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# Pulse Doublets Generated by a Frequency-Shifting Loop Containing an Electro-Optic Amplitude Modulator

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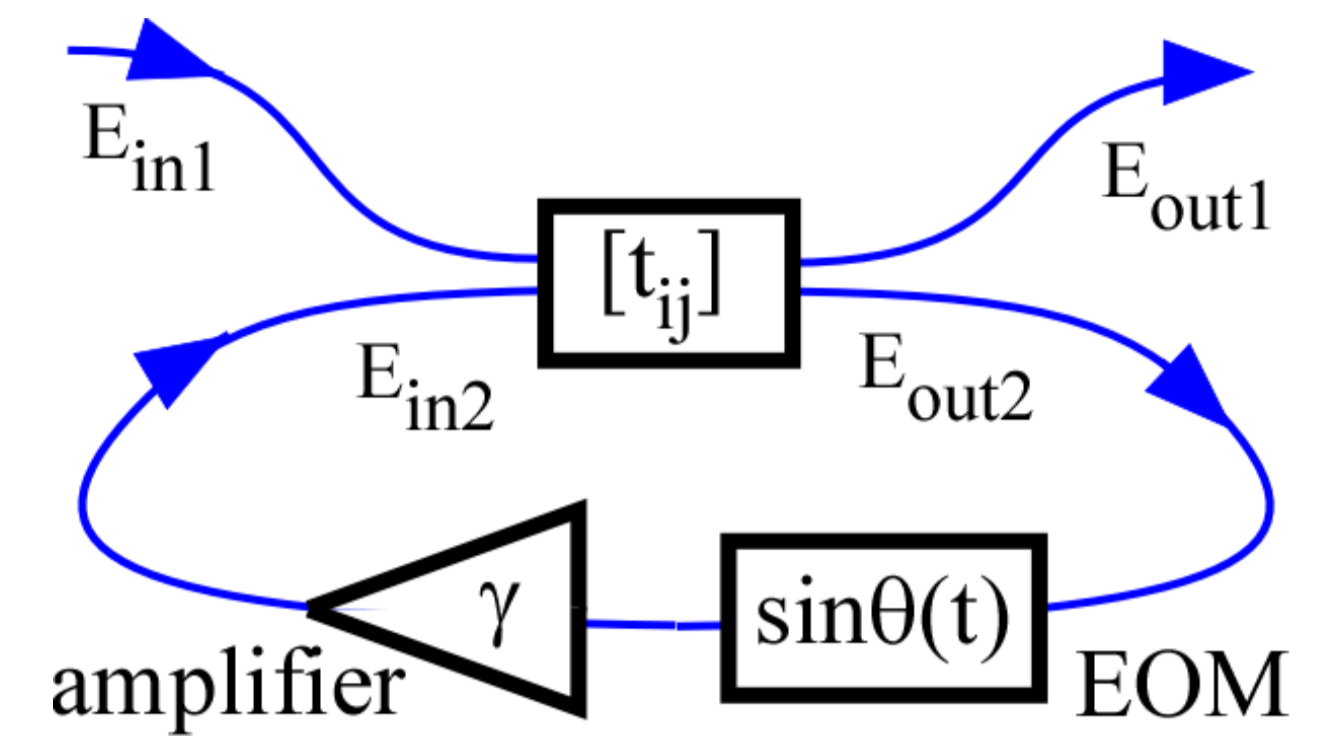
## Introduction

Frequency-Shifted feedback Loops FSL, both active or passive, are promising solutions for pulse generation with high repetition rate. FSL usually contains an acousto-optic frequency shifter AOFS for single-side band modulation [1-3]. This leads to limited tunability and low modulation frequency  $f_m$ .

**Conversely:** the use of in-loop electro-optic amplitude modulators EOM permits high modulation, wide bandwidth and integration [4-5].

However, due to dual-side band modulation, EOM lead to new regimes

→ Here, theoretical and experimental study of FSL with EOM



## Theoretical model

$E_{in1}$  CW:

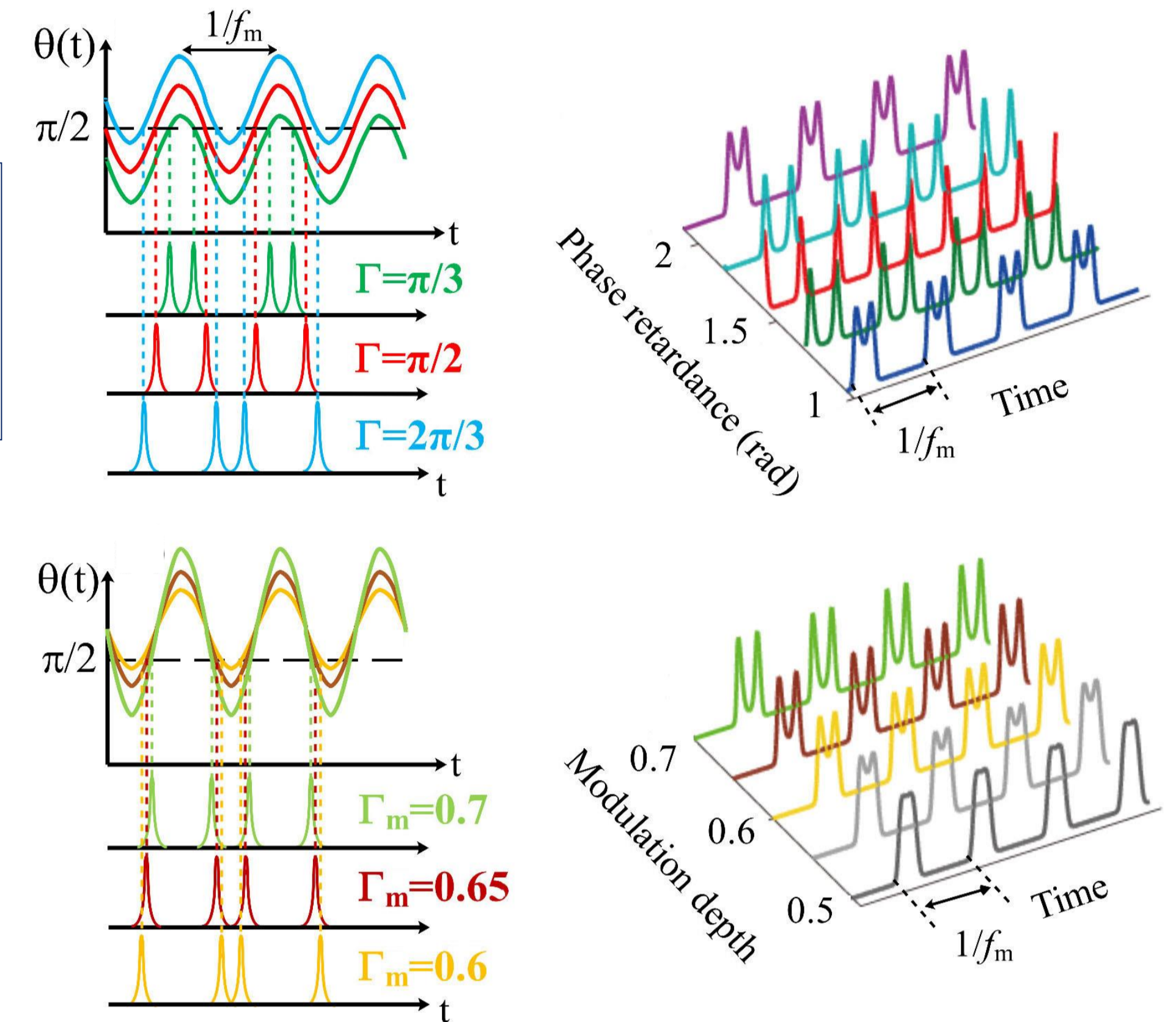
$$E_{out1}(t) = \left( t_{11} + t_{12}t_{21} \sum_{p=1}^N \left( t_{22}^p \gamma^p \prod_{q=1}^p \sin(\theta(t - q\tau)) \right) \right) E_{in1}$$

With modulation at  $f_m$ :  $\theta(t) = \Gamma + \Gamma_m \sin(2\pi f_m t)$   $\Gamma$  phase retardance,  $\Gamma_m$  modulation depth

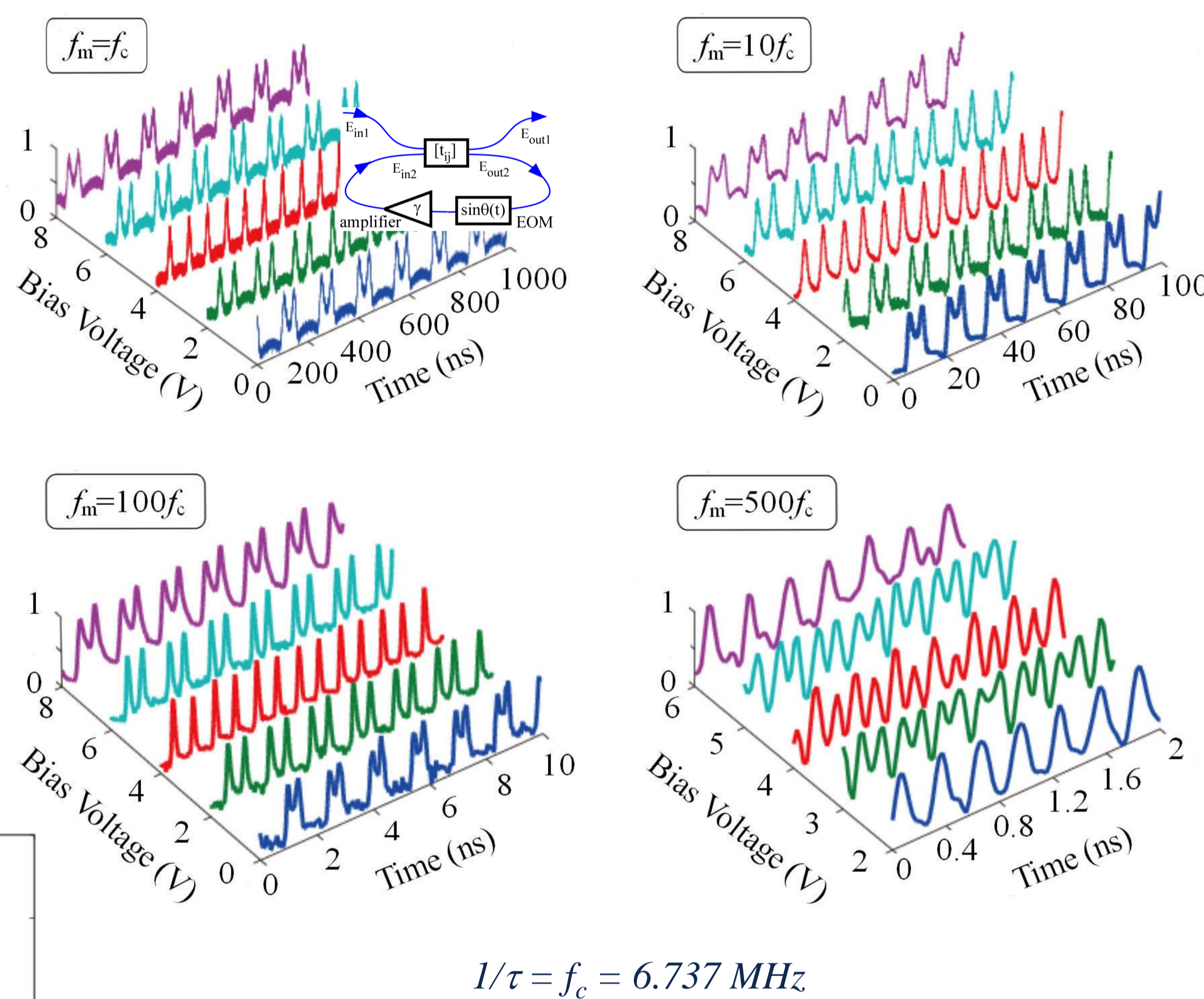
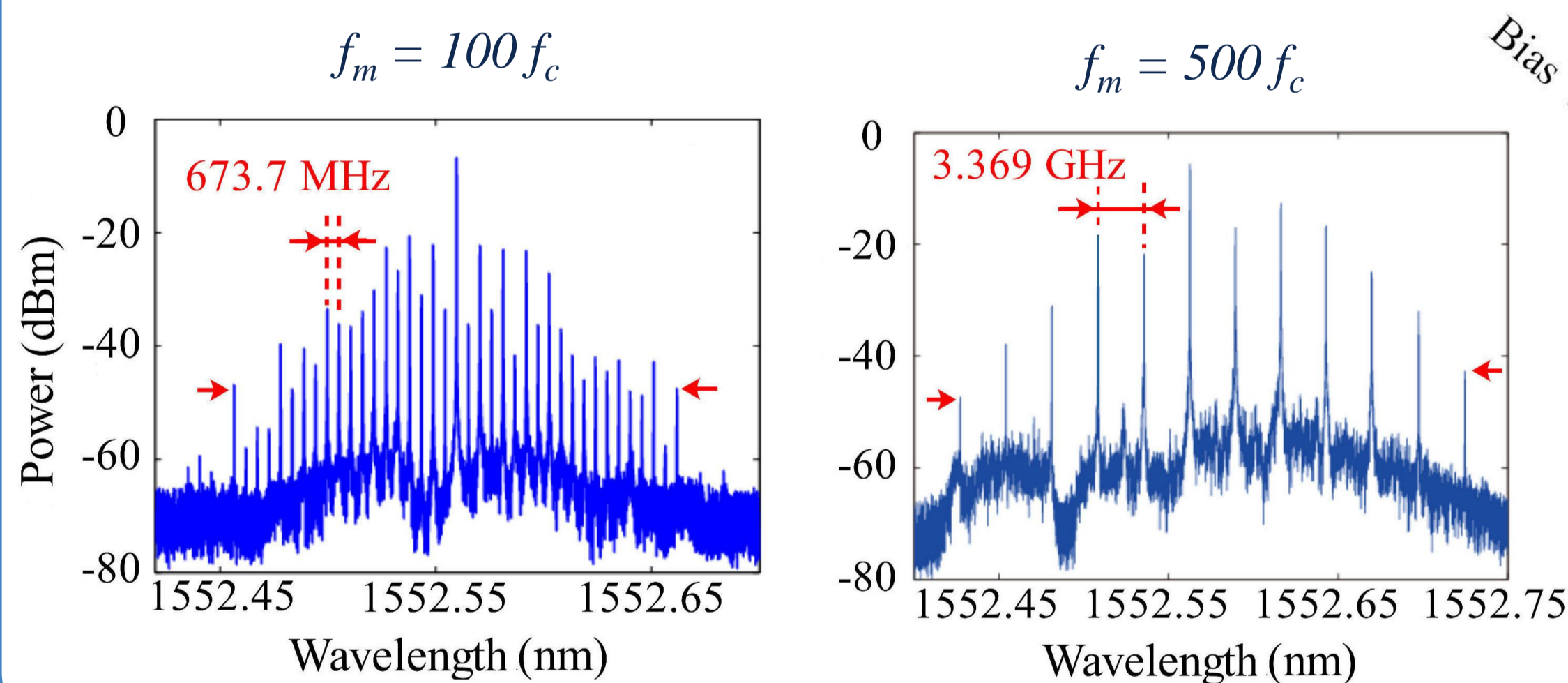
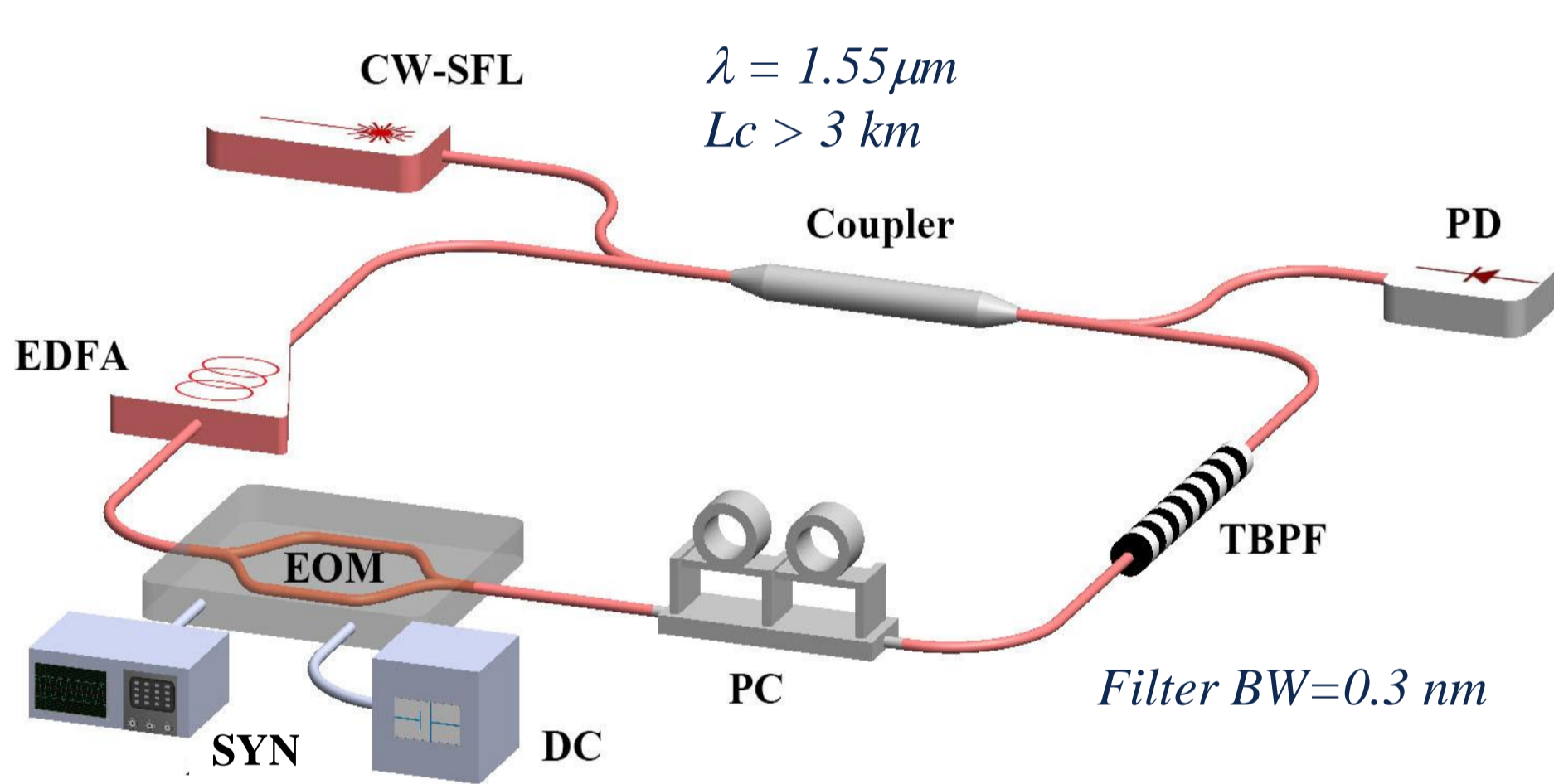
For integer Talbot condition [1-2]:  $f_m = n/\tau$

If  $N \gg 1$   $E_{out1}(t) = \frac{t_{11} - \gamma(t_{11}t_{22} - t_{12}t_{21}) \sin \theta(t)}{1 - \gamma t_{22} \sin \theta(t)} E_{in1}$   $\rightarrow$   $E_{out1}$  pulsed for  $\theta(t) \approx \pi/2$   
2 pulses per period  $1/f_m$

Parameters  
 $[t] = \begin{bmatrix} 0.44 & 0.65i \\ 0.43i & 0.67 \end{bmatrix}$   
 $N = 30$   
 $\gamma = 0.9$



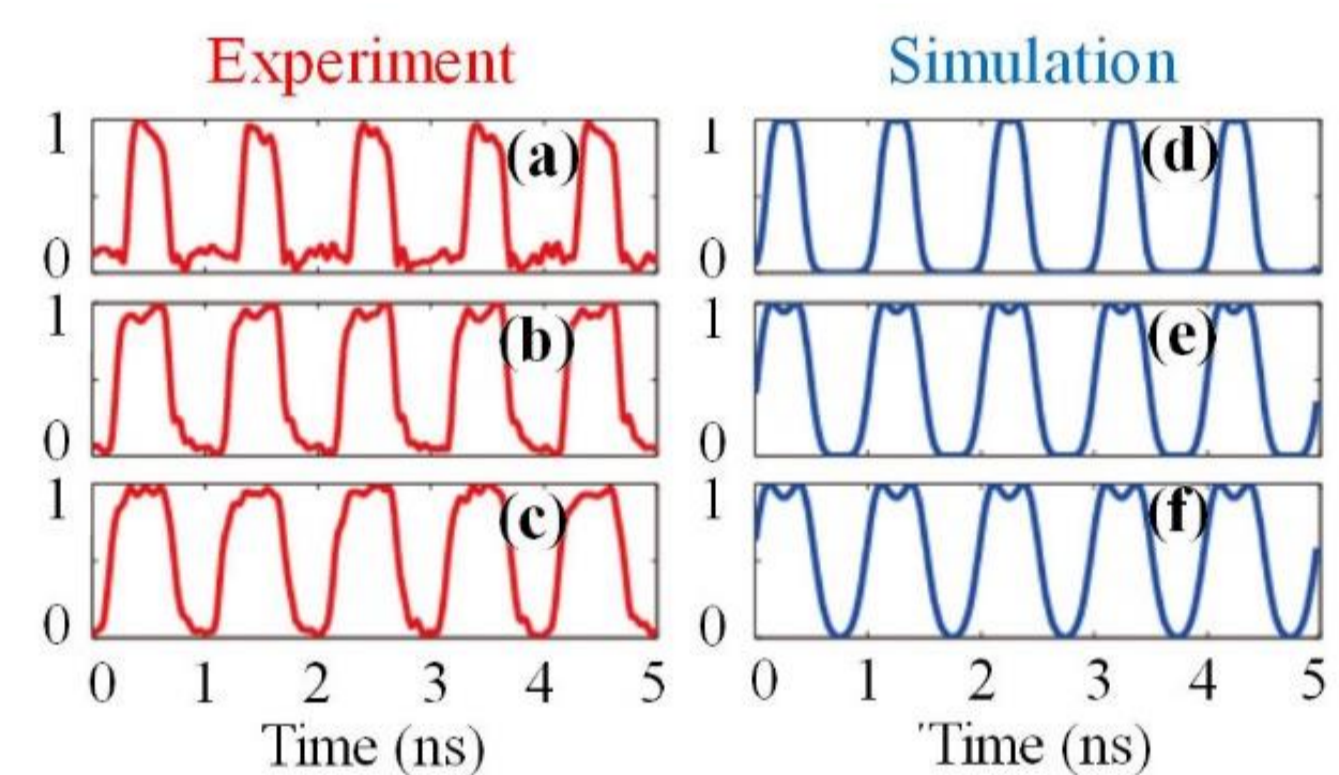
## Experimental results



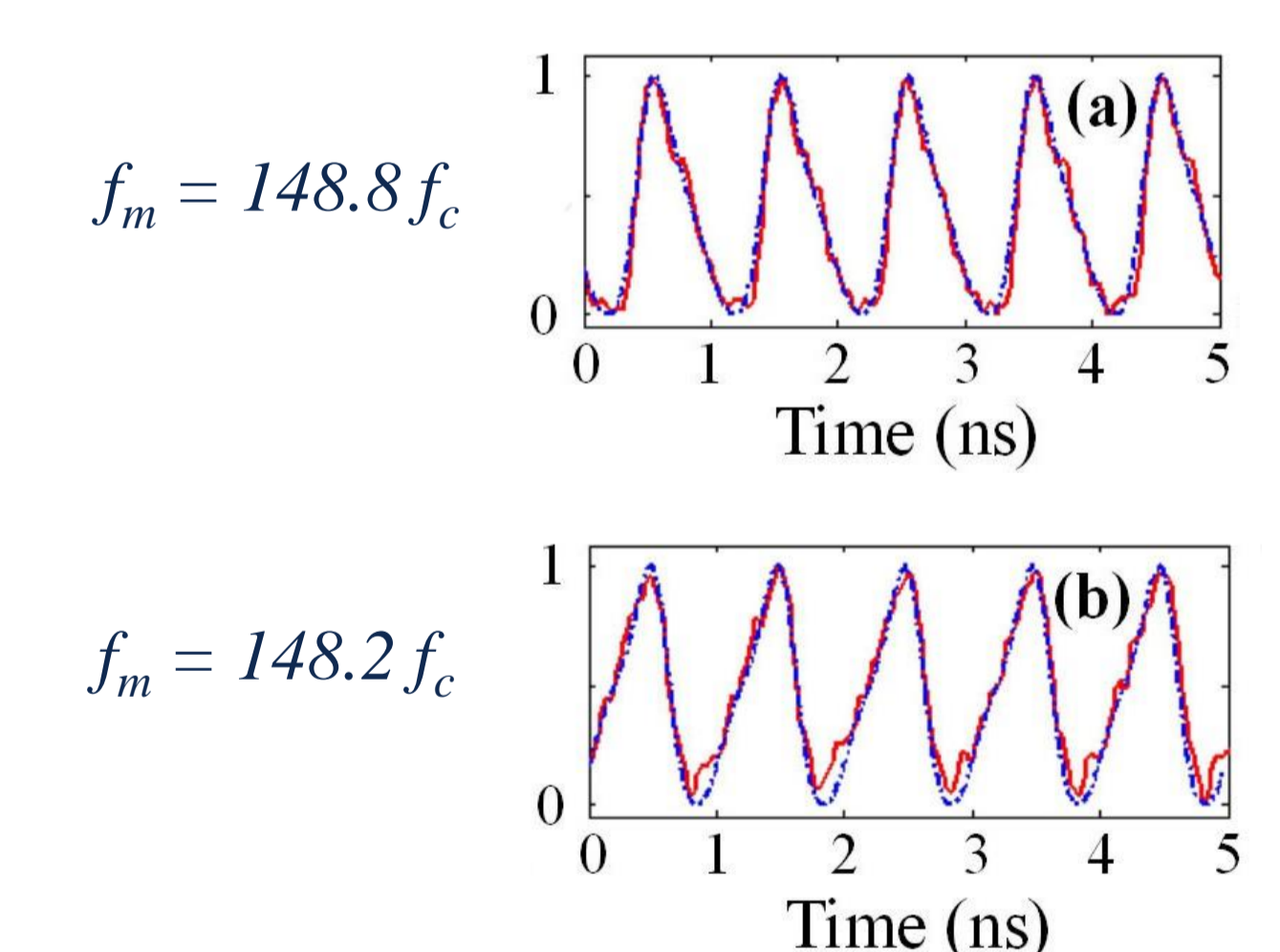
( H. Yang et al , Optics Express, revision )

## Waveform generation

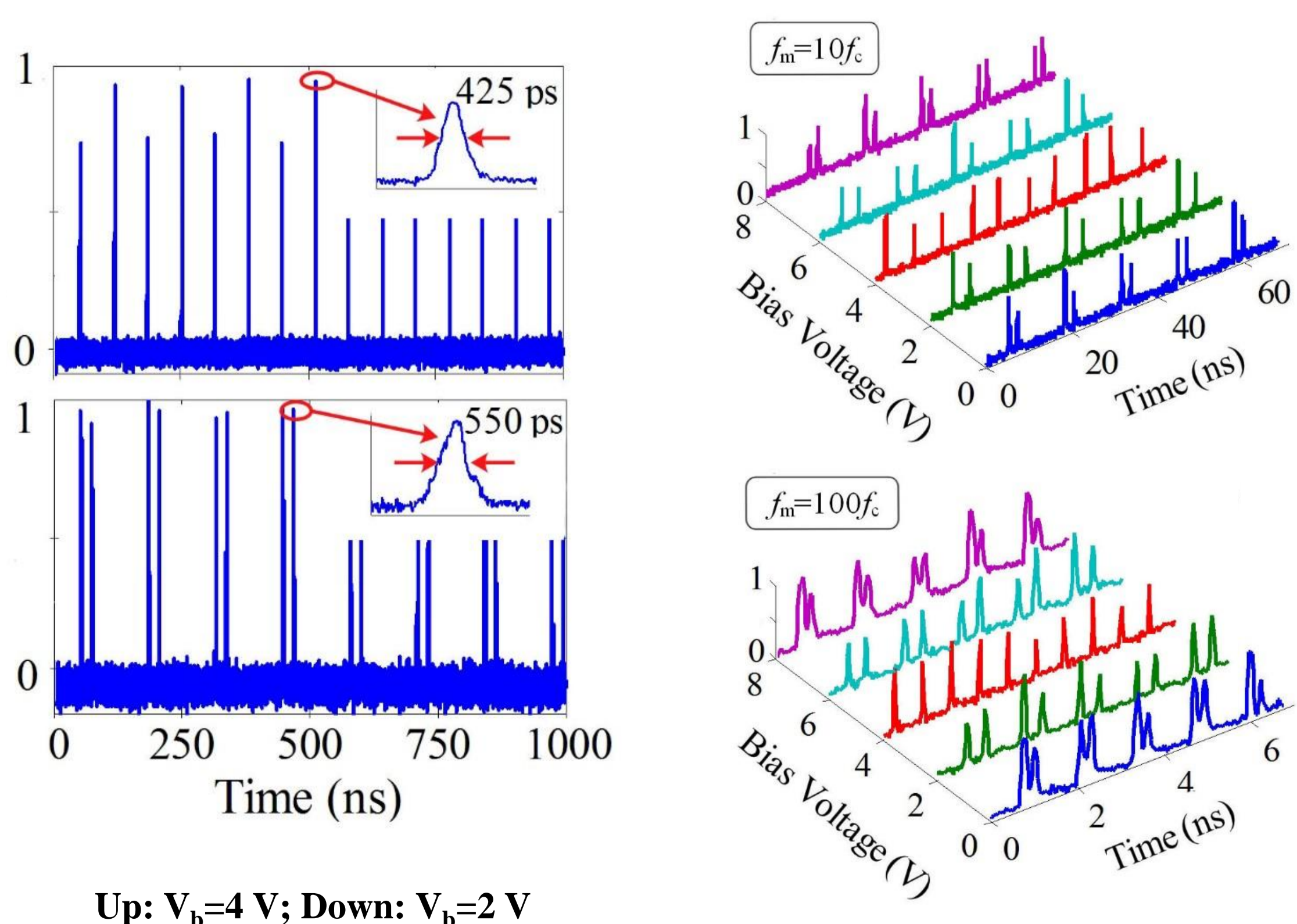
Rectangular shape



Sawtooth waveform



## Mode-locked double-pulse regime



Up:  $V_b = 4$  V; Down:  $V_b = 2$  V

## Conclusion

- Observation of original double-pulse regime
- Theoretical model in agreement with experiments
- Repetition-rate tunability from MHz to GHz
- frequency comb width up to 40 GHz
- waveform generation: rectangle, sawtooth,...

## Forthcoming

- Phase modulation vs intensity modulation
- Frequency-to-time mapping (as in [6] with AOFS)
- Repetition-rate tunability from MHz to GHz
- Fractional Talbot condition  $f_m = p/q f_c$ : towards high repetition rates

## References

- [1] H.G. de Chatellus et al, Phys. Rev. A 2013 [4] L. Wang et al, CLEO 2017  
 [2] C. Schnébelin et al, CLEO 2017 [5] F. Tian, IEEE J. Lightwave Technol. 2011  
 [3] H. Yang et al, IEEE Photon. J. 2017 [6] H.G. de Chatellus et al, Optica 2016