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## **GHz-rate pulse pairs generated by a frequency-shifting loop containing an electro-optic modulator**

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► **To cite this version:**

Hongzhi Yang, Marc Brunel, Marc Vallet, Haiyang Zhang, Changming Zhao. GHz-rate pulse pairs generated by a frequency-shifting loop containing an electro-optic modulator. Journée du Club Optique et Micro-ondes (JCOM 2019), Jun 2019, Brest, France. hal-02470354

**HAL Id: hal-02470354**

**<https://hal.science/hal-02470354v1>**

Submitted on 12 Feb 2020

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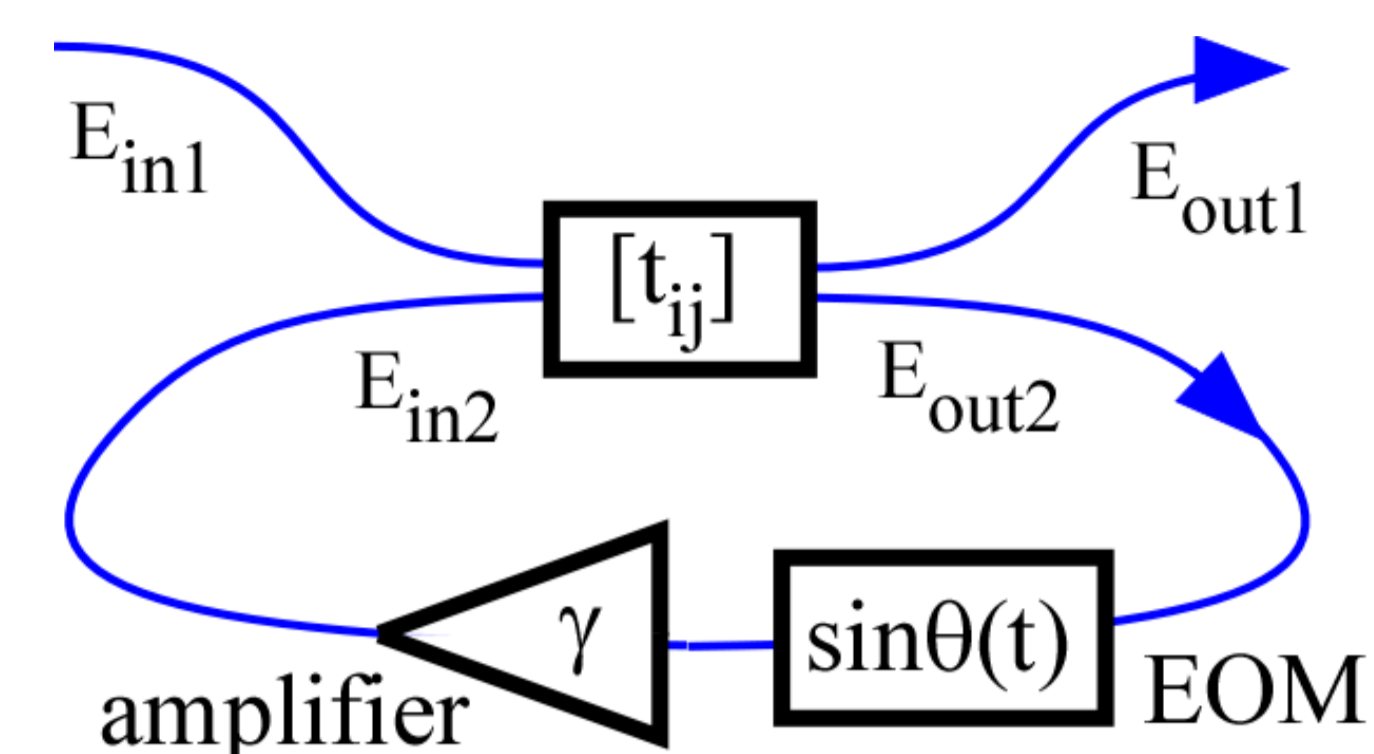
## Introduction

Frequency-shifted feedback loops, both active or passive, are promising solutions for pulse generation with high repetition rate. FSFL usually contains an acousto-optic frequency shifter AOFS for single-side band modulation [1-3]. This leads to poor 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 FSFL with EOM



## Theoretical model $E_{in1}$ cw + modulation at $f_m$

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

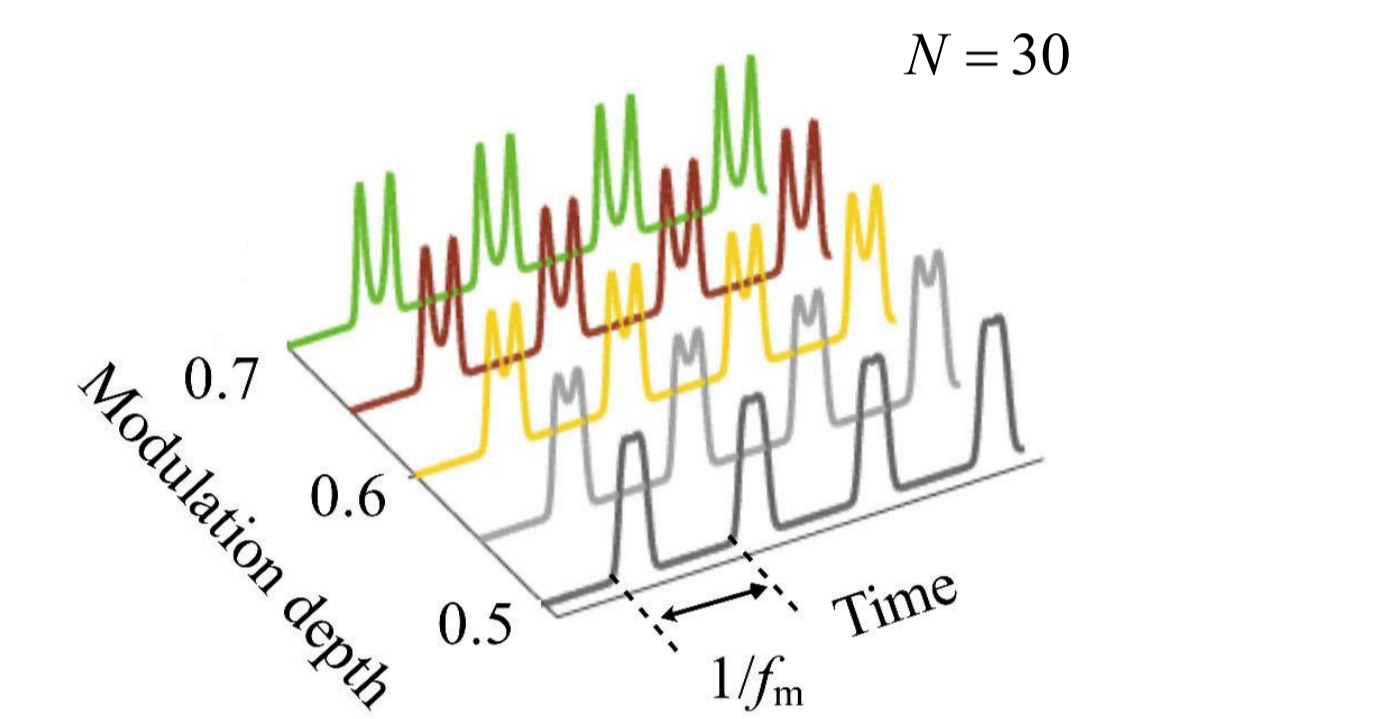
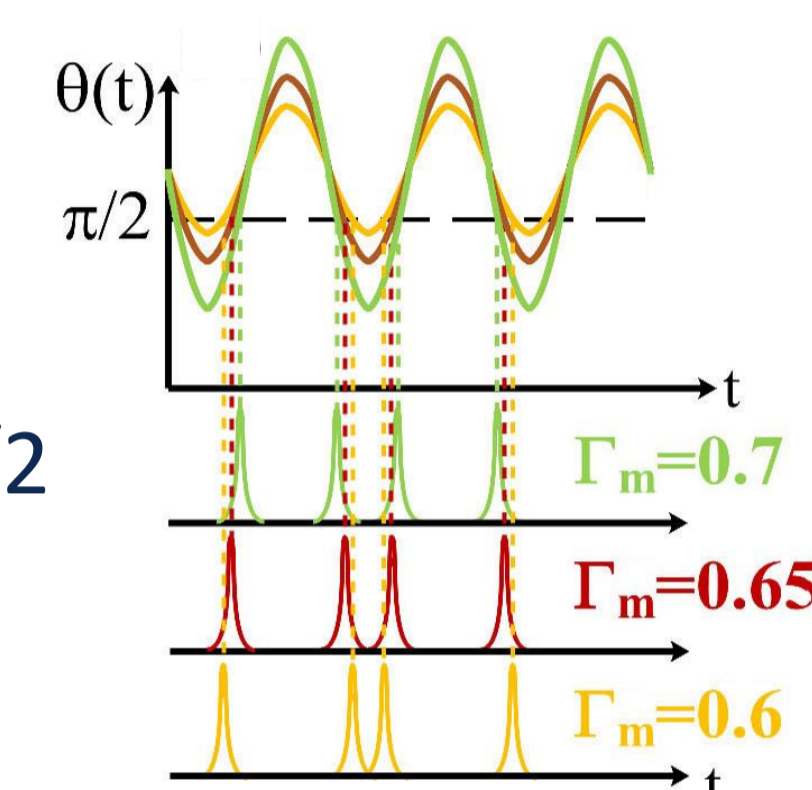
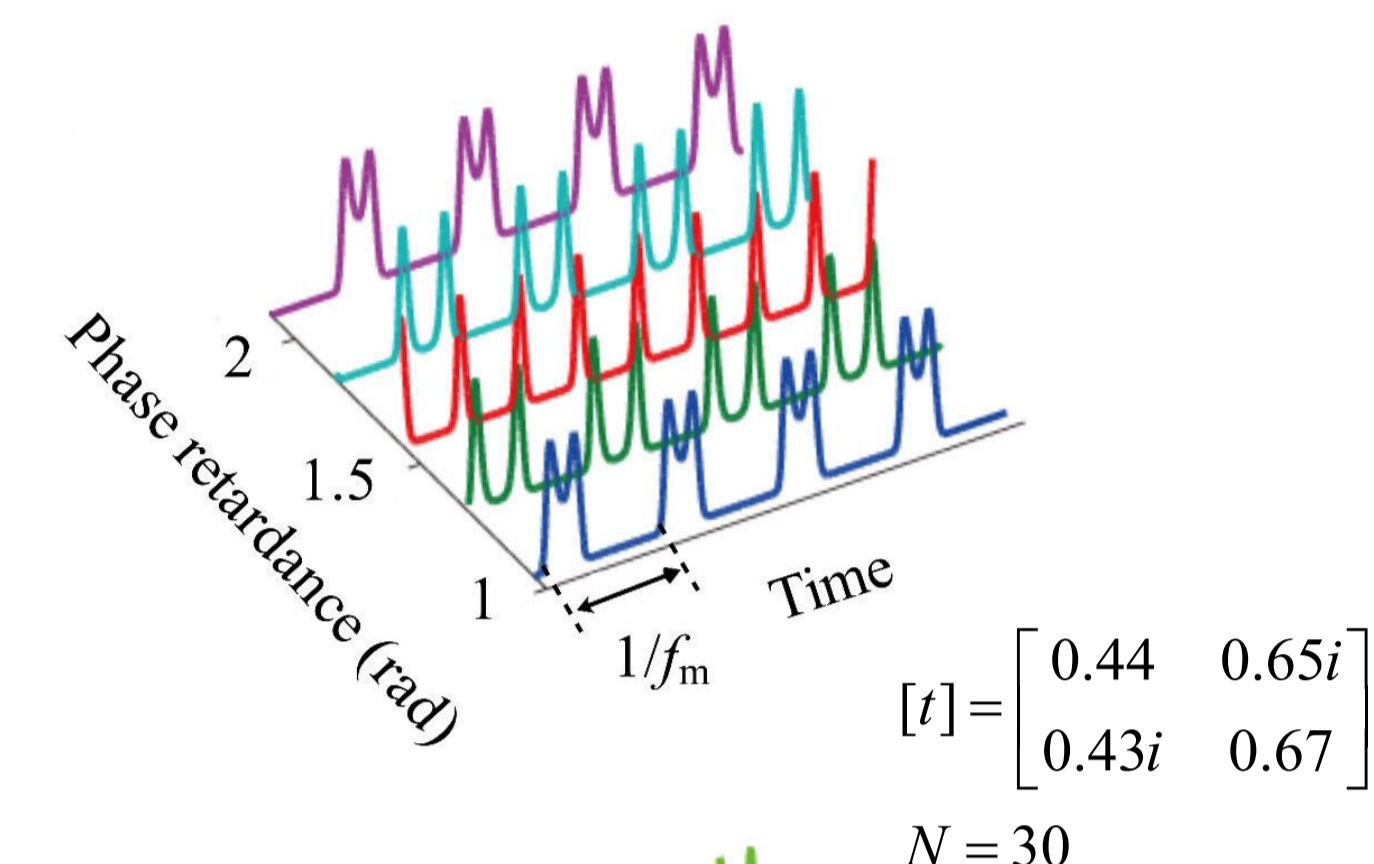
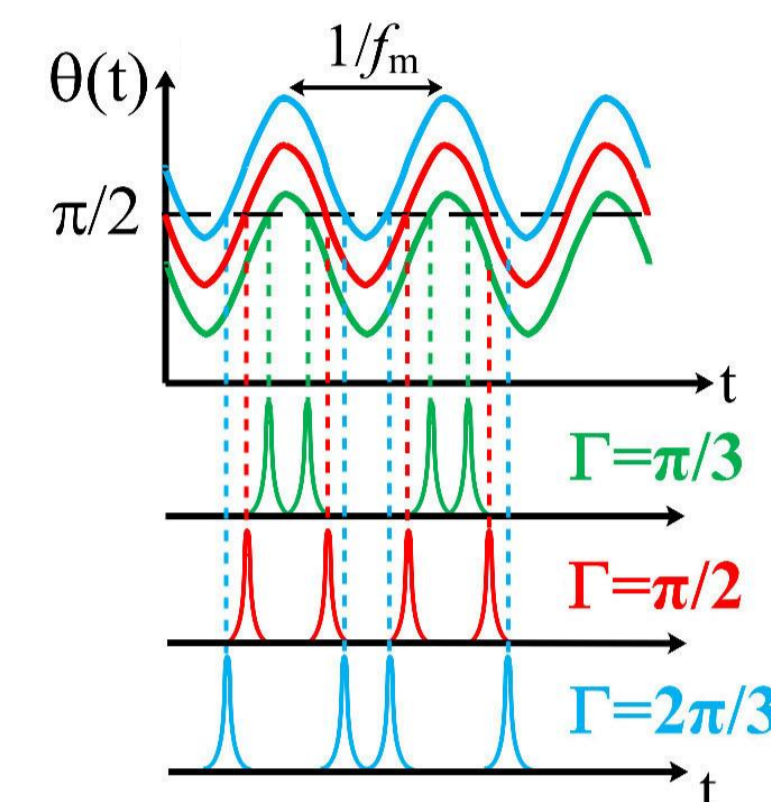
$$\theta(t) = \Gamma + \Gamma_m \sin(2\pi f_m t)$$

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

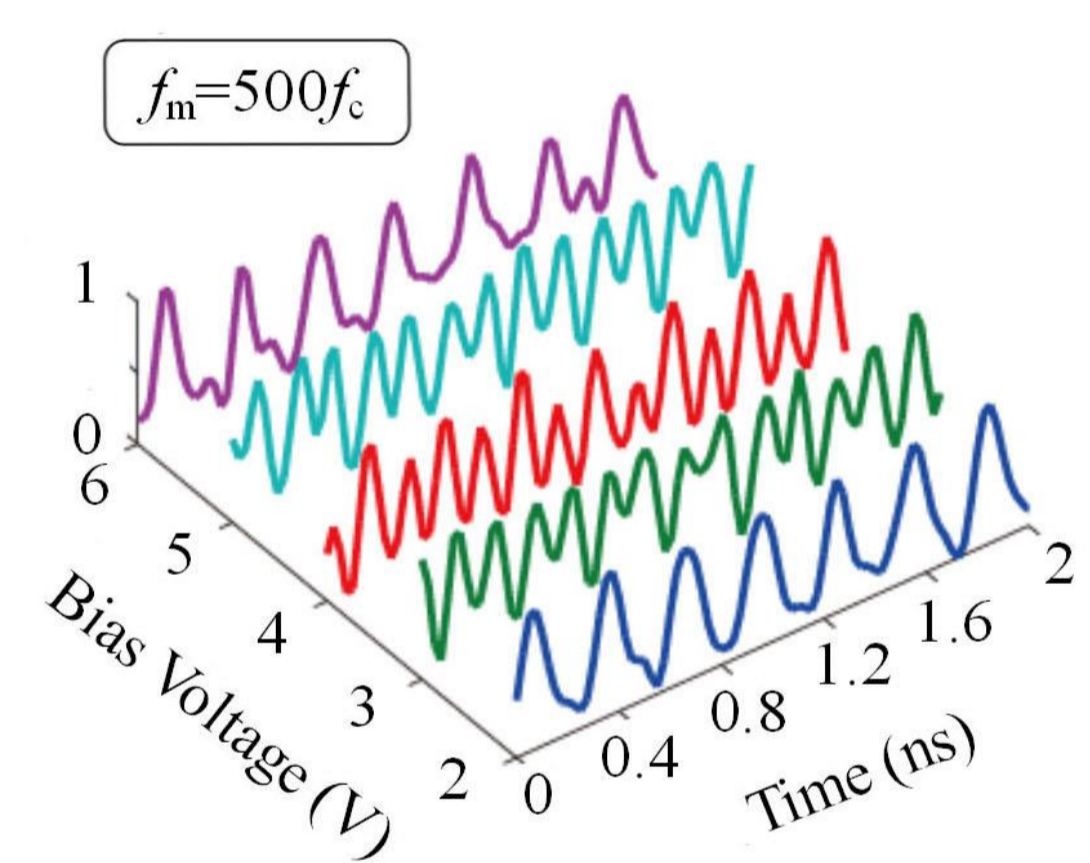
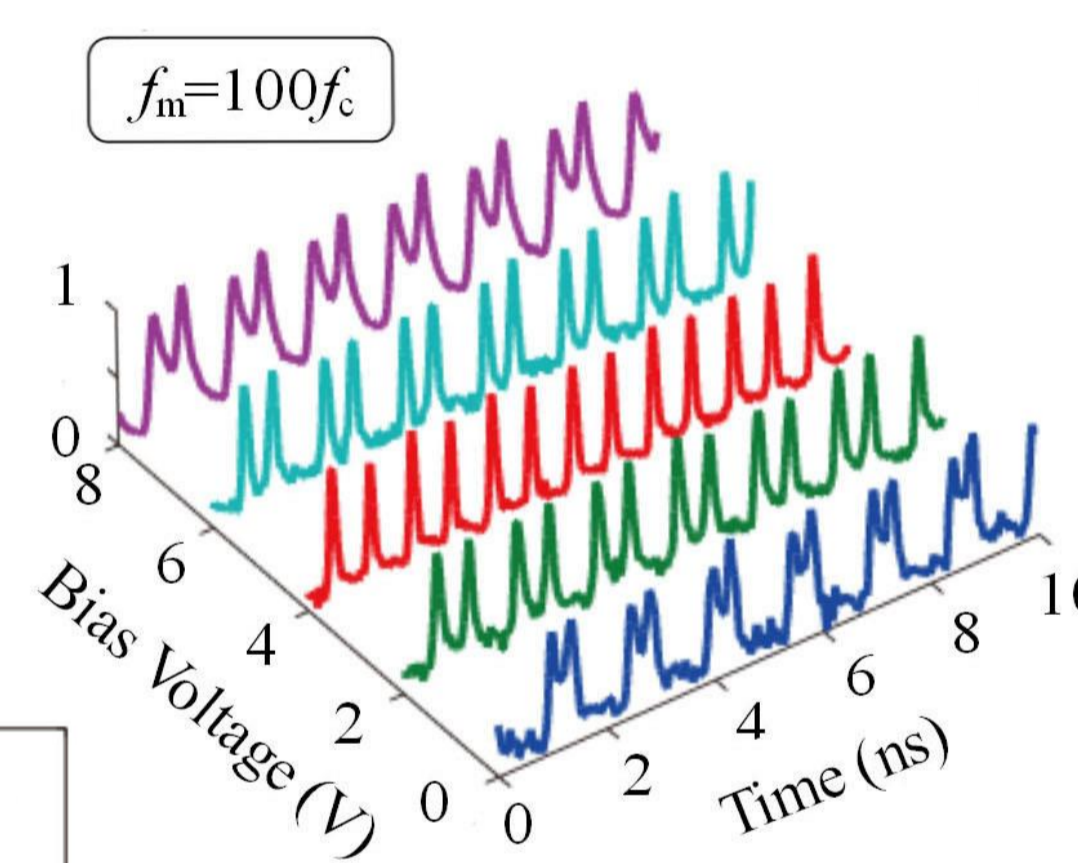
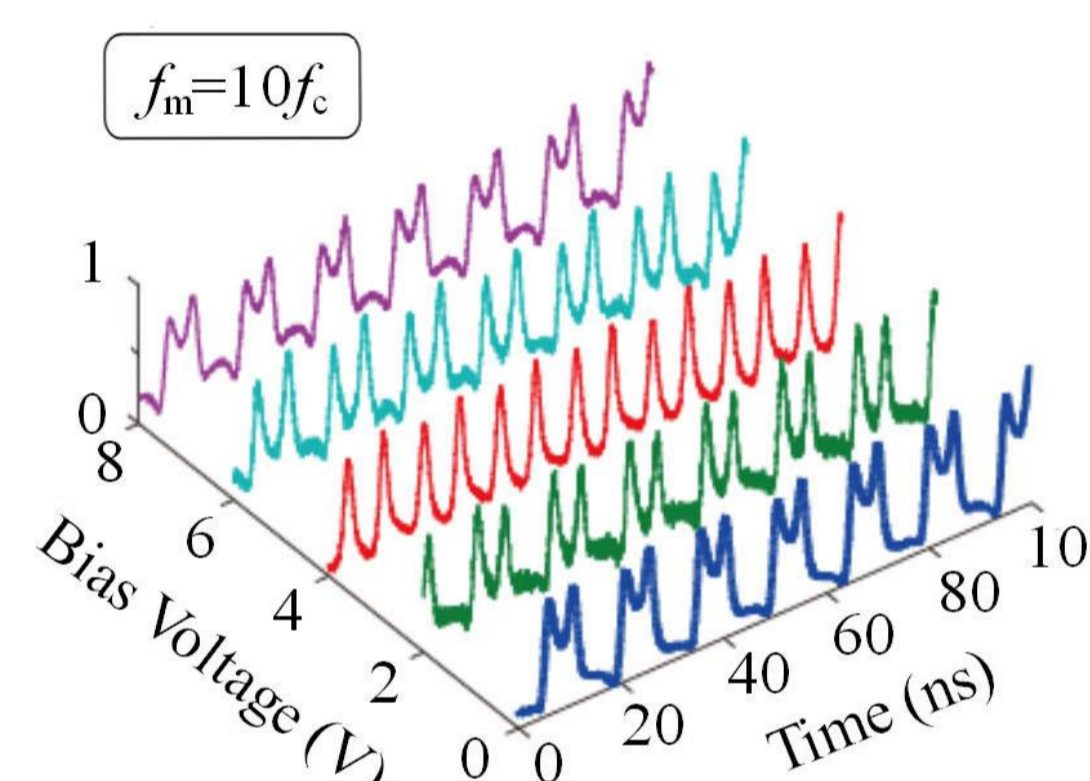
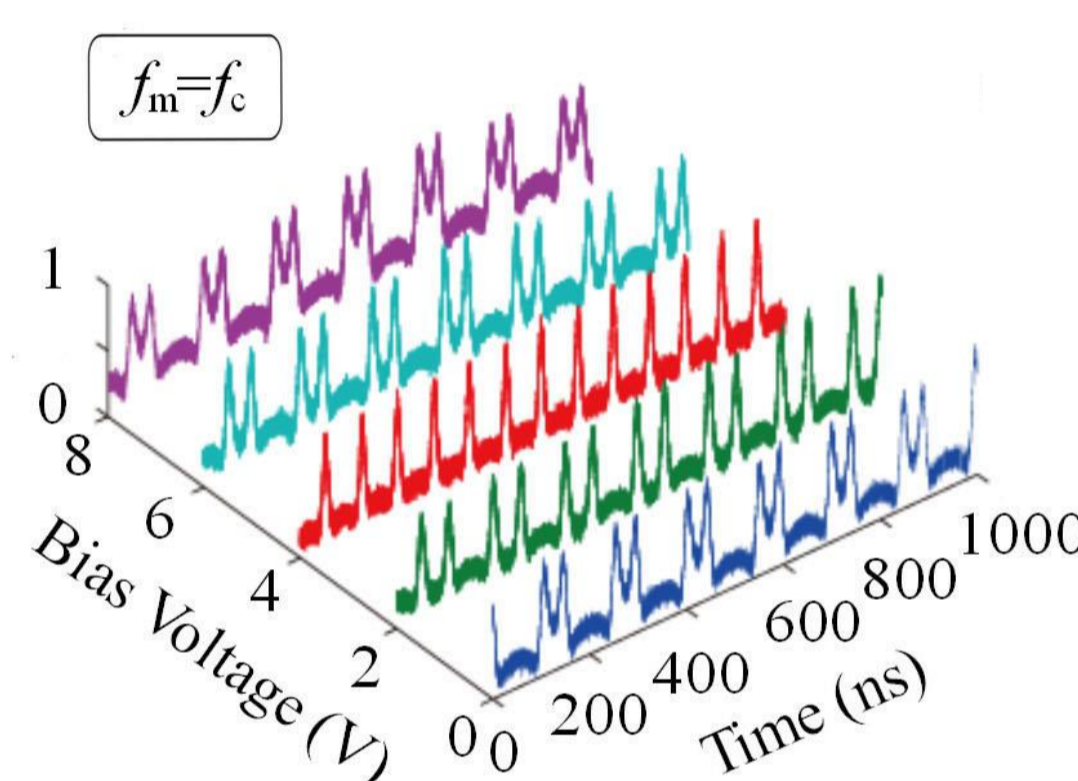
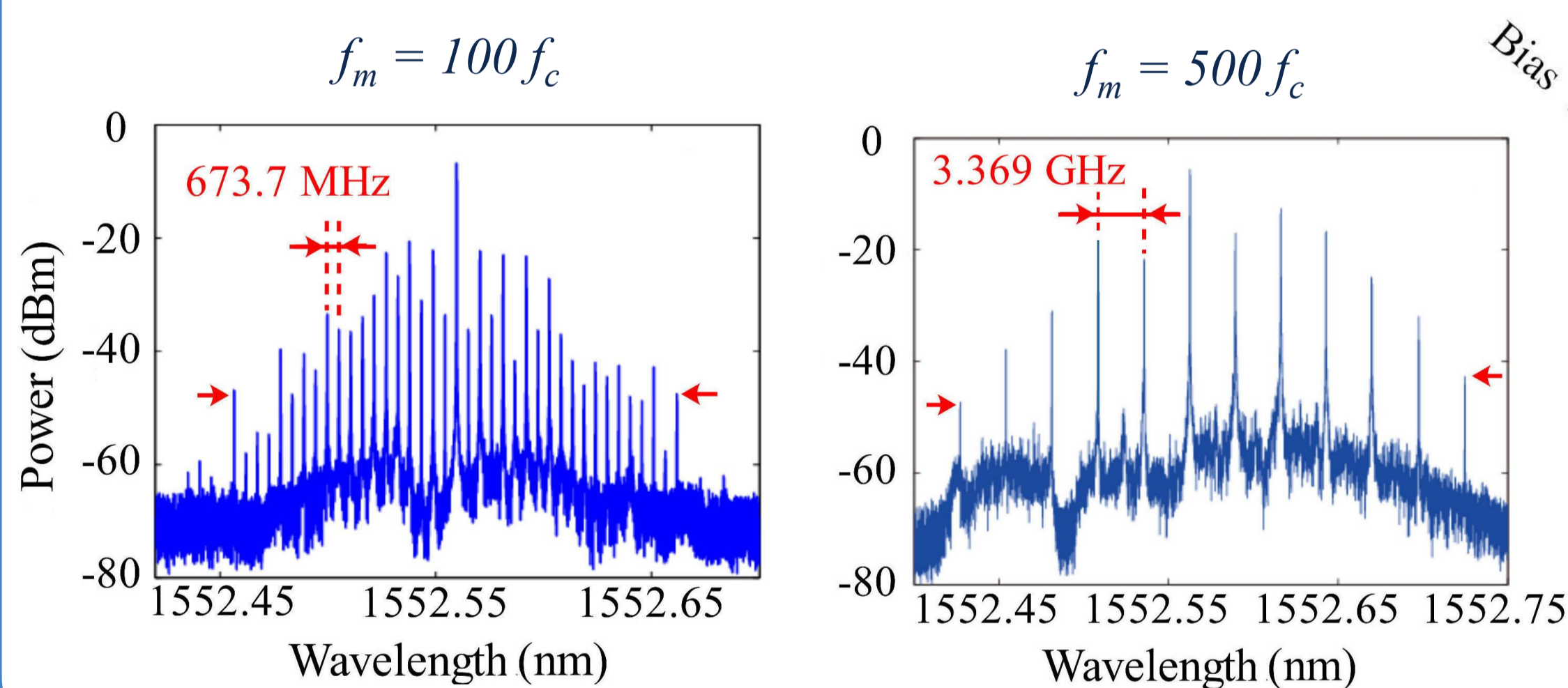
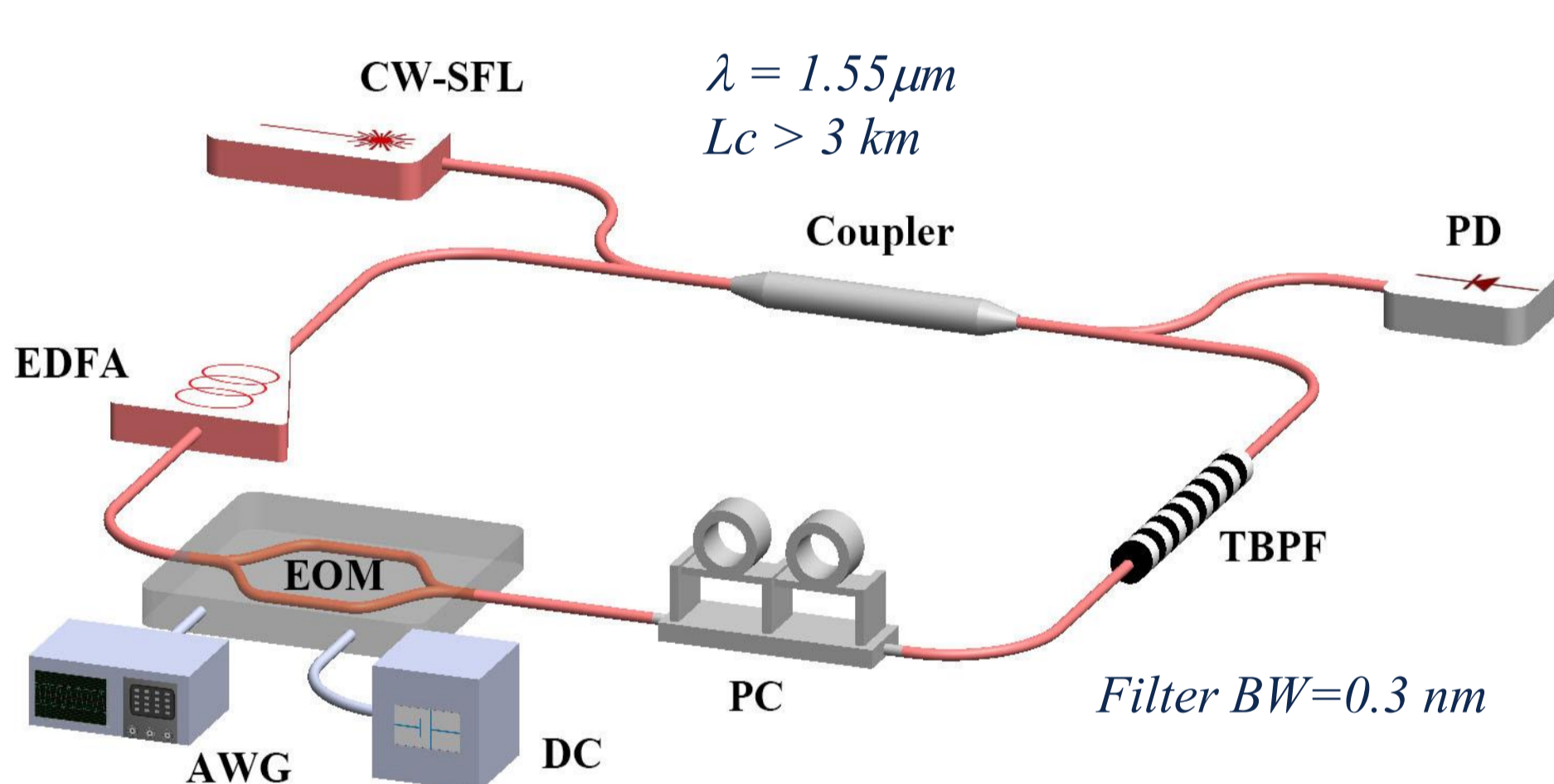
$$\text{If } N \gg 1 \quad E_{out1}(t) = \left( \frac{t_{11} - \gamma(t_{11}t_{22} - t_{12}t_{21}) \sin \theta(t)}{1 - \gamma t_{22} \sin \theta(t)} \right) E_{in1}$$

→ Pulses for  $\theta(t) \approx \pi/2$

$\Gamma$  phase retardance  
 $\Gamma_m$  modulation depth



## Experimental results

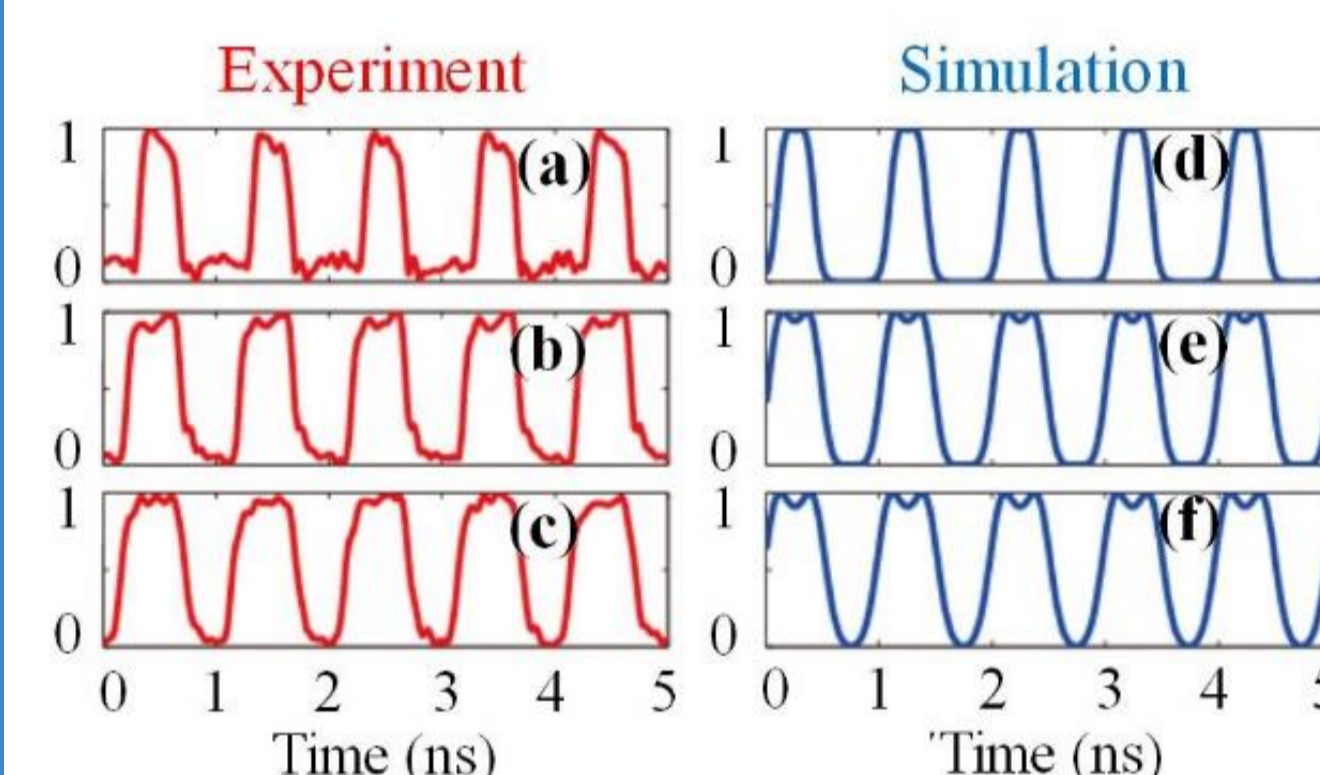


$$1/\tau = f_c = 6.737 \text{ MHz}$$

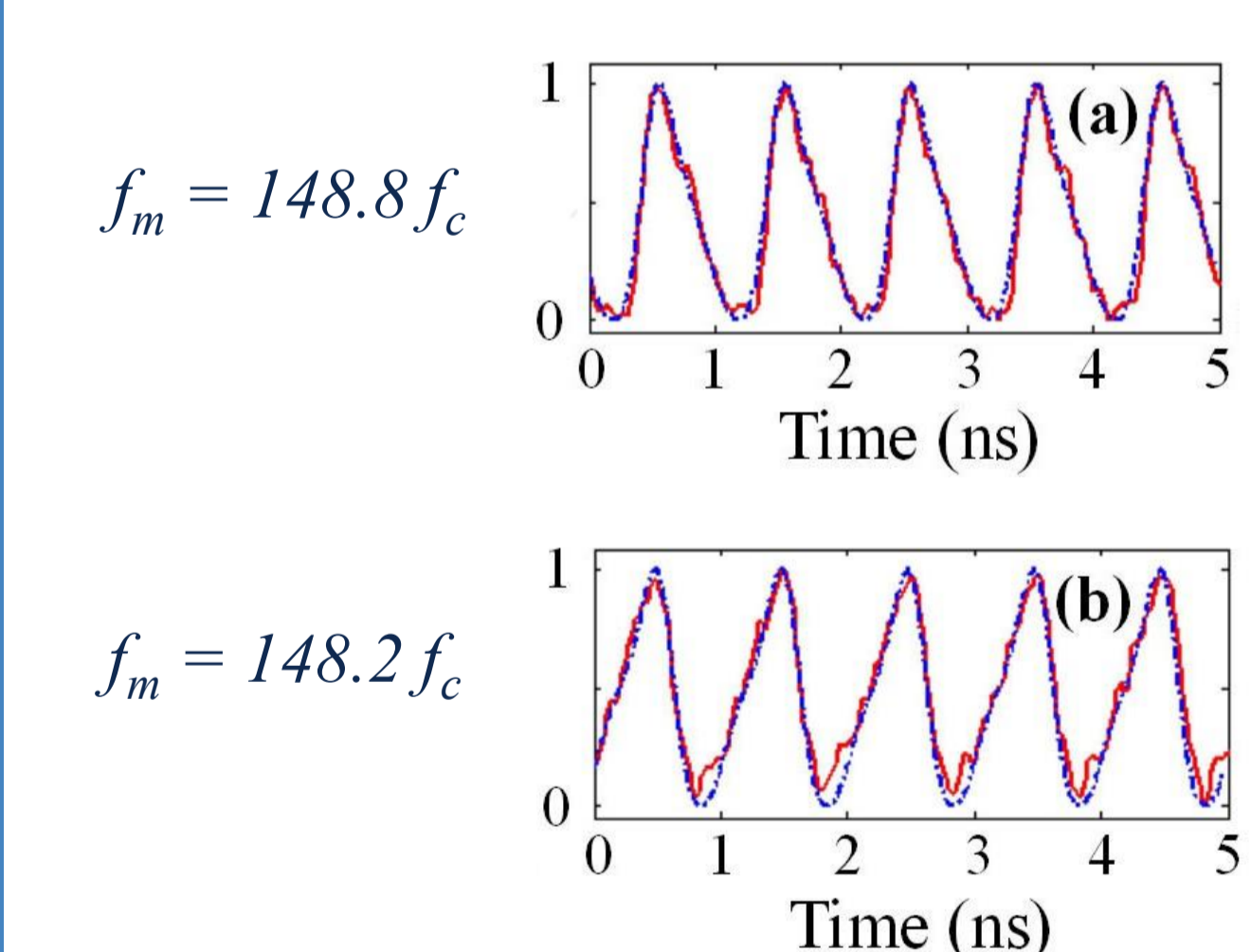
( H. Yang, Optics Express, submitted )

## Waveform generation

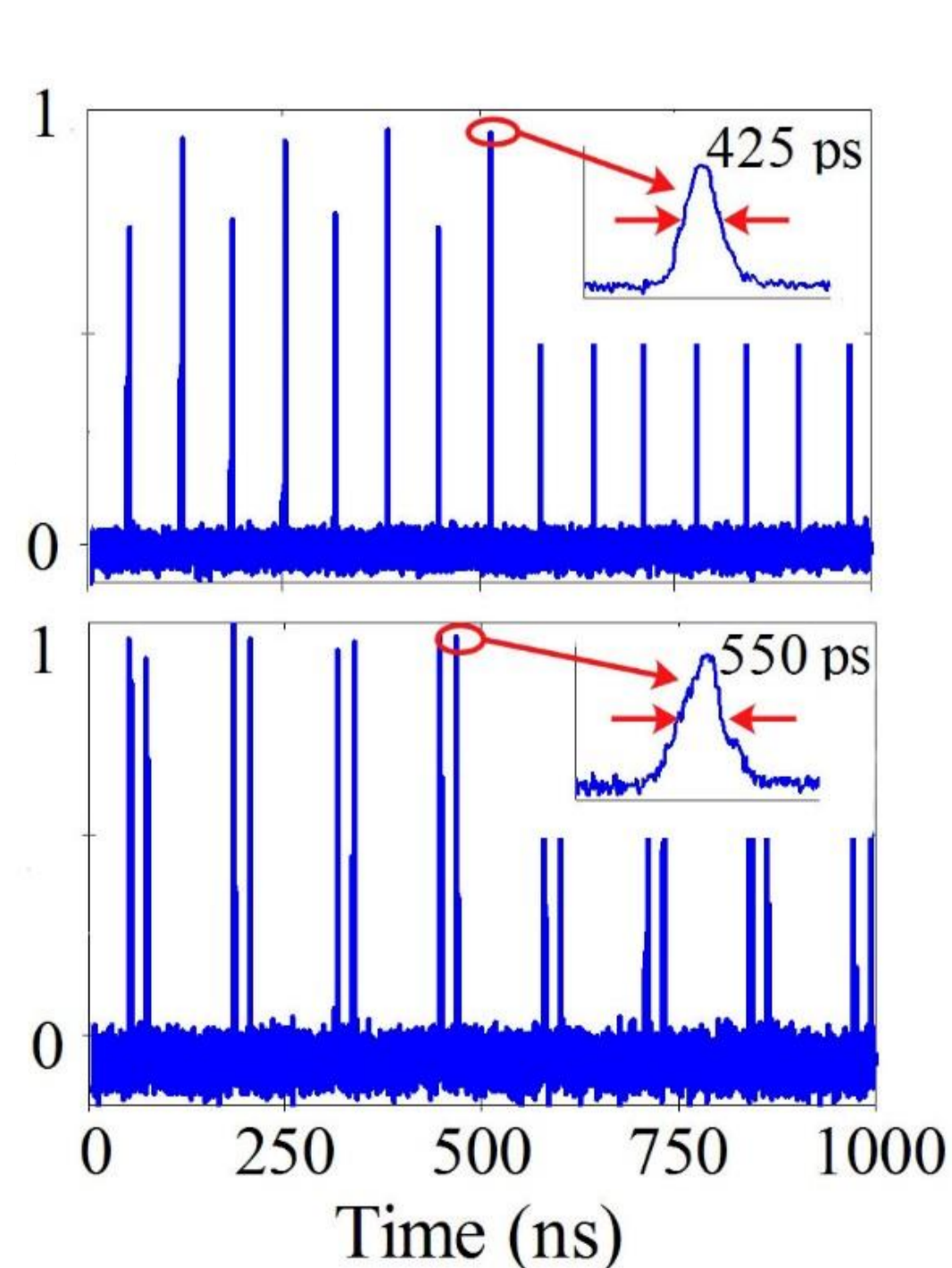
Rectangular shape



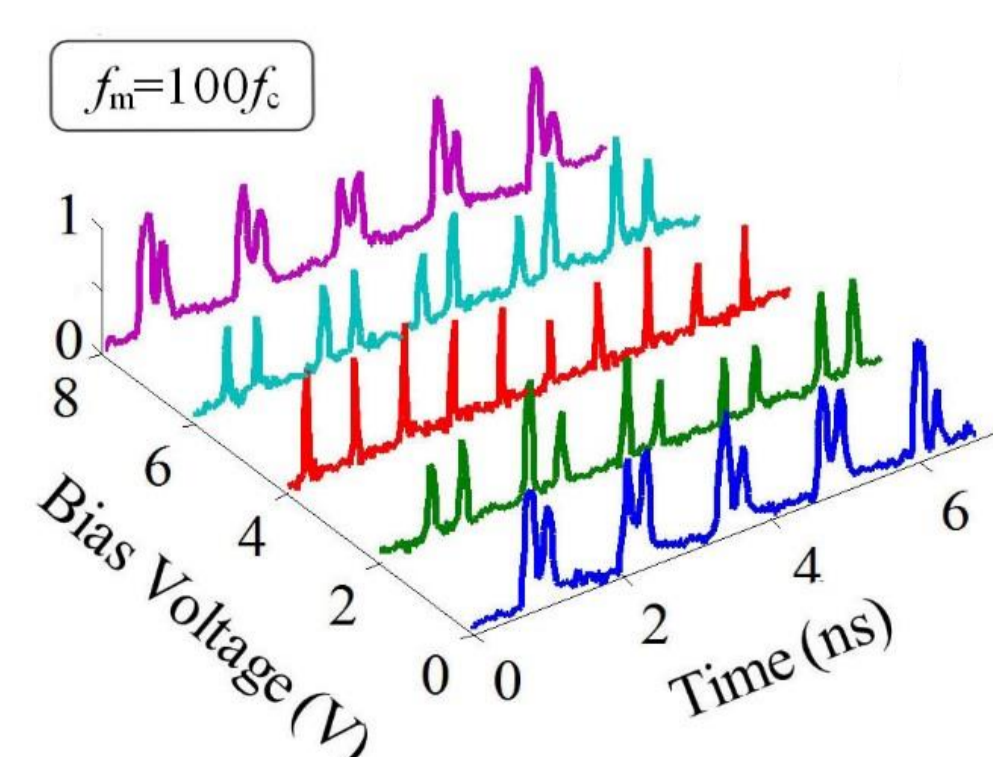
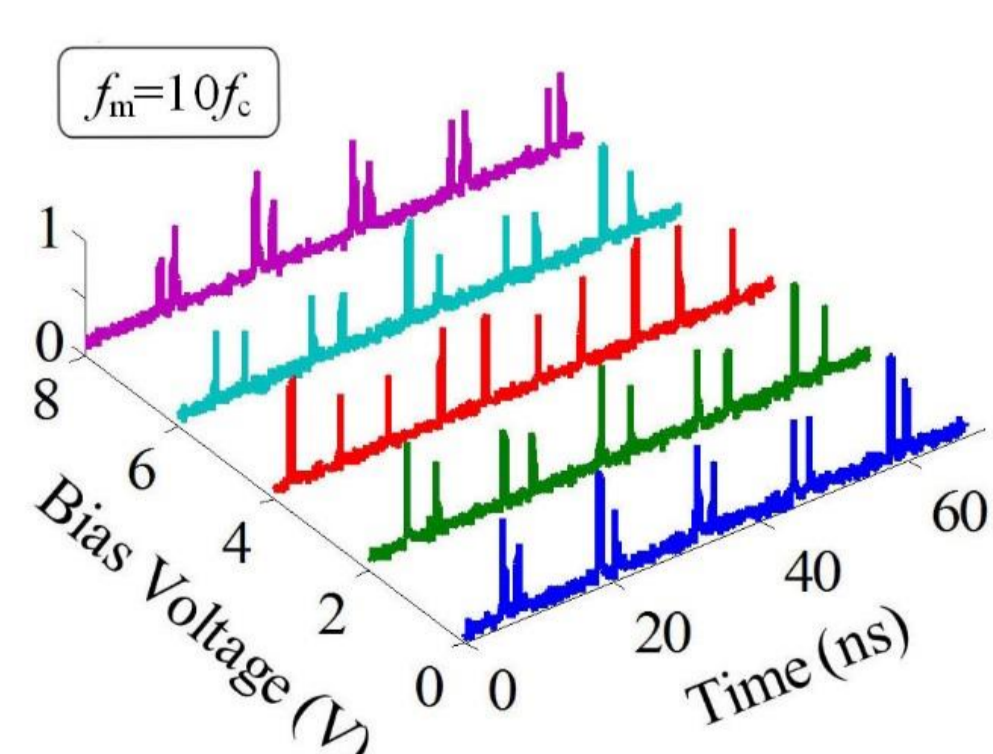
Sawtooth waveform



## 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
- [2] C. Schnébelin *et al*, CLEO Techn. Digest 2017
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- [4] L. Wang *et al*, CLEO Techn. Digest 2017
- [5] F. Tian, IEEE J. Lightwave technol. 2011
- [6] H.G. de Chatellus *et al*, Optica 2016