Ultrafast InGaAs photoswitch for RF signal processing

ONDM 2017 – FiWin5G workshop

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Talk Outline

- Introduction
- What is a photoconductive switch?
- Device characterization and experimental results
- Application of the switch

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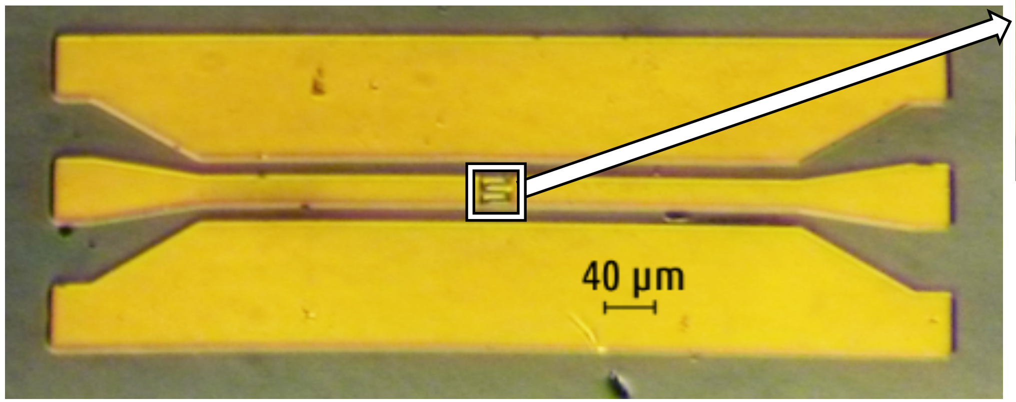
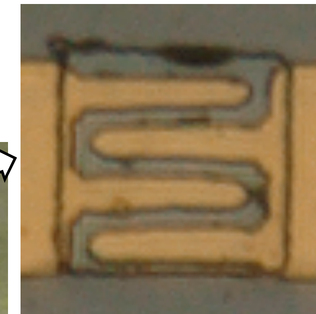
Introduction

- Recent research and developments in telecommunications are aiming for
  - multi-Gbit/s bandwidths and
  - frequencies reaching the lower THz band (>100 GHz) in wireless communications
- Microwave-photonics plays a key role in this area
  - Integrated electronic and photonic components together
- Photonic assisted solutions
  - Compared to fully electronics, performance can be increased by at least one order of magnitude
- Photoconductive switches are an example of photonic assisted device. It can give a robust solution for receiver side signal processing

The photoconductive switch (PSW)

- A light sensitive gap in a coplanar waveguide

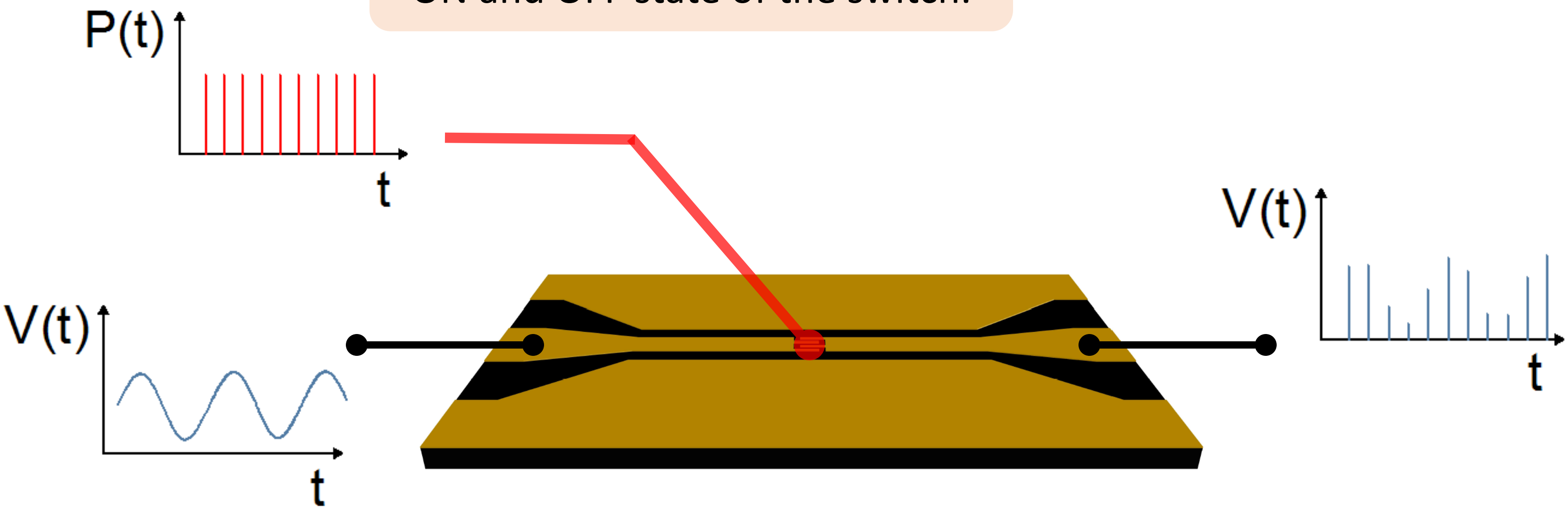




- Material:
  - **Fe:InP** substrate
  - **InGaAs** mesa etched in the gap, implanted with Nitrogen ions to create large number of defects
- InGaAs sensitive to 1550 nm wavelengths
  - Illuminating the mesa with 1550 nm laser we can control its conductance

Basic principle of PSWs

Optical pulses are operating the ON and OFF state of the switch.

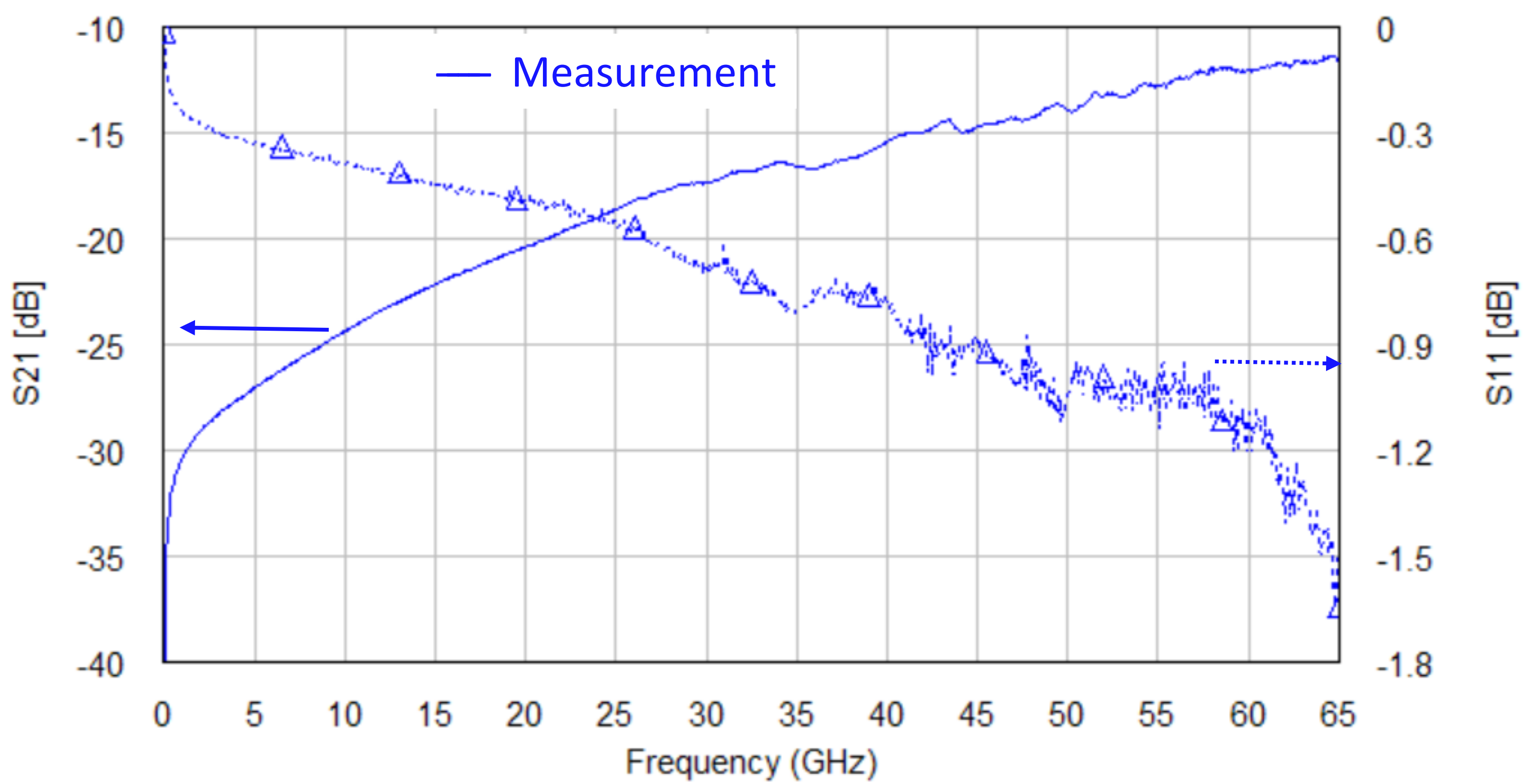


The input of the switch is an analog high-frequency electrical signal.

The output of the switch is the sampled input signal with the repetition rate of the laser pulses

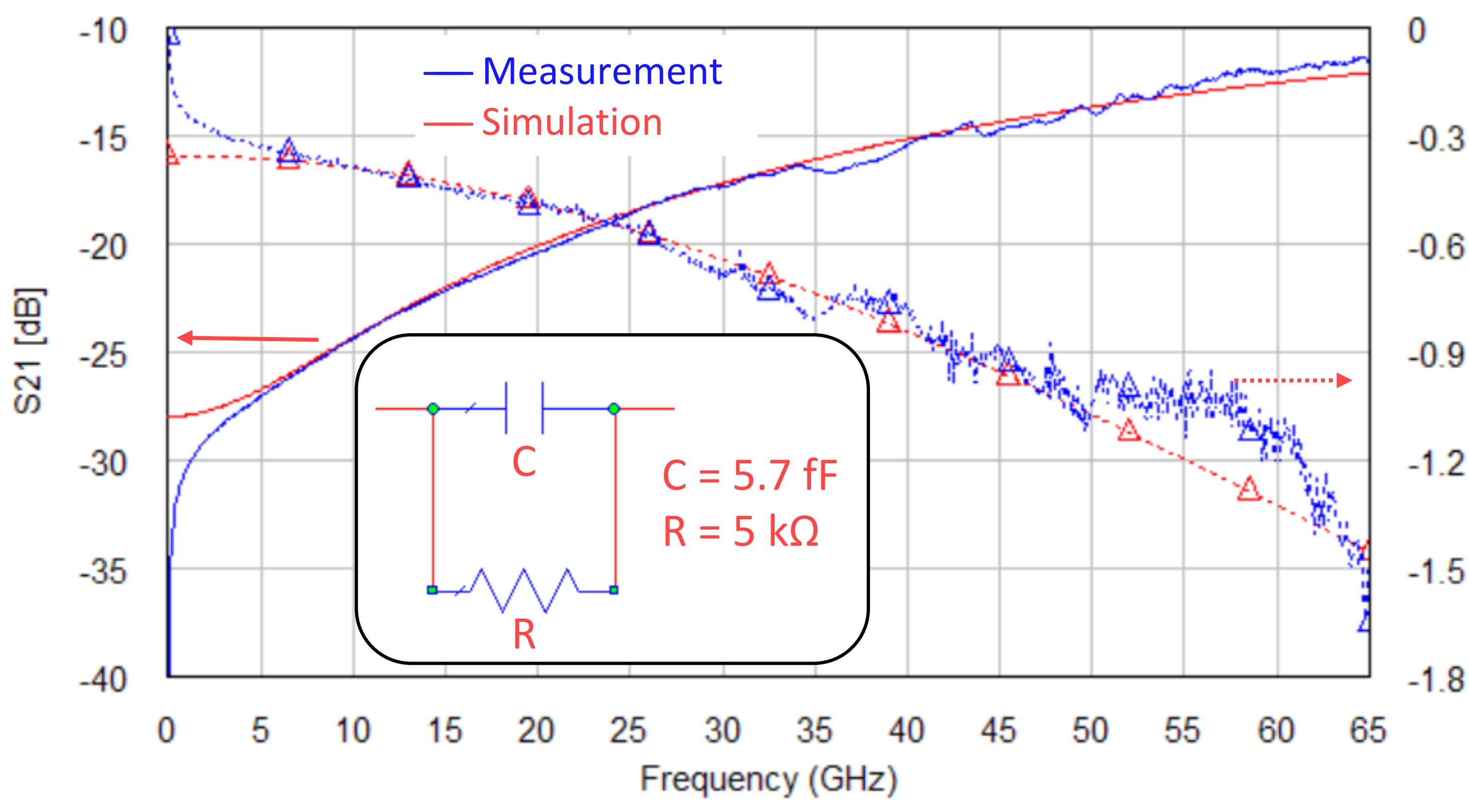
Electrical characterization

- I-V curve shows closely linear response
- Optical power – Output current curve is linear
- Electrical bandwidth measurement:



Electrical characterization

- Electrical bandwidth measurement
  - Based on the VNA results, a lumped element equivalent circuit can be used for high-frequency modelling of the device
  - The low capacitance of the model shows the high electrical bandwidth

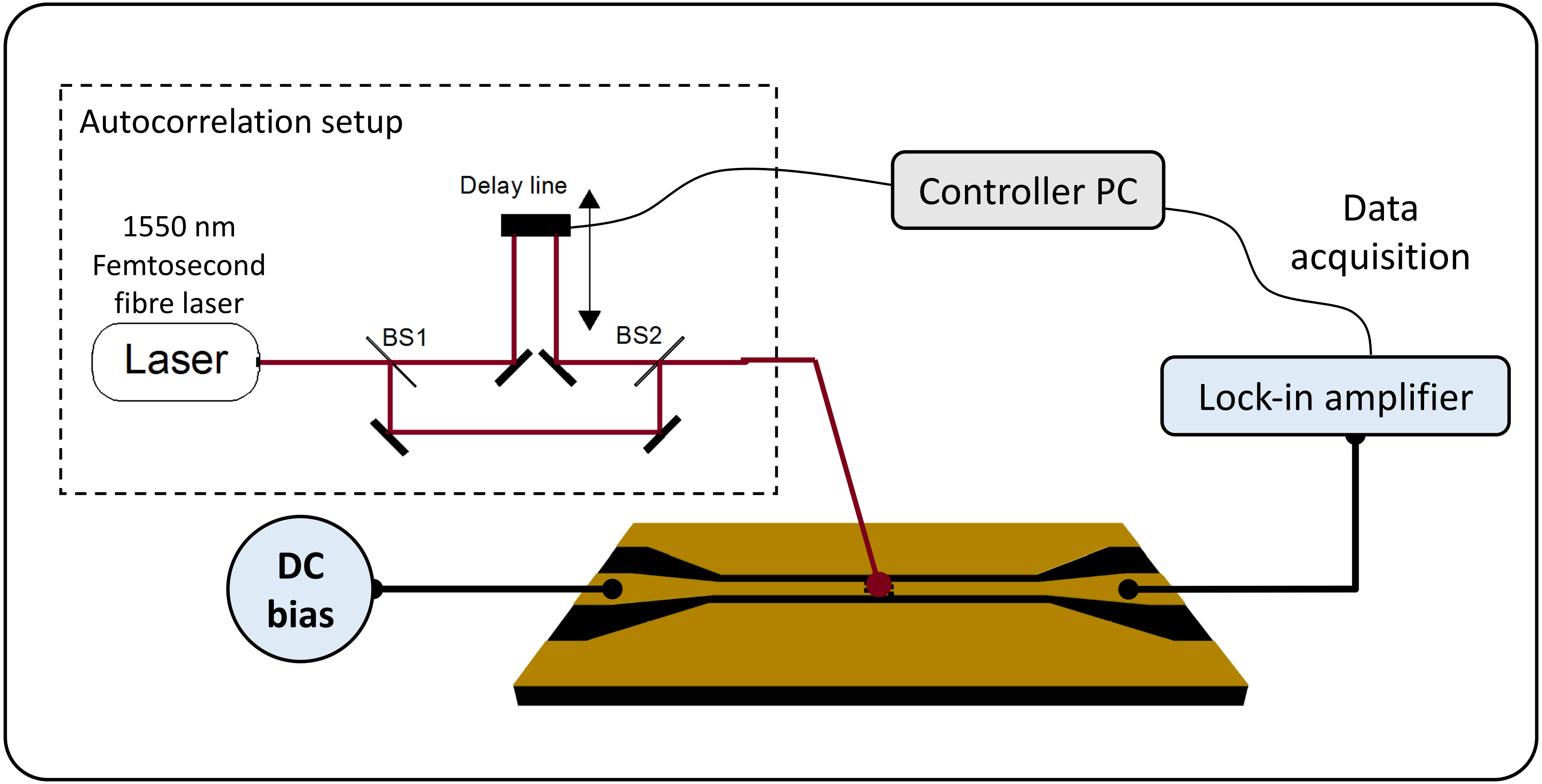


Electro-optic characterization

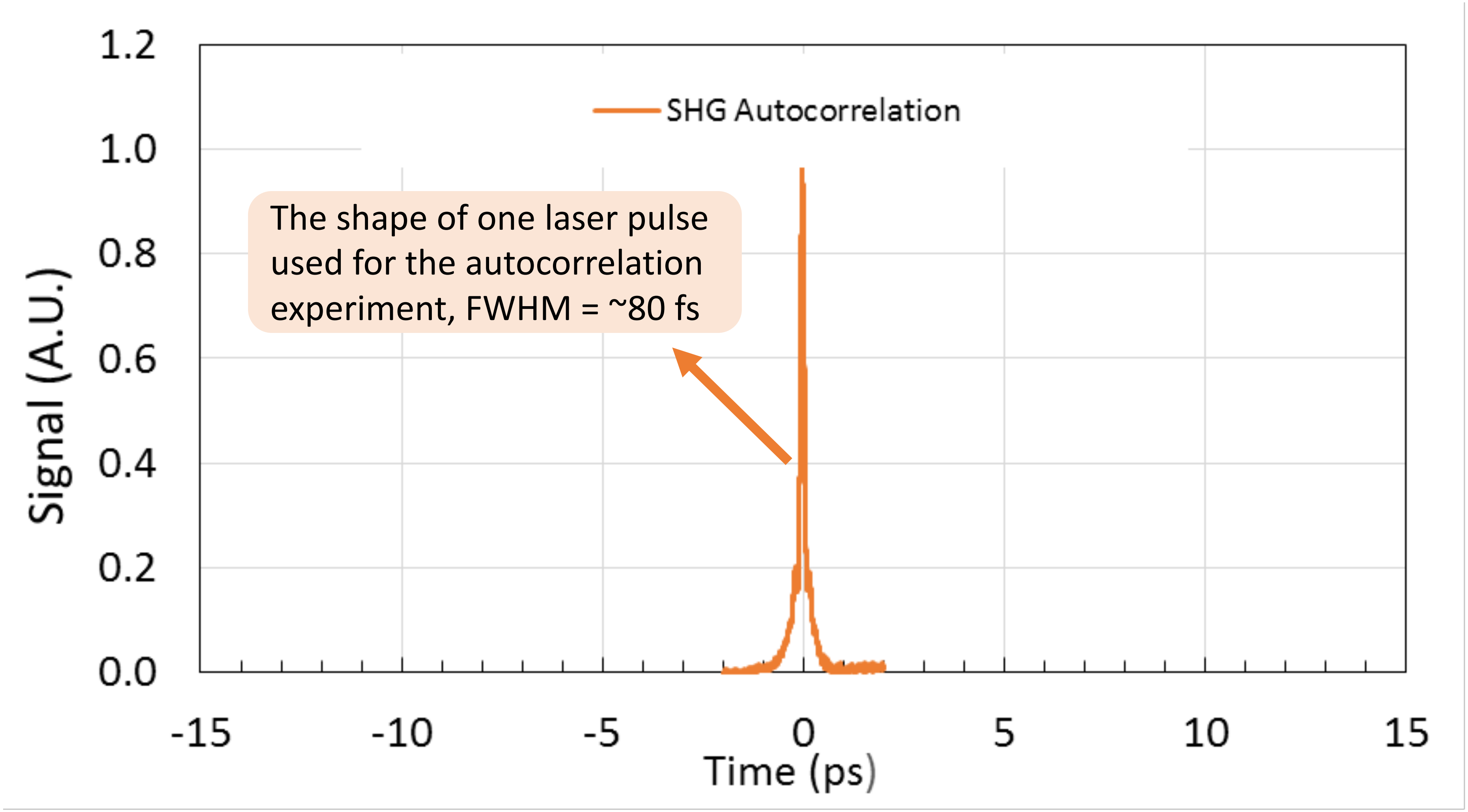
- The large number of defects caused by the **Nitrogen-ion implantation**, ensures a picosecond carrier recombination time in the semiconductor under laser illumination
- This recombination time can be measured by measuring the response of the switch to ultra-short femtosecond laser pulses
- Electro-optic autocorrelation experiments are used to measure the recombination time

Electro-optic characterization

- Electro-optic autocorrelation experiment used to measure the recombination time



Electro-optic characterization



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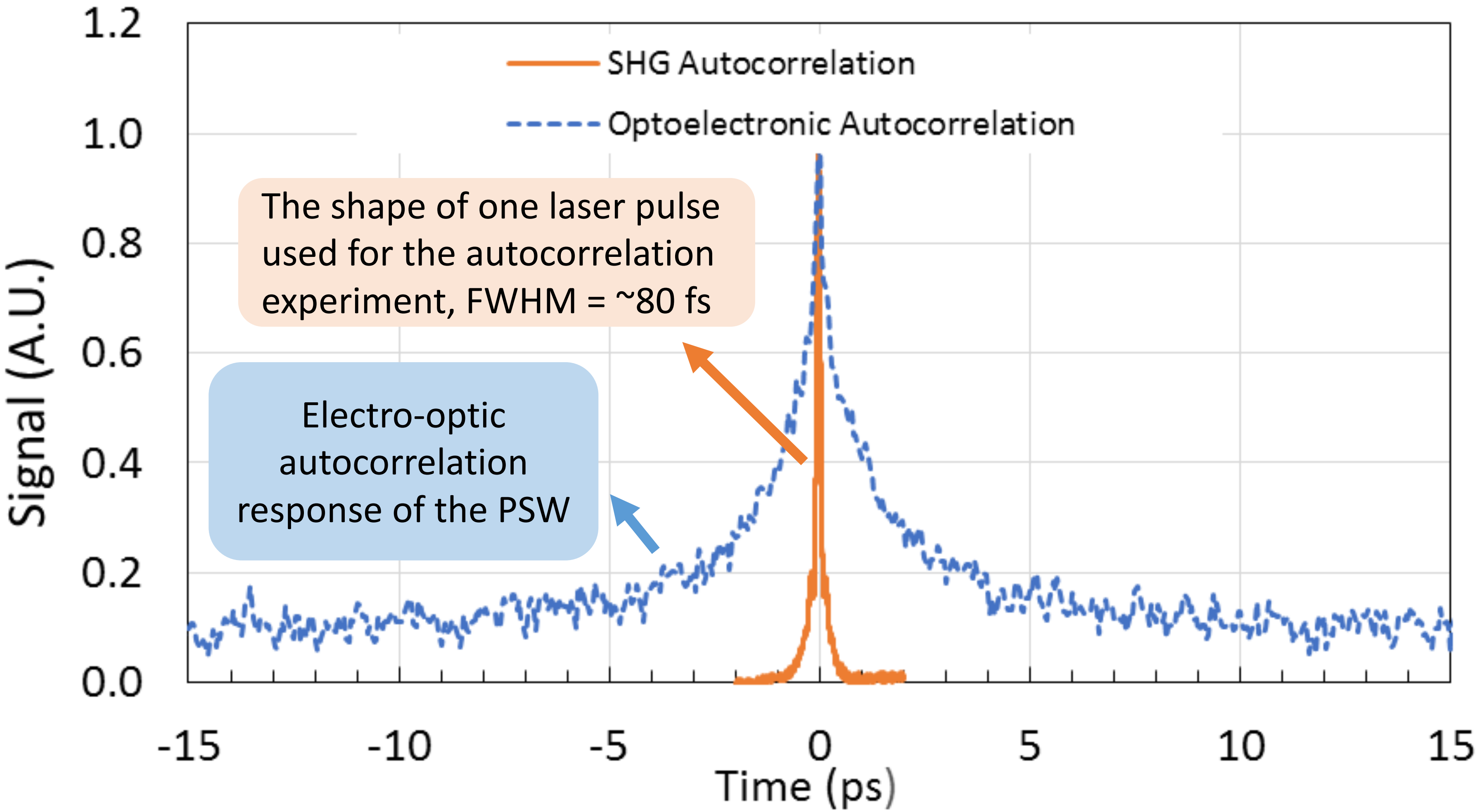

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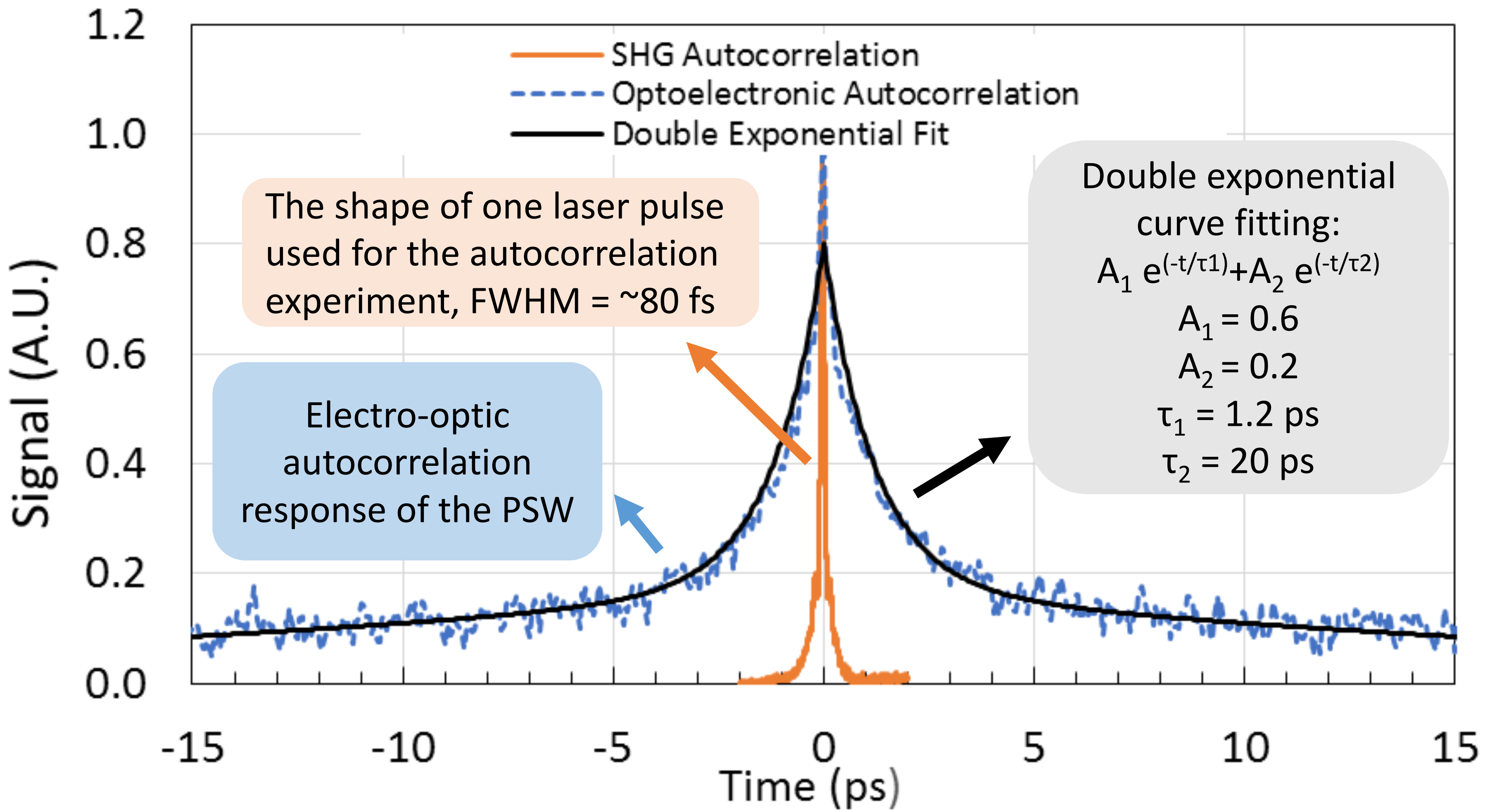
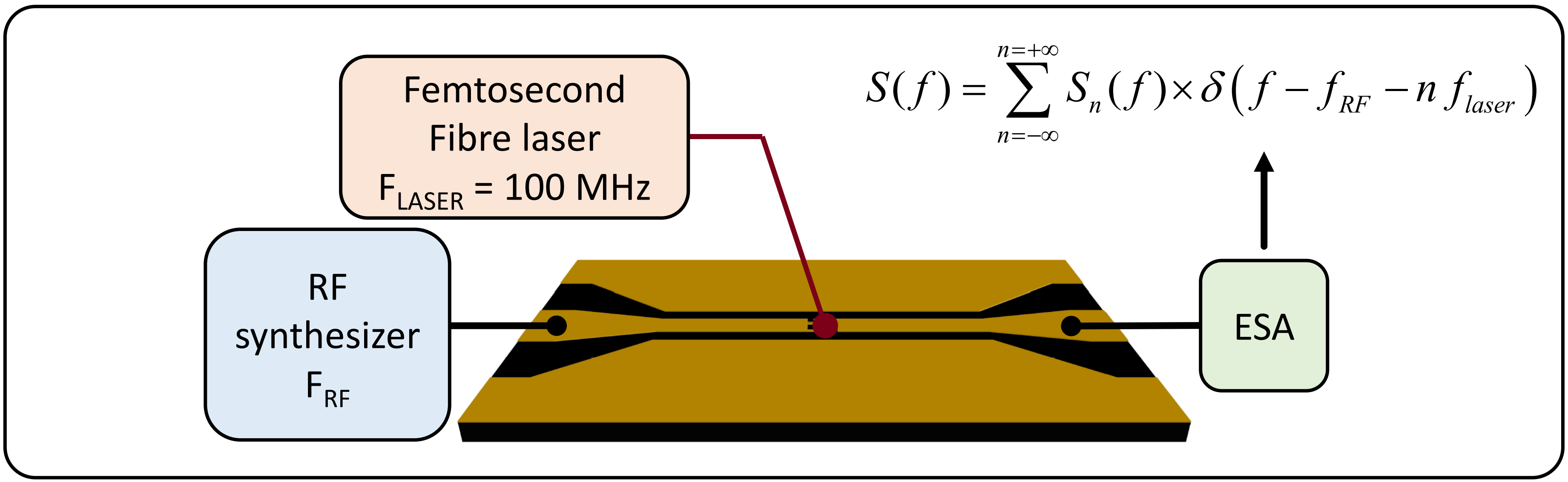


The measured ultra-fast **1.2 ps response time** makes the switch available to have sampling rates (laser pulse repetition rates) up to 100 GHz.

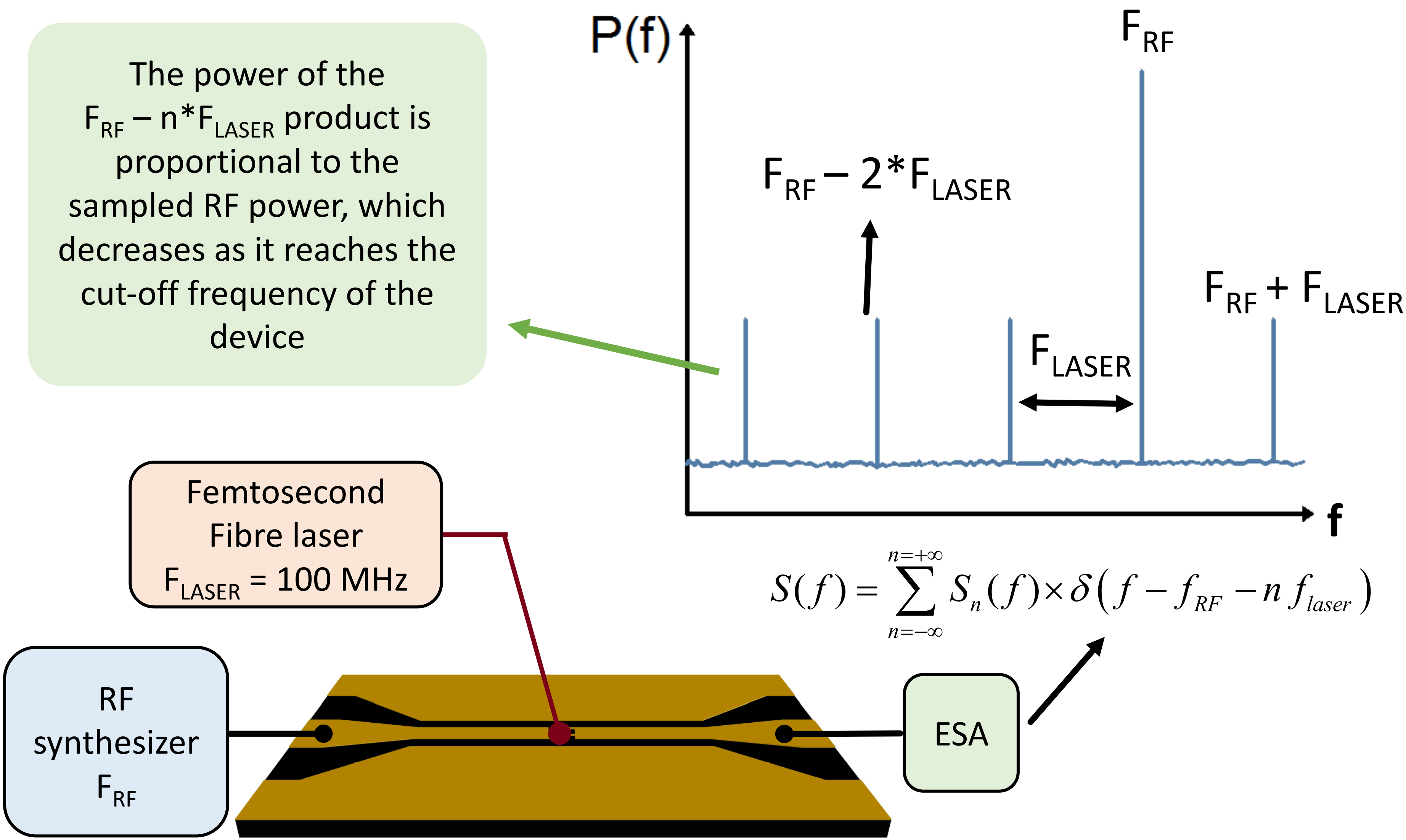
Photoconductive sampling

- Demonstration of the high-bandwidth and sampling capabilities



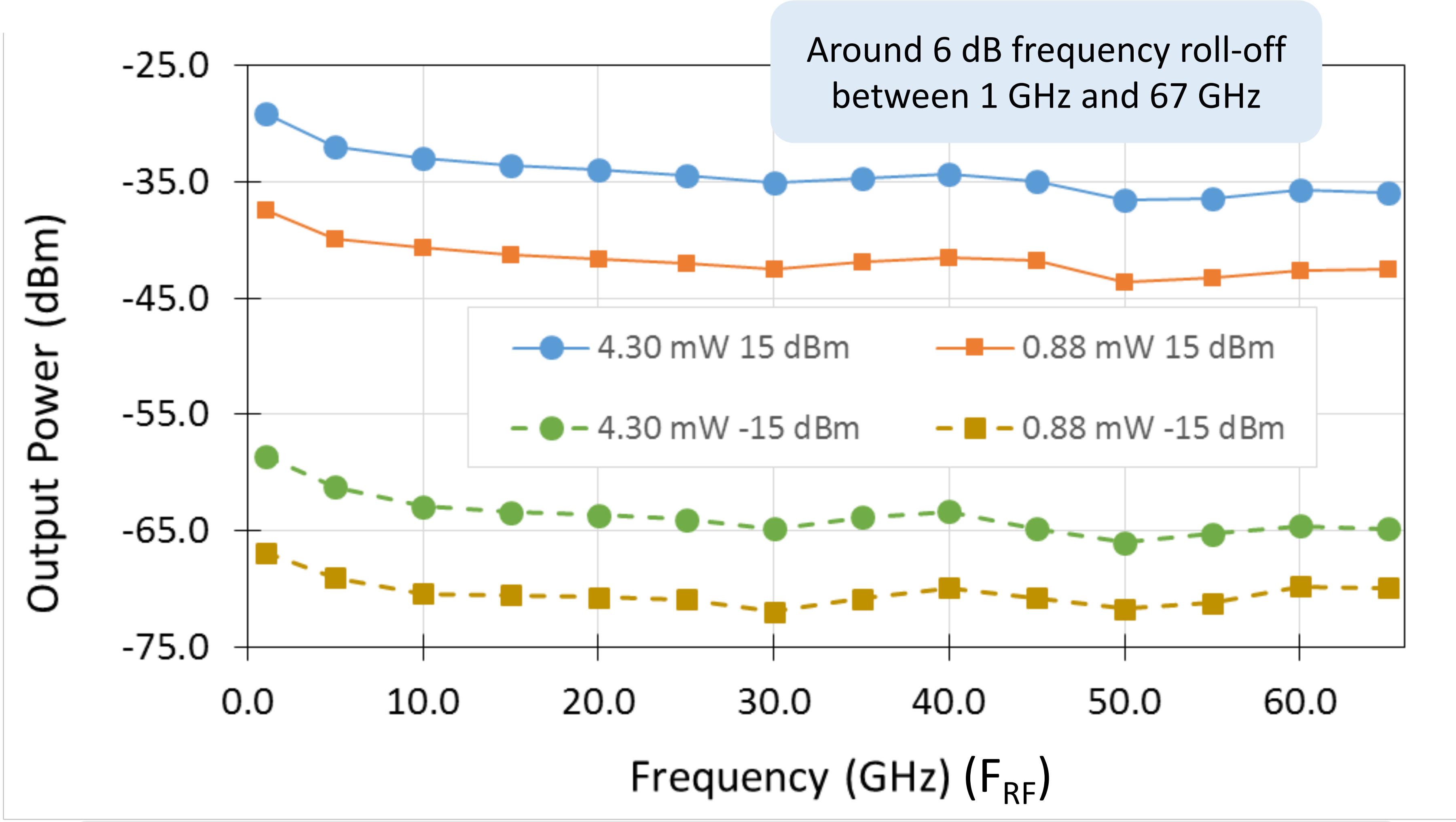
- Laser pulse train as a clock, input analog RF signal to sample
- The two signals are mixing inside the switch, creating a frequency comb output

Photoconductive sampling



$$S(f) = \sum_{n=-\infty}^{n=+\infty} S_n(f) \times \delta\left(f - f_{RF} - n\, f_{laser}\right)$$

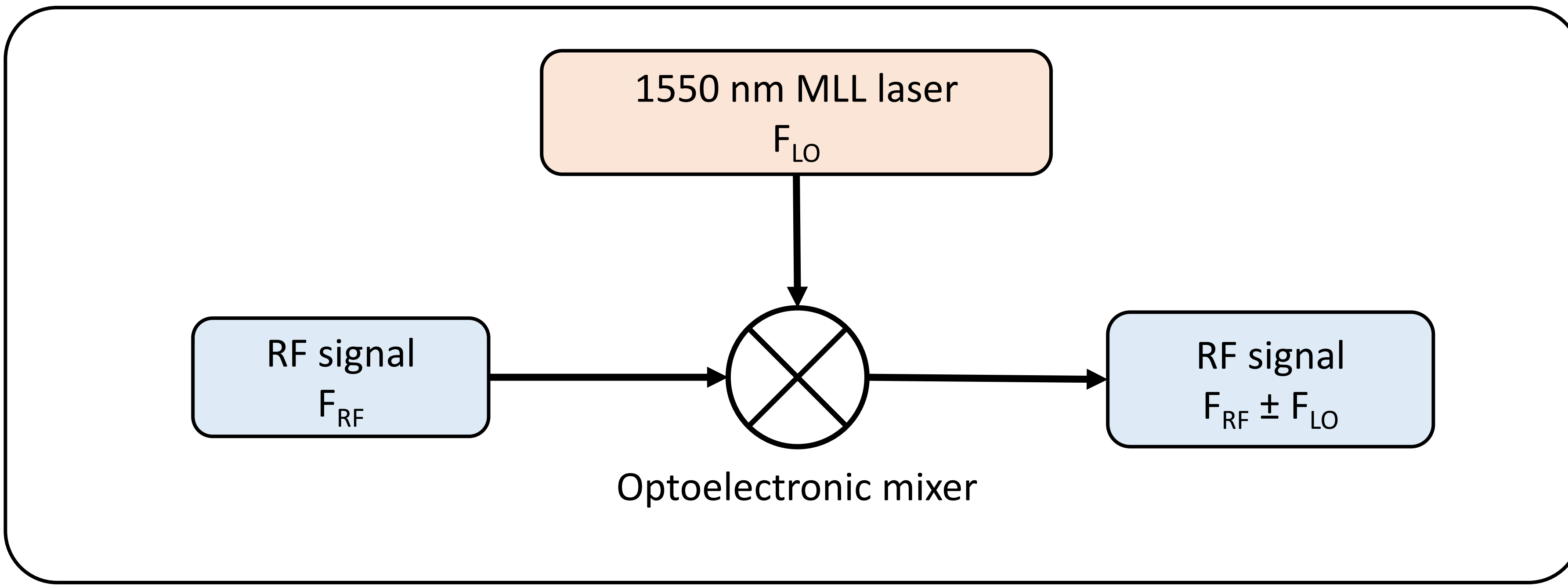
Photoconductive sampling



The low variation of output power confirms the wide electrical bandwidth of the PSW

Heterodyne demodulation

- PSW used as a hybrid mixer
  - Input RF signal 1-67 GHz (F_{RF})
  - InAs/InP quantum-dash mode-locked laser self-oscillating at 58.625 GHz (F_{LO})
- Output: $F_{IF}=F_{RF}-F_{LO}$



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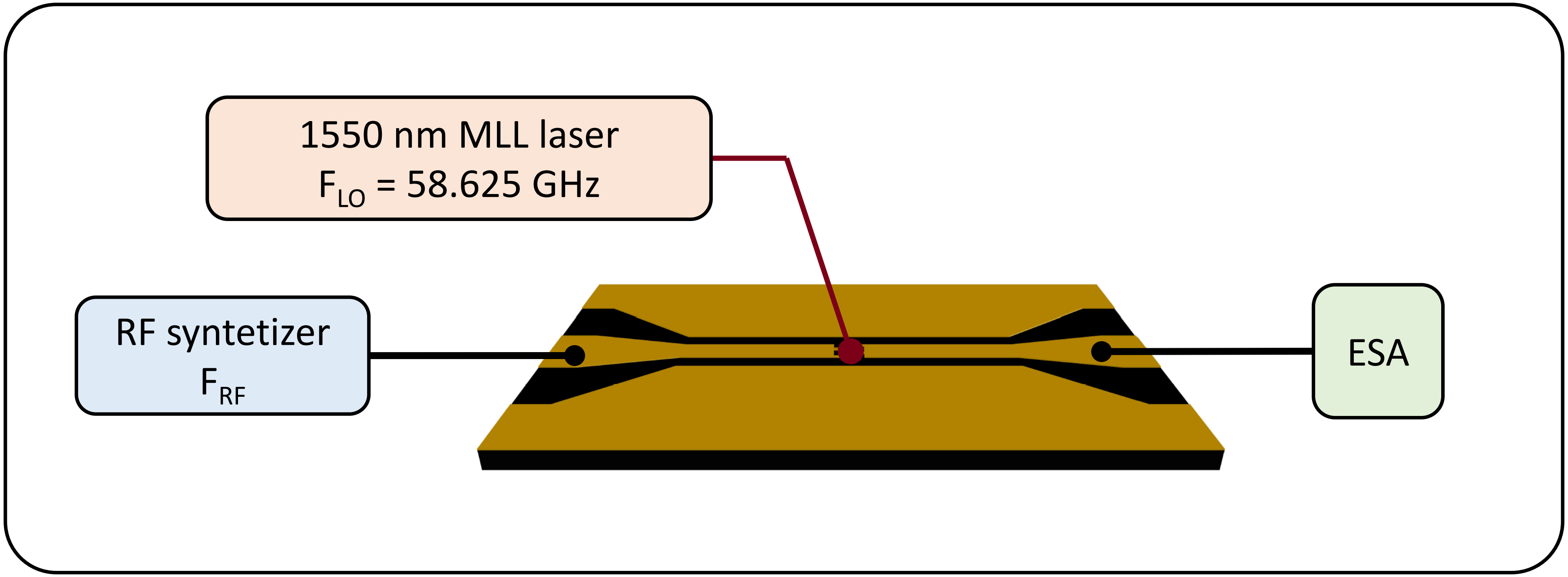
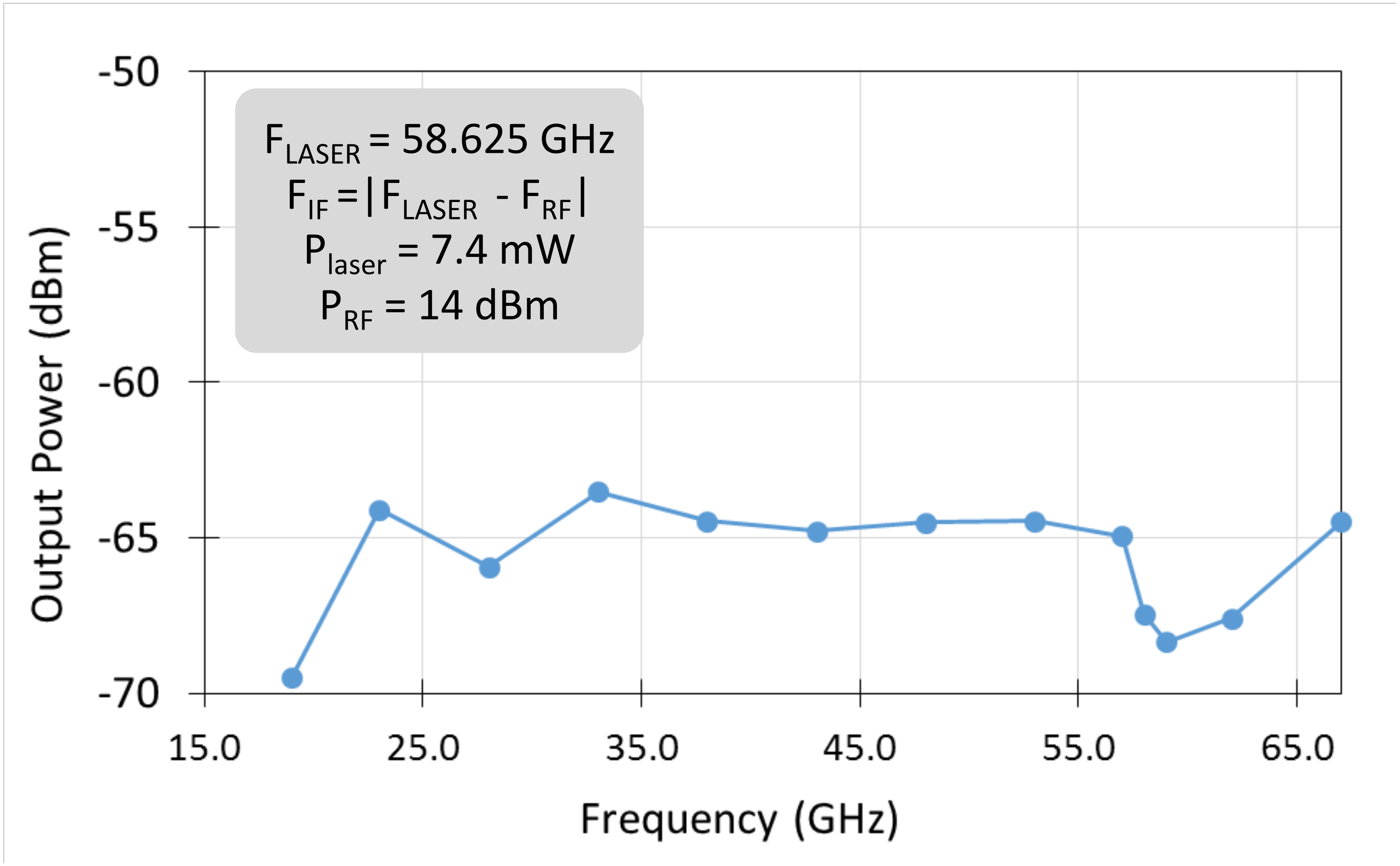


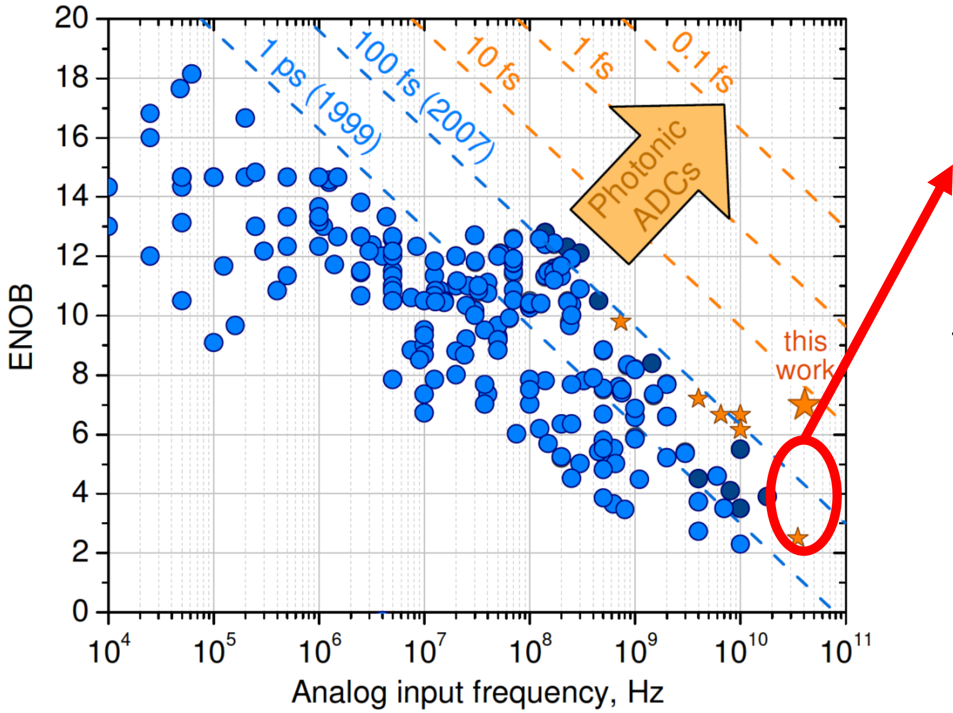
Heterodyne demodulation



The mixing loss around 80 dB, is in the same order of magnitude as unbiased UTC photodiodes used as mixers

Applications

- The PSW can be integrated in an Analog-to-digital converter for the sampling function

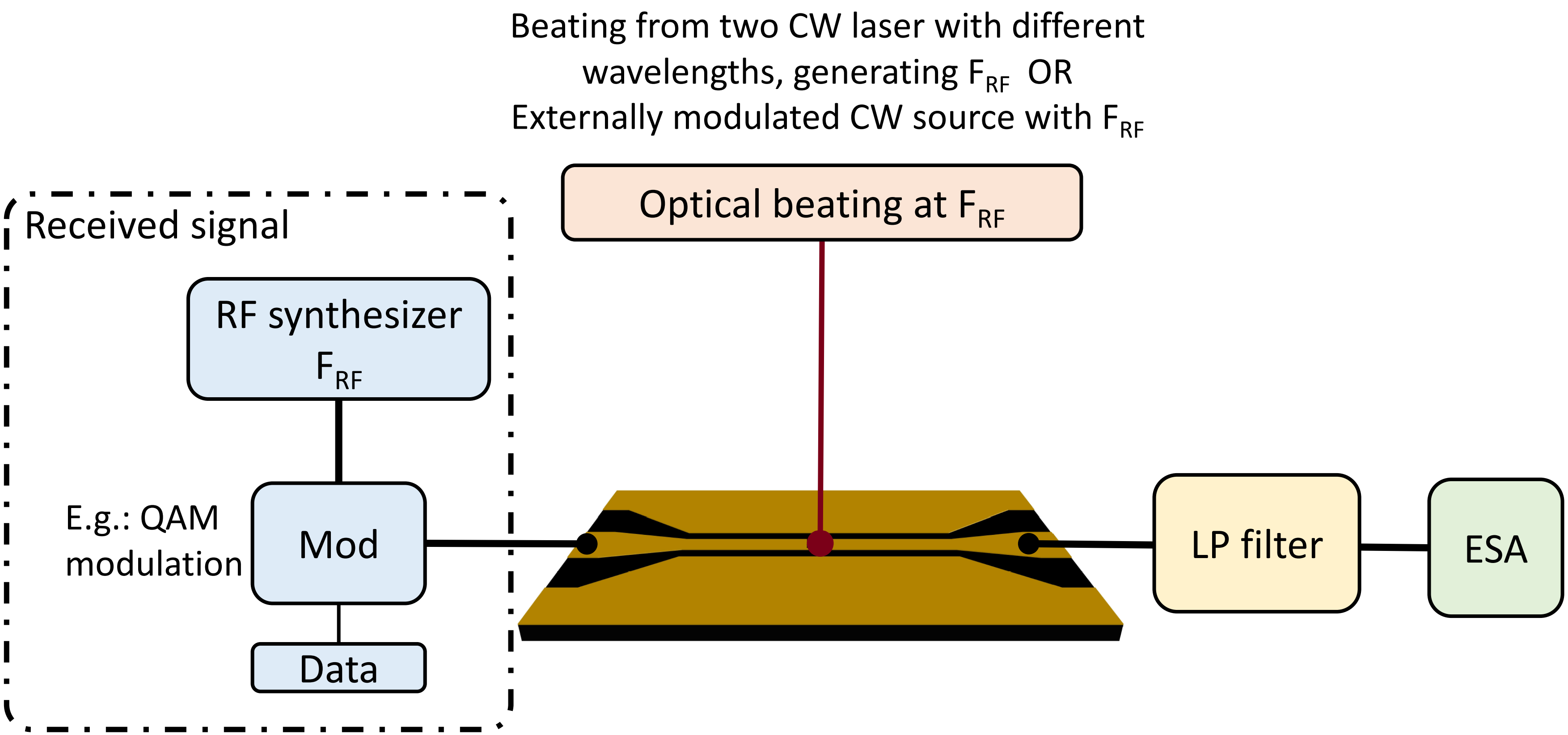


***Source**: Anatol Khilo et al., "Photonic ADC: overcoming the bottleneck of electronic jitter", Optical Express 20, 4454-4469 (2012)*

- Using laser sources as a clock with **ultra-low jitter of 100 fs or lower**, and high repetition rate pulses, the **photonic assisted ADC** could be positioned in the Walden-plot towards the higher performance regions, than the electronic ADCs

Applications for heterodyne demodulation

- Heterodyne demodulation for the receiver side of a high-frequency wireless link



Thank you for your attention!