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

Ricardo M. Ribeiro* [rmr@pq.cnpq.br]
Frédéric Lucarz and Bruno Fracasso

Telecom Bretagne - Optics Department
Technopôle Brest-Iroise, CS 83818, 29280, Brest Cedex 3 - France

* Post-Doc/Sabbatic stay of 1.5 year funded by Capes/MEC – Brasil
August-2012/January-2014

Laboratório de Comunicações Ópticas
Departamento de Engenharia de Telecomunicações
Universidade Federal Fluminense
OUTLINE

Context & motivations

Objective

_o-DRoF_ transceiver: main features

_o-DRoF_ transmitter (*digitiser*)

- Generator
- Sampler
- Interleavers
- Encoder
- Thresholder

_o-DRoF_ receiver (*analogiser*)

Next steps

_o-DRoF_ = optical Digitising Radio-over-Fibre
CONTEXTE & 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

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 ↔ Metropolitan network

FTTH network

Base Station ↔ FTTH 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).

→ 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!

Generation of optical pulses driving an MZM in nonlinear region

Generation of optical pulses using gain-switched laser diode
Generation of optical pulses from a sinusoidal input optical signal.

Mode-locking?
o-GENERATOR - Experimental
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

\[ L_{SOA} = 500 \, \mu m \]
\[ I_{bias} = 100 \, mA \]

**Analogue RoF signal (input)**
500 MHz & 1562.1 nm
Temporal interleaver: \( \text{Att1} = \text{Att2} = 3 \) dB & Delay-1 = 266.6 ps and Delay-2 = 133.3 ps

Simple temporal interleaver: \( \text{Att1} = \text{Att2} = 0 \) dB & Delay-1 = 266.6 ps and Delay-2 = 133.3 ps
o-ENCODER - The « core » of the o-DRoF-T

Interferometric transfer function: \[ P_T = P_T(P_{\text{IN}}, P_C) \]

\[ P_T = P_{\text{IN}} \frac{1}{2} \left\{ 1 - \cos \left[ 2 \frac{\gamma}{\alpha} L_{\text{SOA}} P_{\text{IN}} \frac{1}{2} \left[ 1 - \cos (2 \gamma L_{\text{SOA}} P_C) \right] \right] \right\} \]
The bit resolution may be enhanced and the switching speed is maintained using the same control power $P_c$!

The chain may be extended to contain 3 or more Sagnac rings.
o-ENCODER – Generation of 3-bit digital Gray-code

- 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 $P_{max}$.

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

$P_c \rightarrow$ An optical sample!

<table>
<thead>
<tr>
<th>P$_1$ (rad)</th>
<th>P$_2$ (rad)</th>
<th>P$_3$ (rad)</th>
<th>Digital Gray-code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.47</td>
<td>2.95</td>
<td>5.89</td>
<td>100</td>
</tr>
<tr>
<td>1.28</td>
<td>2.55</td>
<td>5.11</td>
<td>101</td>
</tr>
<tr>
<td>1.08</td>
<td>2.16</td>
<td>4.32</td>
<td>111</td>
</tr>
<tr>
<td>0.88</td>
<td>1.77</td>
<td>3.53</td>
<td>110</td>
</tr>
<tr>
<td>0.69</td>
<td>1.38</td>
<td>2.75</td>
<td>010</td>
</tr>
<tr>
<td>0.49</td>
<td>0.98</td>
<td>1.96</td>
<td>011</td>
</tr>
<tr>
<td>0.30</td>
<td>0.59</td>
<td>1.18</td>
<td>001</td>
</tr>
<tr>
<td>0.10</td>
<td>0.20</td>
<td>0.39</td>
<td>000</td>
</tr>
</tbody>
</table>
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)

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

The real $P_C$ is the half of that shown in the abscissa axis.
P < P_{th} \implies \text{The pulses are reflected from the Sagnac ring, i.e. suppression of residual power into the «0» bit-slot.}

\implies \text{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.}
REFERENCES


2) Ricardo M. Ribeiro, Frédéric Lucarz and Bruno Fracasso, *An All-Optical Sampler for Digitising Radio-over-Fibre Transceivers*, IEEE 18th Conference on Network and Optical Communications (NOC 2013), Graz, Austria, July 10-12, 2013, pp. 27-34.

3) Ricardo M. Ribeiro, Frédéric Lucarz and Bruno Fracasso, *Proposal and Design of an All-Optical Encoder for Digitising Radio-over-Fibre Transceivers*, IEEE 18th Conference on Network and Optical Communications (NOC 2013), Graz, Austria, July 10-12, 2013, pp. 35-42.


6) Ricardo M. Ribeiro, Frédéric Lucarz and Bruno Fracasso, *Design of an Analogiser for Optically Digitised Radio-over-Fibre Signals*, (IN PREPARATION).
THANK YOU! MERCI! OBRIGADO!

Ricardo M. Ribeiro – rmr@pq.cnptq.br
Telecom Bretagne, Technopôle Brest-Iroise, CS 83818, F-29238 Brest Cedex 3 - France