EPIC Technology Meeting on Photonics in Defense
6 September 2023, Starachowice, Poland

David Dupuy, Regional Sales Manager

1 μm and 2 μm,
Doped Fibers, $LiNbO_3$ Phase Modulators, and Variable Optical Delay Lines dedicated to Directed Energy Laser

1. What is the Photonics activity within exail?
2. $LiNbO_3$ Modulators based solutions for Coherent Beams Combining fiber lasers
3. $LiNbO_3$ Modulators for Spectral broadening
4. New 2 μm doped fibers

exail

Stronger together

1500

EMPLOYEES

250+

MILLIONS EUROS
OF TURNOVER

20+

% OF TURNOVER
INVESTED IN R&D

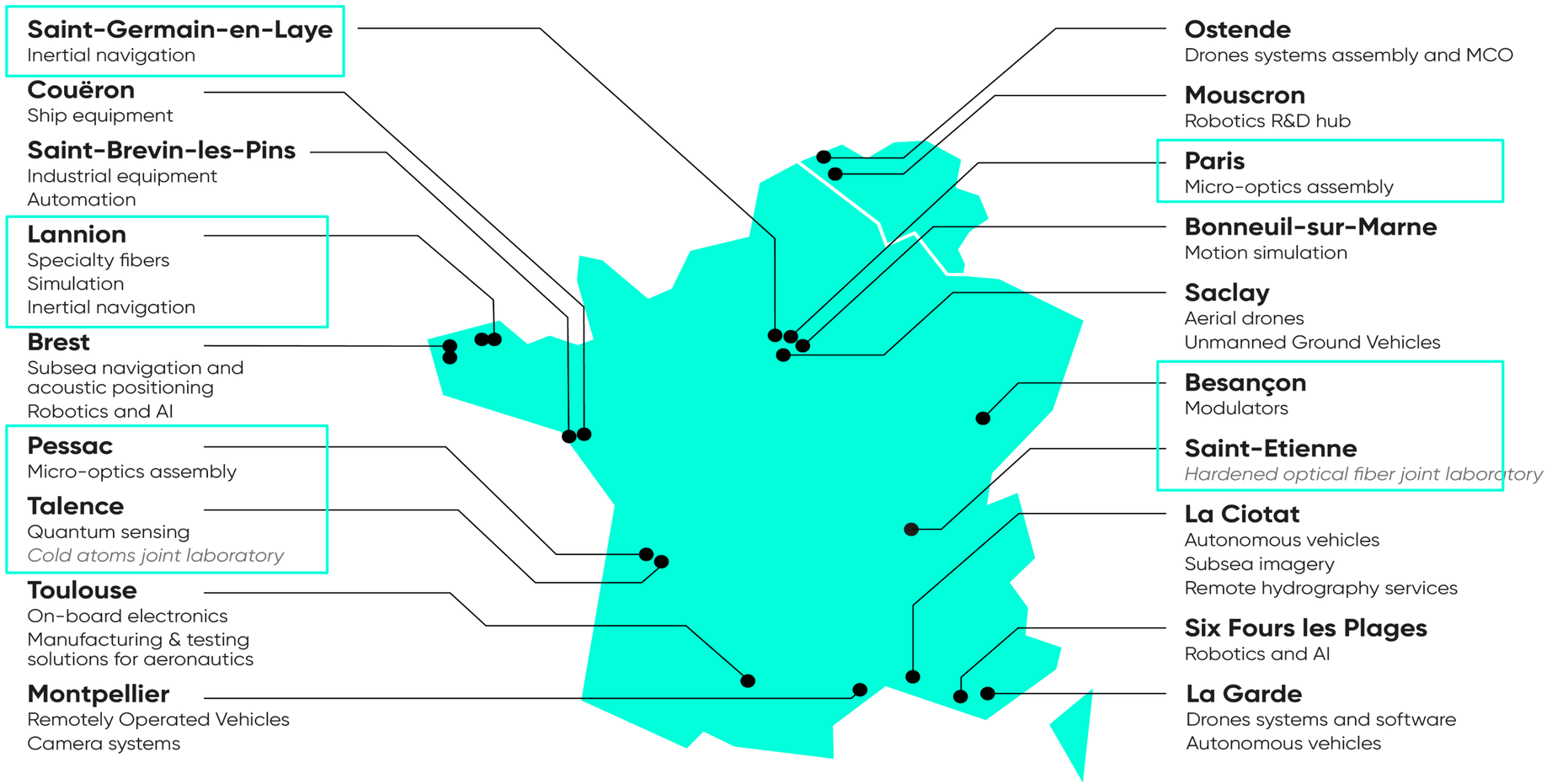
80%

OF TURNOVER
IN EXPORT

1 um and 2 um, Doped Fibers and $LiNbO_3$ Phase Modulators dedicated to Directed Energy Laser

exail

A unique technological know-how



Saint-Germain-en-Laye
Inertial navigation

Couëron
Ship equipment

Saint-Brevin-les-Pins
Industrial equipment
Automation

Lannion
Specialty fibers
Simulation
Inertial navigation

Brest
Subsea navigation and acoustic positioning
Robotics and AI

Pessac
Micro-optics assembly

Talence
Quantum sensing
Cold atoms joint laboratory

Toulouse
On-board electronics
Manufacturing & testing solutions for aeronautics

Montpellier
Remotely Operated Vehicles
Camera systems

Ostende
Drones systems assembly and MCO

Mouscron
Robotics R&D hub

Paris
Micro-optics assembly

Bonneuil-sur-Marne
Motion simulation

Saclay
Aerial drones
Unmanned Ground Vehicles

Besançon
Modulators

Saint-Etienne
Hardened optical fiber joint laboratory

La Ciotat
Autonomous vehicles
Subsea imagery
Remote hydrography services

Six Fours les Plages
Robotics and AI

La Garde
Drones systems and software
Autonomous vehicles

1 um and 2 um, Doped Fibers and $LiNbO_3$ Phase Modulators dedicated to Directed Energy Laser

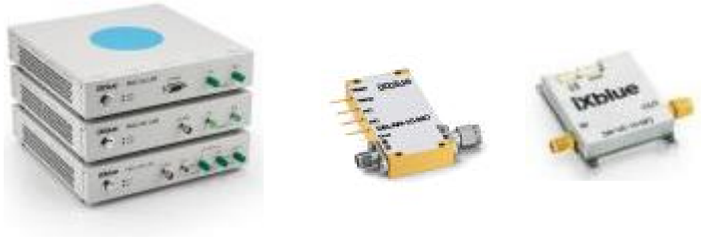
Photonics fibered solutions, from components to instruments

› Scalable technologies to address a full range of applications

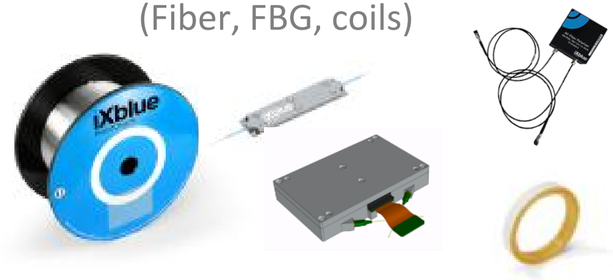
Components

$LiNbO_3$ Phase, Amplitude, IQ Modulators (COTS, Space model)

Modulators Matching components (RF Amplifier, Low Noise Electronic)



Fibers and fiber solutions (Fiber, FBG, coils)



Turn-key devices and systems

µoptics and passive optics integration

Transmitters, transceivers, laser pilot, coherent regeneration station

Lasers (Narrow-linewidth, high-power) Optical Low Noise & Power amplifiers

Instruments

Inertial Measurement Unit

Absolute Quantum Gravimeter

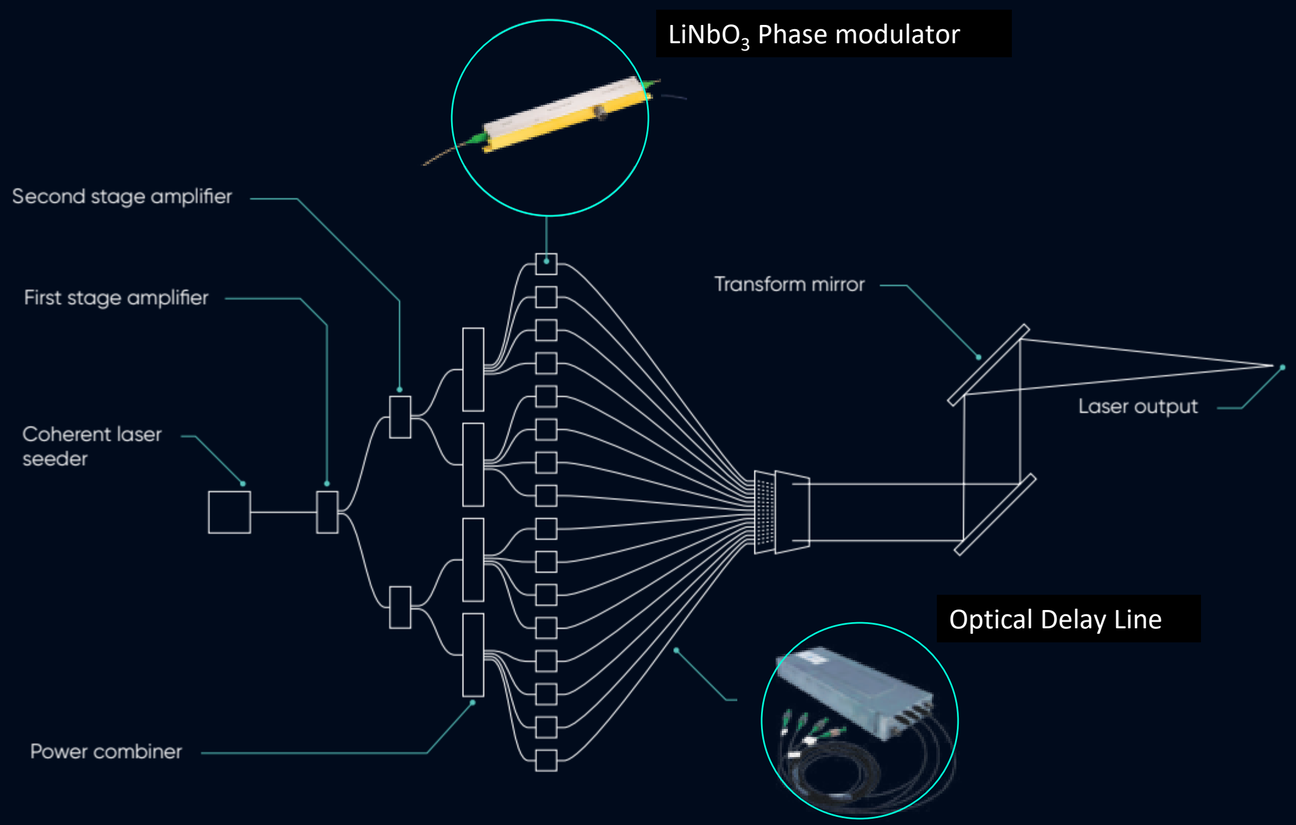
Quantum lasers

1 um and 2 um, Doped Fibers and $LiNbO_3$ Phase Modulators dedicated to Directed Energy Laser

COHERENT BEAM COMBINATION FOR DIRECTED ENERGY LASER

EXAIL OFFERS AN OPTIMIZED SOLUTION FOR THE ACCURATE, ADJUSTABLE, AND RELIABLE PHASELOCK MODULATION BETWEEN SEVERAL LASER BEAMS, USING THE COHERENT BEAM COMBINING TECHNIQUE: THE MODBOX CBC.

Coherent combination of laser beams



- The phase modulators array equalize the optical path for each beam
- A maximum of energy / power is achieved by constructive interference
- One phase modulator is required per beam
- A low frequency modulation is necessary
- Pure Phase modulation required (w/o Residual Amplitude modulation)
  - Key $LiNbO_3$ Phase modulators specification:
    - Low Insertion Loss & high Optical Power Handling Capability
    - DC to 200 MHz

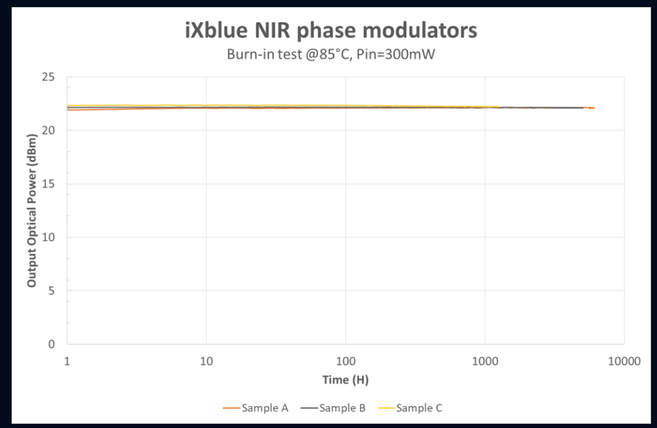
- Optical Delay Line may be required to equalize optical path
  - Key ODL specification:
    - Very precise and stable control of an optical delay
    - Motorized delay control

Coherent combination of laser beams

> **Incomparable optical waveguide and the key optical performances reached:**
  - Annealed Proton Exchange process on a selected $LiNbO_3$ doped wafer.
  - Very low insertion loss: IL < 3 dB. Gaussian distribution with a 2 dB typical mean.
  - High optical power handling capability of up to 300 mW.
  - High resistance to refractive index effect and Pyro-electric effect.

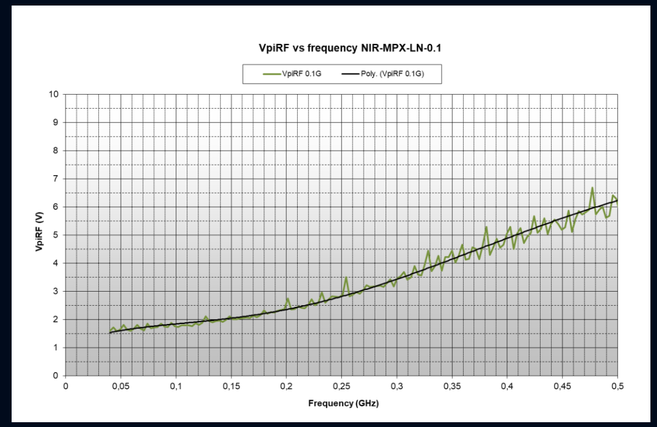
⇒ Exail offers the best $LiNbO_3$ phase modulators optical performances.

⇒ High optical performances stable over the temperature range and over the time



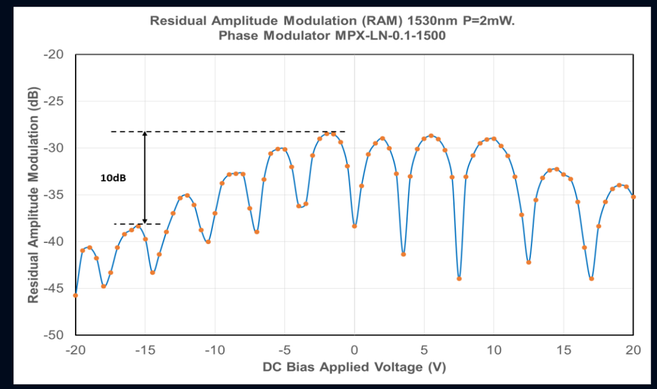
> **Very low Vπ:**
  - Modulator Vπ is proportional to the Electro-Optical bandwidth
  - The NIR-MPX-LN-0.1 features a Vπ of only 1,5 V @ 50 MHz

⇒ Low Vπ at low frequencies minimizes RF to minimize the power consumption

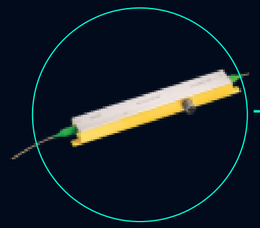


> **Mitigate the RAM effect:**
  - The NIR-MPX-LN-0.1 is a DC coupled device: a permanent DC signal can be applied w/o modulator damages
  - Applying a constant DC voltage allows to reduce the RAM from typically 30dB to near 40dB (patented technique)

⇒ Residual amplitude modulation can be strongly reduced thanks to a permanent DC voltage

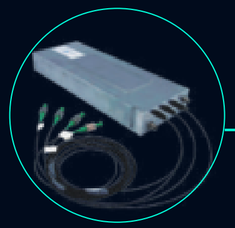


Coherent combination of laser beams: ModBox-CBC-8CHannels



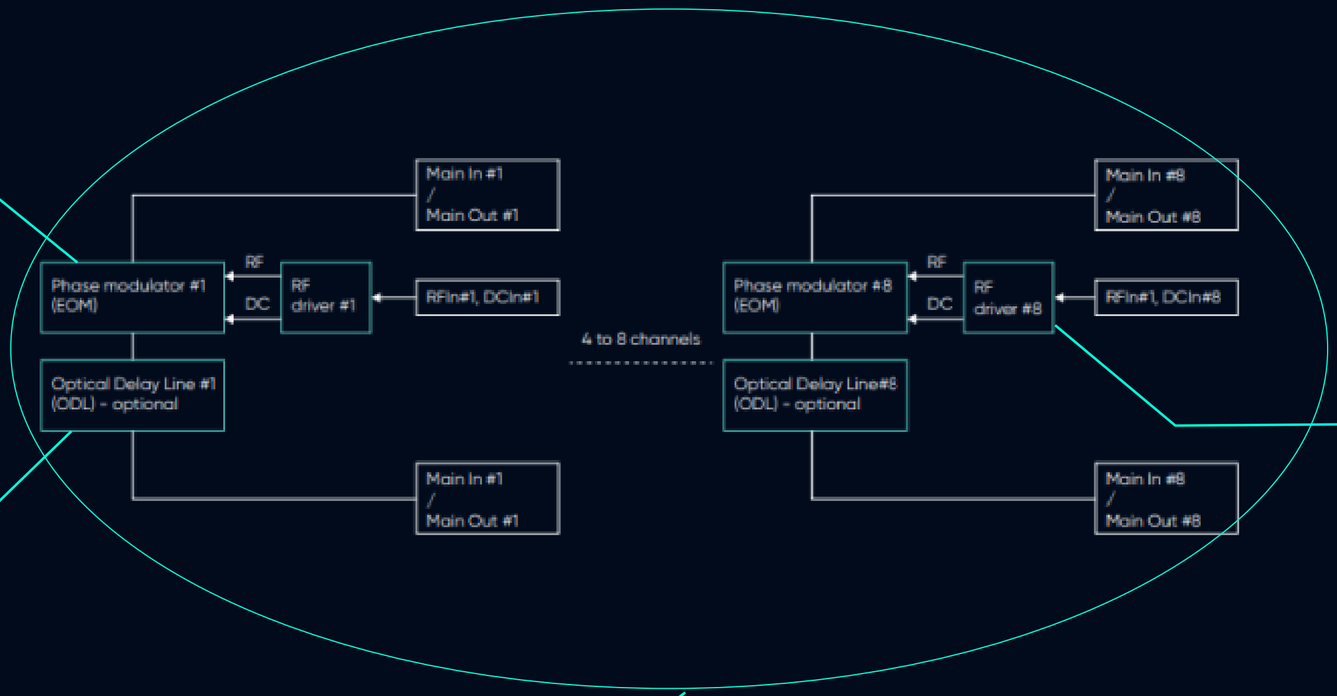
$LiNbO_3$ Phase Modulator Performances Highlight

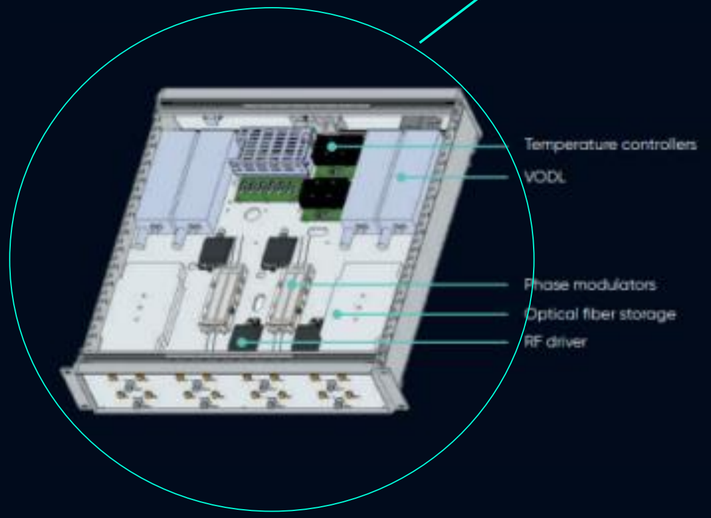
Bandwidth	DC to 300 MHz
Insertion loss	2 dB
Maximum optical power	300 mW



Optical Delay Line Performances Highlight

Insertion losses	2 dB
Insertion losses uniformity	
Minimum incremental motion	Tens fs
Delay range	Up to 12 ns



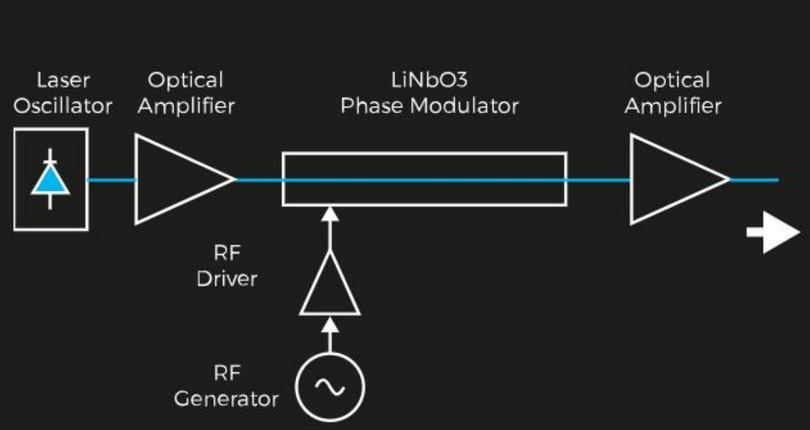


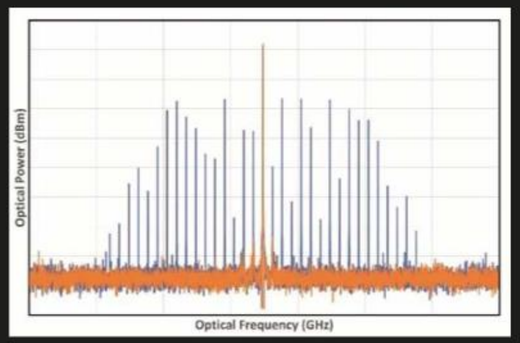
ModBox-CBC Performances Highlight

Number of channels	4or 8	
Operating wavlength	1064 nm	2000 nm
Insertion loss	< 5 dB	< 5 dB
Adjustable delay range	600 ps	600 ps
RAM	Adjustable	Adjustable

SPECTRAL BROADENING For DIRECTED ENERGY

Spectral broadening using large bandwidth phase modulator

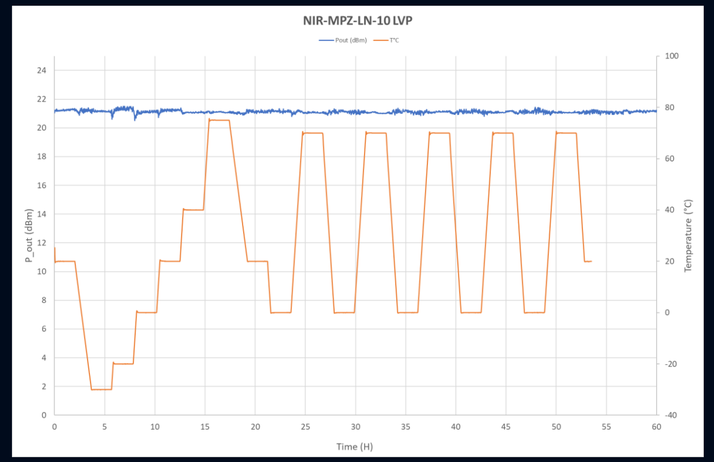




- A phase modulator is required per Fiber Module to suppress the SBS
- One phase modulator is required per beam
- High frequency modulation (several GHz, to 10 GHz, and 20 GHz)

- Key $LiNbO_3$ Phase modulators specification:
  - Several GHz to 10 GHz EO-bandwidth
  - High RF power handling capability
  - High optical power handling capability
  - Low $V\pi$

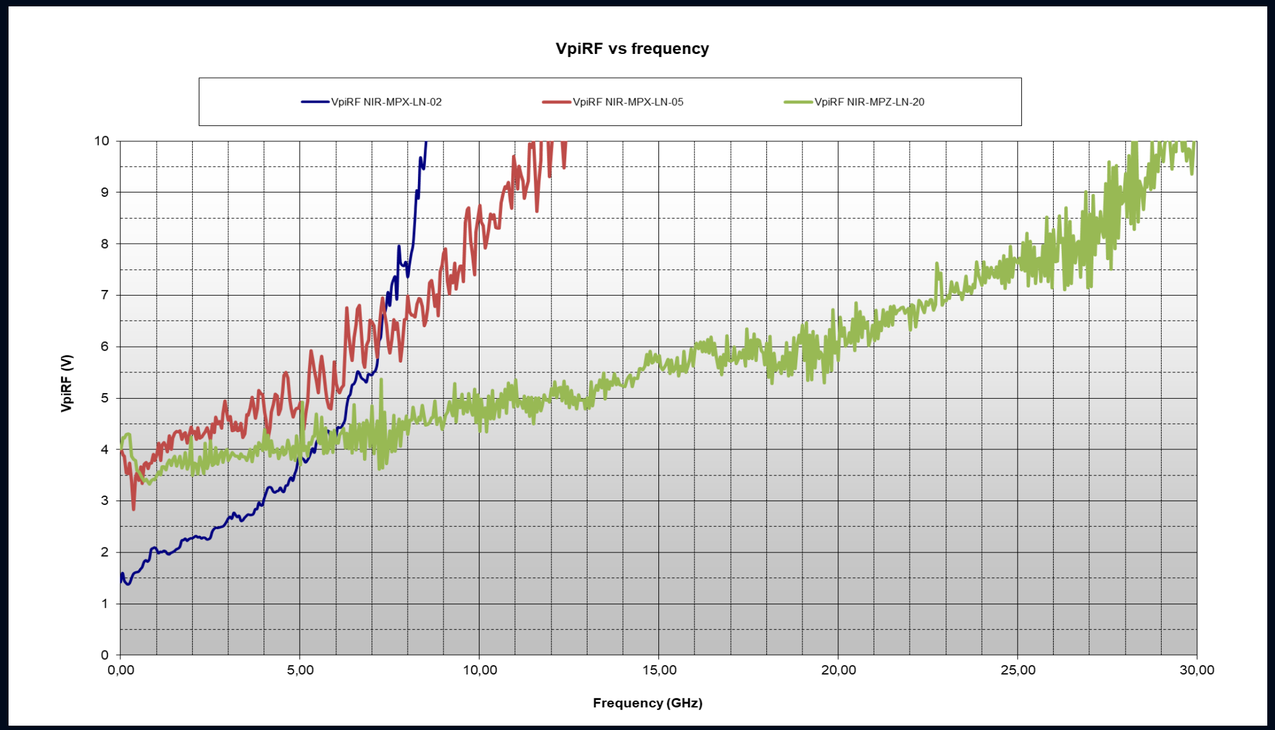
Spectral broadening using large bandwidth phase modulator



> **Incomparable optical waveguide and the key optical performances reached:**
  - Annealed Proton Exchange process on a selected $LiNbO_3$ doped wafer.
  - High optical power handling capability of up to 300 mW.
  - Optical power stability < +/- 0.5 dBm over [-30; +75] °C.
  - Optical power stability < +/- 0.15 dBm over [0; +70] °C

⇒ Exail offers the best $LiNbO_3$ phase modulators optical performances.

⇒ High optical performances stable over the temperature range and over the time



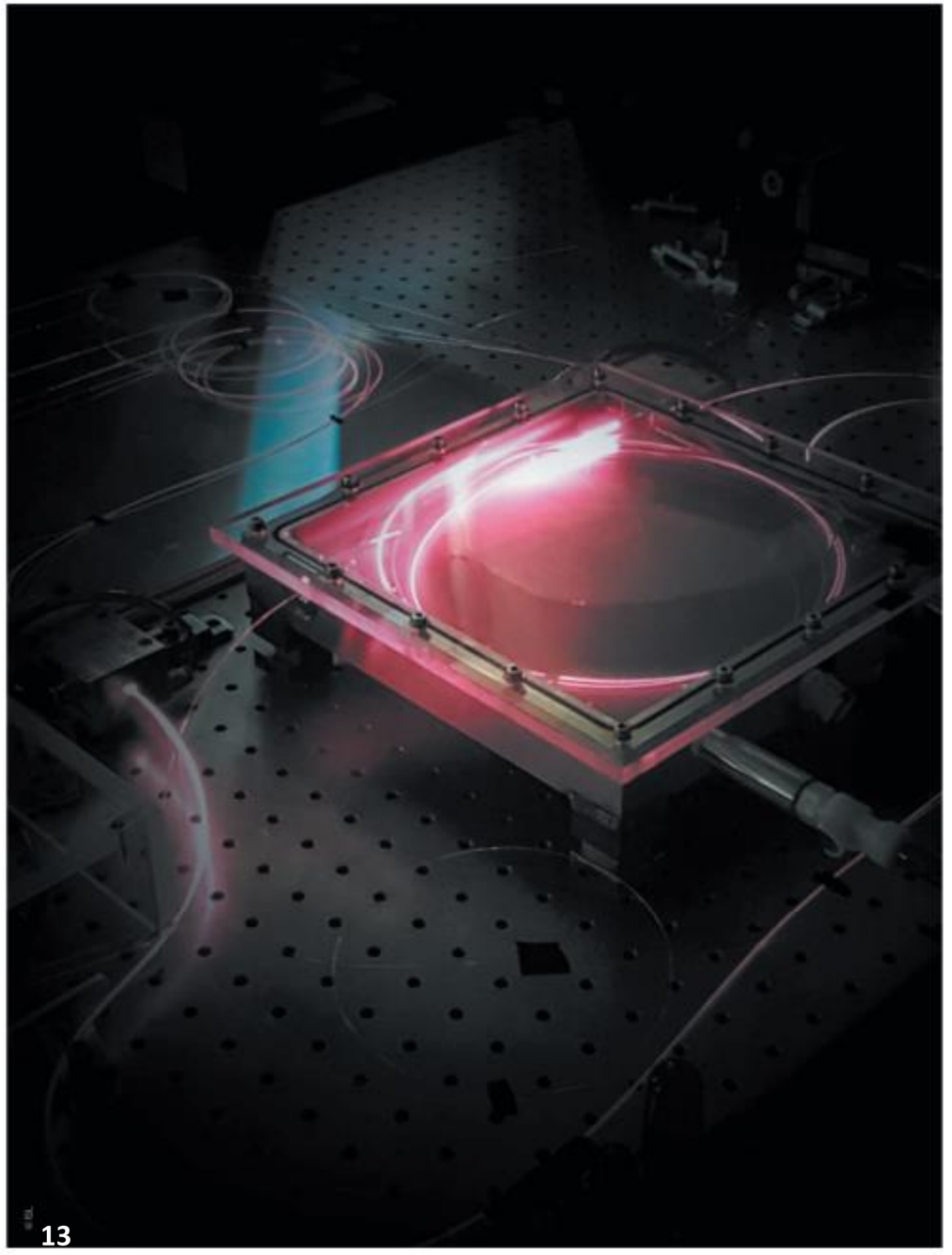
> **Very low Vπ and very large bandwidth modulators choices:**
  - Modulator Vπ is proportional to the Electro-Optical bandwidth

  - The NIR-MPX-LN-02 features
    - Vπ of only 1,5 V @ 50 MHz / 2,5 V @ 3 GHz
    - Bandwidth up to 5 GHz

  - The NIR-MPZ-LN-10 features
    - Vπ of 2,3 V @ 1 GHz / 3 V @ 10 GHz
    - Bandwidth up to 20 GHz

  - The NIR-MPZ-LN-20 features
    - Vπ of 3,5 V @ 1 GHz / 4,5 V @ 10 GHz / 6 V @ 20 GHz
    - Bandwidth up to 30 GHz

⇒ Low Vπ with very large bandwidth frequencies modulators minimizes RF to minimize the power consumption



NEW 2 µm FIBER LASER SOURCES FOR DEFENSE

FOR MANY YEARS NOW, THE FRENCH-GERMAN RESEARCH INSTITUTE OF SAINT-LOUIS (ISL) HAS BEEN A PARTNER OF EXAIL IN THE RISING FIELD OF 2 µm FIBER LASERS. EXAIL SUPPORTS THE EMERGENCE OF INNOVATIONS IN THIS FIELD WITH ITS EXTENSIVE EXPERIENCE AND PORTFOLIO.

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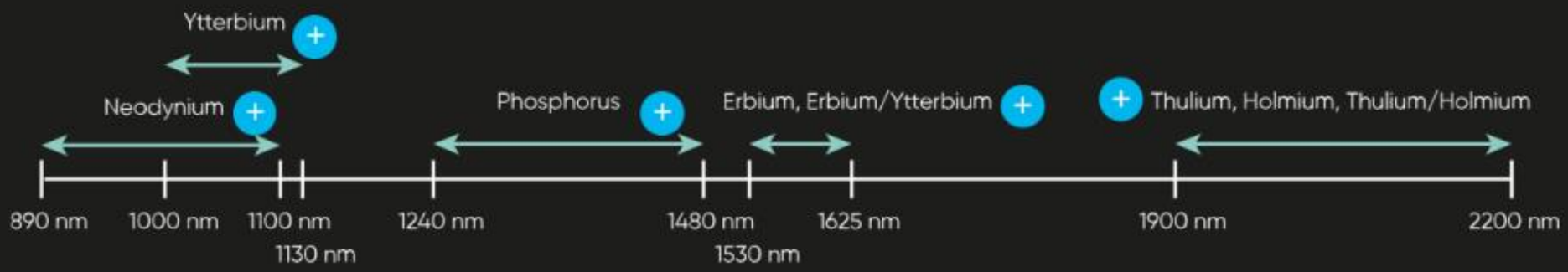
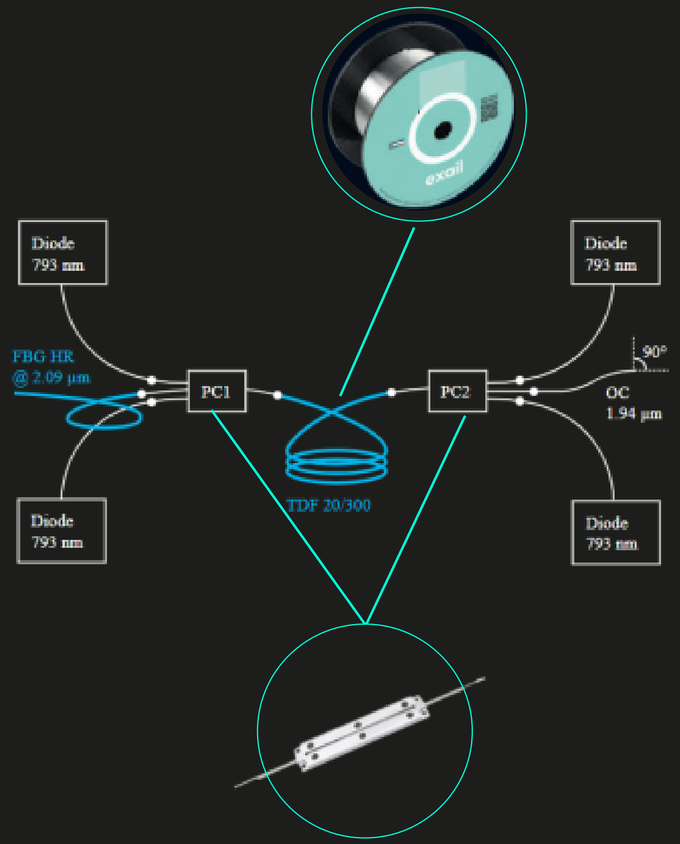
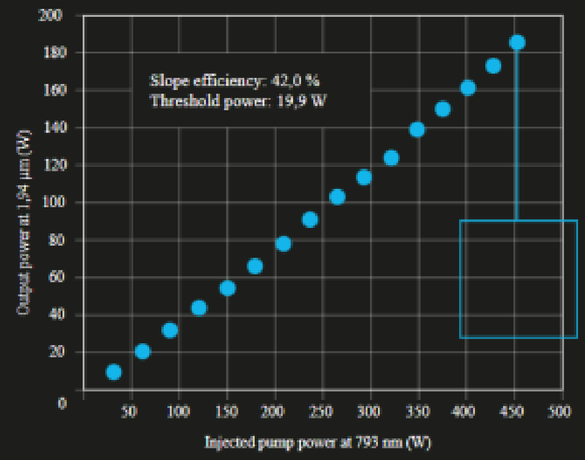
Fiber lasers in the 2 µm range: doped fiber for seeder and amplifier



2 µm doped fibers Highlights

Doping Materials	
Thulium	Single Clad 4 and 5 µm core, PM and non-PM Double Clad 6 to 25 µm core, PM and non-PM
Thulium-Holmium	Double Clad 6 to 25 µm core, PM and non-PM Triple Clad 18µm co
Holmium	Single Clad 8µm core, PM and non-PM Single Clad 20 µm core, PM Triple Clad 20 µm core





Thank you for your attention

david.dupuy@exail.com