Dynamics of electro-optic delay oscillators pumped with two lasers

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Abstract: We study the synchronization of optoelectronic delay oscillators pumped with two lasers with different wavelengths. While only one of them is transmitted, the receiver can still synchronize.

Opto-electronic oscillators (OEOs) can generate a broad range of dynamical regimes from of spectrally pure microwaves to chaos for optical encoded communications. A typical OEO is composed of a Mach-Zehnder interferometer pump by a CW laser, a fibre delay line, a photo-detector and a gain amplifier. The refractive index in one of the arms of the MZ depends on the emitted light after fibre propagation. In the chaotic regime a message can be encoded on top the chaotic carrier and decoded by an appropriate receiver. To increase privacy, we consider here an OEO which is pumped by two lasers with slightly different wavelength (λ₀, λ₁), both playing a role in the generation of the chaotic carrier, but only λ₀ is transmitted using a demultiplexer.

The dimensionless voltage of the emitter operating in phase modulation, is governed by

\[ x + \frac{d}{dt}x = \beta_0 \cos^2(x(t-T_1) - x(t-T_1 - \delta T) + \phi_1) + \beta_1 \cos^2(x(t-T_2) - x(t-T_2 - \delta T) + \phi_2) \]

Where \( \delta T \) is the time-imbalanced interference between the arms of the MZ. \( T_1 \) and \( T_2 \) are the time delays for \( \lambda_0 \) and \( \lambda_1 \), which differ due to fibre dispersion. \( \phi \) is the delay phase and \( \beta_0 \) and \( \beta_1 \) are related to the power of the lasers emitting at \( \lambda_0 \) and \( \lambda_1 \). The receiver is operating in open loop for \( \lambda_0 \) but in close loop for \( \lambda_1 \), which is generated locally.

\[ y + \frac{d}{dt}y = \beta_0 \cos^2(x(t-T_1) - x(t-T_1 - \delta T) + \phi_1) + \beta_1 \cos^2(x(t-T_2) - x(t-T_2 - \delta T) + \phi_2) \]

\[ z + \frac{d}{dt}z = \beta_0 \cos^2(x(t-T_1) - x(t-T_1 - \delta T) + \phi_1) + \beta_1 \cos^2(x(t-T_2) - x(t-T_2 - \delta T) + \phi_2) \]

We have studied chaos generated in this form as well as the synchronization between emitter and receiver. For typical parameter values we find that chaos entropy increases with \( \beta_1 \) as shown in (Fig. 1). Despite the increase in entropy and the fact that the receiver has now to generate its own \( \lambda_1 \) synchronization is still good for \( \beta_1 \geq 1.5 \) (Fig. 1). Beyond this value, instabilities occur in the system and therefore the synchronization is seriously degraded. The threshold for \( \beta_1 \) depends slightly on the value of the main gain \( \beta_0 \), and increasing \( \beta_0 \) to 5.0, synchronization occurs up to 1.75.

![Fig. 1. Set-up.](image)

![Fig. 2. Entropy of the transmitter (left) and synchronization error between transmitter and receiver (right) as function of \( \beta_1 \).](image)