tau)$, where ρ is the sensitivity and $R$is the output impedance