Chaos-based optical Communication Using Opto-electronic Devices With Two Wavelength multiplexing

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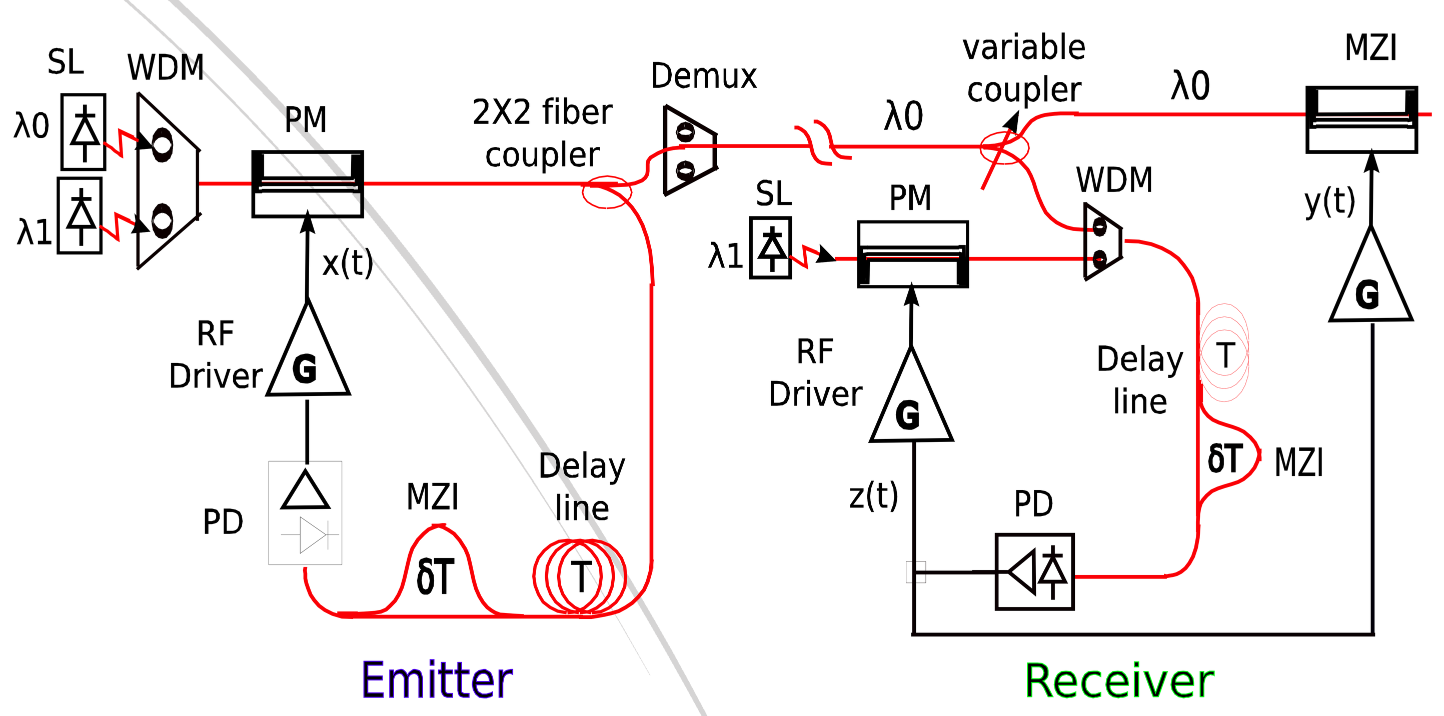
Introduction

we propose a new model of optoelectronic delay device based on non-local non linearity, which highlights the enhancement of security level in chaos communications. The model principle consists in generating chaotic carriers from two wavelengths and transmitting only the main driving the message through the optical fibre. By the means of synchronization error and the largest conditional Lyapunov exponent, we establish the conditions filled by the non-transmitted wavelength to preserve complete synchronization.

Set-up and Model

setup



Equations: The model is described in terms of normalized RF voltage x(t) applied to the Mach-Zehnder modulator.

EMITTER

$$X+\tau_1\frac{dX}{d\theta}+\frac{1}{\theta_1}\int_{t0}^{t}X(s)\,ds=\beta_0\cos^2[X(t-T_1)-X(t-T_1-\delta T)+\Phi_1]+\beta_1\cos^2[X(t-T_2)-X(t-T_2-\delta T)+\Phi_2]$$

RECEIVER

$$y+\tau_2\frac{dy}{d\theta}+\frac{1}{\theta_2}\int_{t0}^{t}y(s)\,ds=\beta_0\cos^2[X(t-T'_1)-X(t-T'_1-\delta T)+\Phi'_1]+\beta_1\cos^2[z(t-T'_2)-z(t-T'_2-\delta T)+\Phi'_2]$$

$$z+\tau_3\frac{dz}{d\theta}+\frac{1}{\theta_3}\int_{t0}^{t}z(s)\,ds=\beta_0\cos^2[X(t-T'_1)-X(t-T'_1-\delta T)+\Phi'_1]+\beta_1\cos^2[z(t-T'_2)-z(t-T'_2-\delta T)+\Phi'_2]$$

The emitter consists of a phase modulator (PM) pumped by two CW lasers with different wavelengths mixed by a multiplexer (WDM), Mach-Zehnder interferometer (MZI), a fiber delay line, a photodetector and a gain amplifier [2]. Using demultiplexer (DEMUX), only the main wavelength with optoelectronic gain β_0 is transmitted to the receiver. The non-transmitted wavelength is generated in the receiver side so as to match the emitter. The receiver is therefore composed of one close loop which generates the non-transmitted wavelength light and the open loop in transmitted wavelength beam.

high frequency cutoff $\tau_1=\tau_2=\tau_3=12.2\,ps$
low frequency cutoff $\theta_1=\theta_2=\theta_3=5\,\mu s$
Imbalancing time $\delta T=260\,ps$
Normalized opto-electronic feedback β_0, β_1
delay time $T_1=T'_1=31.7\,ns$; $T_2=T'_2=32\,ns$
offset phase $\Phi_1=\Phi'_1=0.3$; $\Phi_2=\Phi'_2=0.35$

Results

Following the Krasoviskii theory [3], the Krasovskii-Lyapunov functional is defined as

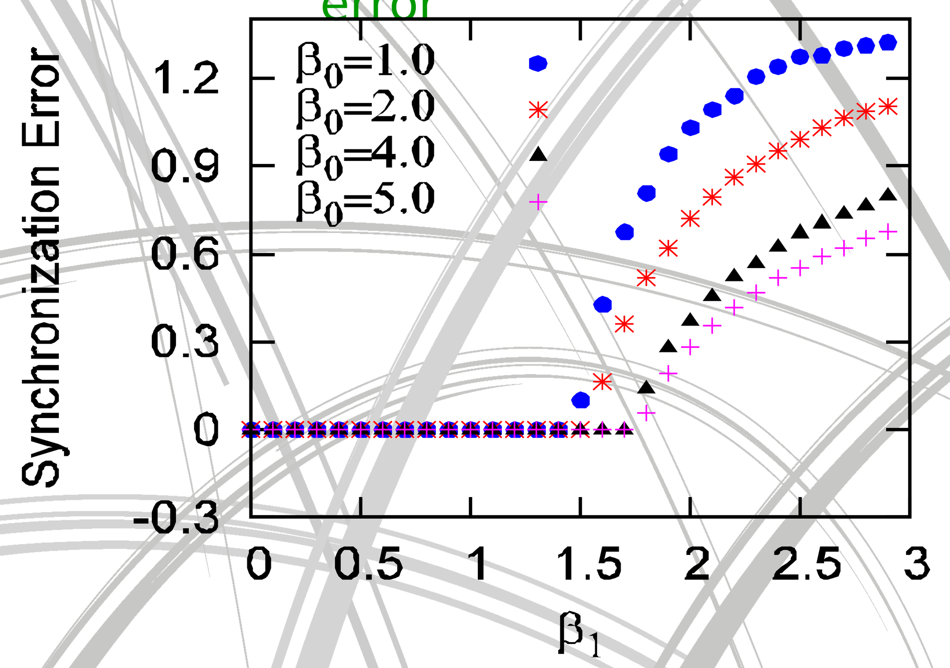
$$v(t)=\frac{1}{2}(\Delta+\varepsilon)^2+h_1(t)\int_{-R2}^{0}\Delta^2(t+\varphi_1)\,d\varphi_1+h_2(t)\int_{-R2-\delta R}^{0}\Delta^2(t+\varphi_2)\,d\varphi_2 \qquad \Delta(t)=y(t)-x(t)\ \text{and}\ +\varepsilon(t)=\int_{to}^{t}\Delta(s)\,ds$$

And the sufficient condition for complete synchronization fulfills $\beta_1<\frac{2-\tau/\theta}{2}\quad 1$

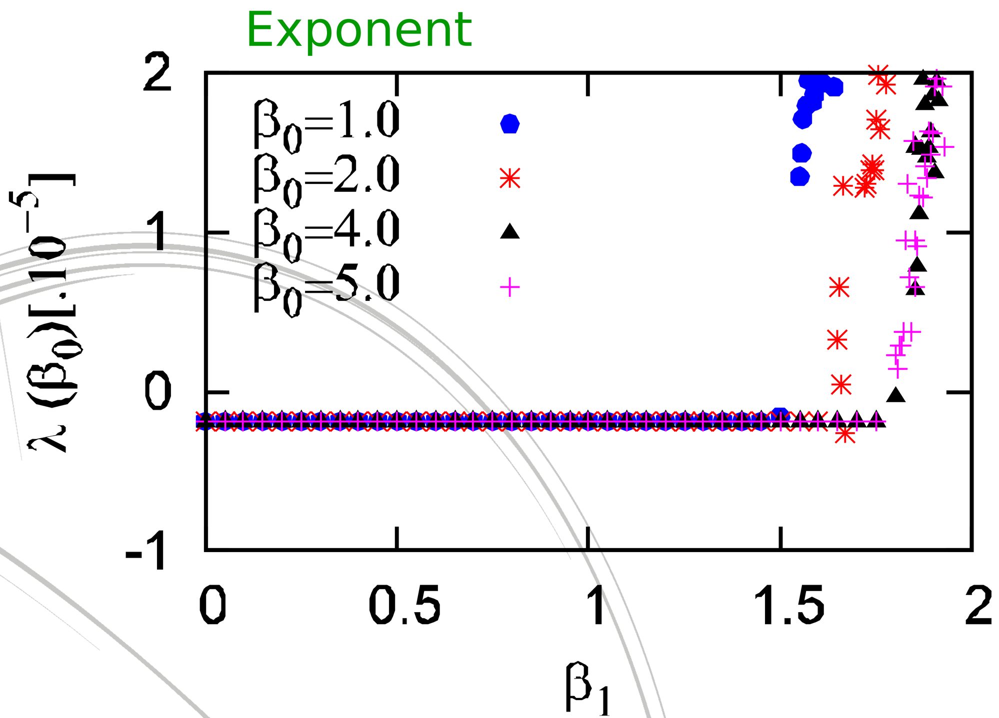
The largest conditional Lyapunov exponent

$$\lambda(\beta_0)=\lim_{t\to\infty}\frac{1}{t}\ln\left\{\frac{\left[\int_{-R_2-\delta R}^{0}\Delta^2(t+v)dv\right]^{1/2}}{\left[\int_{-R_2-\delta R}^{0}\Delta^2(v)dv\right]^{1/2}}\right\}$$

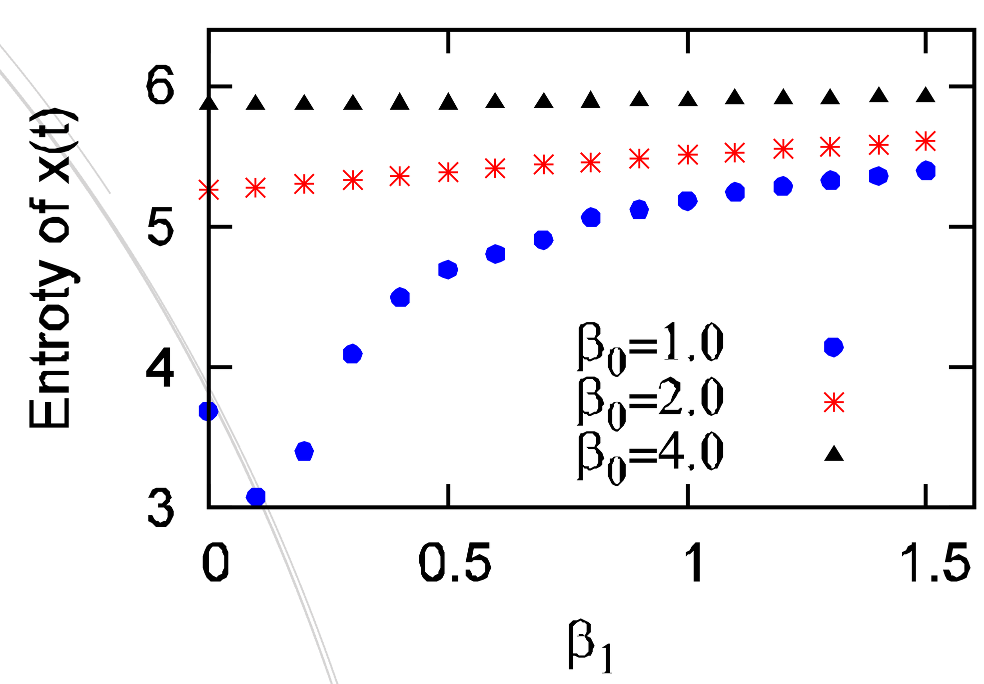
Synchronization error



Conditional Lyapunov Exponent



Entropy



From the synchronization error and the largest conditional Lyapunov exponent λ, three domains of β_1 are distinguished: the first one from 0 to about 1.5 reveals complete synchronization without any influence of the main loop gain β_0. The second between approximately $1.5<\beta_1<1.8$, the synchronization strongly depends on β_0 while it is practically destroyed beyond $\beta_1>1.8$. As it was expected, the entropy of the system increases with the gain β_1

Summary

We have proposed a dynamical model of opto-electronic delay oscillator pumped simultaneously by two different wavelength beams. We have established the conditions in which synchronization is possible even though only one of the wavelengths is transmitted.

References

1) P. Ashwin, J. Buescu, and I. Stewart, Phys. Lett A. **193**, 126 (1994); Nonlinearity, **9**, 703 (1996)
2) R. Lavrov, M. Peil, M. Jacquot, L. Larger, V. Udaltsov, and J. Dudley, *Electro-optic delay oscillator with non-local nonlinearity: Optical phase dynamics, chaos, and synchronization*, to be published.
3) J.K. Hale and S.M.V. Lunel, *Introduction to Functional Differential Equations* (Springer, 1993)