R&D of an All-Photonic Digitising/Analogiser Radio-over-Fibre Transceiver

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OUTLINE

Context & motivations

Objective

o-DRoF transceiver: main features

o-DRoF transmitter (digitiser)

- *o-Generator*
- *o-Sampler*
- *o-Interleavers*
- *o-Encoder*
- *o-Thresholder*

o-DRoF receiver (analogiser)

Next steps

o-DRoF = optical Digitising Radio-over-Fibre

CONTEXT & MOTIVATIONS

- **Convergence** of fibre-optic wireline and radiofrequency (RF) wireless access networks.

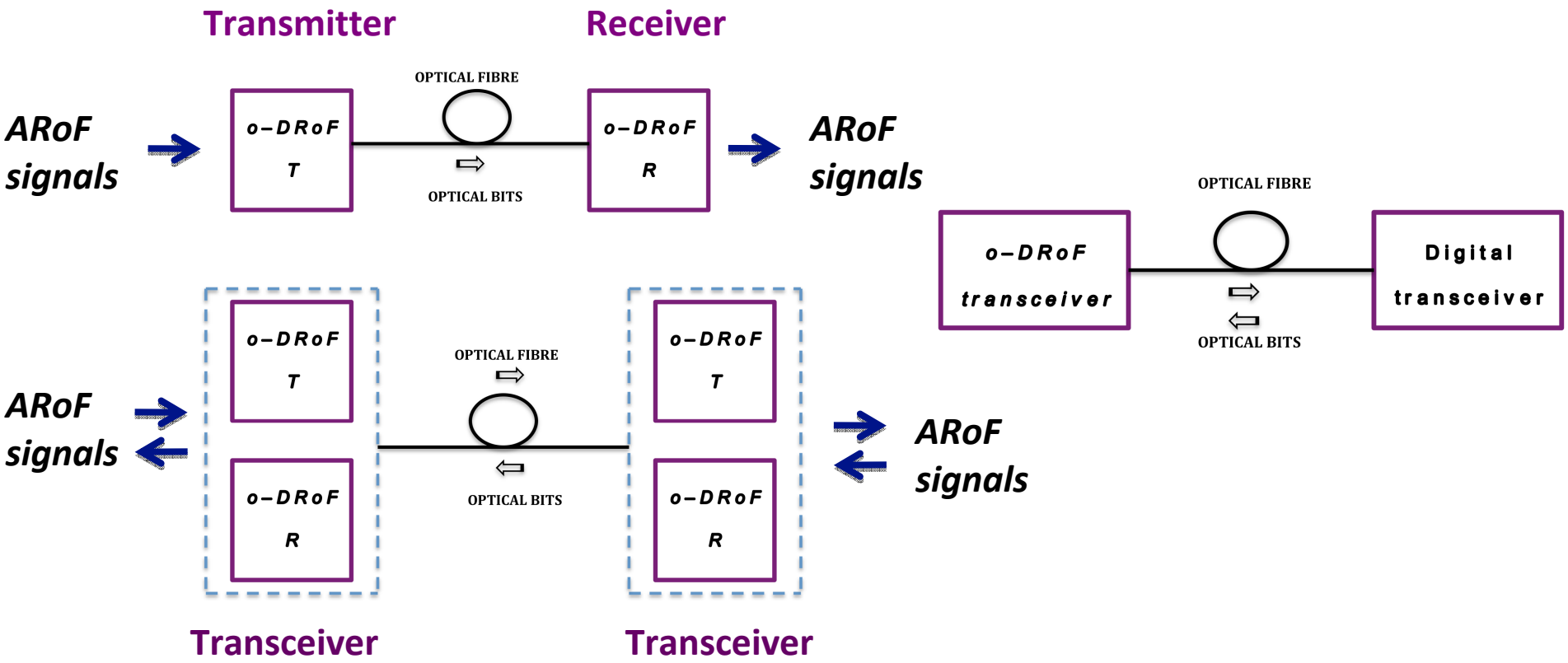
- **Interconnecting** analogue Radio-over-Fibre (RoF) and optical digital networks using centralised digital processing and links with higher dynamic range.

- **All-optical signal processing**: no O/E conversions (**transparent networks**), high-speed, low latency, multi-functional, compactness, non-electrical, potential cost reduction and energy saving.

OBJECTIVE

Basic links

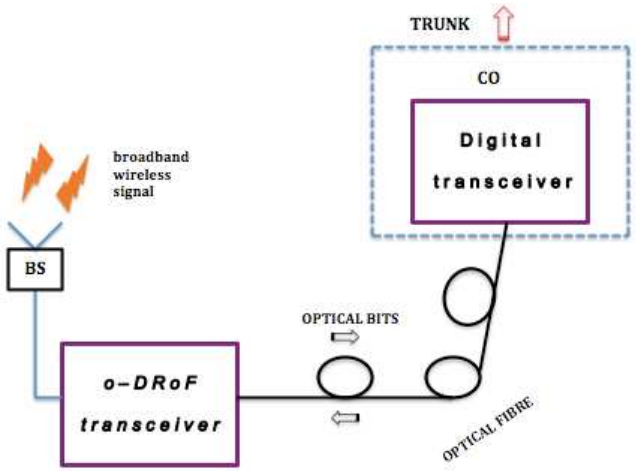
To research & develop a novel all-photonic digitising/analogising «*o-DRoF*» transceiver for Analogue RoF signals (ARoF).



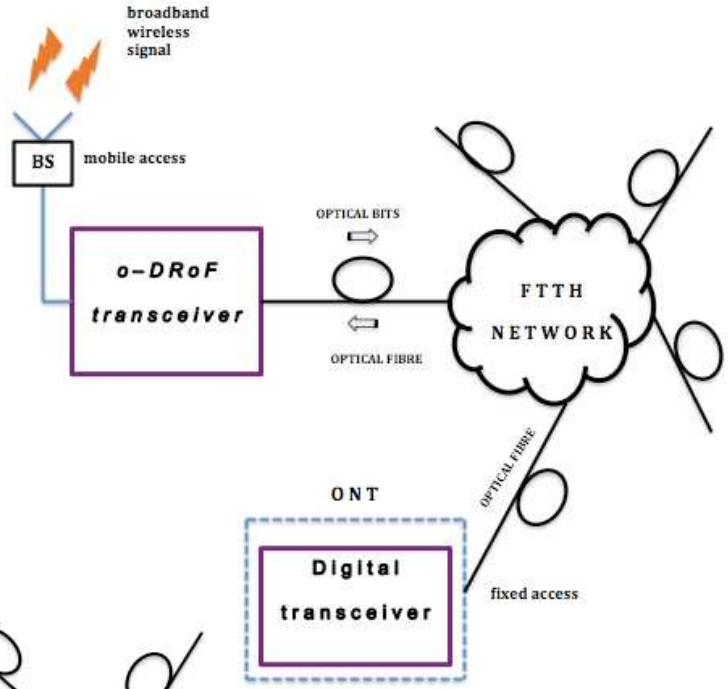
OBJECTIVE

Possible scenarios

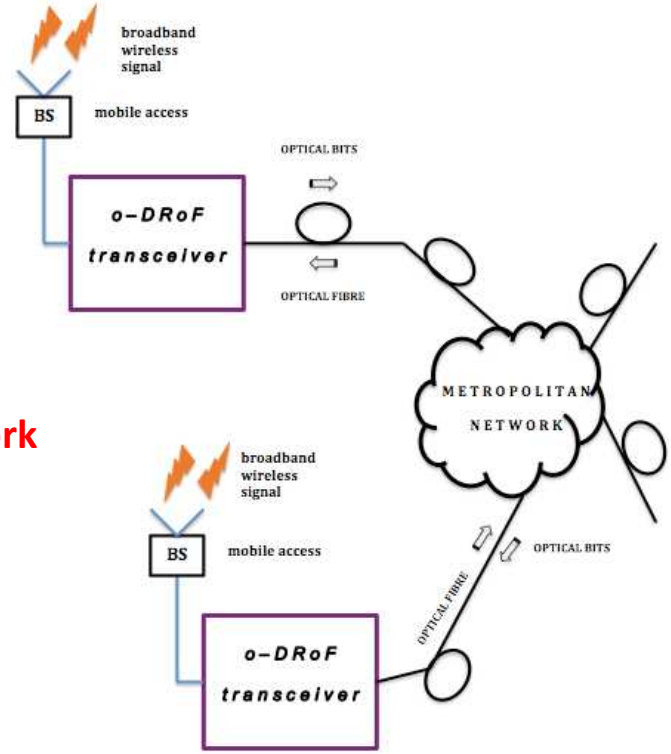
Base Station ←→ Central Office



Base Station ←→ FTTH network



Base Station ←→ Metropolitan network

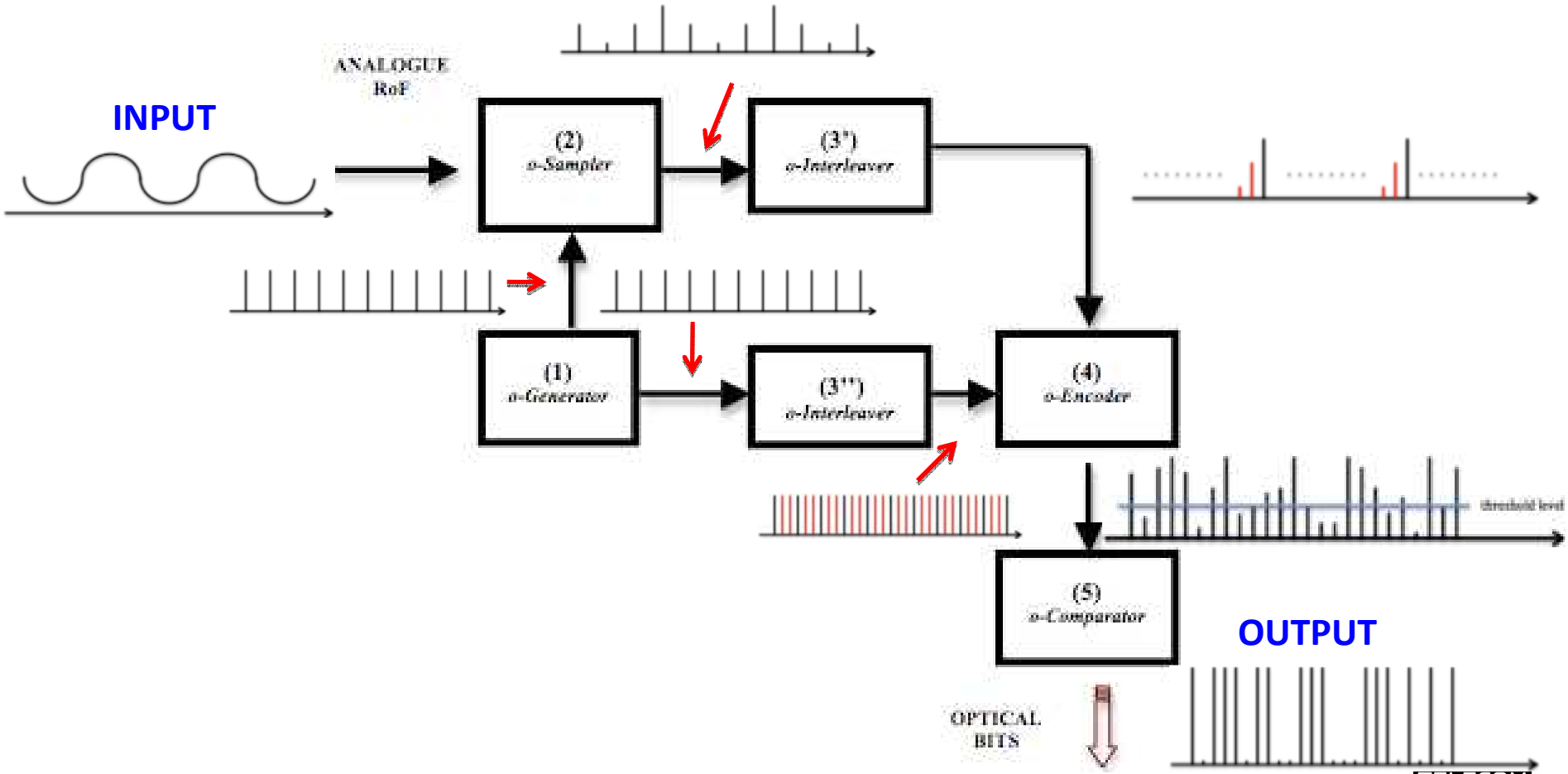


o-DRoF TRANSCEIVER : MAIN FEATURES

- ✔ Optical circuits are based on the Semiconductor Laser Amplifier Loop Mirror (SLALOM) configuration.
- ✔ Operation in the C-band.
- ✔ SOA as a non-linear element: compactness → optical integration.
- ✔ SOA: low optical control power requirements (µW – mW range).
- ✔ Additional all-optical processing (e.g. wavelength conversion and 3R in the receiver module).

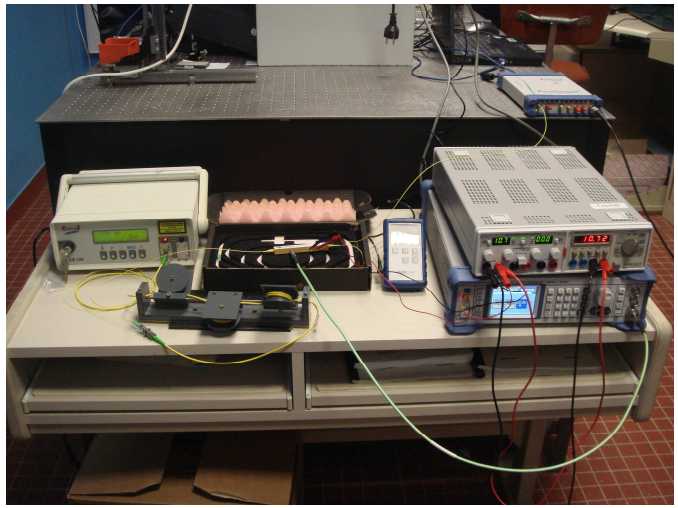
→ *Proof-of-principle* by software simulations – *VPI Transmission Maker™* platform.
→ SOA model: Bulk with 500 µm length and ~ 1 ns gain recovery time.
→ Mechanisms: SPM and XPM.

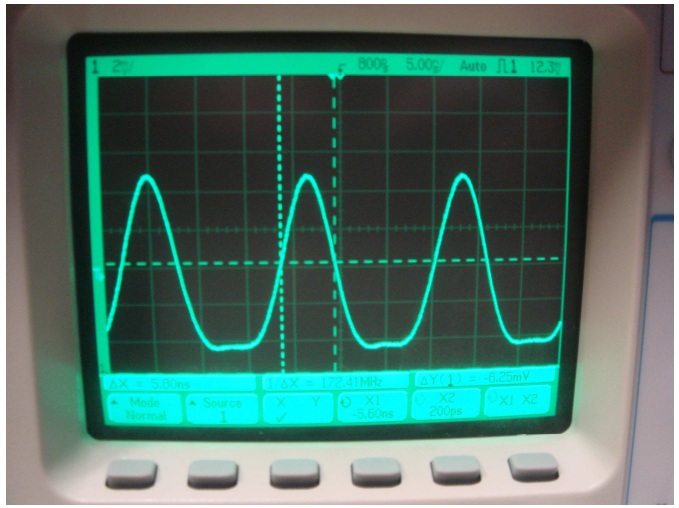
FLOWCHART – *o-DRoF* TRANSMITTER 3-bit digitiser



o-GENERATOR – The key module for low jitter optical sampling

➔ **The only module not originally scheduled to be developed in Telecom Bretagne!**





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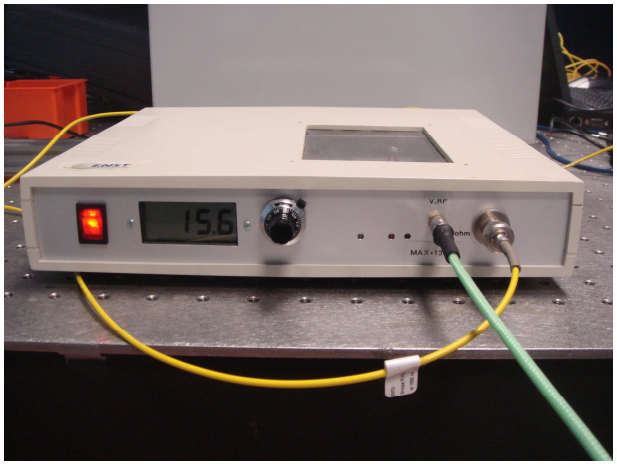
Generation of optical pulses driving an MZM in nonlinear region

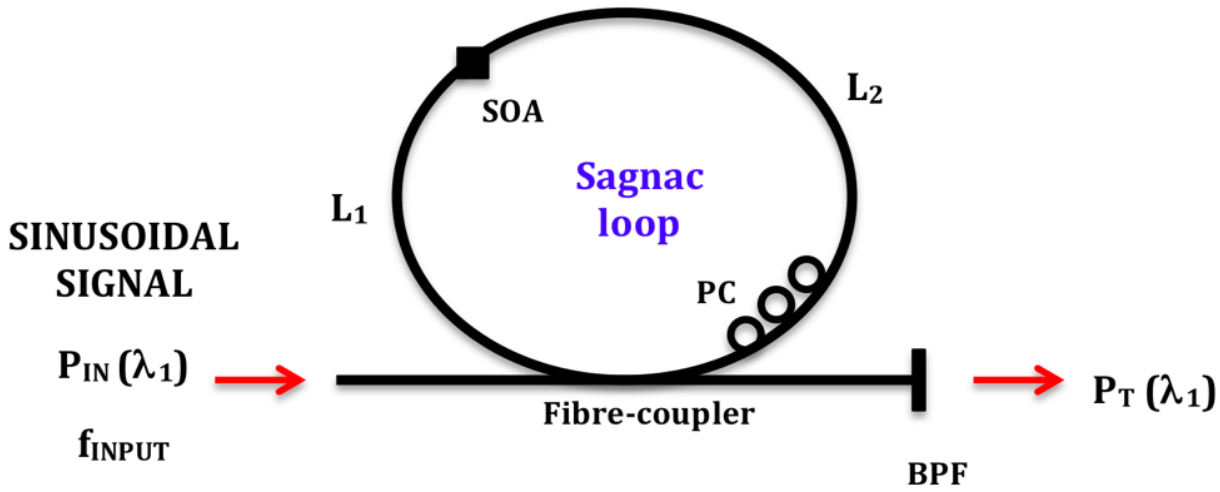


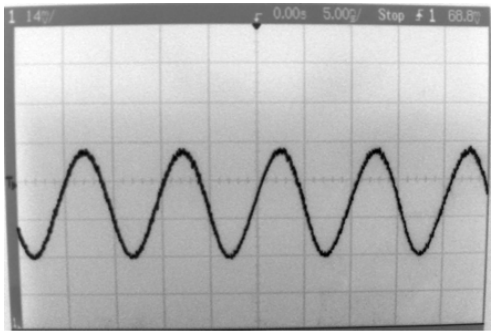
🡐

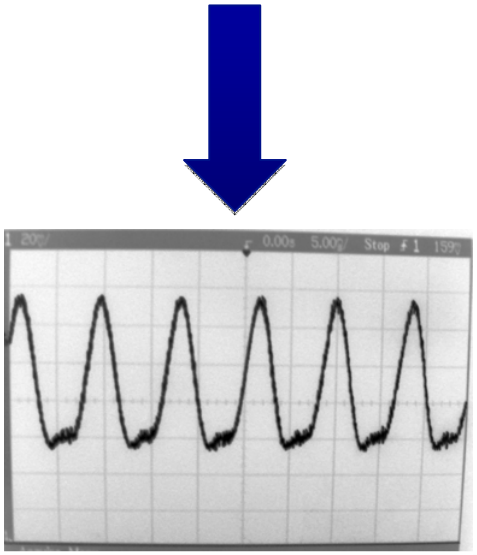
Generation of optical pulses using gain-switched laser diode

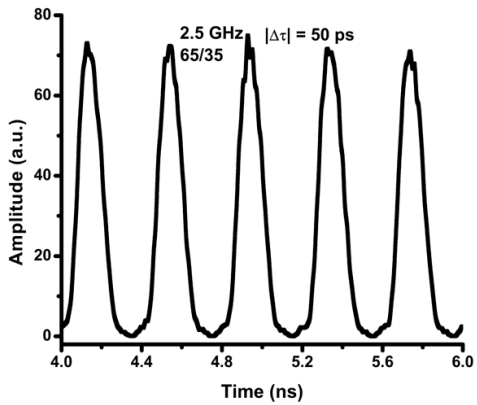
o-GENERATOR - Experimental

➔ **Generation of optical pulses from a sinusoidal input optical signal.**



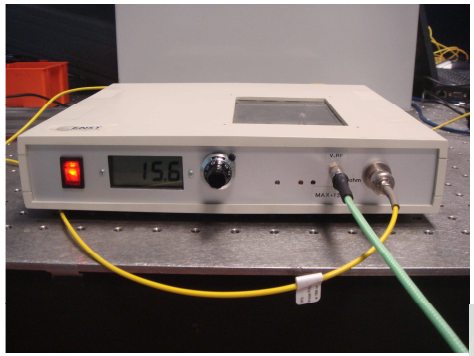


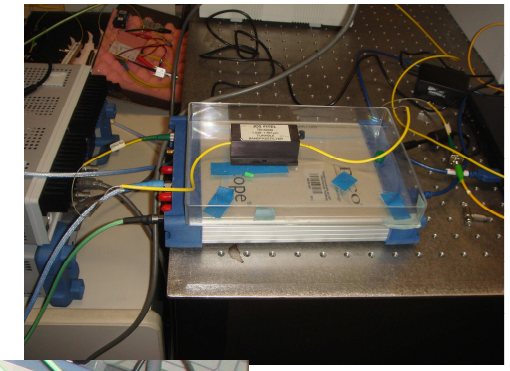


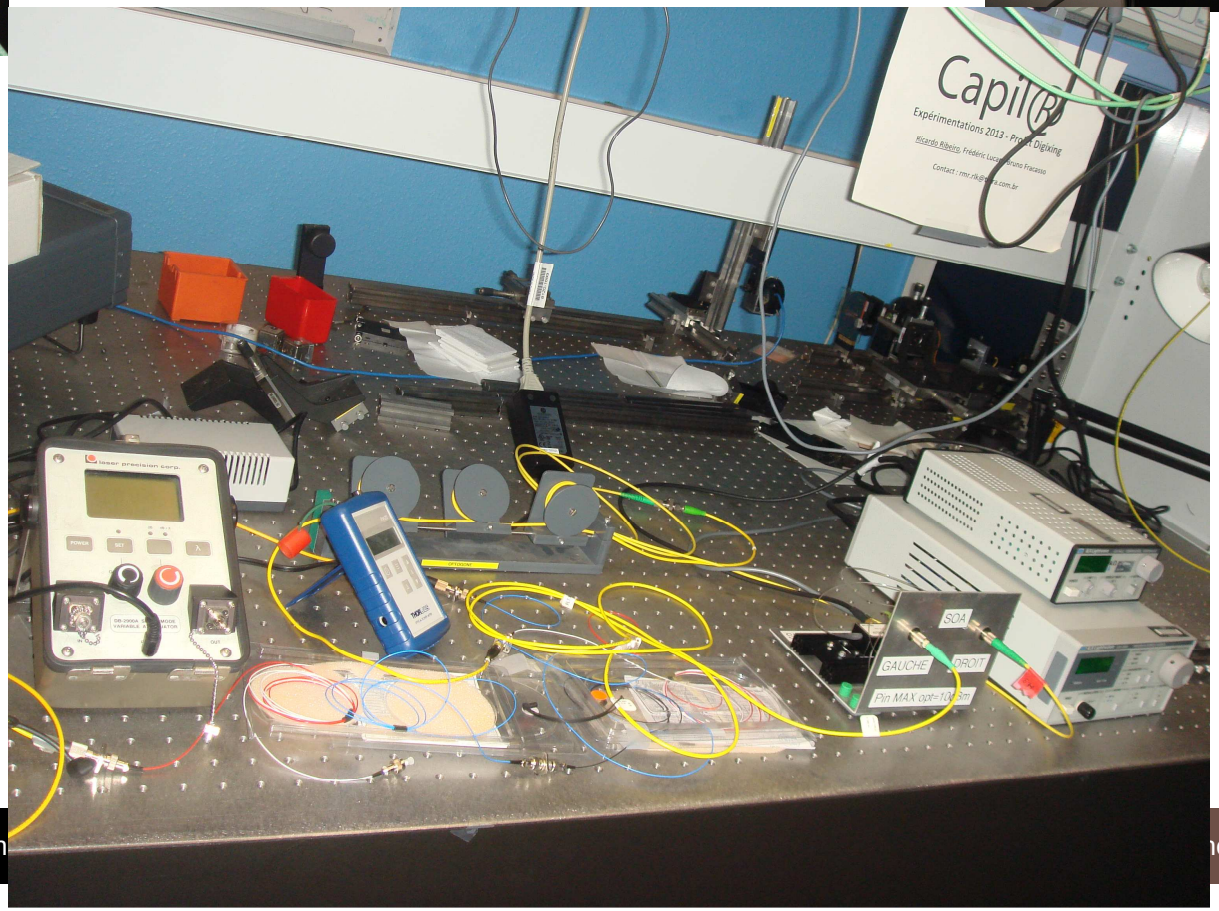


Mode-locking?

o-GENERATOR - Experimental







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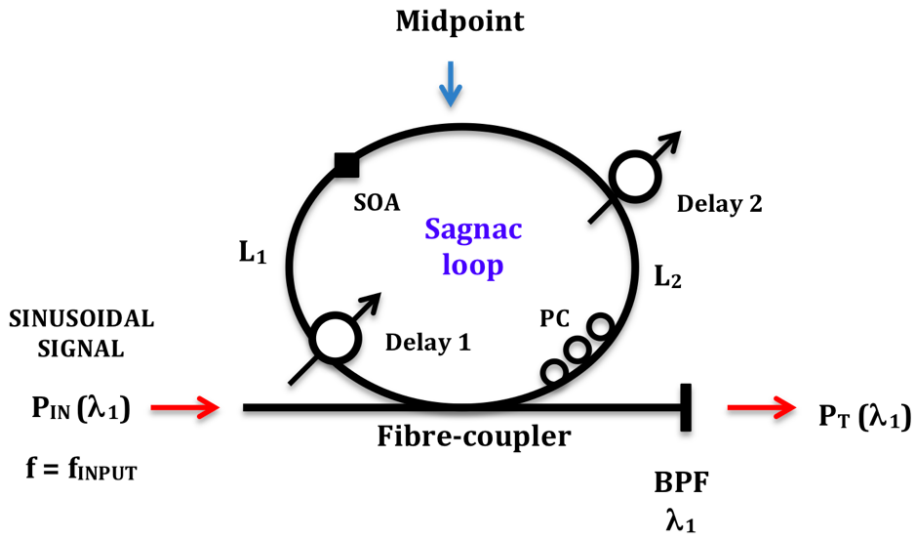
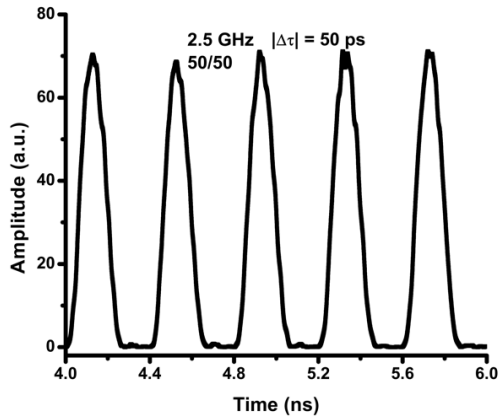
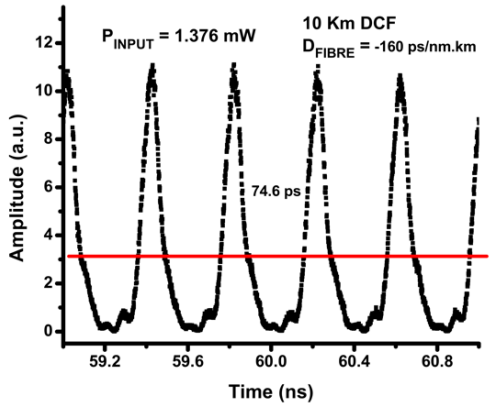
o-GENERATOR – Simulations (pulse compression)

➔ **Generation and compression of optical pulses from a sinusoidal 2.5 GHz input optical signal.**





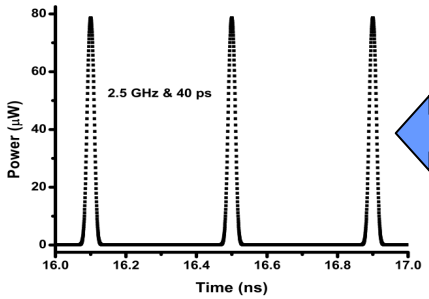


75 ps timewidth pulses ➔ 5 samples for each analogue period

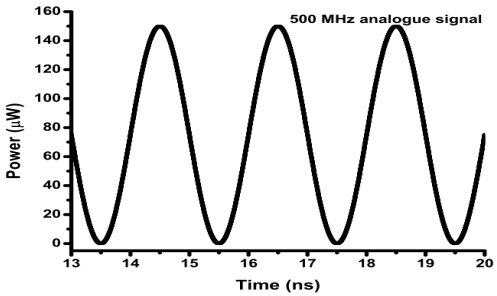
Self-sampling?

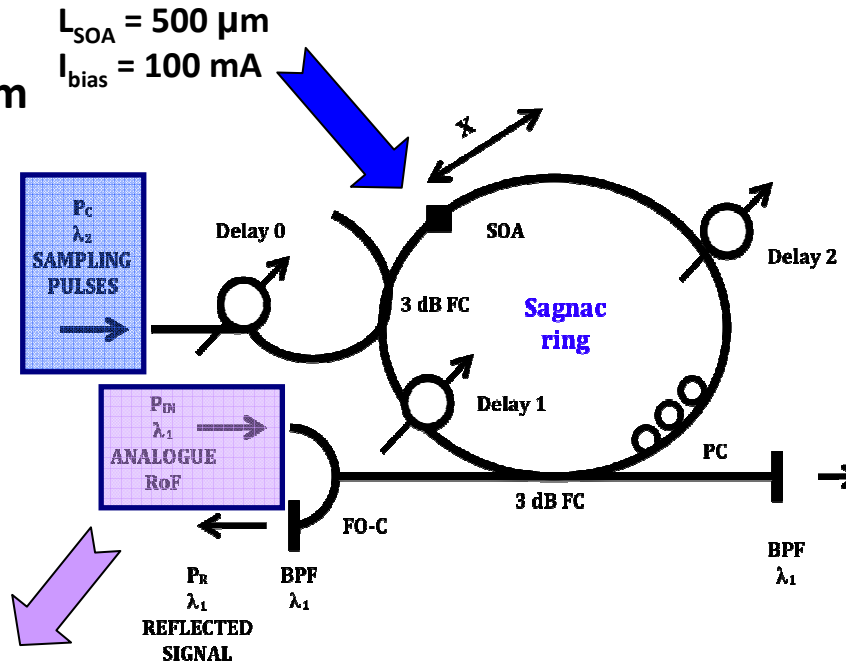
o-SAMPLER – Generation of an analogue envelope of pulses

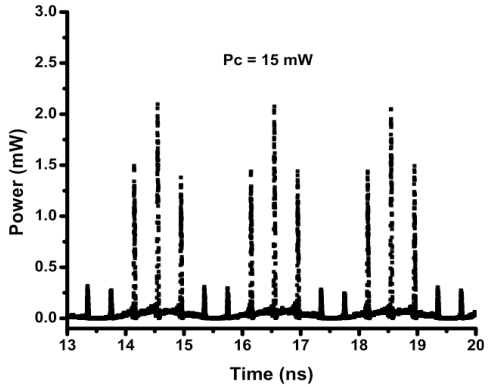
Sampling pulses
2.5 GHz & 40 ps & 1546.0 nm

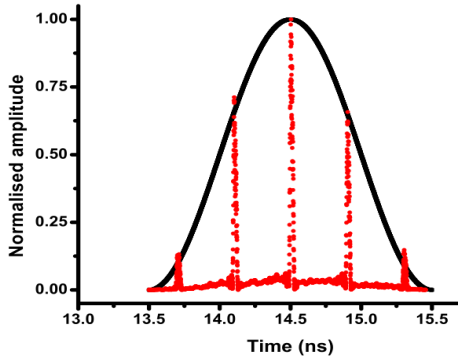


Analogue RoF signal (input)
500 MHz & 1562.1 nm

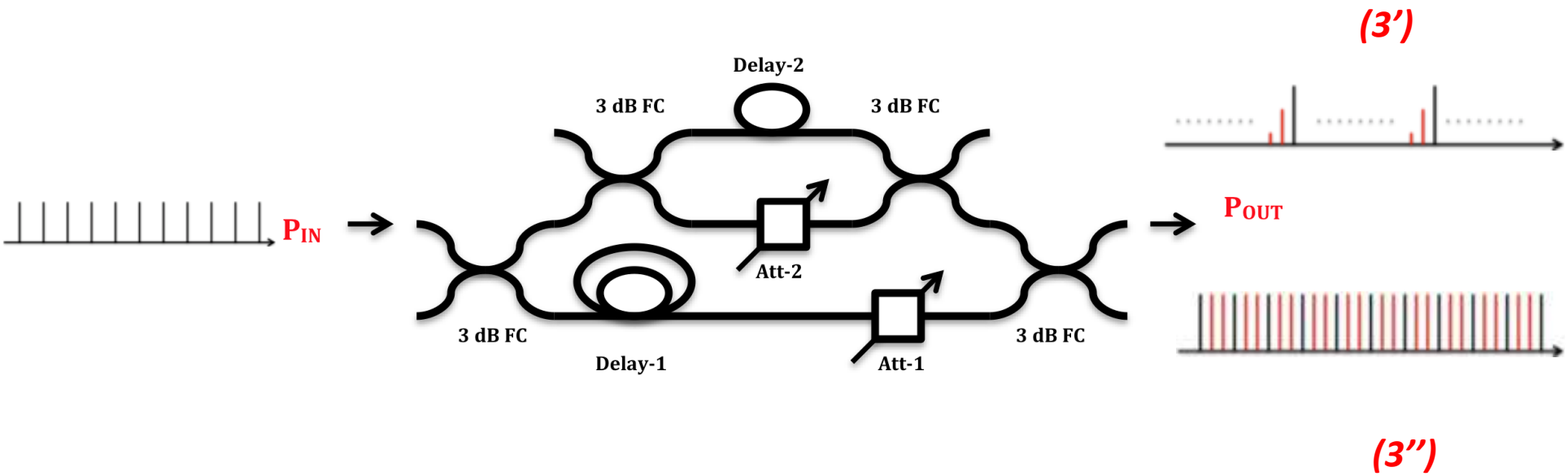








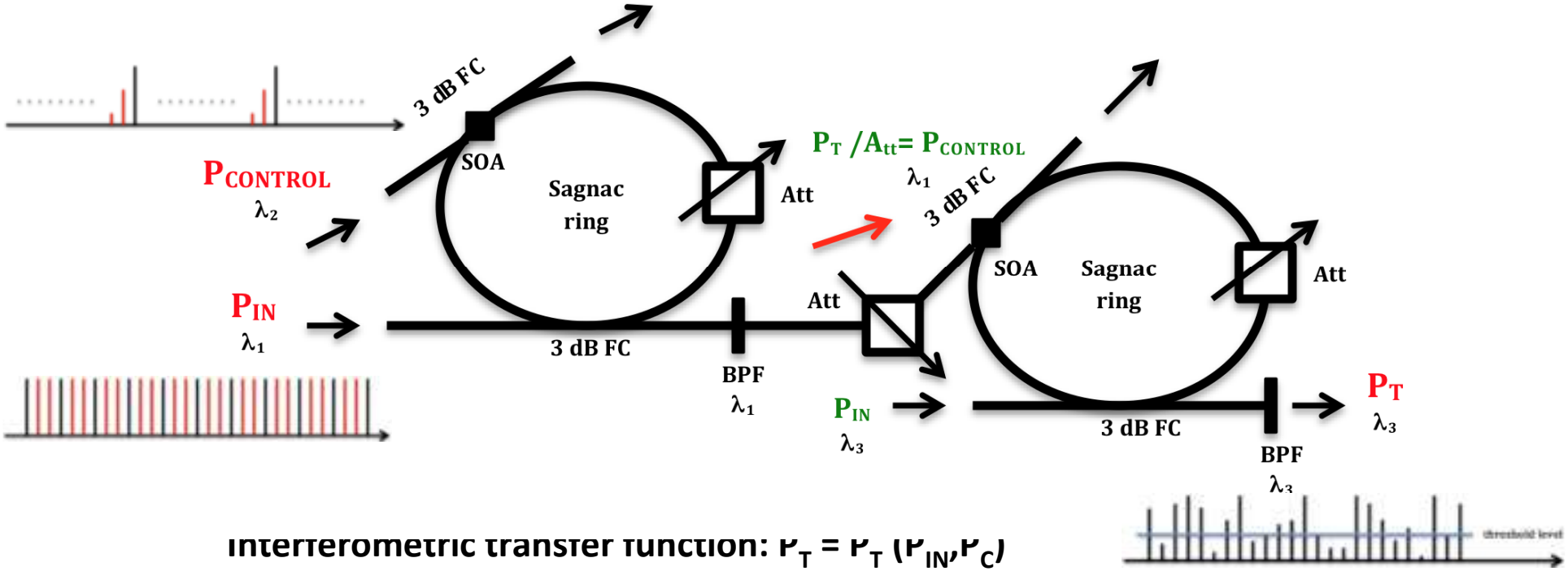
o-INTERLEAVERS 3-bits & 2.50 GHz



(3') ➔ ***T*emporal interleaver: Att1 = Att2 = 3 dB & Delay-1 = 266.6 ps and Delay-2 = 133.3 ps**

(3'') ➔ **Simple temporal interleaver: Att1 = Att2 = 0 dB & Delay-1 = 266.6 ps and Delay-2 = 133.3 ps**

o-ENCODER - The « core » of the *o-DRoF-T*

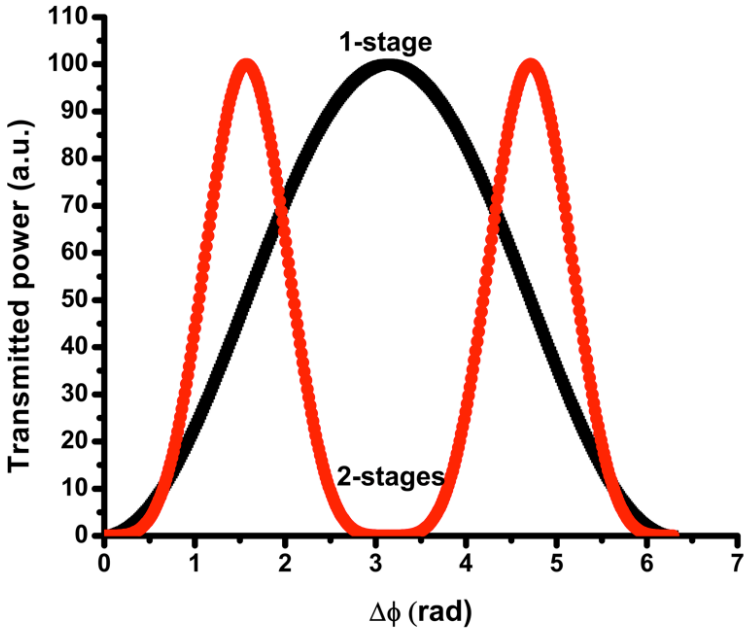


Interferometric transfer function: $P_T = P_T(P_{IN}, P_C)$

$$P_T = P_{IN}\frac{1}{2}\left\{1-\cos\left[2\frac{\gamma}{\alpha}L_{SOA}P_{IN}\frac{1}{2}\left[1-\cos\left(2\gamma L_{SOA}P_C\right)\right]\right]\right\}$$

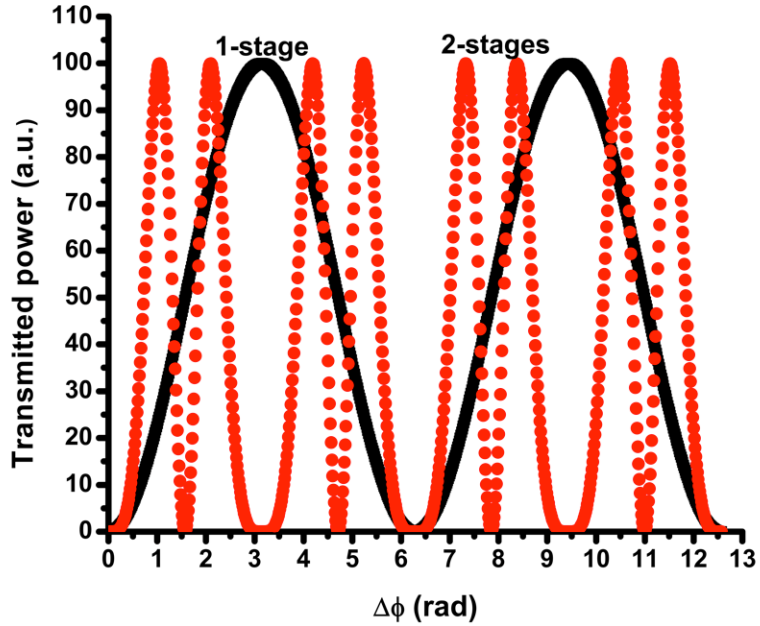
o-ENCODER - Principle

2-bits ➔ ***3-bits***



$$\Delta\phi = 2\gamma L_{SOA} P_C$$

3-bits ➔ ***5-bits***

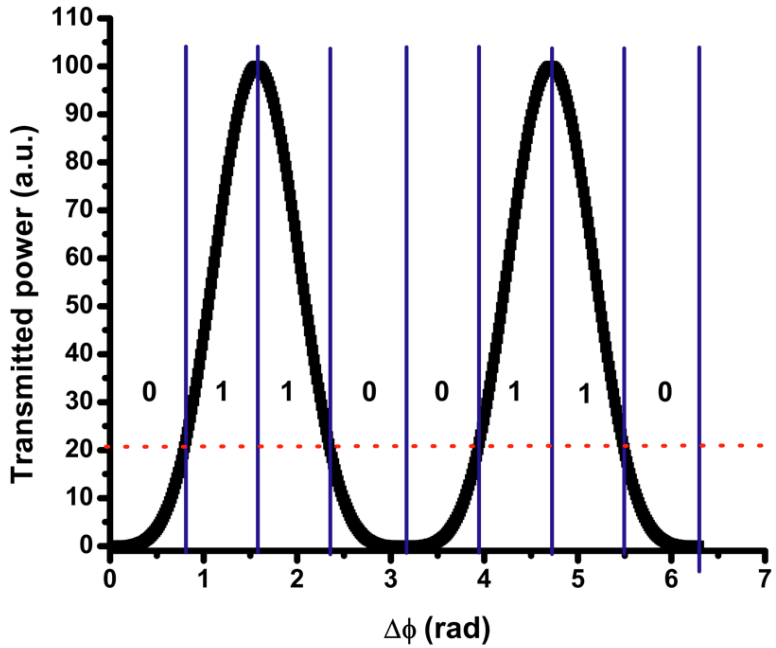


$$\Delta\phi = 2\gamma L_{SOA} P_C$$

➔ ***The bit resolution may be enhanced and the switching speed is mantained using the same control power Pc!***

➔ ***The chain may be extended to contains 3 or more Sagnac rings.***

o-ENCODER – Generation of 3-bit digital Gray-code



$$\Delta\phi = 2\gamma L_{SOA} P_C$$

P_C ➔ An optical sample !

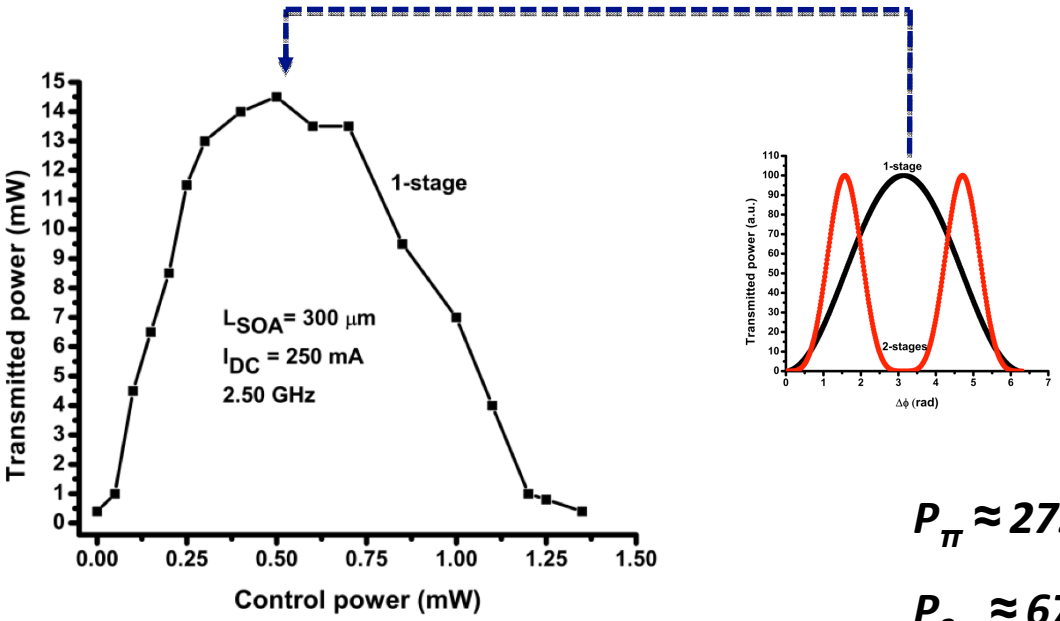
P_1 (rad)	P_2 (rad)	P_3 (rad)	Digital Gray-code
1.47	2.95	5.89	**100**
1.28	2.55	5.11	**101**
1.08	2.16	4.32	**111**
0.88	1.77	3.53	**110**
0.69	1.38	2.75	**010**
0.49	0.98	1.96	**011**
0.30	0.59	1.18	**001**
0.10	0.20	0.39	**000**

➔ ***The threshold level is placed at ~ 20% of the maximum transmitted power.***

➔ ***The o-Encoder is able to generate the digital Gray-code.***

➔ ***For 5-bit resolution the cycles are more sharply and threshold level < 20% of P_{max}.***

o-ENCODER - Preliminary design results



$$\Delta\phi = 2\gamma L_{SOA} P_C$$

40-ps control pulses (1562.1 nm)
20-ps probe pulses (1554.0 nm)

Att = 12 dB (between circuits)
Att = 11 dB (Sagnac ring)

$P_\pi \approx 275\ \mu W$

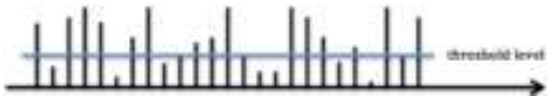
$P_{2\pi} \approx 675\ \mu W$

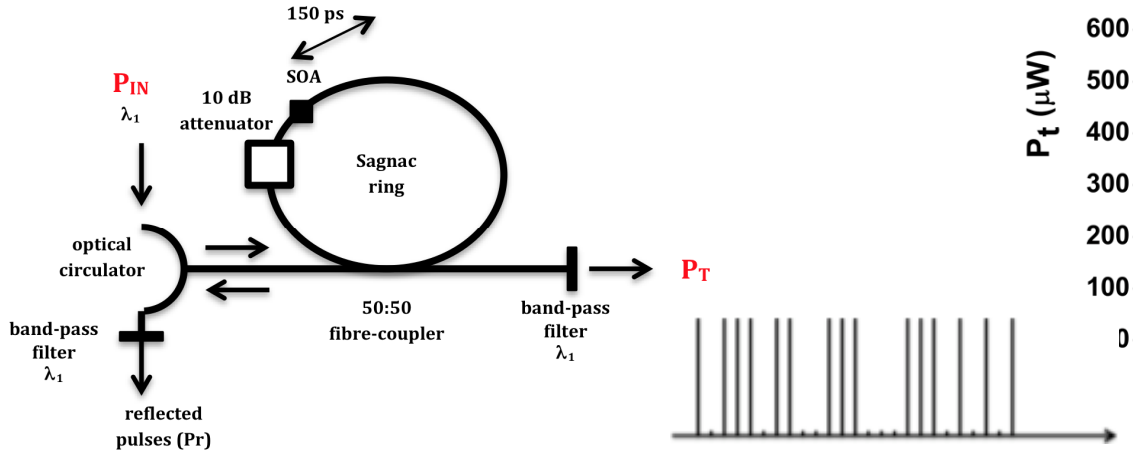
➔ $P_{2\pi}/P_\pi = 2.45$

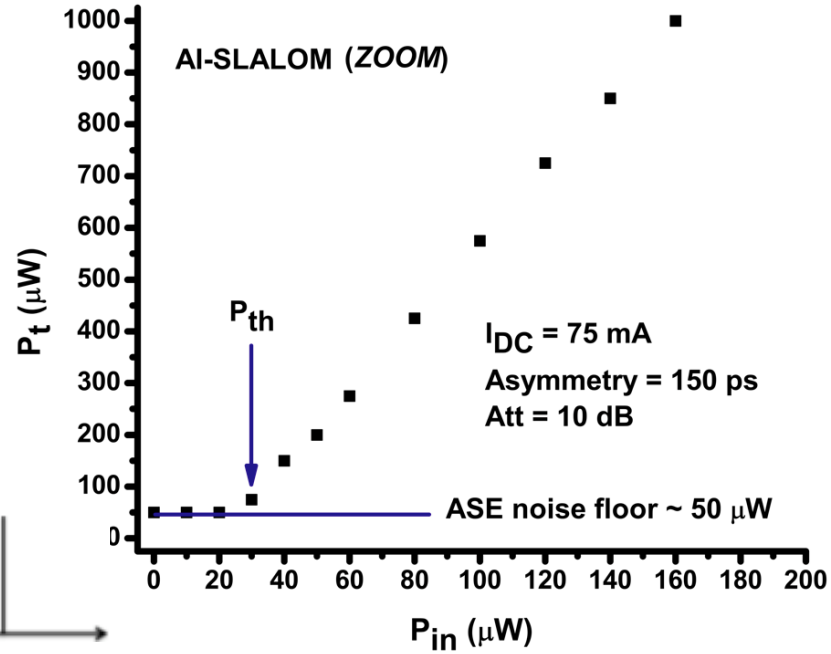
$P_{2\pi}/P_\pi = 2.00$ *(ideal)*

➔ ***The real P_C is the half of that shown in the abscissa axis.***

o-THRESHOLDER – An optical comparator and limiter







P < P_{th} ➔ ***The pulses are reflected from the Sagnac ring, i.e. suppression of residual power into the « 0 » bit-slot.***

➔ ***By cascading 2 or 3 o-Thresholders based on present design and parameters, it is also possible to transmit « 1 » bits limited at 6 mW peak power.***

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THANK YOU! MERCI! OBRIGADO!

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