Ghost resonance in coupled

C. M. González, J. M. Buldú, J.Trull
Universitat Politècnica de Catalunya

Electronic address :

Introduction:

An excitable system subject to two different periodic signals exhibits a resonance at a frequency not present in the input driving[1].

Input : $f_1 = kf_0 + \Delta f$, $f_2 = (k+1)f_0 + \Delta f$,…. , $f_n = (k+n-1)f_0 + \Delta f$; $k>1$

Output: $$f_r = f_0 + \frac{\Delta f}{k + \frac{(n-1)}{2}}$$

semiconductor lasers

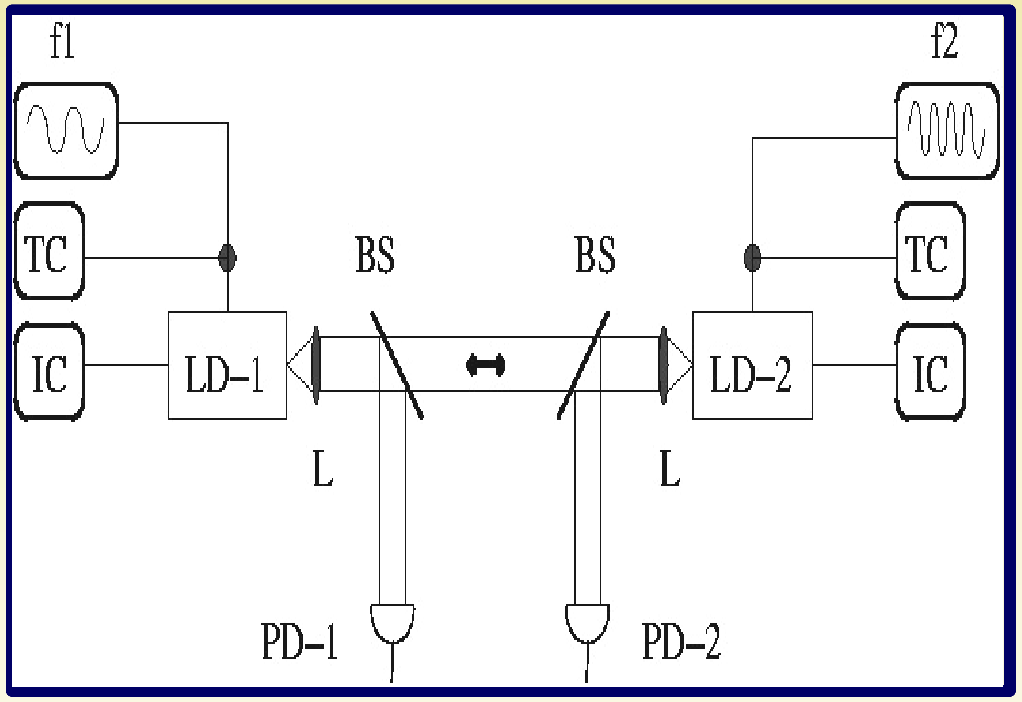
M. C. Torrent and Jordi García-Ojalvo.
Colom 11 E-08222 Terrassa, España.

cristina.martinez-g@upc.edu
javier.martin-buldu@upc.edu

System :

•Two semiconductor lasers coupled bidirectionally via the mutual injection of their output intensities.

•This coupled system has been shown to have a pulsated output[3], similar to that observed in a single semiconductor laser with optical feedback in the low-frequency fluctuations regime. Previous studies have shown that coupling in this system enhances the response of both lasers to a single periodic driving of one of the lasers[5].



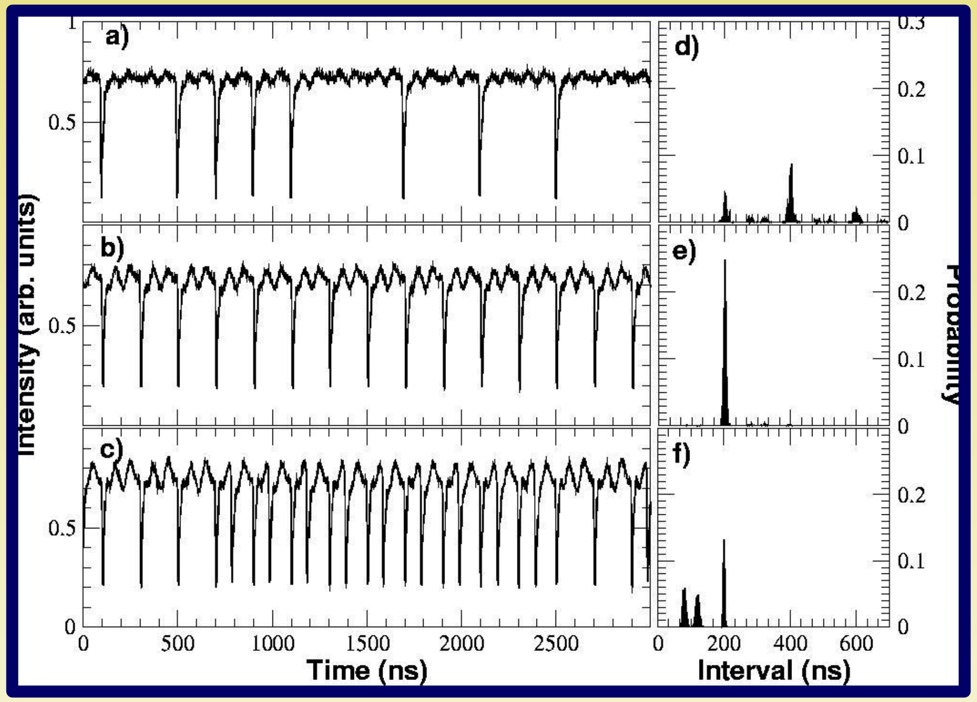
•When both lasers are independently modulated with two frequencies as $f_1 = kf_0$ and $f_2=(k+1)f_0$, coupling induces entrainment to a frequency not present at the input of any of the two lasers

Experimental results.

•Output intensity of one of the synchronized lasers in a LFF regime and the corresponding probability distribution functions (PDF) for increasing values of the modulation amplitude.

•For intermediate values of the modulation amplitude, the system show a single sharp peak at the ghost interval T_r =200ns.

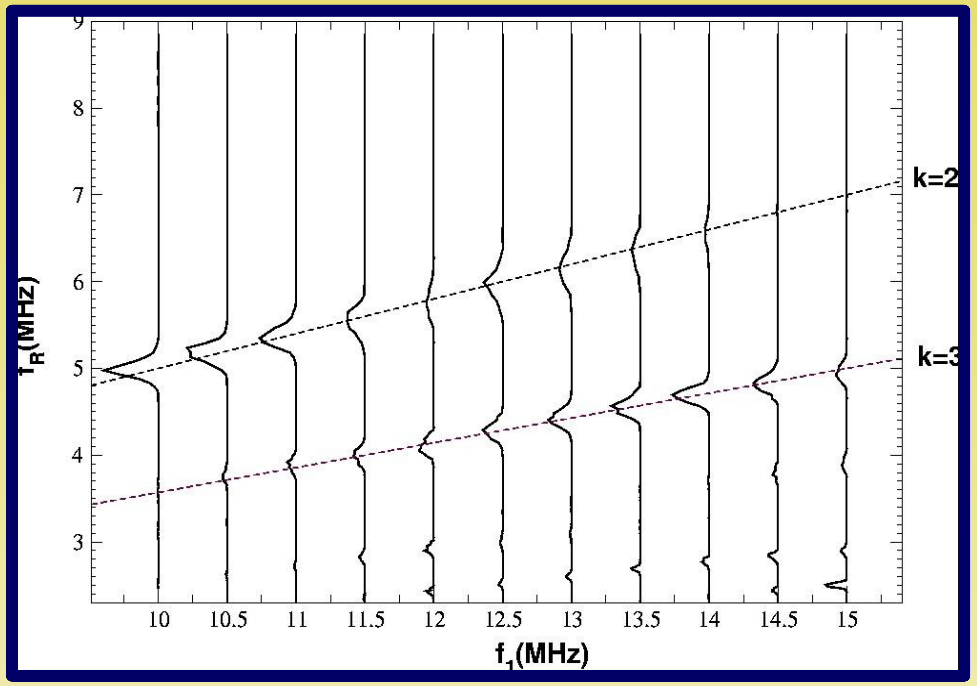
f_1=10 MHz ; f_2=15 MHz;
$\Delta f=0$, k=2 $\Rightarrow$ fr = fo = 5 MHz.



•Experimentally observed output intensity of LD-1 (left column) and the corresponding PDF for increasing values of modulation amplitude.

•This results do not correspond to a trivial resonance at the difference between f_1 and f_2. We introduce detuning ($\Delta f \neq 0$) in the input (incommensurate frequencies).The resonance frequency increases linearly with detuning, even though the difference between them is f_0.

$$f_r = f_0 + \frac{\Delta f}{k + \frac{1}{2}}$$

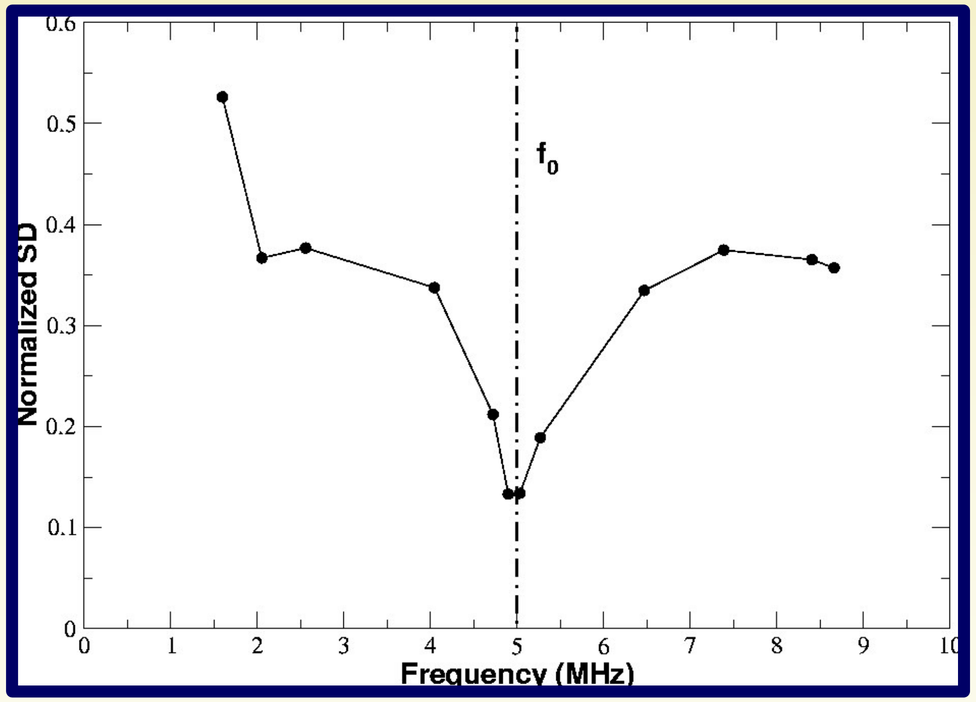


•Experimental PDFs vs the response frequency, for increasing values of f_1.

•Statistically analysis of output series for different modulation amplitudes.

•Evaluation of the average and the relative standard deviation of the inter-dropout intervals at each amplitude.

•Standard deviation minimal for average inter-dropout frequency f_r=5 MHz, which indicates that the periodicity is maximal at that output frequency.



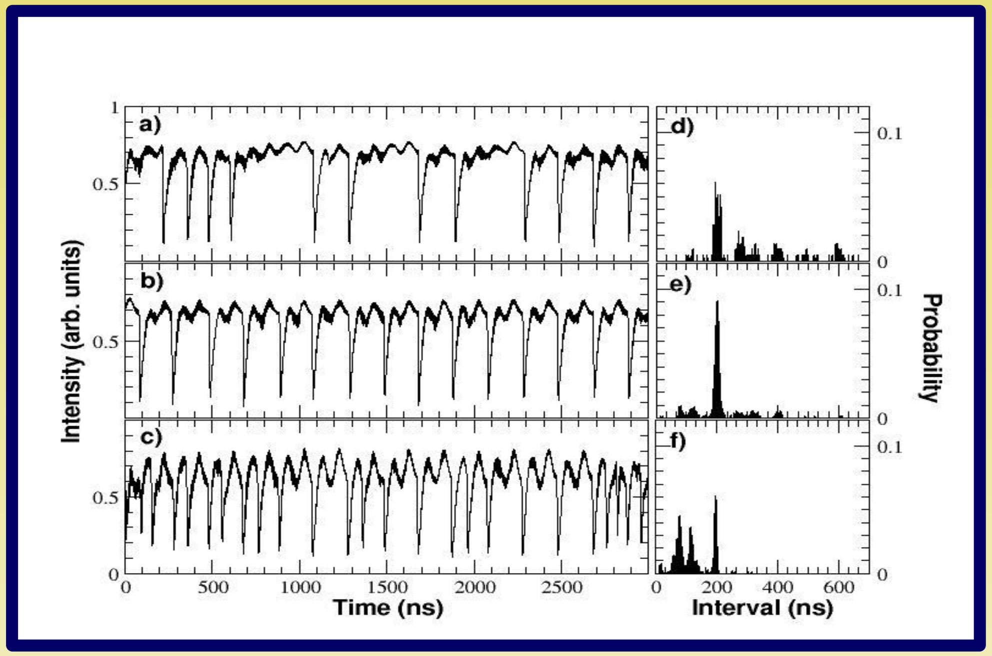
Numerical simulations

•System of delay-coupled rate equations. Extension of the Lang and Kovayashi model[4] :

$$\frac{dE_{1,2}}{dt} = \frac{(1+i\alpha)}{2}[G_{1,2} - \gamma_{1,2}]E_{1,2} + $$

$$+ \kappa_c e^{i(\omega_2-\omega_1)\tau_c} E_{1,2}(t-\tau_c) + \sqrt{2\beta N_{1,2}}\,\varepsilon_{1,2}(t)$$

$$\frac{dN_{1,2}}{dt} = \frac{I_{1,2}}{e} - \gamma_{e1,2}N_{1,2} - G_{1,2}P_{1,2}(t)$$



$E_{1,2}$, $N_{1,2}$→ optical fields and their corresponding carrier number.

$\omega_{1,2}$ → free running optical frequencies of the two lasers (the same)

$P_{1,2}(t) = |E_{1,2}(t)|^2$ → number of photons inside the cavity.

κ_c, τ_c → coupling strength and coupling time.

β, $\varepsilon(\tau)$ → spontaneous emission rate and Gaussian white noise.

•Numerical computed output intensity of LD-1 (left column) and the corresponding PDF of the inter-dropouts intervals for increasing values of the modulation amplitude

•Pumping modulation:

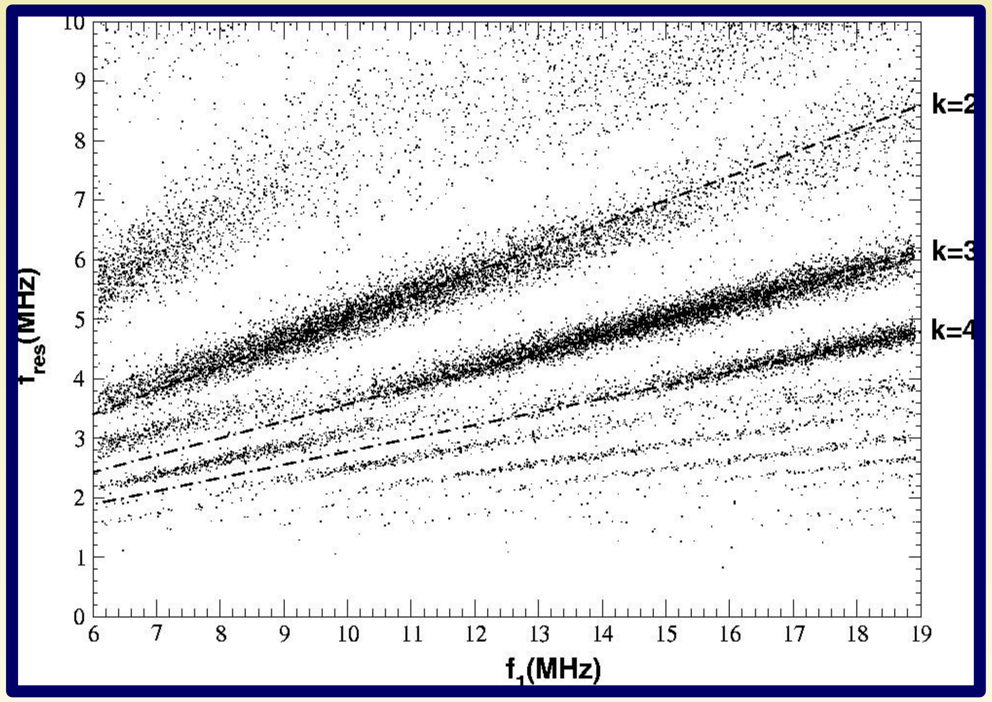
$$I_{1,2} = I_{DC1,DC2}\,[1 + A_{1,2}\sin(2\pi f_{1,2} t)]$$

$I_{DC1,DC2}$ → Pumping currents.

$A_{1,2}$, $f_{1,2}$ → Modulation amplitudes and frequencies.

•Algorithm : Runge- Kutta fourth order.

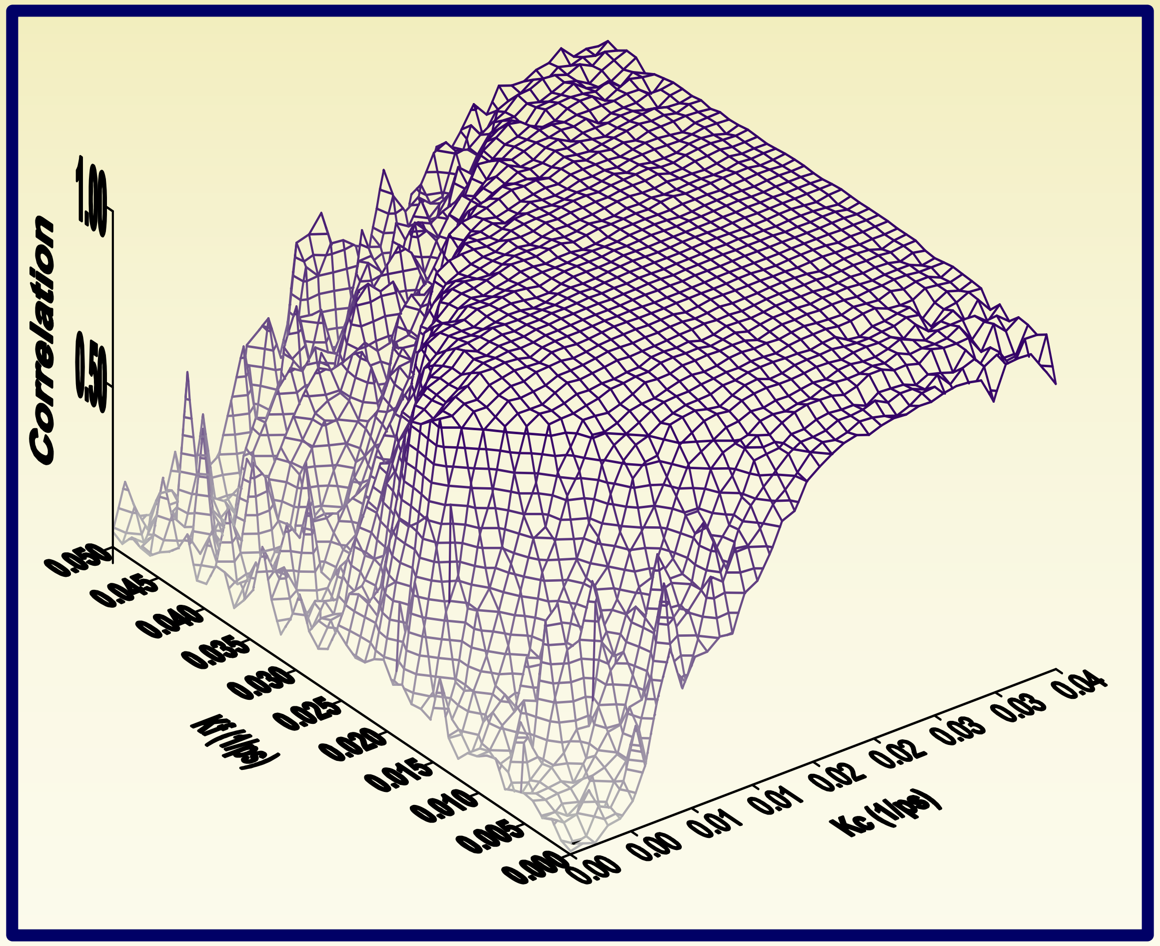
•Response frequency between dropouts as a function of f_1. Dashed lines corresponds to theoretical predictions. As f_1 increases, the maximum response frequencies (resonance frequencies) jump to a higher value of the k parameter (k=2 to k=3). This dependence of f_r with Δf indicates that the ghost resonance is a nontrivial resonance.



•Numerically determined response frequency between dropouts f_{res} as a function of f_1

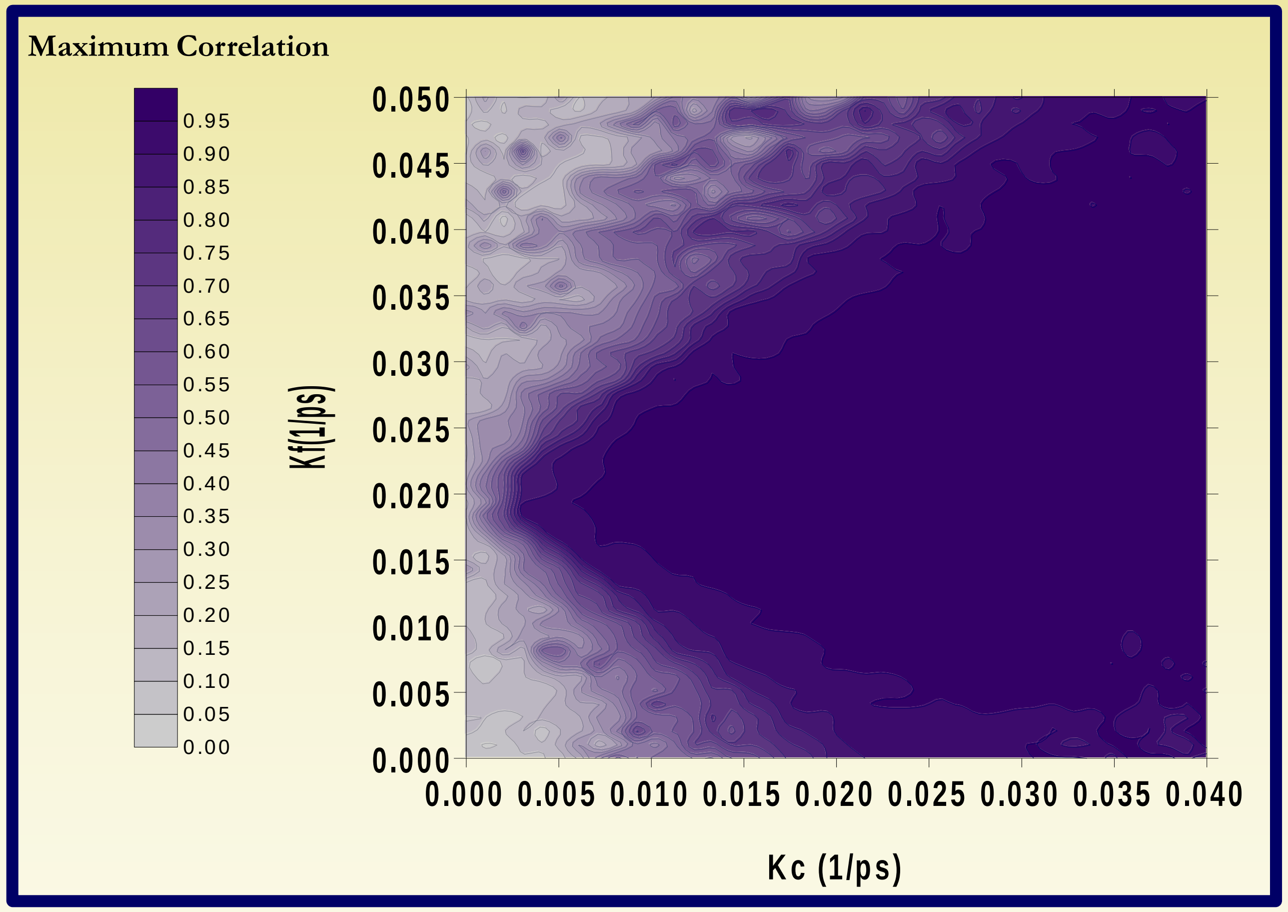
•We consider two bidirectionally coupled semiconductor lasers with external optical feedback to show that ghost resonance occurs in a system intrinsically excitable.

•Numerically results show that for low coupling the two lasers exhibit unsynchronized pulses, whereas the pulses become synchronized for large coupling.



•Coupling-induced ghost resonance can also be observed in coupled lasers with feedback (which correspond to two coupled excitable systems).

•We can see with the maximum of correlation that for certain values of coupling occurs the ghost resonance. Next step is to define this zone of occurrence.



•Maximum of correlation function as a function of the coupling constant (Kc) and feedback rate (Kf) of LD-1 (feedback strength of LD-2 fixed at 20ns^{-1})

Conclusions

•When two mutually coupled semiconductor lasers are perturbed by two independent periodic signals, a resonance arises at a third frequency not present in the input (ghost resonance).

•The resonance is not trivial, since it persists in the case of incommensurate input.

•With two bidirectionally coupled semiconductor lasers without feedback ,coupling has the additional role of inducing the excitable behaviour itself (the lasers are stable without coupling), but the optical feedback for both lasers shows that the ghost resonance also arises in coupled excitable lasers (lasers subject to optical feedback are independently excitables).

•Now we try to define the limits of parameters (coupling rate and feedback rate) for wich the ghost resonance occurs.

References

[1]. D. R. Chialvo, O. Calvo, D. L. Gonzalez, O. Piro and G. V. Savino, Phys. Rev. E 65 ,050902 (R) (2002).

[2]. J. M. Buldú, D . R. Chialvo, C. R. Mirasso, M. C. Torrent and J. García-Ojalvo, Eurpophys. Lett. 64, 178 (2003).

[3]. T. Heil, I. Fischer, W. Elsässer, J. Mulet and C. R. Mirasso, Phys. Rev. Lett. 86, 795 (2001).

[4]. J. Mulet, C. Masssoller and C. R. Mirasso, Phys. Rev. A 65,063815 (2002).

[5]. J. M. Buldú, R. Vicente, T. Perez, C. R. Mirasso ,M. C. Torrent and J. García-Ojalvo, Appl. Phys. Lett. 27, 5105 (2002).