Optimal entrainment of intensity dropouts of a semiconductor laser in the LFF regime

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Denmark, September 2017

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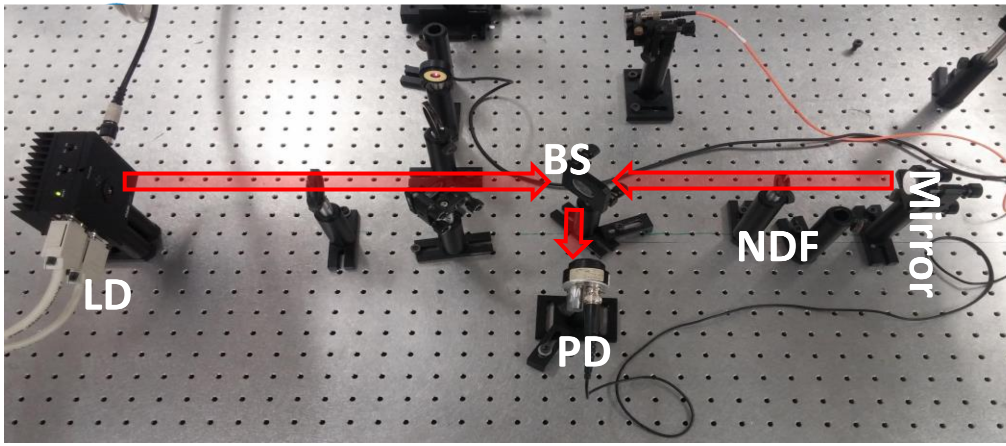
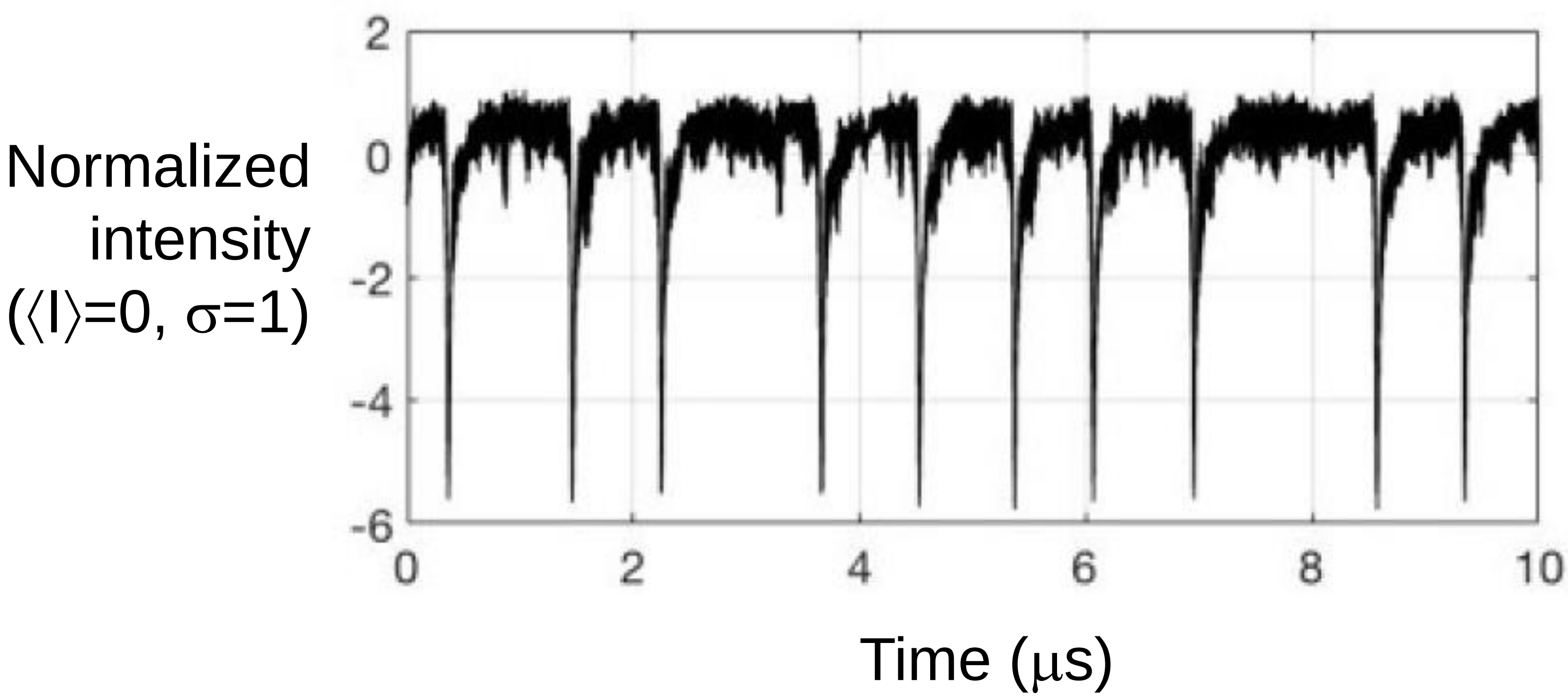
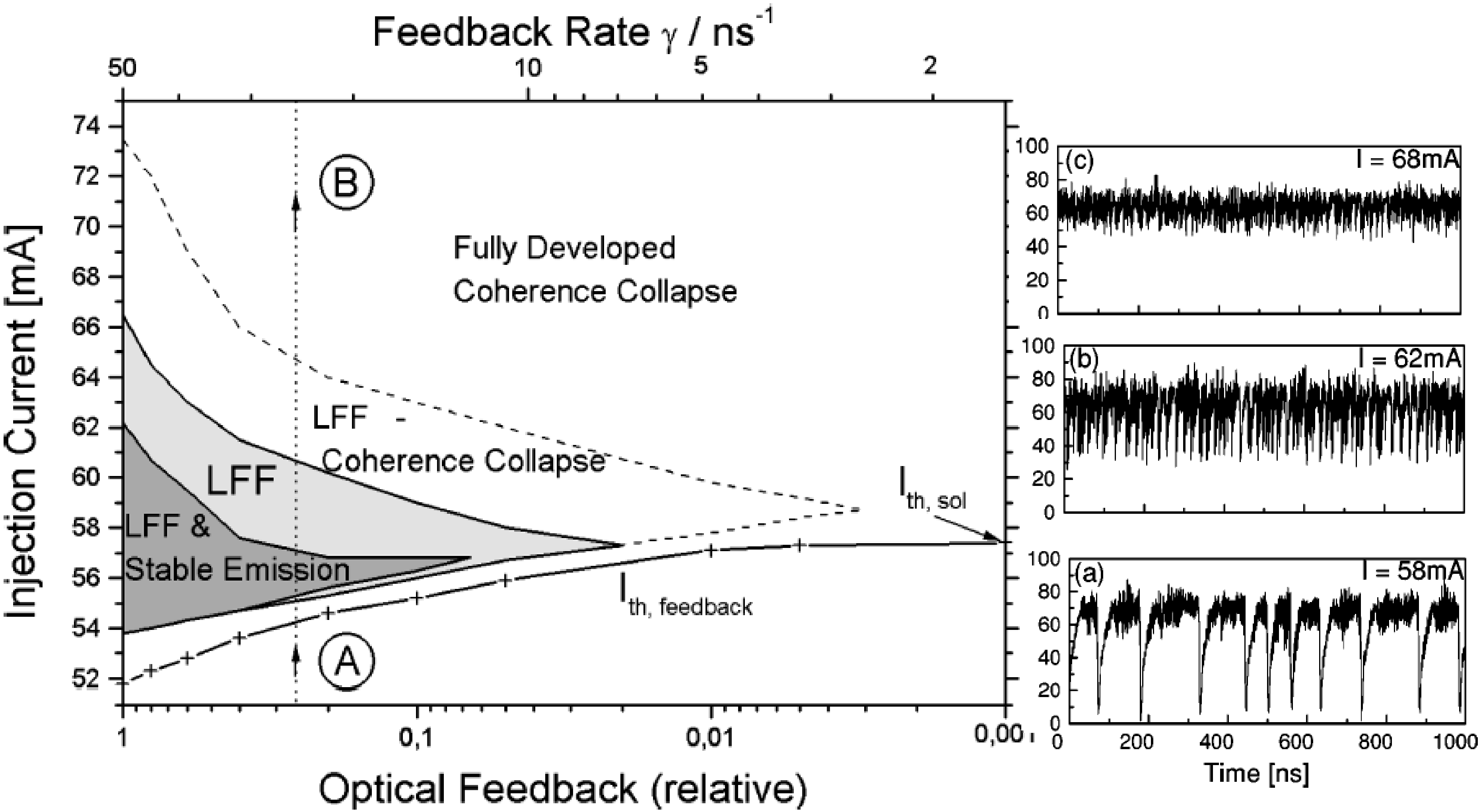


Low frequency fluctuations induced by optical feedback



Dynamical regimes



T. Heil, I. Fischer, and W. Elsaßer, PRA 58, R2672, 1998

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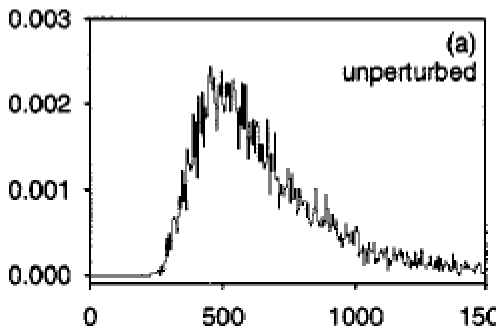
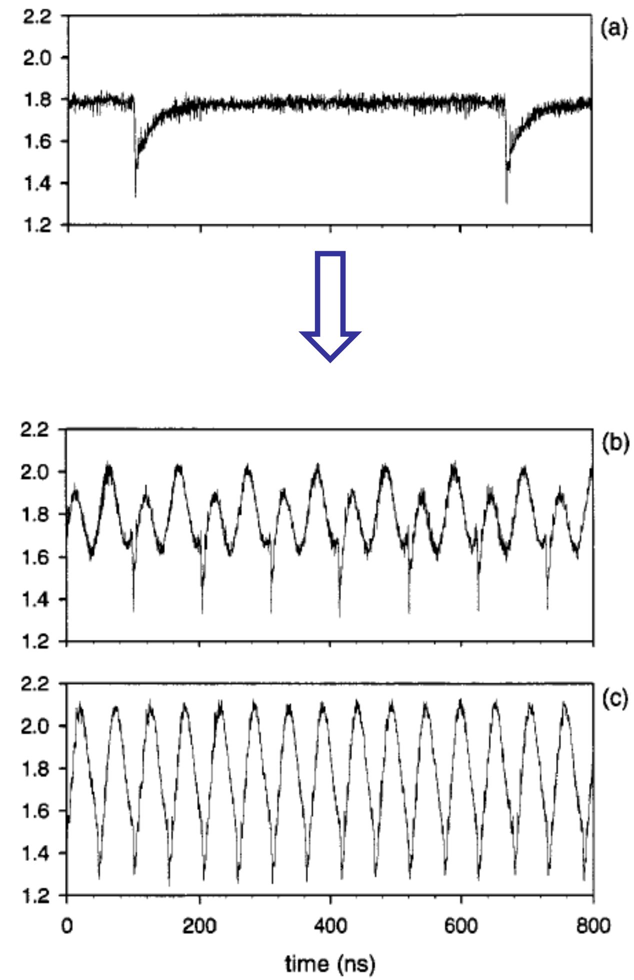
LFF entrainment via sinusoidal current modulation

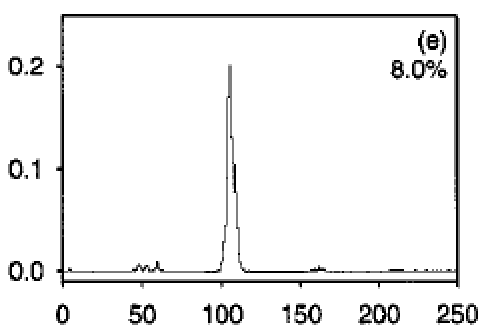
PDF(ΔT)

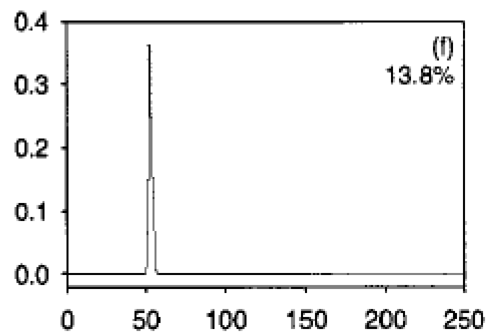


inter-dropout interval, ΔT



PDF(ΔT)





inter-dropout interval, ΔT

Sukow and Gauthier IEEE JQE 2000

Questions

- Which waveform is optimal for entraining LFFs?

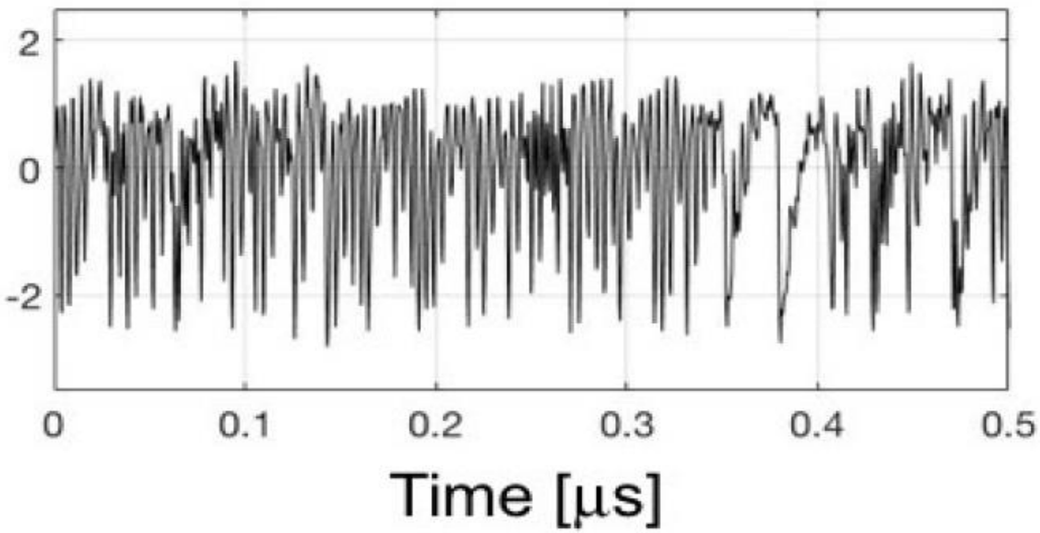
⇒ we compare three waveforms:
  – pulse up
  – pulse down
  – Sinusoidal

- Where is easier to entrain the LFFs?

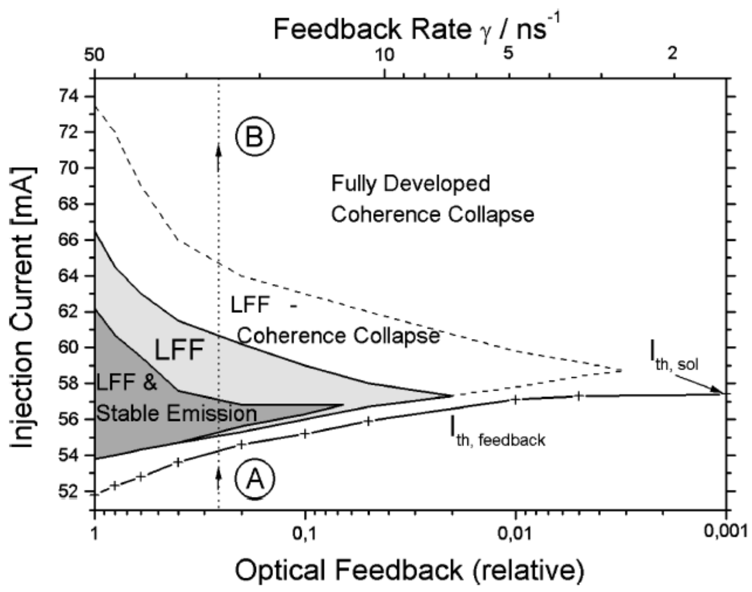
⇒ we compare three regions:
  – Noisy LFFs
  – Regular LFFs
  – Irregular LFFs (onset of coherence collapse)

Motivation: gain insight of the entrainment of nonlinear oscillators to an external forcing signal (cardiac rhythms, circadian rhythms, etc.)

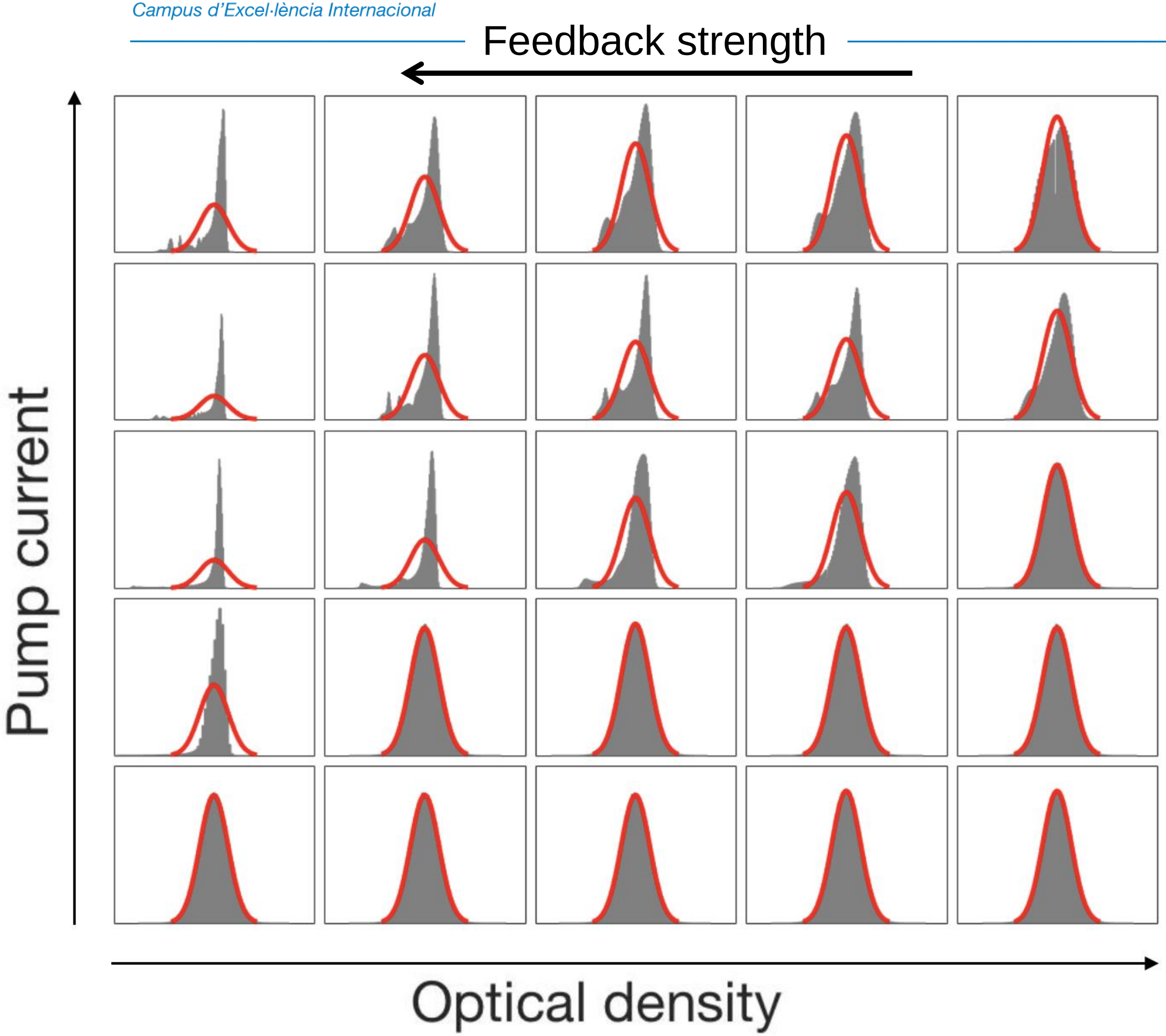
Quantitative identification



Noise? LFFs? CC?



First method: intensity PDF



$$\sigma^2 = \frac{\sum_i I_i^2}{N-1}$$

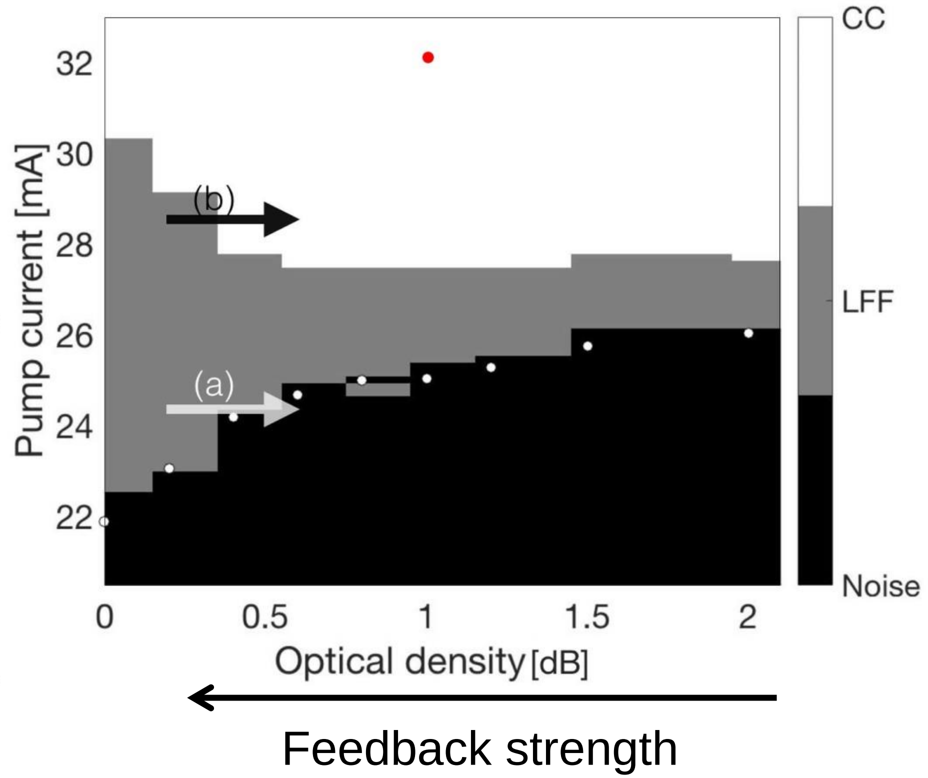
$$S = \frac{\sum_i I_i^3}{(N-1)\sigma^3}$$

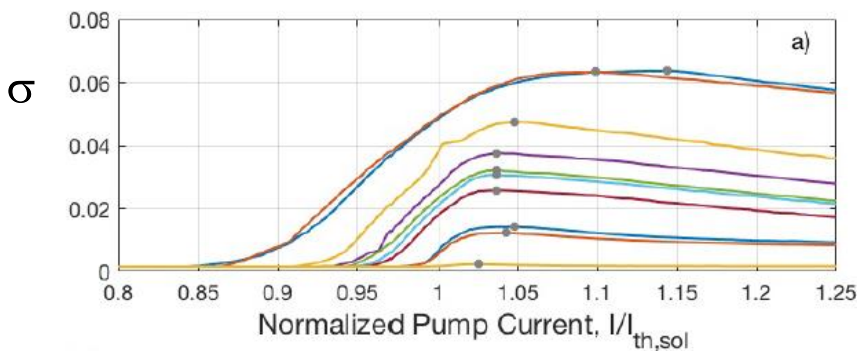
$$K = \frac{\sum_i I_i^4}{(N-1)\sigma^4}$$

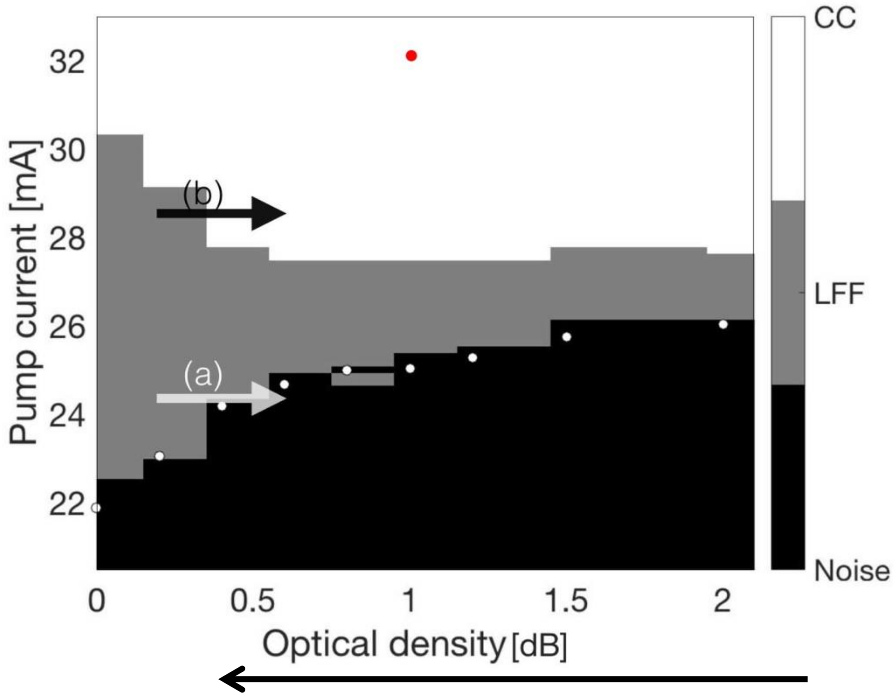
If: $3 < S < 3.3$ (10% of normal)
and
$| K | < 0.04$ (max sol. laser K)
$\Rightarrow$ Noise

Else: LFF or CC

LFF and CC are then distinguished depending on how σ varies with the pump current while keeping the feedback strength constant.

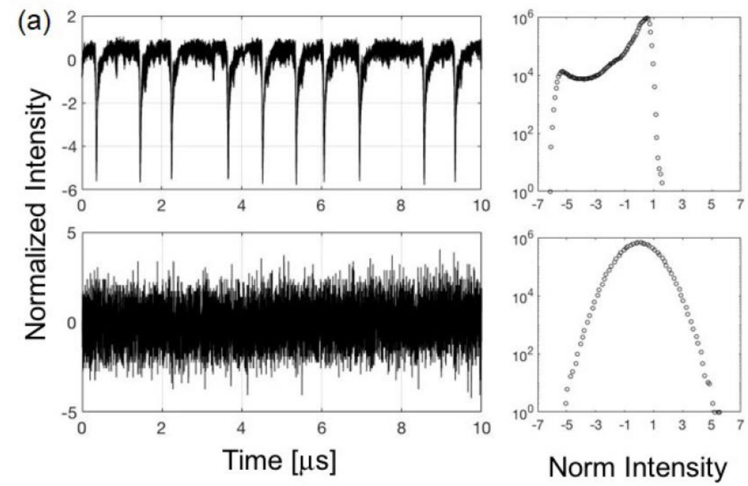




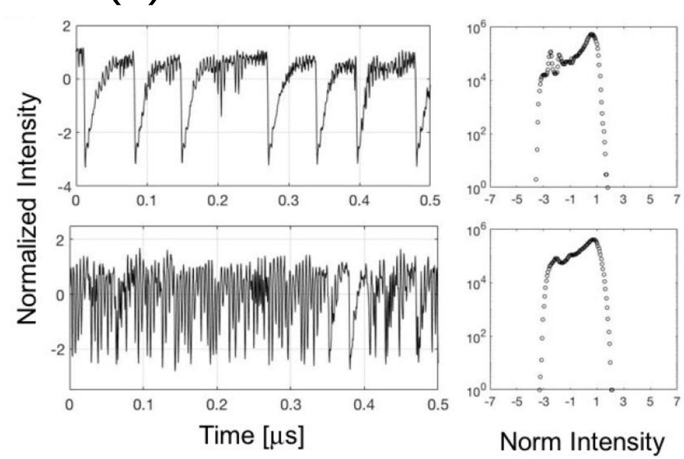


Feedback strength

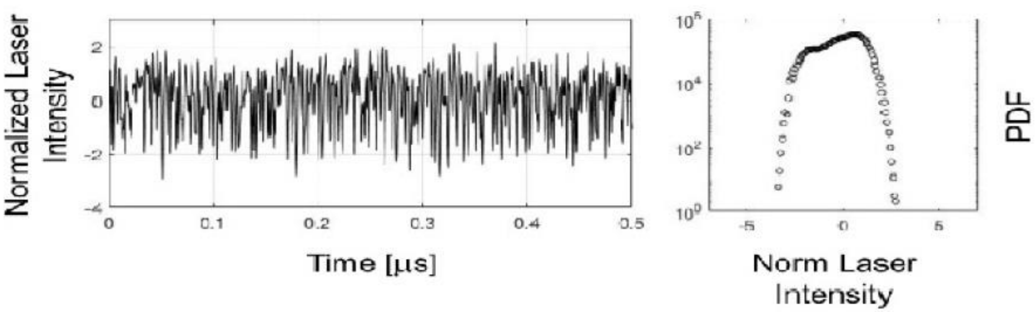
(a) LFF → NOISE



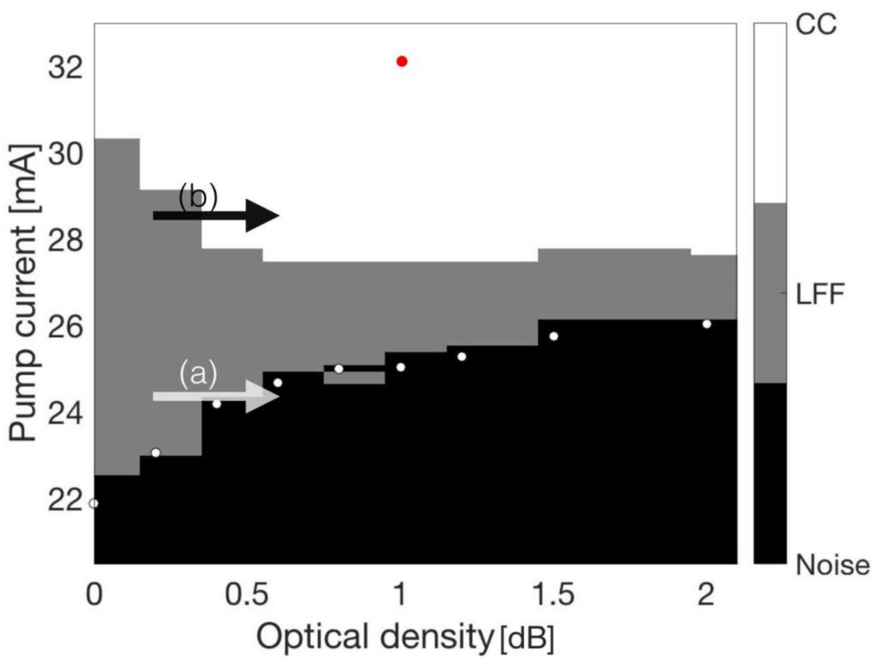
(b) LFF → CC



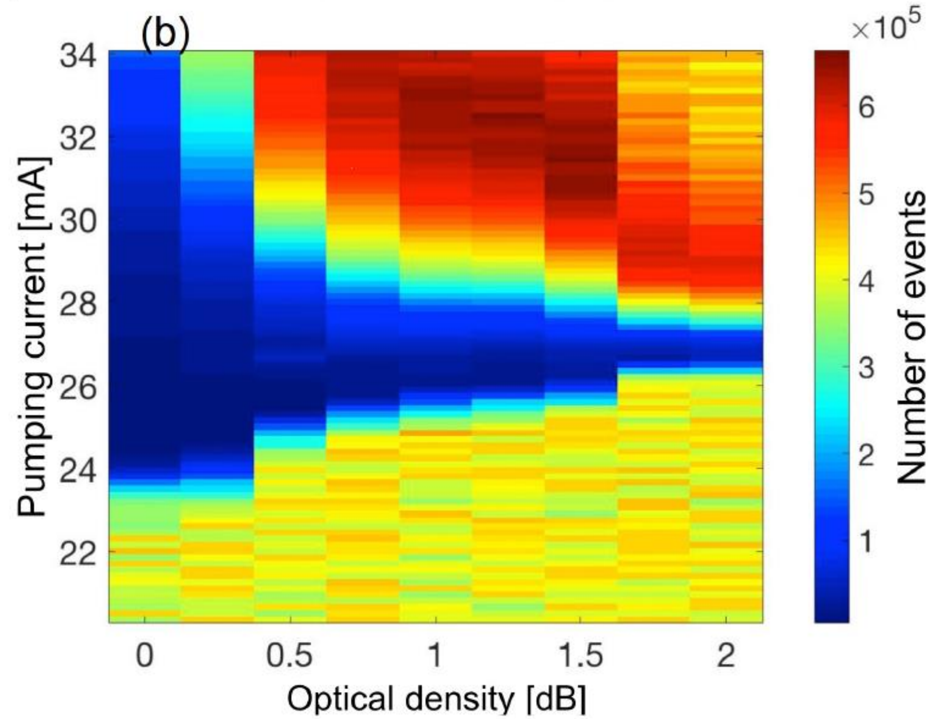
(red dot) fully developed CC



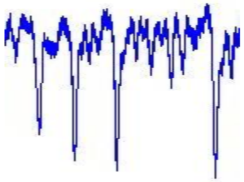
Second method to quantify the boundaries between noise-LFF-CC



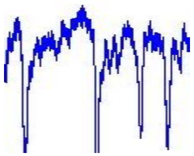
Number of dropouts below -1.5σ



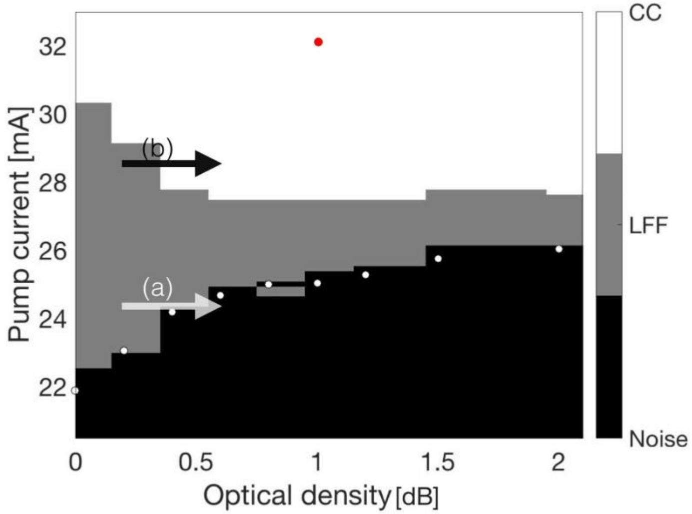
Third method to quantitatively discriminate noise-LFF-CC



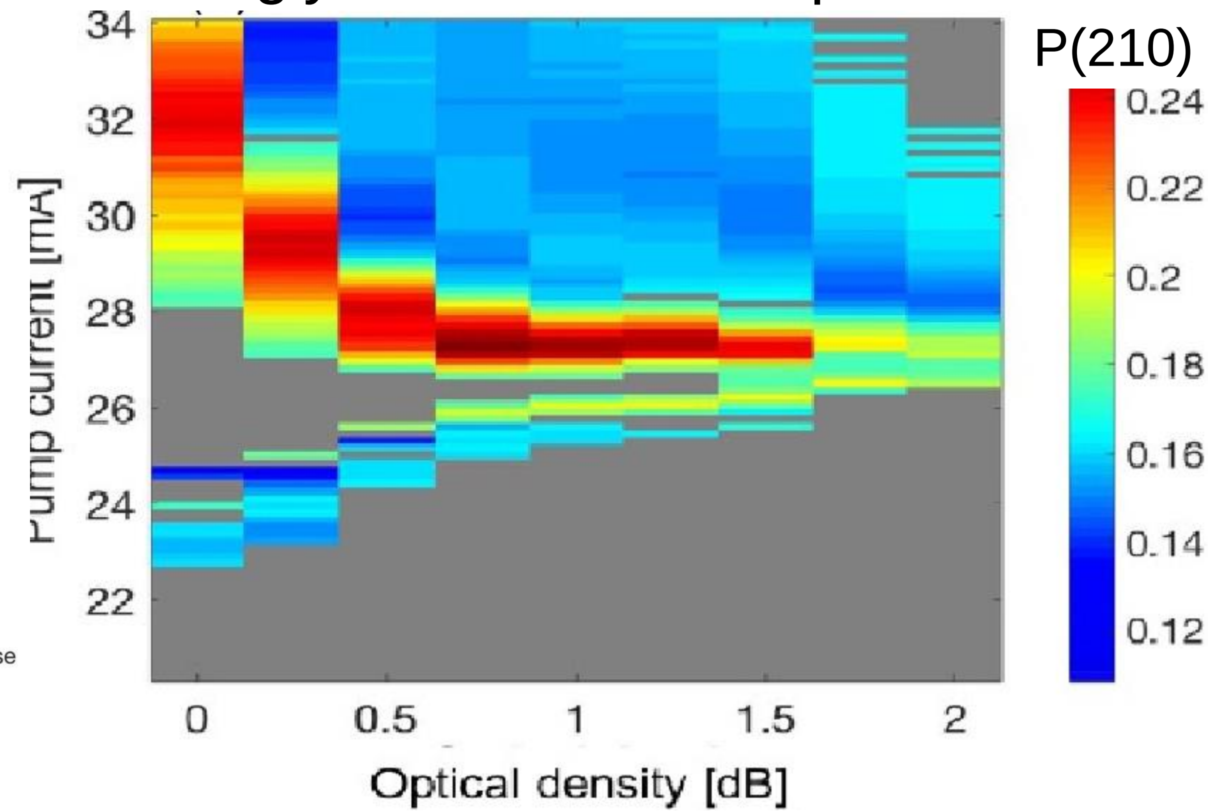
⇒**012**



⇒**210**



Probability of three consecutive increasingly shorter inter-dropout intervals



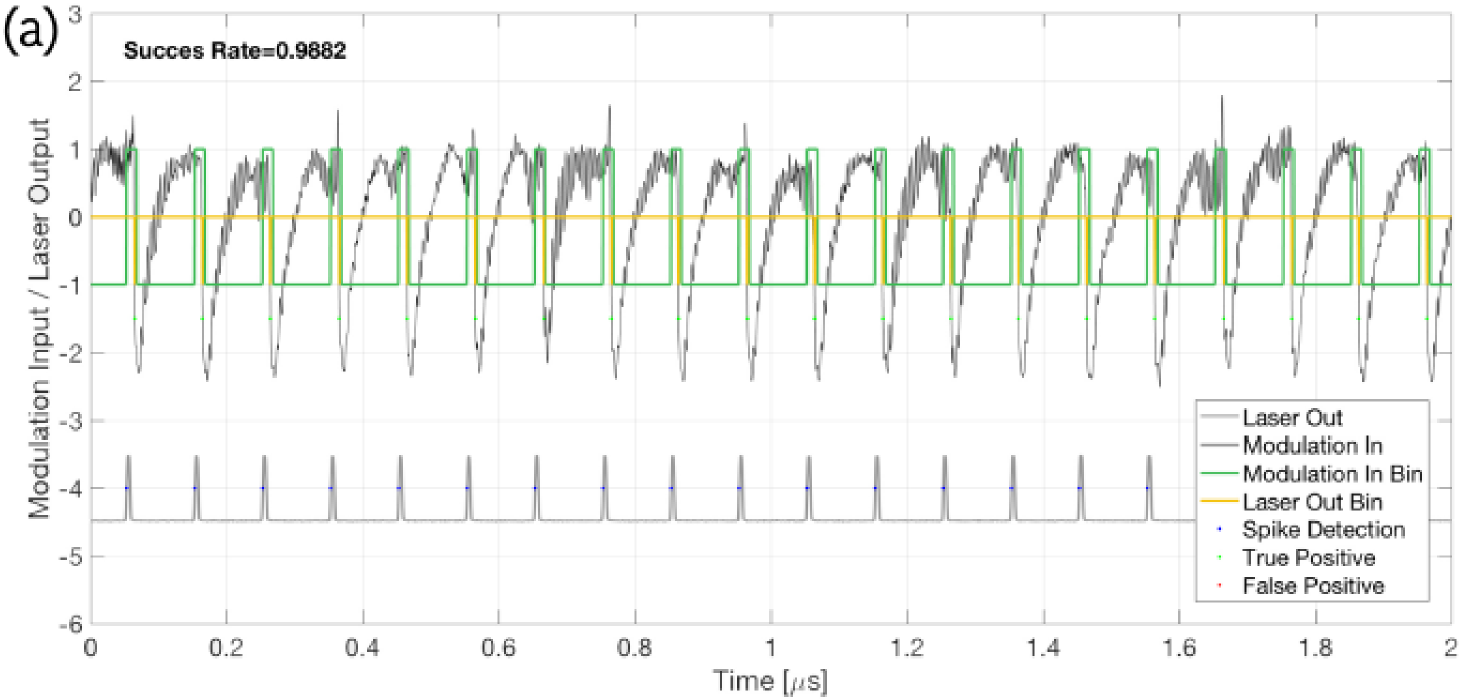
M. Panozzo, C. Quintero-Quiroz, J. Tiana-Alsina, M. C. Torrent, and C. Masoller, "*Experimental characterization of the transition to coherence collapse in a semiconductor laser with optical feedback*", submitted (2017).

- Which waveform is optimal for entraining LFFs?
- Where is easier to entrain the LFFs?

First we need a measure to quantify entrainment

Success rate:
SR = number of dropouts / number of cycles

Extra parameter: Interval τ after each pulse



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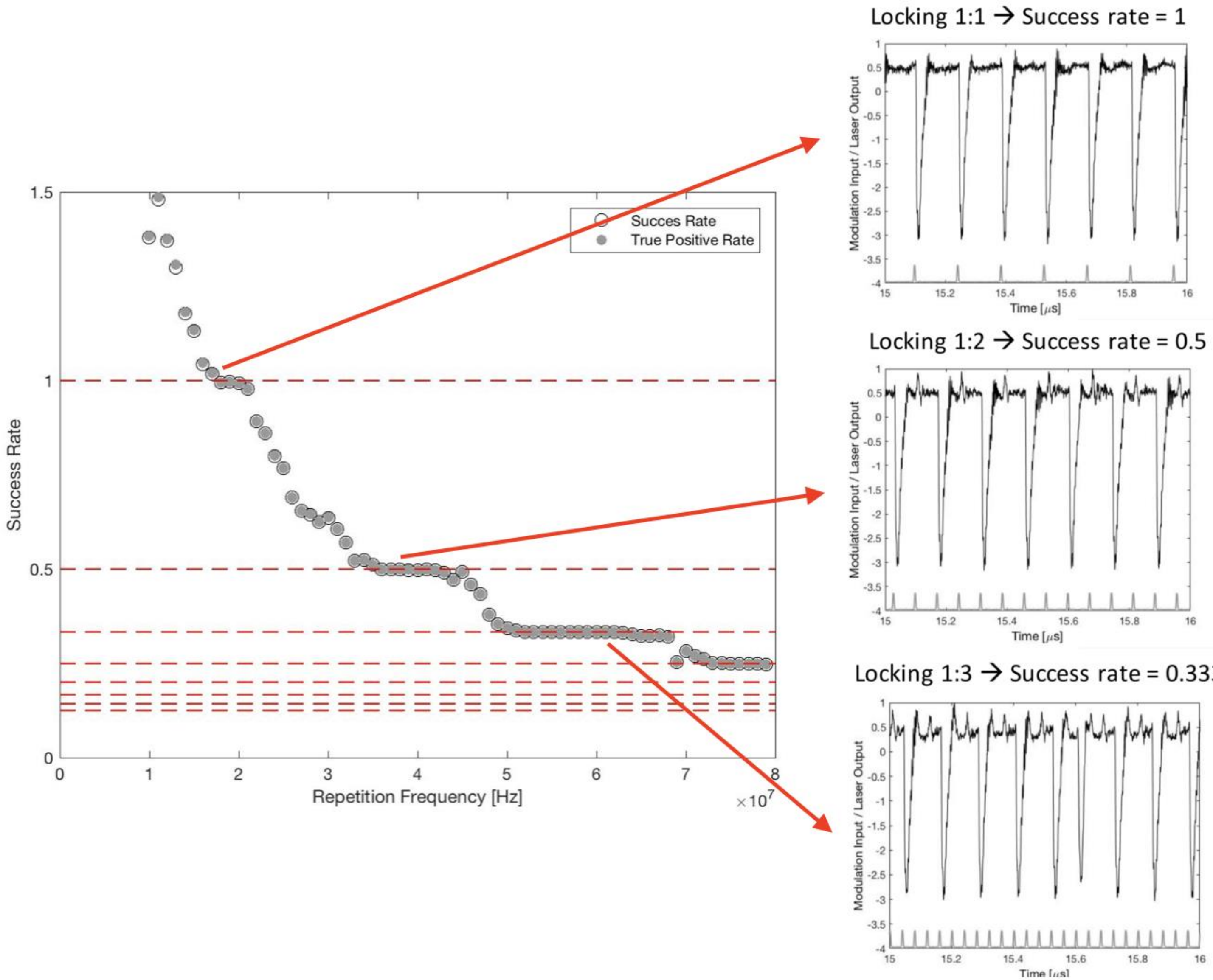
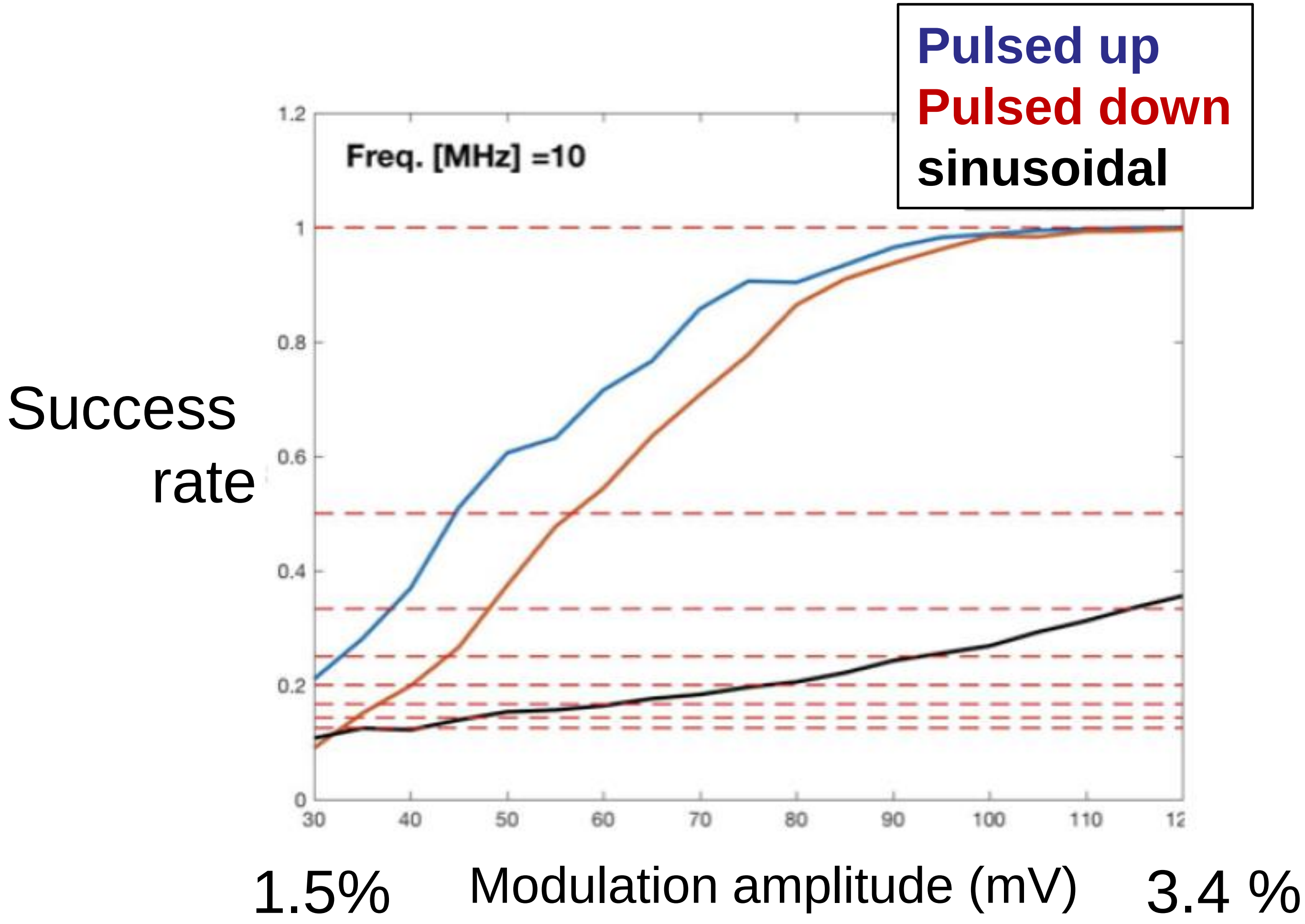
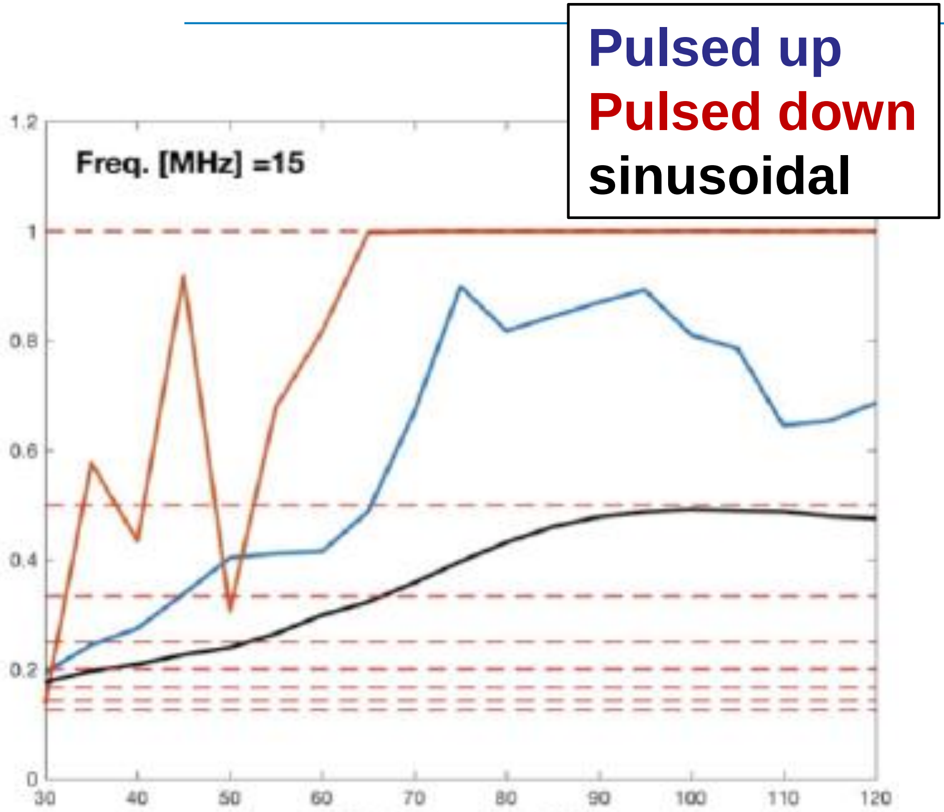
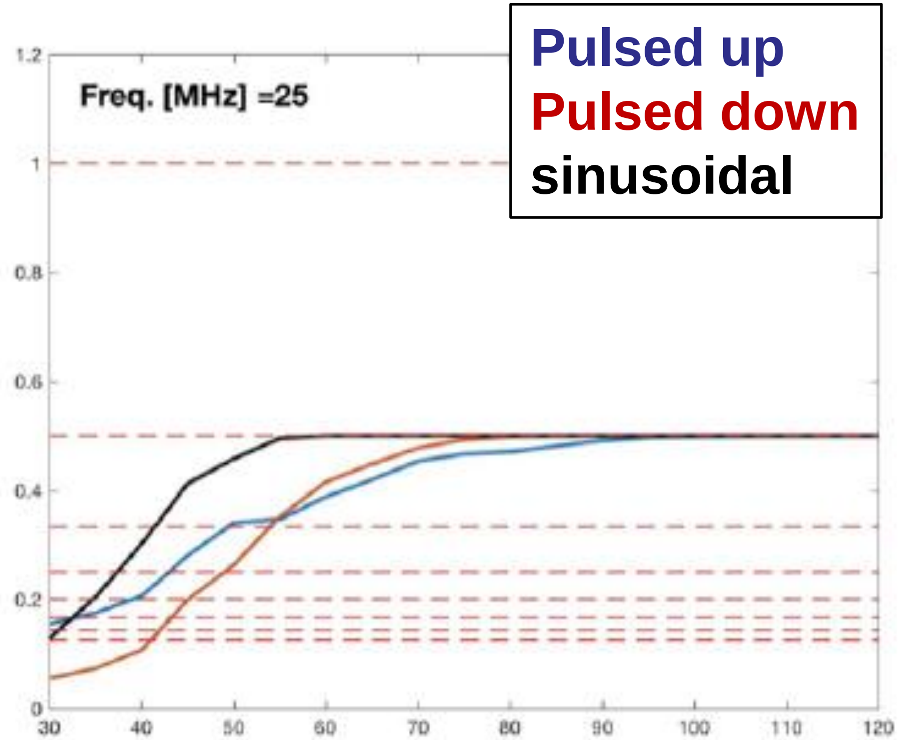
Success rate as a function of the repetition frequency



Comparison of different modulation waveforms




Pulsed up
Pulsed down
sinusoidal
Freq. [MHz] =15
1.2
1
0.8
0.6
0.4
0.2
0
30
40
50
60
70
80
90
100
110
120


Pulsed up
Pulsed down
sinusoidal
Freq. [MHz] =25
1.2
1
0.8
0.6
0.4
0.2
0
30
40
50
60
70
80
90
100
110
120

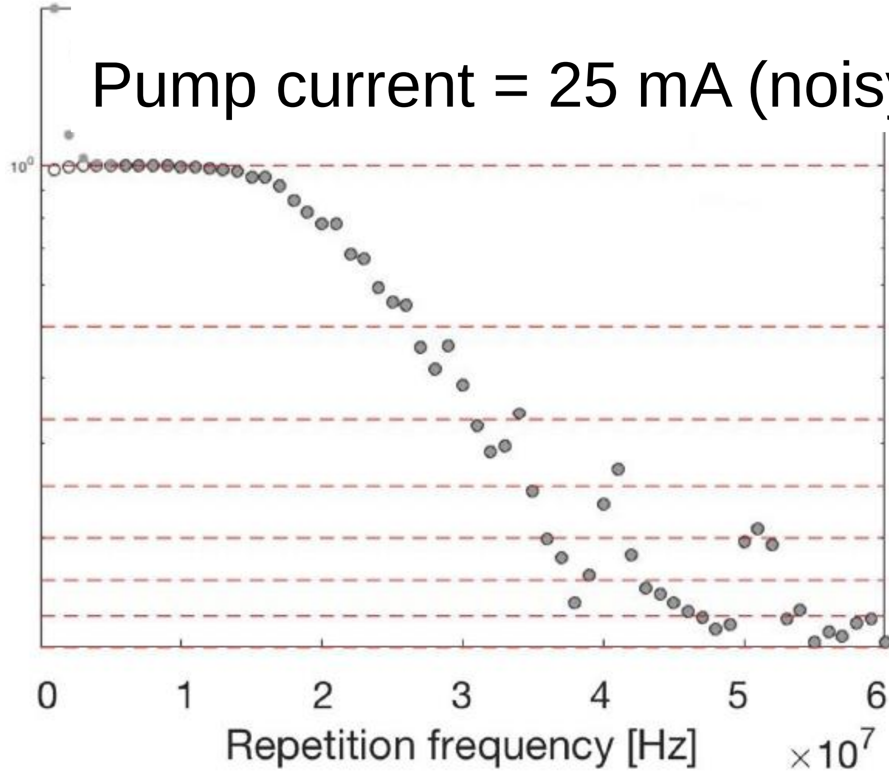
Where is easier to entrain LFFs?

Using the inverted pulsed waveform

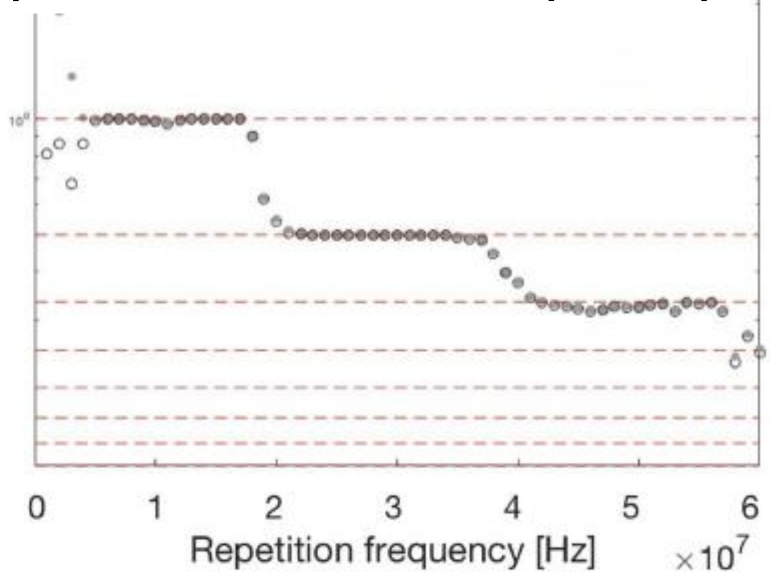
Pump current = 25 mA (noisy LFFs)

Locking 1:1

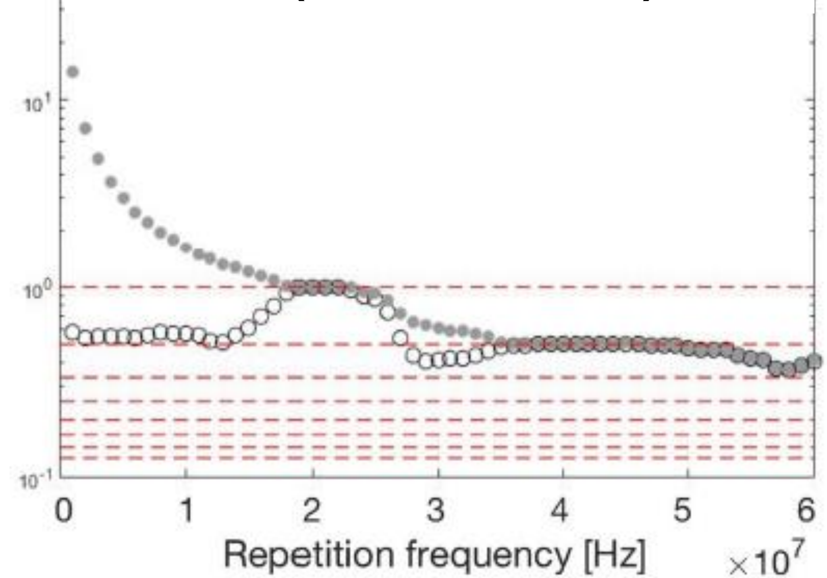
Success rate



Pump current = 26 mA (LFFs)



27 mA (onset of CC)



Conclusions

- "Pulse up" and "pulse down" waveforms produce locking 1:1, 1:2, 1:3; with sinusoidal locking at 1:1 not seen.
- Inverted pulse: lower amplitude needed to obtain locking.
- Locking is easier in the region of well-defined LFFs.

Thank you for your attention !

J. Tiana-Alsina et al, "Optimal entrainment of LFF dropouts", in preparation (2017)

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