Optics Communications 381 (2016) 174–179

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Concealment of time delay signature of chaotic output in a slave semiconductor laser with chaos laser injection

Tianan Wu*, Weiyang Sun, Xiaoxu Zhang, Shenghai Zhang

School of Natural and Applied Science, The PLA Information Engineering University, Zhengzhou 450000, China

ARTICLE INFO

Article history:
Received 10 June 2016
Accepted 29 June 2016

Keywords:
Semiconductor lasers
Chaos injection
Time delay signature
Double optical feedback
Detuning frequency

ABSTRACT

An improved chaotic laser system, which has a slave semiconductor laser (SL) injected by a master SL with double optical feedback (DOF), is proposed, so that the time delay (TD) signature can be successfully concealed from both intensity and phase chaos via choosing appropriate parameters. The TD signature is investigated by employing autocorrelation function (ACF) and mutual information (MI) function. Through analyzing the influence on TD signature in the region of injection current and injection strength for the slave SL, we find that, for both intensity chaos and phase chaos, the TD signature can be easily concealed under weak injection strength. When the injection strength is strong, we can not only successfully conceal TD signature, but also improve the bandwidth of chaotic laser output by choosing the optimal detuning frequency.

1. Introduction

The chaotic laser has become a more attractive research object for its potential applications, such as secure optical communication, chaotic radar and high speed random number generators (RNG) etc. [1–10]. The approaches with optical feedback or optical injection are adopted to obtain chaotic output due to its high bandwidth. However, for large feedback strength or injection strength, the TD signature of chaotic output will be extracted successfully via time series analysis techniques such as ACF, permutation entropy (PE) and delayed MI [11,12], which in turn threatens the security of chaotic communication system and reduces the randomness of RNG. Therefore, it is necessary to develop some methods to eliminate or pretend the TD signature for improving the quality of random number generation and ensuring the system security.

In recent year, many schemes have been proposed to suppress the TD signature in the literature. For example, Rontani et al. pioneered the suppression of TD signature by optimizing the feedback strength in the simplest feedback configuration, which employs only one mirror [11]. Wu et al. experimentally and numerically demonstrated that the time delay signature could be suppressed from the intensity chaos by adopting double optical feedback in SL [13]. However, those conventional methods, which were concerned by Guo et al. [14,15], can hardly completely eliminate the TD signature. Subsequently, more complicated configurations for feedback were reported to conceal the TD signature, such as using three cascade-coupled laser diodes [16], Phase-modulated dual-path feedback [17] and frequency-detuned grating feedback [18]. These approaches of TD signature suppression typically involved increasing the hardware complexity of the setup.

In this paper, in order to simplify the constructions of these systems and improve the chaos bandwidth, a system of concealing TD signature, which is consist of two SLs, is proposed. The chaotic output is produced by a slave SL, which is injected by a master SL with DOF.

2. Theoretical model and method

Fig. 1 shows the schematic of simulation model. Chaotic fluctuation of laser output is generated in a master semiconductor laser with DOF and the chaotic output is injected into a slave semiconductor laser for hiding the TD signature.

2.1. Rate equation models

The well-known Lang–Kobayashi equations are widely adopted to simulate the dynamics of SL with optical feedback [19]. In this paper, we consider the Lang–Kobayashi equations including the gain saturation effect to reproduce a similar histogram of the laser intensity distribution to that observed in experiments [20].

---

* Corresponding author.

http://dx.doi.org/10.1016/j.optcom.2016.06.083
0030-4018/

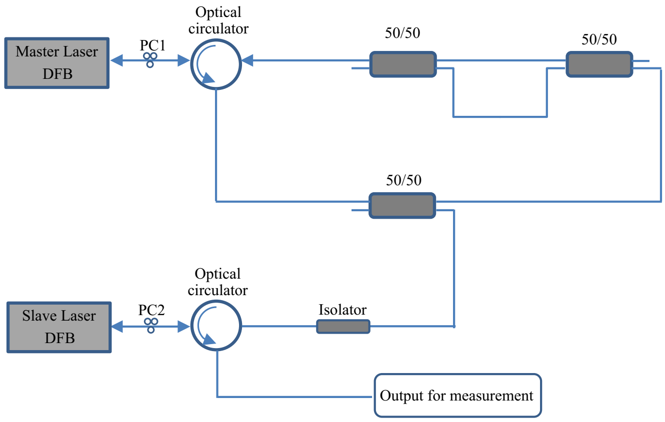

Fig. 1. Schematic diagram of simulation model. DBF: single-mode distributed-feedback laser; PC: polarization controller; 50/50: 50/50 optical fiber coupler.

$$\frac{dE_i(t)}{dt} = \frac{1}{2}\left[\frac{G_N[N_i(t) - N_0]}{1 + \varepsilon E_i^2(t)} - \frac{1}{\tau_p}\right]E_i(t) + k_{f1}E_i(t - \tau_1)\cos\left[\theta_1(t)\right] + k_{f2}E_i(t - \tau_2)\cos\left[\theta_2(t)\right] \tag{1}$$

$$\frac{d\phi_i(t)}{dt} = \frac{\alpha}{2}\left[\frac{G_N[N_i(t) - N_0]}{1 + \varepsilon E_i^2(t)} - \frac{1}{\tau_p}\right] - k_{f1}\frac{E_i(t - \tau_1)}{E_i(t)}\sin\left[\theta_1(t)\right] - k_{f2}\frac{E_i(t - \tau_2)}{E_i(t)}\sin\left[\theta_2(t)\right] \tag{2}$$

$$\frac{dN_i(t)}{dt} = J_i - \frac{N_i(t)}{\tau_n} - \frac{G_N[N_i(t) - N_0]}{1 + \varepsilon E_i^2(t)}E_i^2(t) \tag{3}$$

$$\frac{dE(t)}{dt} = \frac{1}{2}\left[\frac{G_N\left[N(t) - N_0\right]}{1 + \epsilon E^2(t)} - \frac{1}{\tau_p}\right]E(t) + k_{in}E_i\cos\left[\beta(t) - \Delta\omega t\right] \tag{4}$$

$$\frac{d\phi(t)}{dt} = \frac{\alpha}{2}\left[\frac{G_N\left[N(t) - N_0\right]}{1 + \epsilon E^2(t)} - \frac{1}{\tau_p}\right] - k_{in}\sin\left[\beta(t) - \Delta\omega t\right] \tag{5}$$

$$\frac{dN(t)}{dt} = J - \frac{N(t)}{\tau_n} - \frac{G_N[N(t) - N_0]}{1 + \varepsilon E^2(t)}E^2(t) \tag{6}$$

$$\theta_1(t) = \omega_i\tau_1 + \phi_i(t) - \phi_i(t - \tau_1)\theta_2(t) = \omega_i\tau_2 + \phi_i(t) - \phi_i(t - \tau_2)\beta(t) = \phi(t) - \phi_i(t)$$

Where E_i and E are the electric field amplitude, ϕ_i and ϕ are the electric field phases, N_i and N are the carrier density. (Eqs. (1)–3) for master semiconductor laser with double optical feedback. The last two terms in (Eqs. (1) and 2) represent optical feedback, k_{f1} and k_{f2} are feedback strength, τ_1 and τ_2 are feedback delay time. (Eqs. (4)–6) for slave semiconductor laser with chaos optical

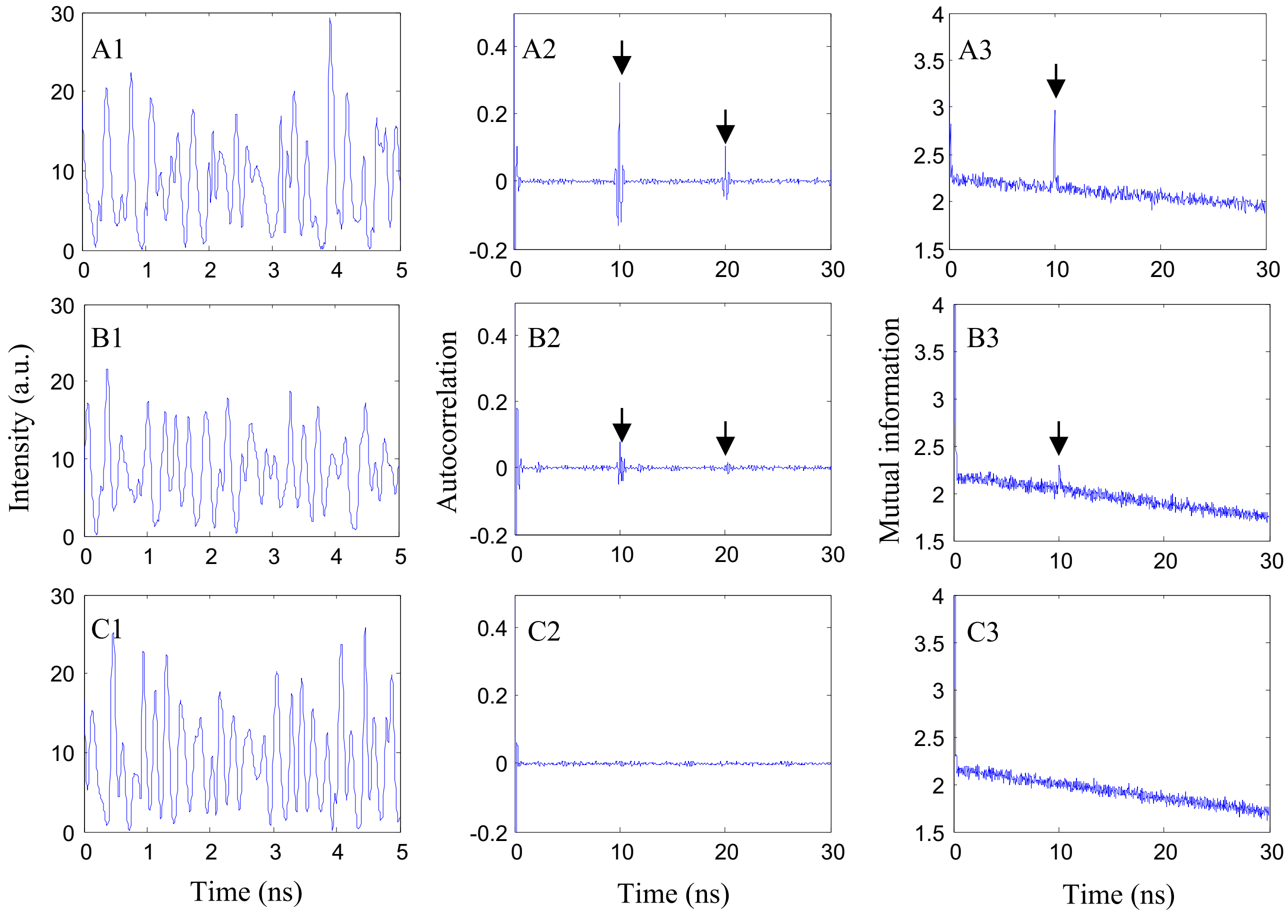

Fig. 2. Intensity time series (left column), ACF (middle column), and MI (right column); (A1–A3) correspond to SL with SOF, (B1–B3) correspond to master SL with DOF, (C1–C3) correspond to slave SL with chaos injection; with k_f=13.8 ns^{-1}, τ=10 ns, k_{f1}=k_{f2}=6.9 ns^{-1}, τ_1 =10 ns, τ_2=10.1 ns, k_{in}=16 ns^{-1}, J_i=1.44*J_{th}, J=1.46*J_{th}, and detuning frequency Δf=0.