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September 9th, 2024

Hervé Gouraud
Exail Photonics Division & Modulation Solution Sales Director

Stronger together

2000

EMPLOYEES

320+

MILLIONS EUROS
OF TURNOVER

20+

% OF TURNOVER
INVESTED IN R&D

80%

OF TURNOVER
IN EXPORT

1 μm $LiNbO_3$ Phase Modulators dedicated to CBC and SBC laser architectures

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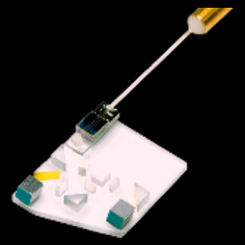
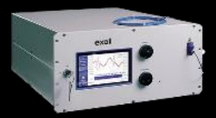
From components to complex systems

Components

Photonics





Equipment

Inertial navigation

Sonars & positioning

Quantum instruments

On-board electronic

Simulators

Platforms

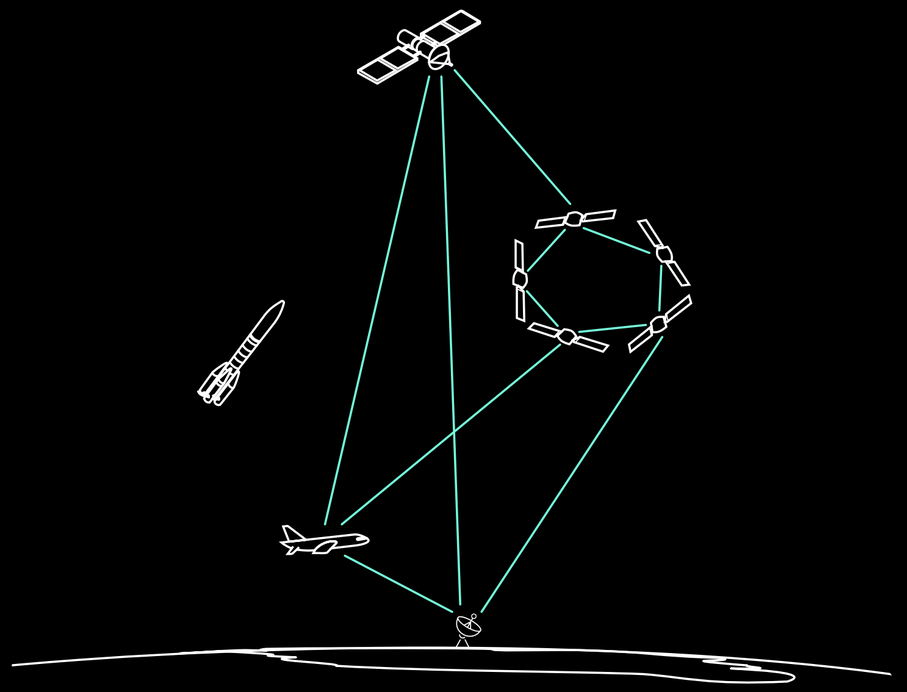
Surface drones

Underwater drones

Unmanned ground & aerial vehicles

Complex systems

NAVIGATION + COMMUNICATION



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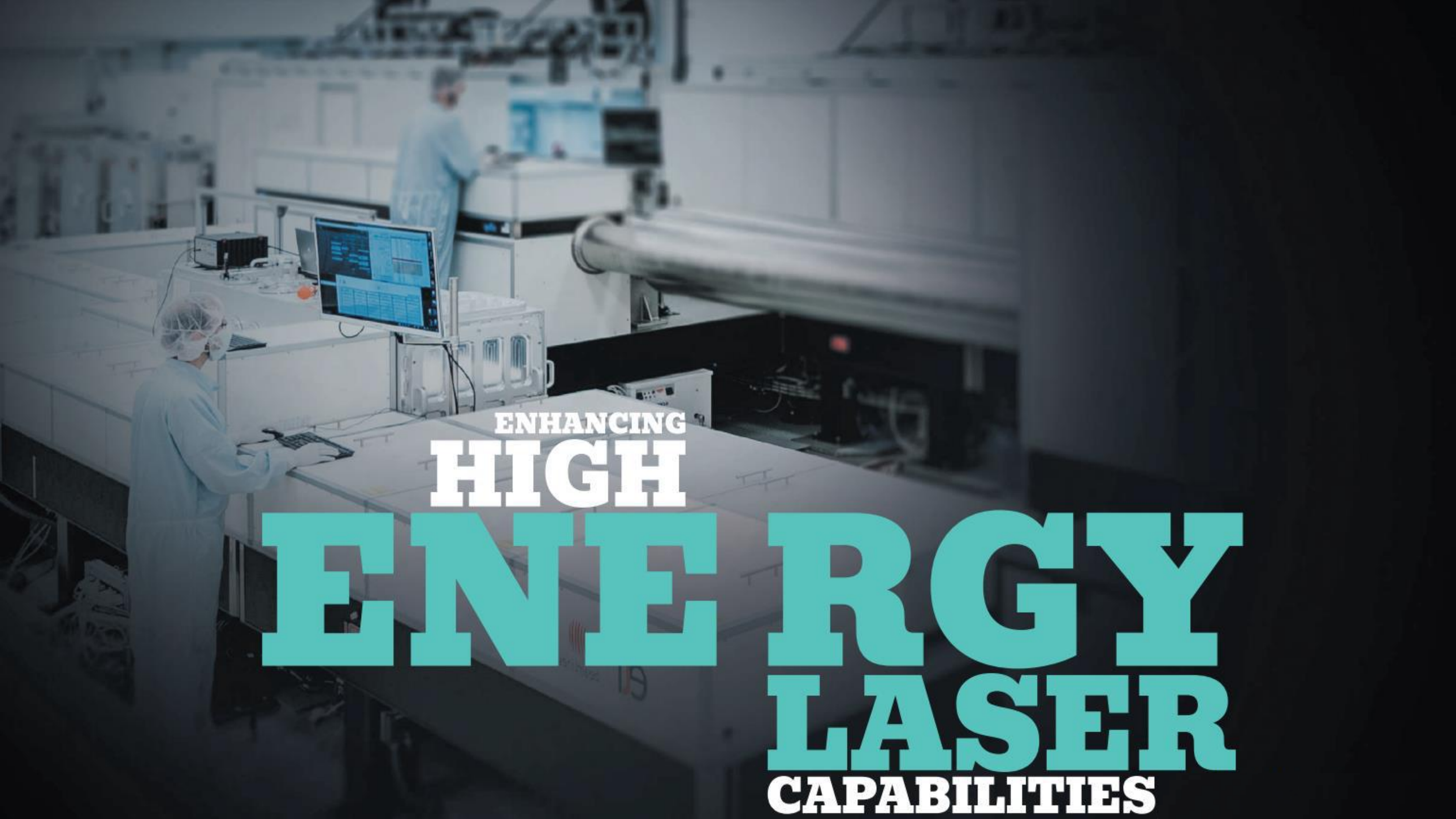

ENHANCING HIGH ENERGY LASER CAPABILITIES

$LiNbO_3$ Phase Modulators dedicated to CBC and SBC laser architectures

1. $LiNbO_3$ modulators based solutions for Coherent Beams Combining (CBC) fiber lasers

2. Spectral Boroadening for Directed Energy Laser

   2.1. Up to 5 GHz Electro-optical usable bandwidth and low $V\pi$ phase modulator: the NIR-MPX-LN-02

   2.2. Broadband Z-cut $LiNbO_3$ NIR phase modulators

   2.3. Up to 20 GHz Electro-optical usable bandwidth and low $V\pi$ phase modulator: the NIR-MPZ-LN-10

   2.4. Up to 30 GHz Electro-optical usable bandwidth phase modulator: the NIR-MPZ-LN-20

3. New 2 μm laser sources for Defense

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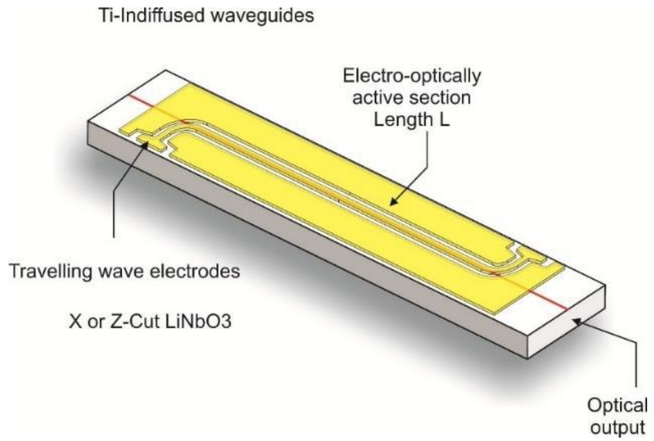
The $LiNbO_3$ Phase modulators principle and the application needs

Principle:

- Expression of the optical field modulated by sine voltage $E(t) = E_0 \ e^{j\omega t} e^{j\gamma \sin(\Omega t)}$ with $\gamma = \pi . \frac{V_0}{V_\pi(\Omega)}$: the modulation index.

Applications:

- Spectroscopy and laser cooling experiments
- Fiber lasers for frequency broadening and Brillouin effect suppression
- Fiber Laser based on Coherent Beams Combining
- Fiber Laser based on Spectral Beams Combining
- Frequency stabilization of lasers when using the Pound Drever Hall locking technique
- Terrestrial and space modulation DPSK
- Sensors: lidar, gyroscope



Specifications:

- Optical input power, Vπ, Insertion loss
- RAM, PDL, PER, DC Coupled, Resonant, Chip on base plate, High optical or RF input powers, Fibered, Free space, Radiation resistant,…

1 μm $LiNbO_3$ Phase Modulators dedicated to CBC and SBC laser architectures

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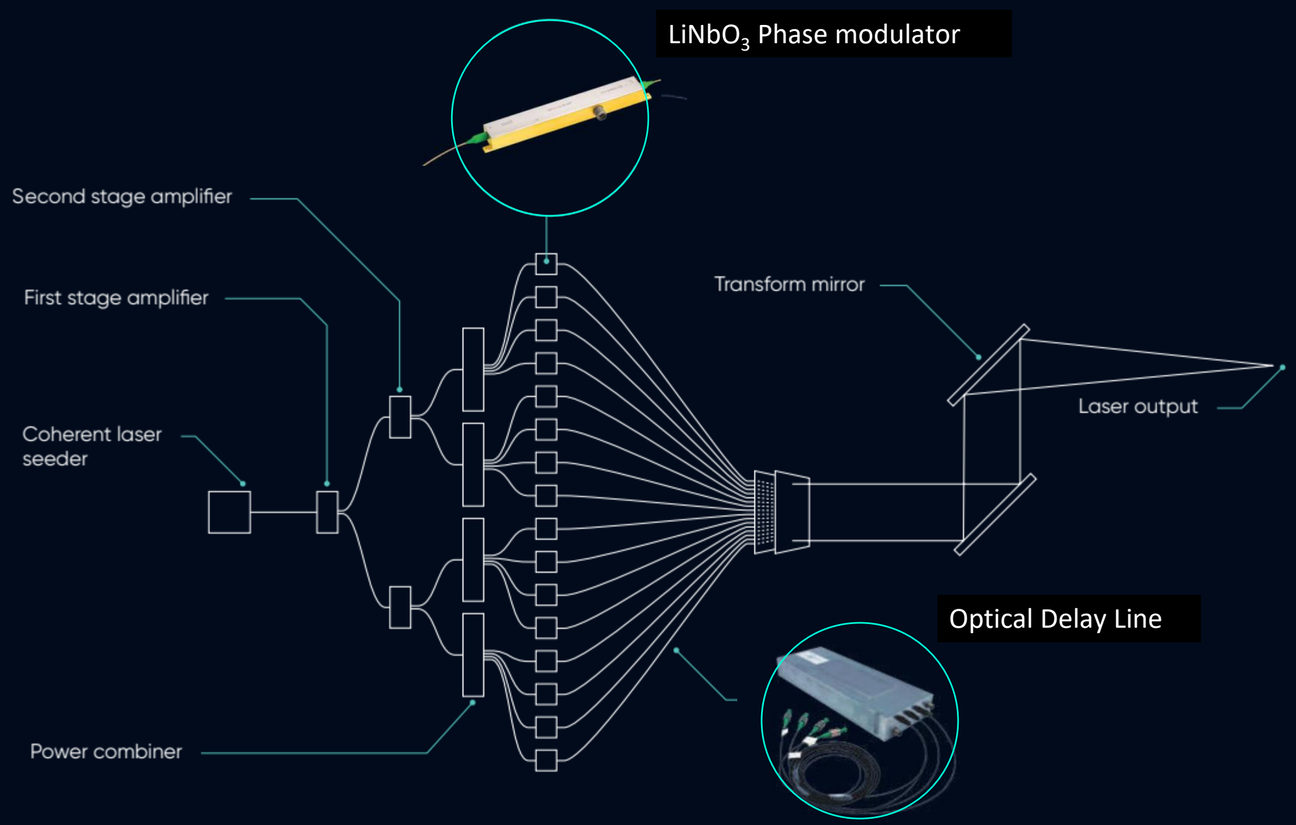
1

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

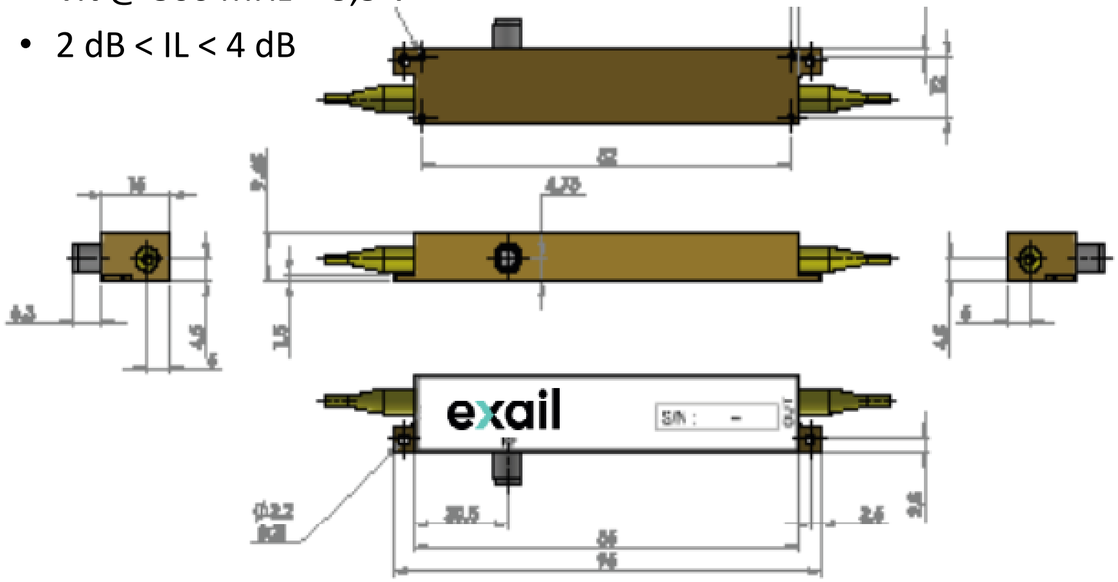
The NIR-MPX-LN-0.1 general specification

NIR-MPX-LN-0.1:

- DC coupled phase modulator with a very low Vπ adapted for low frequencies.
- Low Insertion Loss (LIL) option (IL < 3 dB)

Key parameters:

- DC to 300 MHz
- High impedance RF input
- Vπ @ 50kHz = 1,5 V
- Vπ @ 300 MHz = 3,5 V
- 2 dB < IL < 4 dB



Housing #A: Standard Modulator housing

NIR-MPX-LN-0.1

300 MHz Phase Modulator

Electrical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Electro-optical (EO) bandwidth	S_{21}	-	150	-	-	MHz
Usable EO bandwidth	t_r / t_f	-		300	-	MHz
Vπ RF @50 kHz	$V\pi_{RF\ 50\ kHz}$	RF electrodes	-	1.5	2	V
RF input impedance	Z_{in-RF}	-	-	10 000	-	Ω

Optical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Crystal	-	-	Lithium Niobate X-Cut Y-Prop			
Waveguide process	-	-	Proton exchange			
Operating wavelength	λ	-	950	1060	1150	nm
Insertion loss	IL	Without connectors [1]	-	3	4	dB
Low insertion loss	LIL	Without connectors [1]	-	-	3	dB
Polarization Extinction ratio	PER	Standard, Without connectors [1]	20	-	-	dB
		Optional, w/ or w/o connectors [1]	25	30	-	dB
Optical return loss	ORL	-	-40	-45	-	dB

All specifications given at 25°C, 1060 nm, unless differently specified.
[1] Consider an extra-loss up to 0.4 dB for each FC/APC optical connector.

Absolute Maximum Ratings

Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. These are absolute stress ratings only. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of the data sheet. Exposure to absolute maximum ratings for extended periods can adversely affect device reliability.

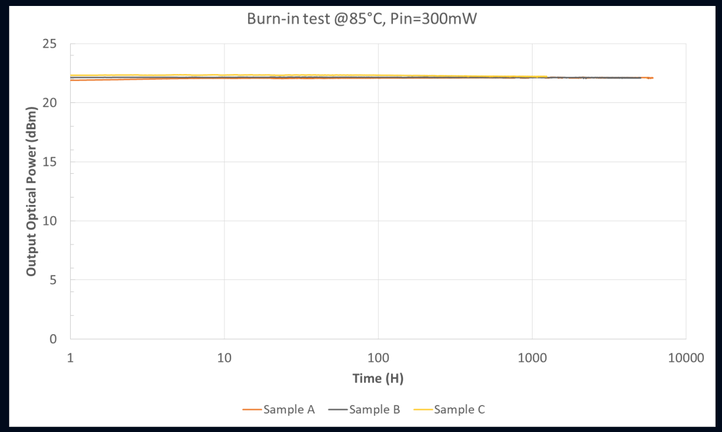
Parameter	Symbol	Min	Max	Unit
Modulation voltage range	EV_{in}	-20	+20	V
Optical input power (CW mode)	OP_{in}	-	+25	dBm
Operating temperature	OT	0	+70	°C
Storage temperature	ST	-40	+85	°C

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.

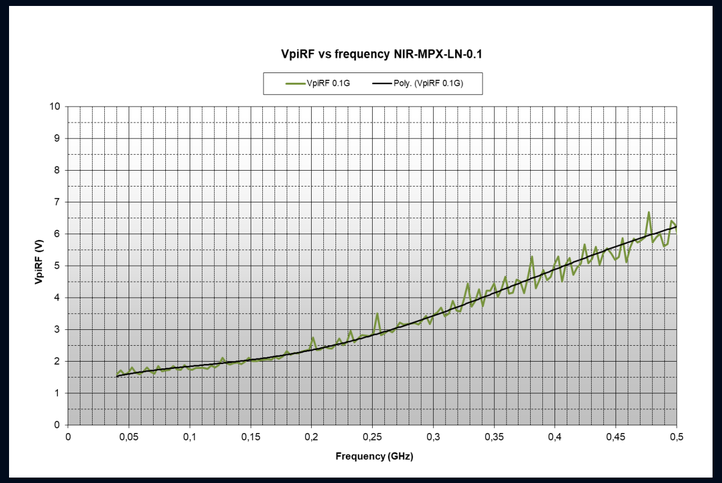
⇒ Exail offers the best $LiNbO_3$ phase modulators optical performances.

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



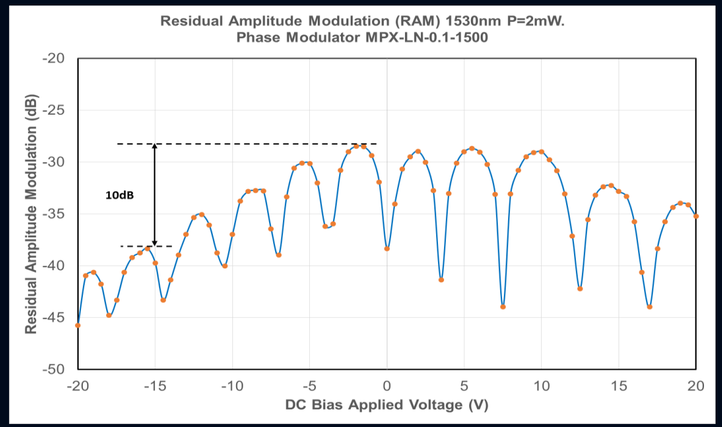
> **Very low Vπ:**
  - Modulator Vπ is proportional to the Electro-Optical bandwidth
  - The NIR-MPX-LN-0.1 features a Vπ of only 1,5 V @ 50 MHz

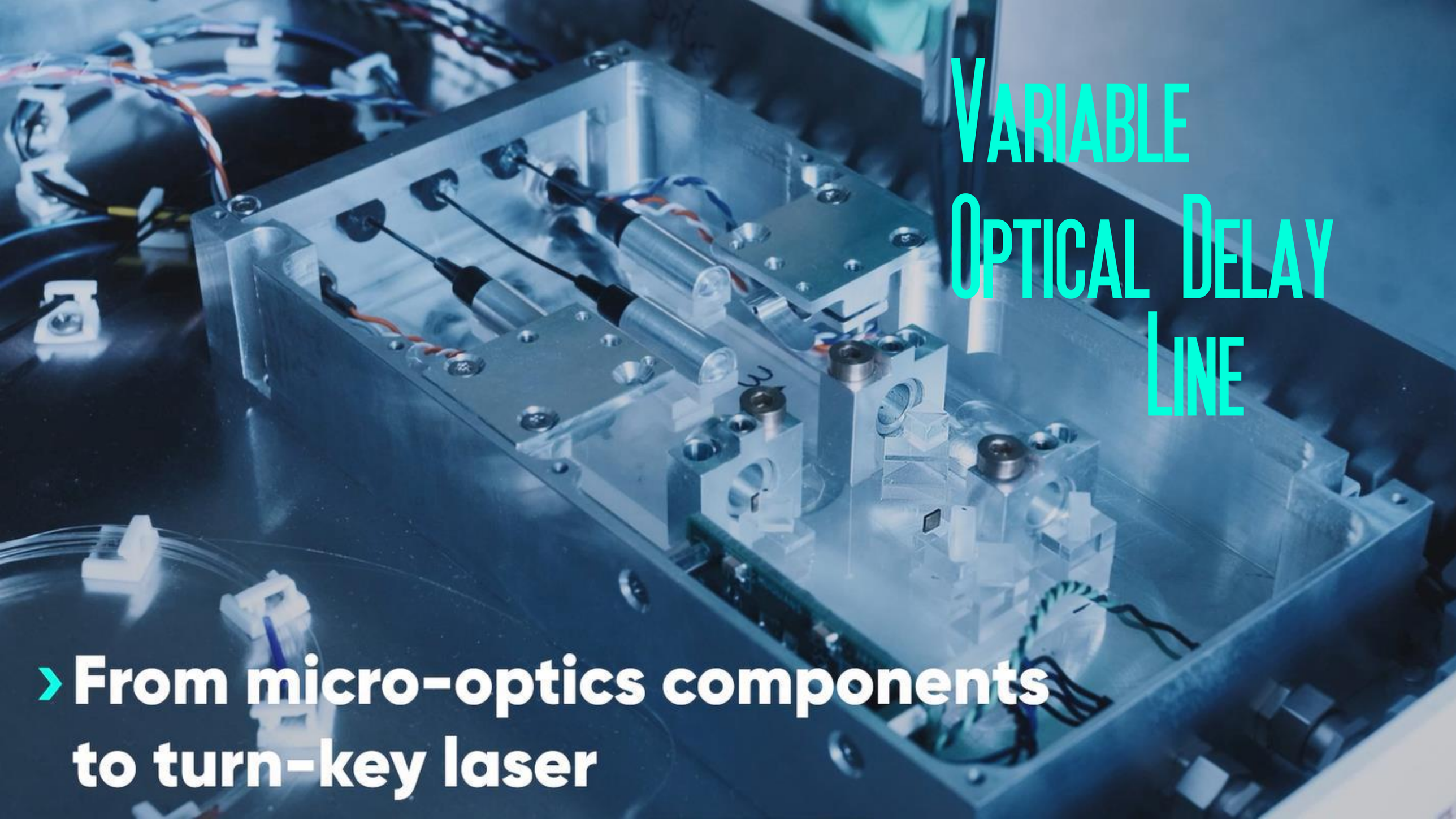
⇒ Low Vπ at low frequencies minimizes RF to minimize the power consumption



> **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

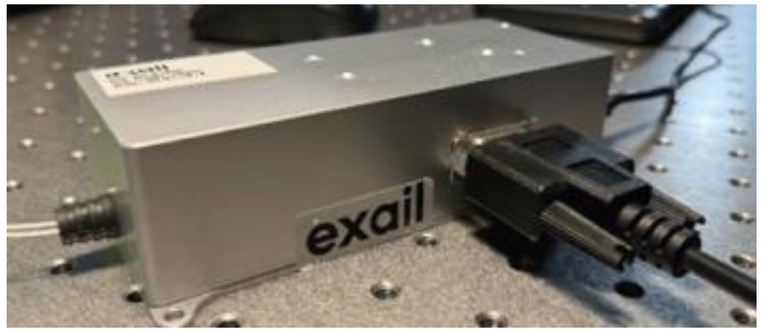




Variable Optical Delay Line

› From micro-optics components to turn-key laser

New Variable Optical Delay Line



Features

- Delays an optical signal
- Enables a very precise and stable control of an optical path length

Our patent

- Offers not only directional invariance, but also positional invariance
- Reduces Insertion Loss
- Allows to compensate for any translation misalignement

Custom products

- Our free-space technology enables us to easily customize our products.

300 ps

- Manual version
- Motorized version

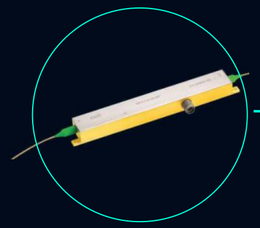
600 ps

- Manual version
- Motorized version

3 ns, 6 ns, 9 ns or 12 ns

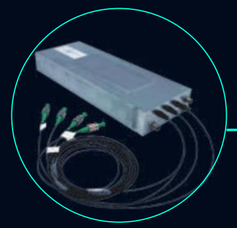
- Motorized version

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



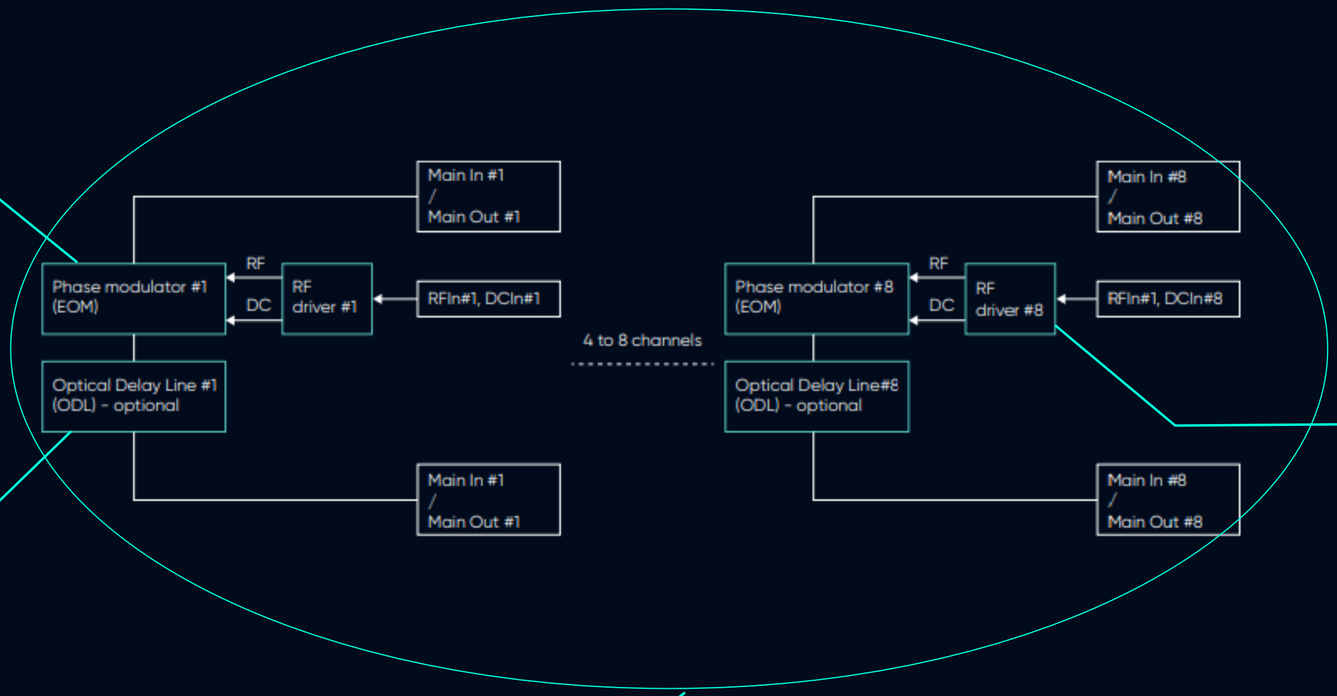
$LiNbO_3$ Phase Modulator Performances Highlight

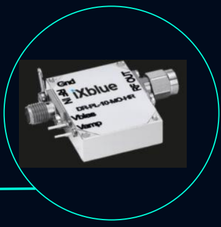
Bandwidth	DC to 300 MHz
Insertion loss	2 dB
Maximum optical power	300 mW

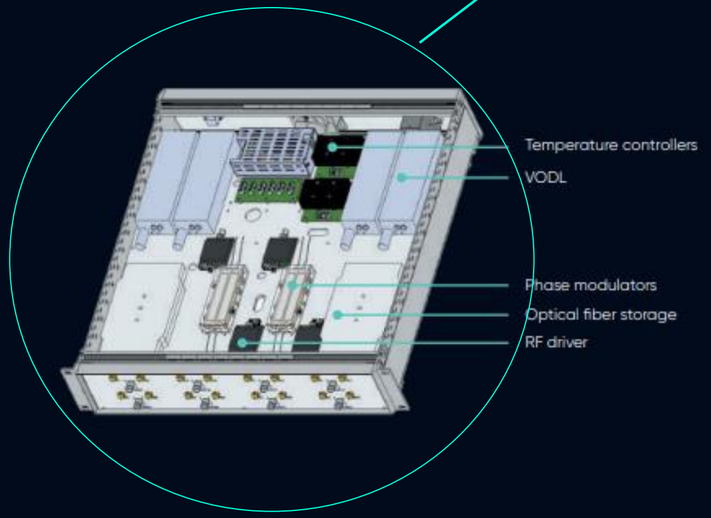


Optical Delay Line Performances Highlight

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

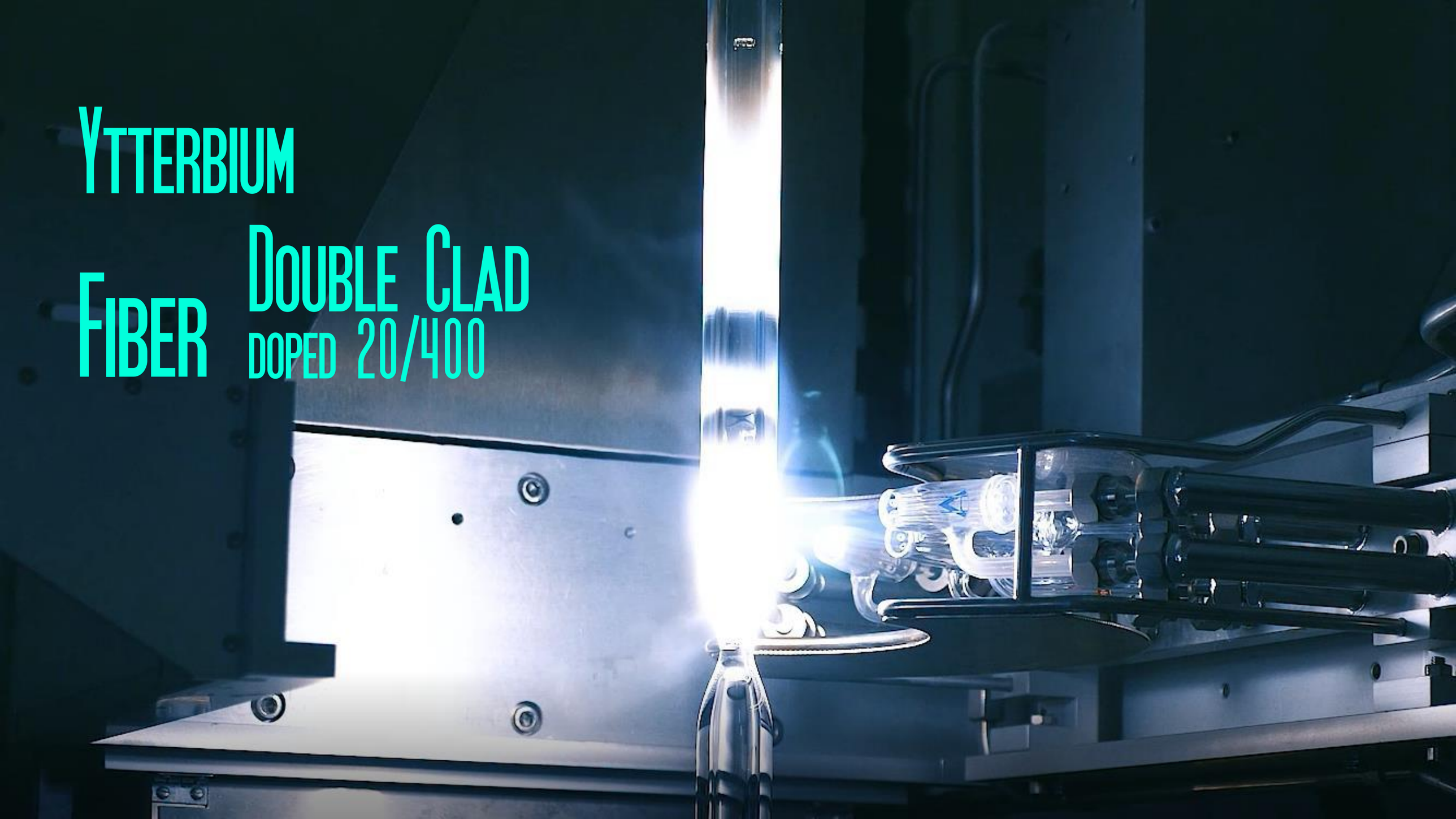






ModBox-CBC Performances Highlight

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


Ytterbium
Fiber
Double Clad
doped 20/400

High Power Double Clad Ytterbium 20/400 µm Fiber

IXF-2CF-Yb-O-20-400-0065

Key Specifications

- 20 µm core, 400 µm octogonal clad
- 0,065 Numerical Aperture, high beam quality: M^2=1,24
- 0,4 dB/m absorption @ 915 nm ; 1,5 dB/m absorption @ 976 nm
- State of the art fiber matrix for high efficiency (~80%) and low photodarkening
- No pedestal for seamless integration

Applications

- 1 µm kW CW Laser & Amplifier
- Directed Energy Laser
- Industrial Laser

Key Advantages

- Performances at industry level
- Made in France, EU origin
- Free of export control
- Independent supplier
- Available from stock
- Matching components: passive fibers, FBG Laser mirrors

Parameters

Core diameter (µm)	20 ± 1.5
Clad diameter (µm)	400 ± 10
Coating diameter (µm)	520 ± 15
Core NA	0.065 ± 0.005
Cladding NA	≥ 0.46
Clad absorption @915nm (dB/m)	0.4 ± 0.05
*Core absorption @976nm (dB/m)**	*1.5 ± 0.2*
Multimode background losses (dB/km)	< 20
Core background loss @1200 nm (dB/km)	< 30
Core-clad offset µm	< 1.0
Proof test level	100

** Calculated from the absorption value measured at 915 nm*

1 µm $LiNbO_3$ Phase Modulators dedicated to CBC and SBC laser architectures

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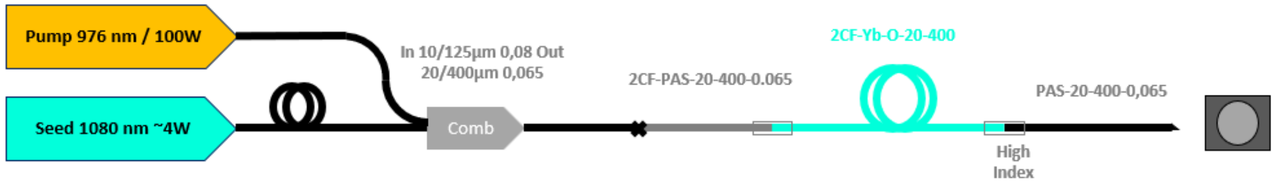
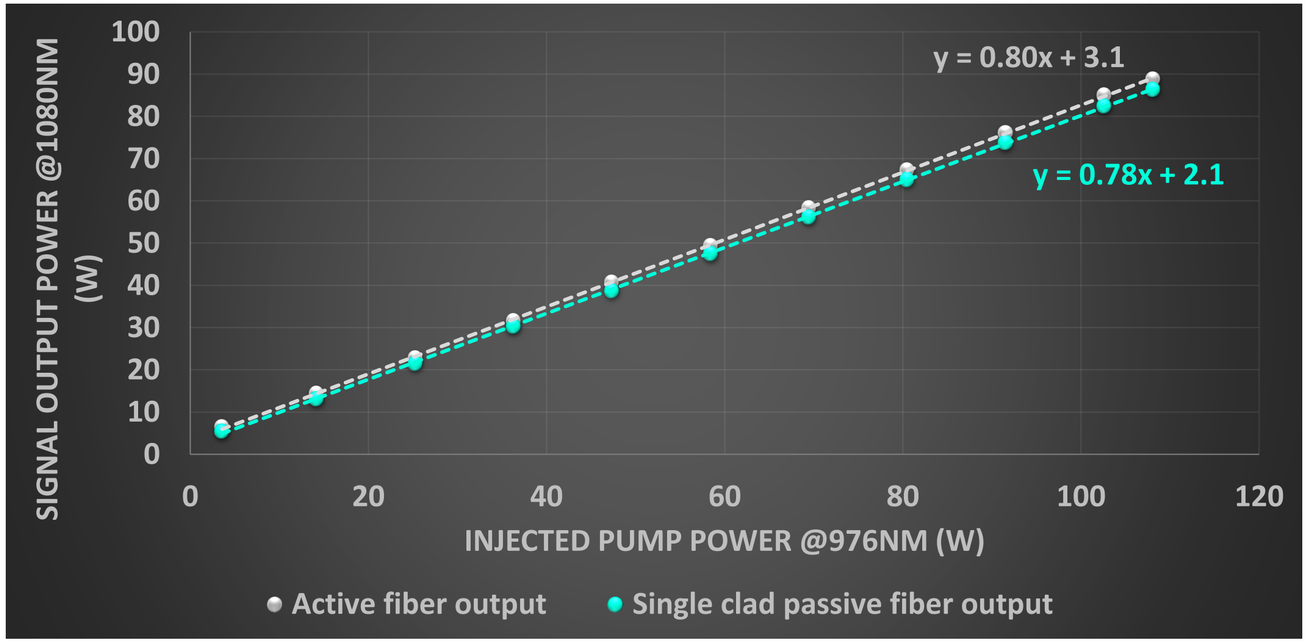
IXF-2CF-Yb-O-20-400-0065 - CW test results

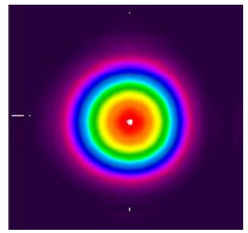
Low power, 976 nm pump

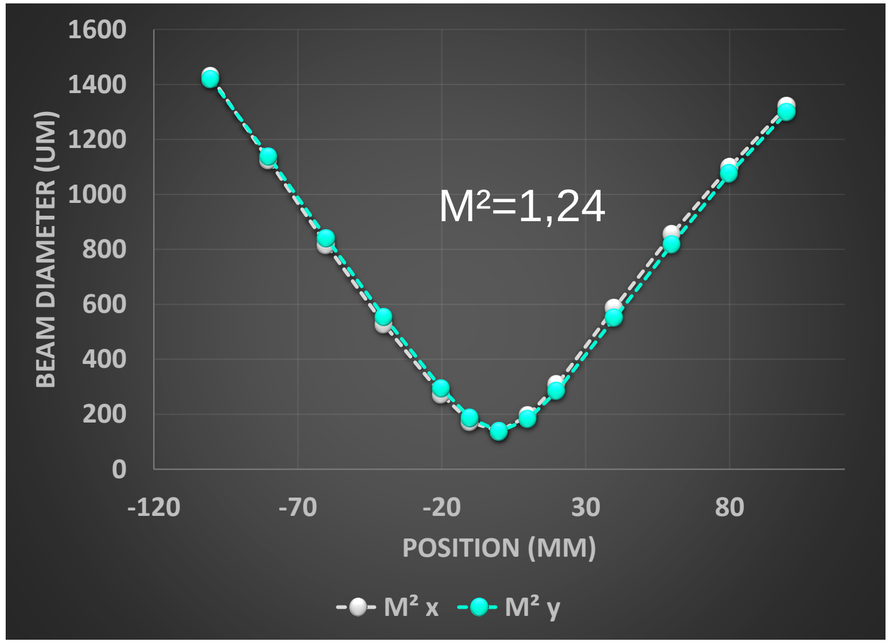
› **PCE measurement: ~80%**





› **Beam quality (output of active fiber) :**





IXF-2CF-Yb-O-20-400-0065 – CW test results

kW level

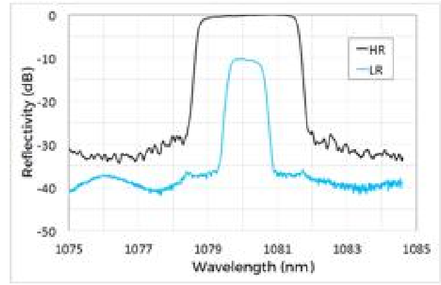
- **Done**
  - **> 1,4 kW** signal obtained
  - 1080 nm seeder (78 W)
  - Pump at 915 nm, forward pumping scheme.
  - Output power limited by pump power avaibility (~2kW)
- **Higher Power test**
  - planned Q4 2024

High Power Double Clad Ytterbium 20/400µm Fiber

Complimentary producs - Made in France, EU origin

Matching Passive fibers

- Double Clad : IXF-2CF-PAS-20-400-0065
- Single Clad: IXF-PAS-20-400-0065



FBG Laser Mirrors

- High power kW class
- Optimised design for low heat: Thermal slope reduced by a factor 10
- Dissipative package for easy integration

Thermal responses with IR thermograph

Yb doped fibers for first stage amplifiers or Laser Cavity Seeder

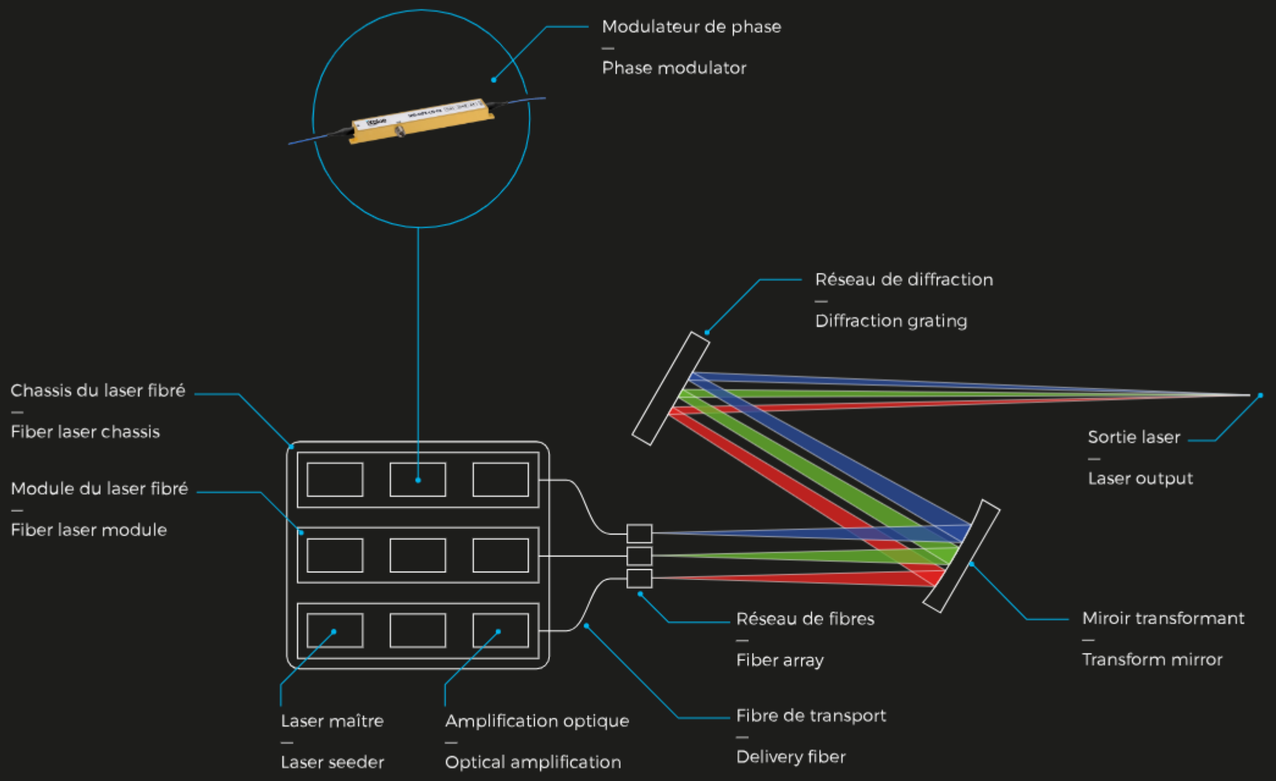
- 10/130 , 008 NA : IXF-2CF-Yb-O-11-130-008-CL
- PM version available
- Made in France, EU origin

2

SPECTRAL BROADENING

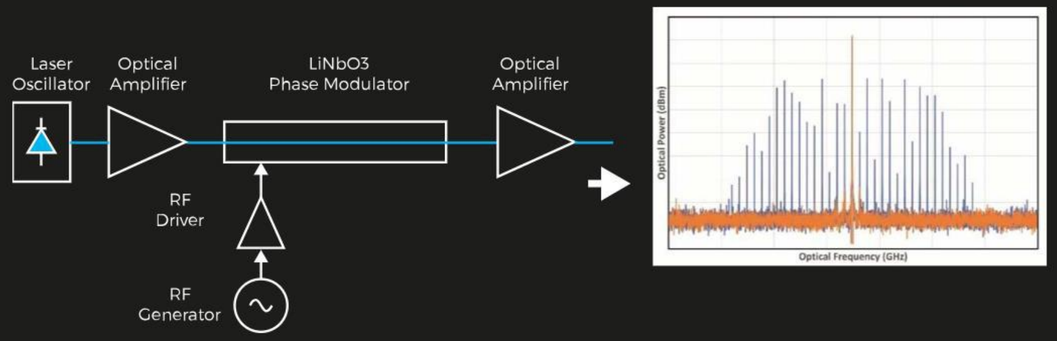
FOR DIRECTED ENERGY LASER

Spectral broadening using large bandwidth phase modulator for SBC & SBS



- 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 10s GHz EO-bandwidth
  - High RF power handling capability
  - High optical power handling capability
  - Low $V\pi$



2.1
UP TO 5 GHZ EO USABLE BANDWIDTH AND LOW VPI PHASE MODULATOR:

THE NIR-MPX-LN-02

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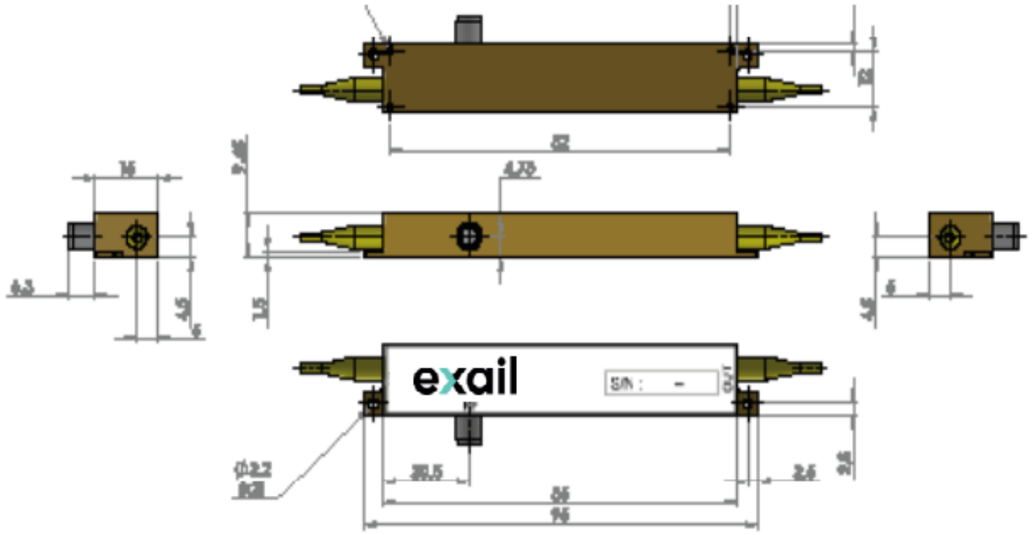
The NIR-MPX-LN-02 general specification

NIR-MPX-LN-02:

- New optical broadband (-3dB@2GHz) phase modulator with a very low Vπ.
- Low Insertion Loss (LIL) option (IL < 3 dB)

Key parameters:

- Usable Electro-Optical Bandwidth up to 5 GHz
- Vπ @ 50kHz = 1,5 V
- Vπ @ 3 GHz = 2,5 V
- 2 dB < IL < 4 dB



Housing #A: Standard Modulator housing

NIR-MPX-LN-02

5 GHz Phase Modulator

Electrical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Electro-optical (EO) bandwidth	S_{21}	-	2	-	-	GHz
Usable EO bandwidth	S_{21}	-	-	5	-	GHz
Ripple S_{21}	ΔS_{21}	-	-	0.5	1	dB
Electrical return loss	S_{11}	-	-	-10	-8	dB
Vπ RF @50 kHz	$V\pi_{RF\ 50\ kHz}$	-	-	1.5	2	V
RF input impedance	Z_{in-RF}	-	-	50	-	Ω

Optical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Crystal	-	-	Lithium Niobate X-Cut Y-Prop			
Waveguide process	-	-	Proton exchange			
Operating wavelength	λ	-	950	1060	1150	nm
Insertion loss	IL	Without connectors [1]	-	3	4	dB
Low insertion loss	LIL	Without connectors [1]	-	-	3	dB
Polarization Extinction ratio	PER	Standard, without connectors [1]	20	-	-	dB
		Optional, w/ or w/o connectors [1]	25	30	-	dB
Optical return loss	ORL	-	-40	-45	-	dB

All specifications given at 25°C, 1060 nm, unless differently specified.
[1] Consider an extra-loss up to 0.4 dB for each FC/APC optical connector

Absolute Maximum Ratings

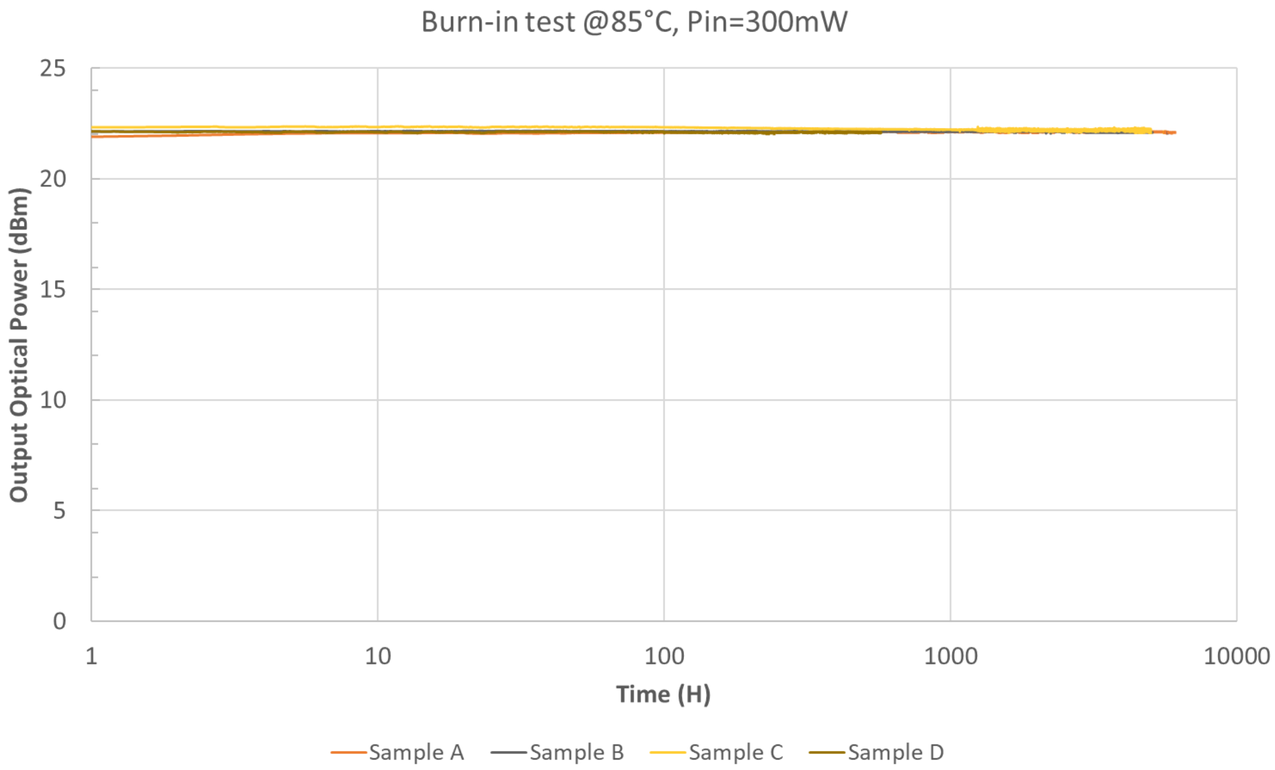
Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. These are absolute stress ratings only. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of the data sheet. Exposure to absolute maximum ratings for extended periods can adversely affect device reliability.

Parameter	Symbol	Min	Max	Unit
Modulation voltage range	EV_{in}	-	+33	dBm
Optical input power (CW mode)	OP_{in}	-	+25	dBm
Operating temperature	OT	0	+70	°C
Storage temperature	ST	-40	+85	°C

Accelerated aging test @ high optical input power level

- **Setup conditions:**
  - Optical Pin= 300 mW @1064 nm.
  - T = 85 °C.
  - Optical Pout recorded.

		Initial Test Before Screening (ITBS)	Final Test After Screening (FTAS)
Sample A	**IL (dB)**	2,4	2,3
Sample B		2,8	2,6
Sample C		2,3	2,6



- **Results:**
  - No degradation after a cumulated time of 16500 H.
  - Insertion loss variations < 0,3 dB.

2.2
BROADBAND Z-CUT $LINBO_3$ NIR PHASE MODULATORS

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Broadband Z-cut $LiNbO_3$ NIR PHASE MODULATORS

- **Exail proposes very high efficient low frequency X-cut LiNbO3 phase modulators (DC -> few GHz):**
  - NIR-MPX-LN-0.1
  - NIR-MPX-LN-02

- **For higher frequencies, need to use the Z-cut configuration (better electro-optic efficiency which means lower Vpi).**

- **However, Z-cut is know to be more sensitive to environmental conditions than X-cut. It thus restrict them to specific conditions of use (temperature stabilization, low input optical power levels).**

- **Exail has developped a new range of stable Z-cut phase modulators with key characteristics:**
  - Broadband EO bandwidth (wide usable electro-optic bandwidth).
  - Low Vpi.
  - High optical power handling capability.
  - Low temperature sensitivity.

2.3
UP TO 20 GHZ EO USABLE BANDWIDTH AND LOW VPI PHASE MODULATOR:

THE NIR-MPZ-LN-10

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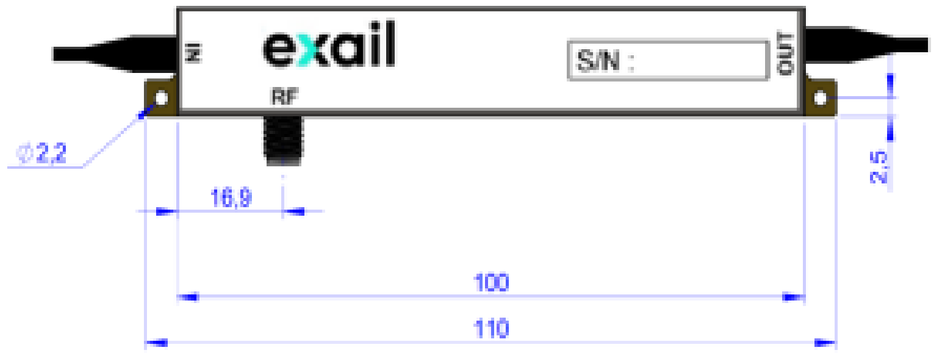
The NIR-MPZ-LN-10-LVP general specification

NIR-MPZ-LN-10-LVP:

- New optical broadband (-3dB@10GHz) phase modulator with a low Vpi characteristic.
- Complementary to the NIR-MPX-LN-02 and the NIR-MPZ-LN-20.

Key parameters:

- Usable Electro-Optical Bandwidth up to 20 GHz
- Vpi @ 50kHz = 2 V
- Vpi @ 10 GHz = 3 V
- 2 dB < IL < 4 dB
- Longer mechanical housing (+15mm)



Housing #B: Modulator housing with LVP (NIR-MPZ-LN-10-LVP)

NIR-MPZ-LN-10-LVP

20 GHz Phase Modulator

Electrical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Electro-optical (EO) bandwidth	S_{21}	-	10	12	-	GHz
Usable EO bandwidth	S_{21}	-	-	20	-	GHz
Ripple S_{21}	ΔS_{21}	-	-	0.5	1	dB
Electrical return loss	S_{11}	-	-	-13	-10	dB
Vπ RF @50 kHz / 1 GHz	$V\pi_{RF\ 50\ kHz/1\ GHz}$	-	-	2 / 2.3	-	V
Vπ RF @10 GHz	$V\pi_{RF\ 10\ GHz}$	-	-	3	-	V
RF input impedance	Z_{in-RF}	-	-	50	-	Ω

Optical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Crystal	-	-	Lithium Niobate X-Cut Y-Prop			
Waveguide process	-	-	Proton exchange			
Operating wavelength	λ	-	950	1060	1150	nm
Insertion loss	IL	Without connectors [1]	-	3	4	dB
Polarization Extinction ratio	PER	Standard, without connectors [1]	20	-	-	dB
		Optional, w/ or w/o connectors [1]	25	30	-	dB
Optical return loss	ORL	-	-40	-45	-	dB

All specifications given at 25°C, 1060 nm, unless differently specified.
[1] Consider an extra-loss up to 0.4 dB for each FC/APC optical connector

Absolute Maximum Ratings

Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. These are absolute stress ratings only. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of the data sheet. Exposure to absolute maximum ratings for extended periods can adversely affect device reliability.

Parameter	Symbol	Min	Max	Unit
Modulation voltage range	EV_{in}	-	+33	dBm
Optical input power (CW mode)	OP_{in}	-	+25	dBm
Operating temperature	OT	0	+70	°C
Storage temperature	ST	-40	+85	°C

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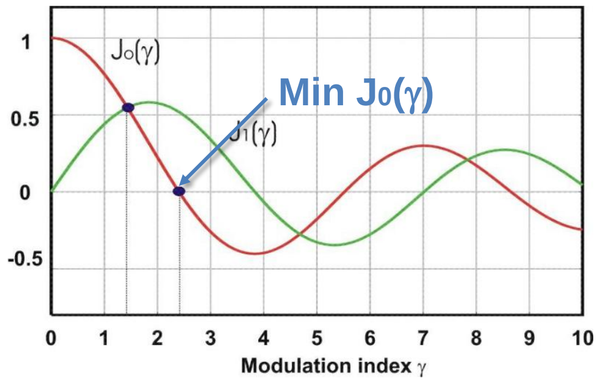
Key improvement: Vπ vs frequency evaluation

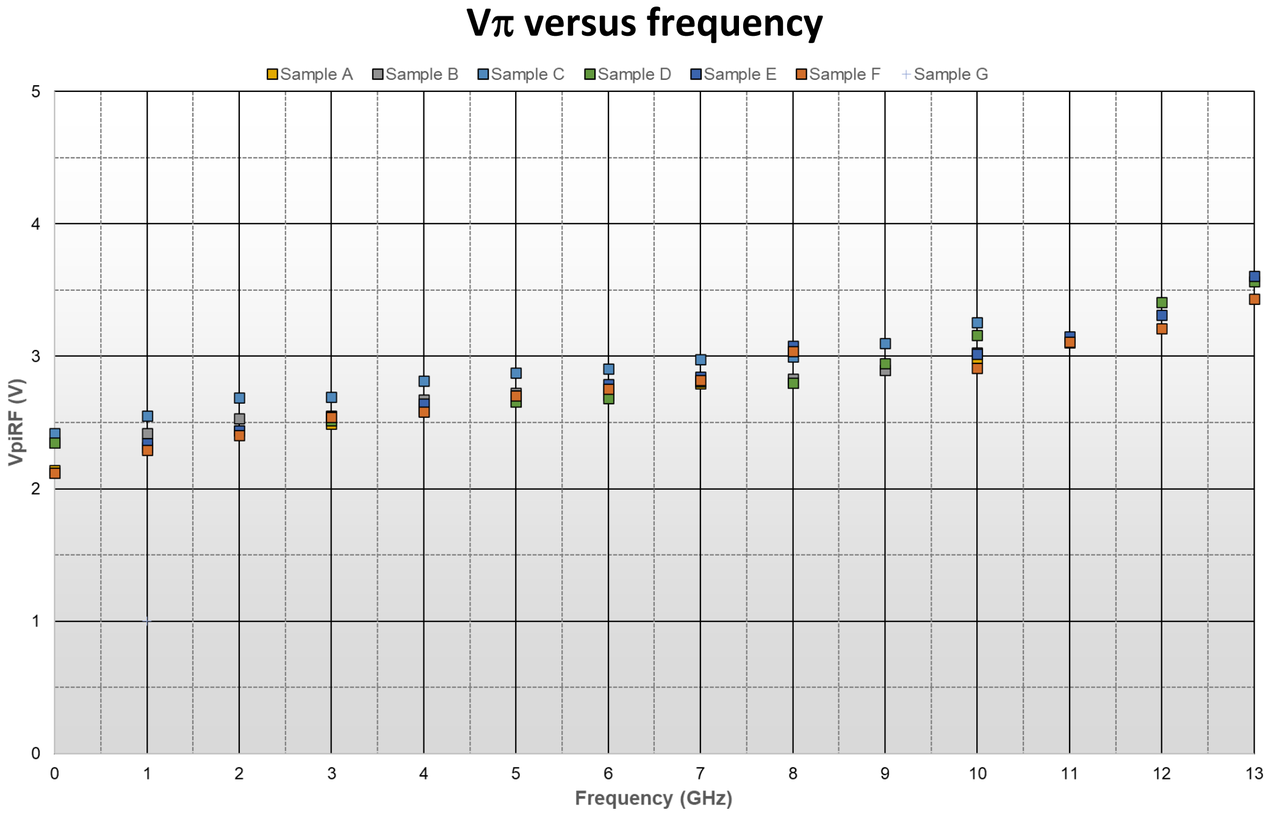
Measurement setup:

- λ = 1060nm
- Sinusoidal electrical modulation @ different frequencies
- Vpi (f) deduced from optical spectrum analysis (vanish the optical carrier).



Results:

- Vpi @ 1 GHz = 2.3 V (25% gain compared to the NIR-MPZ-LN-20)
- Vpi @ 10 GHz = 3 V (30% gain compared to the NIR-MPZ-LN-20)



Key improvement: Optical stability vs temperature & high optical power level

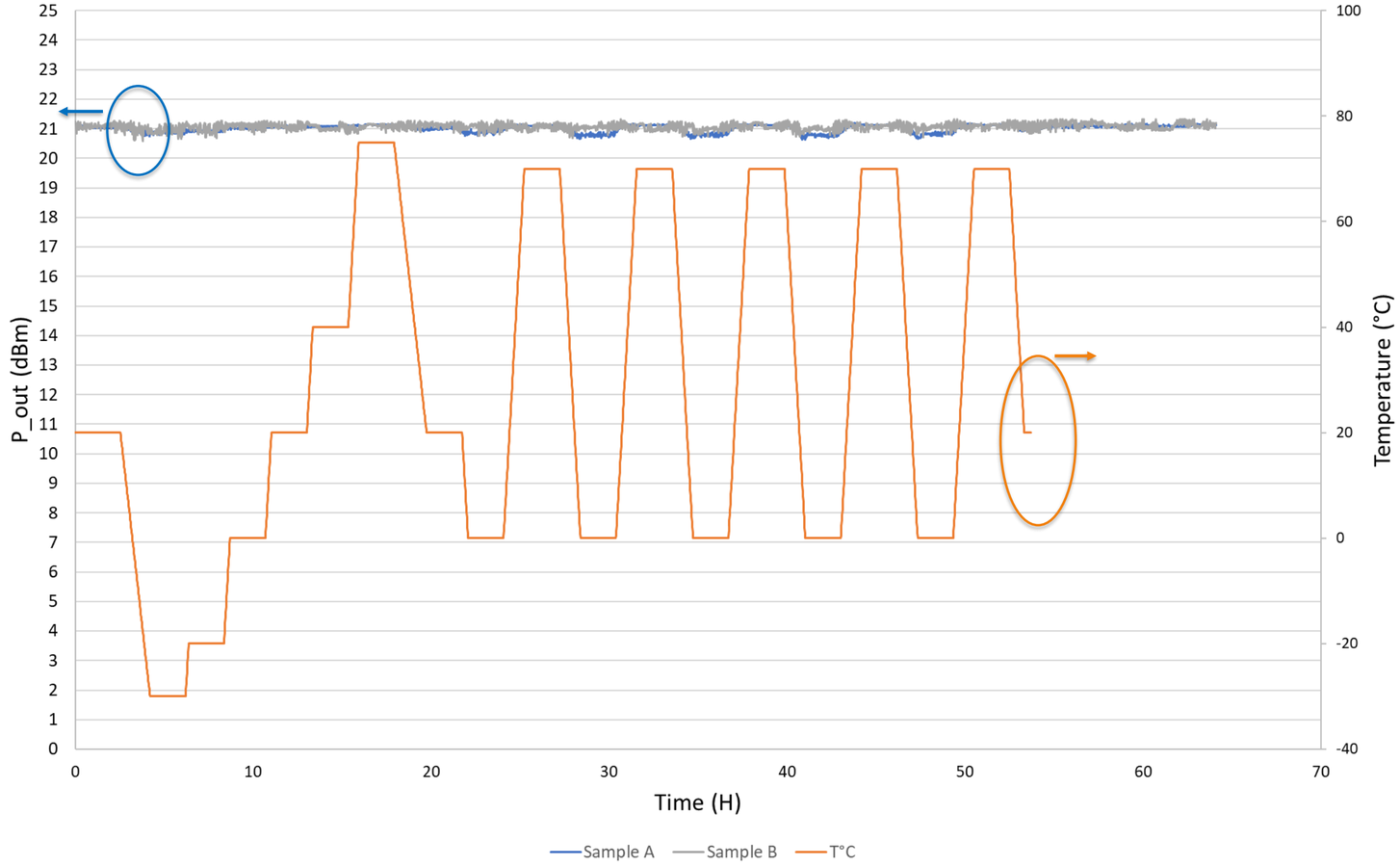
Setup:

- λ = 1060nm
- Pin = 300 mW CW (+25 dBm)
- Thermal cycling [-30; +75] °C, max ramp 1°C/min
- Pout monitored

Preliminary results:

- Output optical power > + 20 dBm.
- Optical power stability < +/- 0.5 dBm over [-30; +75] °C.

Output power monitoring with temperature variation



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2.4
UP TO 30 GHZ EO USABLE BANDWIDTH PHASE MODULATOR:

THE NIR-MPZ-LN-20

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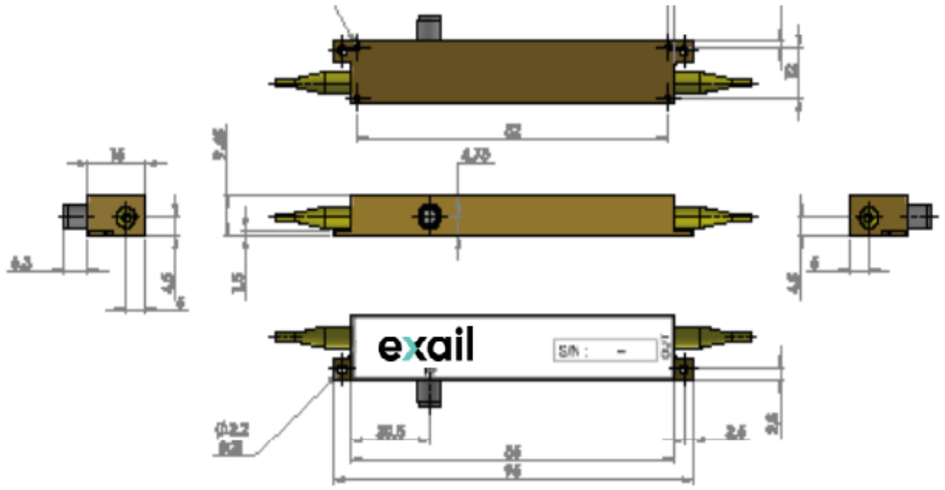
The NIR-MPZ-LN-20 general specification

- **Key parameters:**
  - Vpi @ 50 kHz = 3,5 V
  - 2 dB < IL < 4 dB (Low IL available)
  - Usable electro-optic bandwidth up to 30 GHz



Housing #A: Standard Modulator housing

NIR-MPZ-LN-20

30 GHz Phase Modulator

Electrical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Electro-optical (EO) bandwidth	S_{21}	–	16	20	–	GHz
Usable EO bandwidth	S_{21}	–	–	30	–	GHz
Ripple S_{21}	ΔS_{21}	–	–	0.5	1	dB
Electrical return loss	S_{11}	–	–	-13	-10	dB
Vπ RF @50 kHz	$V\pi_{RF50\ kHz}$	–	–	3.5	4	V
Vπ RF @20 GHz	$V\pi_{RF20\ GHz}$	–	–	6	–	V
RF input impedance	Z_{in-RF}	–	–	50	–	Ω

Optical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Crystal	–	–	Lithium Niobate Z-Cut Y-Prop			
Waveguide process	–	–	Proton exchange			
Operating wavelength	λ	–	950	1060	1150	nm
Insertion loss	IL	Without connectors [1]	–	3	4	dB
Low insertion loss	LIL	Without connectors [1]	–	2.5	3	dB
Polarization Extinction ratio	PER	Standard, without connectors [1]	20	–	–	dB
Optical return loss	ORL	–	-40	-45	–	dB

All specifications given at 25 °C, 1060 nm, unless differently specified.
[1] Consider an extra-loss up to 0.4 dB for each FC/APC optical connector

Absolute Maximum Ratings

Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. These are absolute stress ratings only. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of the data sheet. Exposure to absolute maximum ratings for extended periods can adversely affect device reliability.

Parameter	Symbol	Min	Max	Unit
RF input power (CW mode)	EP_{in}	–	+33	dBm
Optical input power (CW mode)	OP_{in}	–	+25	dBm
Operating temperature	OT	-30	+70	°C
Operating temperature variation rate	OT_{vt}	–	1	°C/min
Storage temperature	ST	-40	+85	°C
Vibration	Vib	MIL-STD-883J method 2007.3 – Test condition B		
Mechanical shock	Shock	MIL-STD-882J method 2002.5 – Test condition B		

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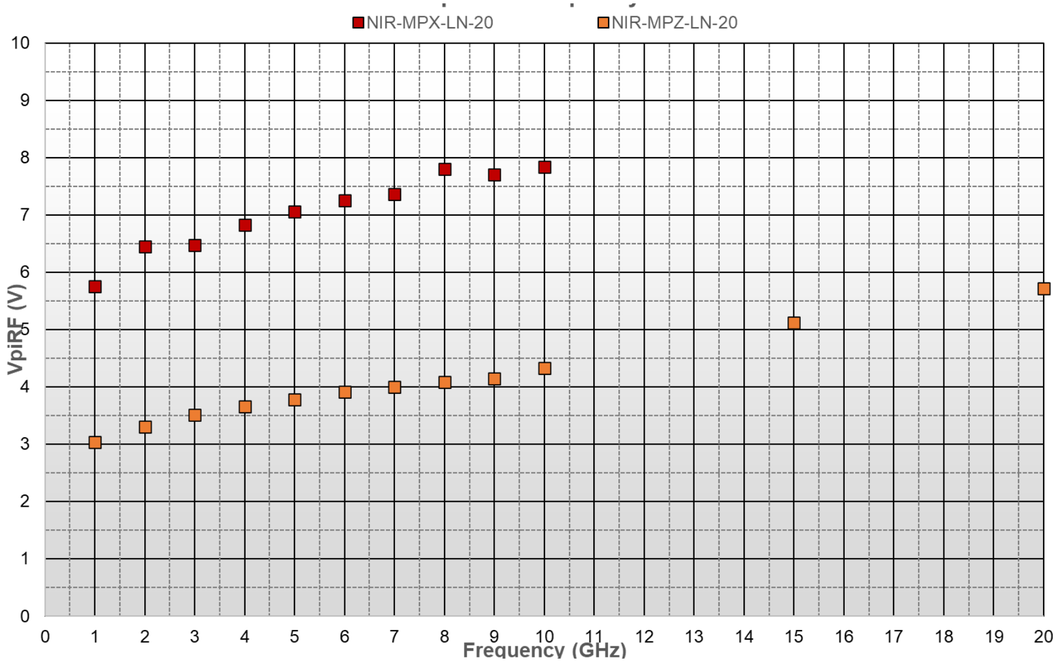
1 μm $LiNbO_3$ Phase Modulators dedicated to CBC and SBC laser architectures

Electro-optic characteristics

- **Strong electro-optic enhancement with the new generation.**

- **Vπ vs f measurement setup**
  (improvement vs obsolete NIR-MPX-LN-20)

Phase modulators comparison with Vπ versus frequency



1 μm $LiNbO_3$ Phase Modulators dedicated to CBC and SBC laser architectures

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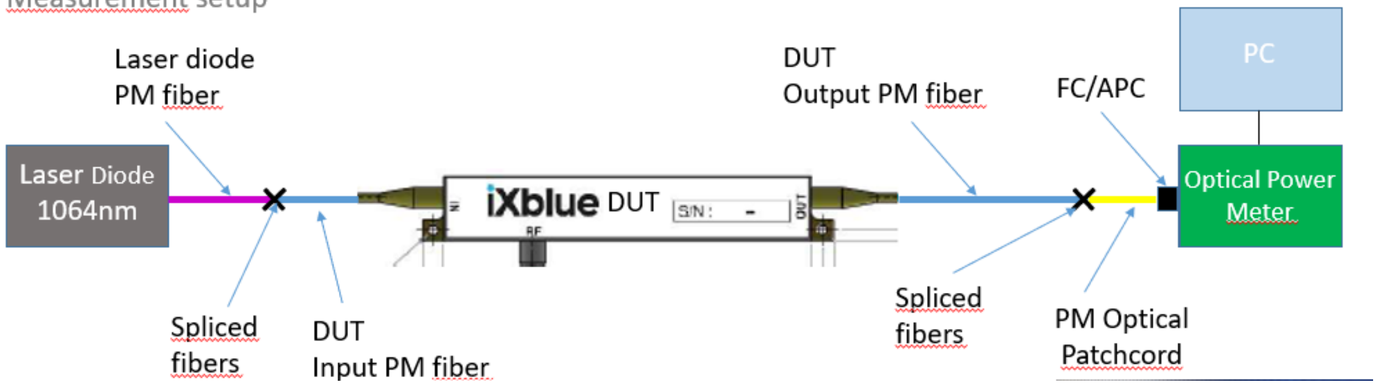
Optical power handling

Measurement setup

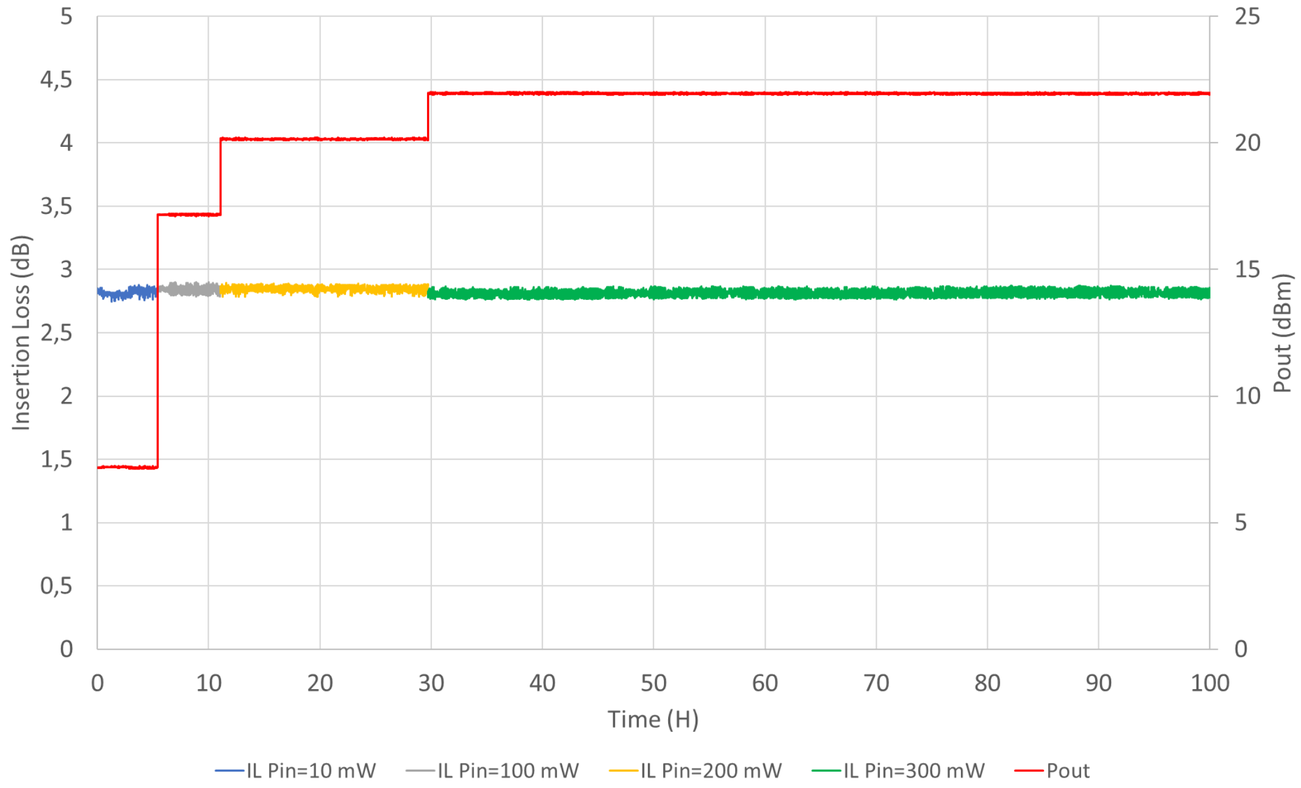


Setup:

- Temperature: 22°C
- Input optical power vairable (CW): 10 / 100 / 200 / 300mW
- Wavelength: 1060 nm
- Output optical power measured

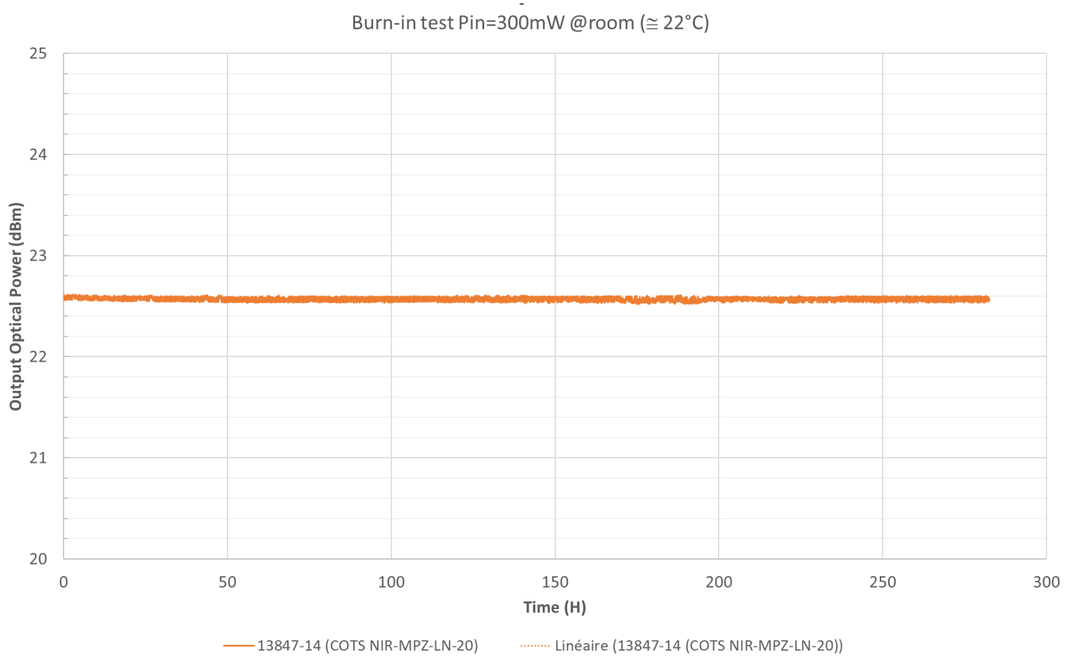
Results:

- Output optical power stable > +20dBm
- No IL degradation (whatever the input optical power level).
- Low IL stable (< 3 dB).

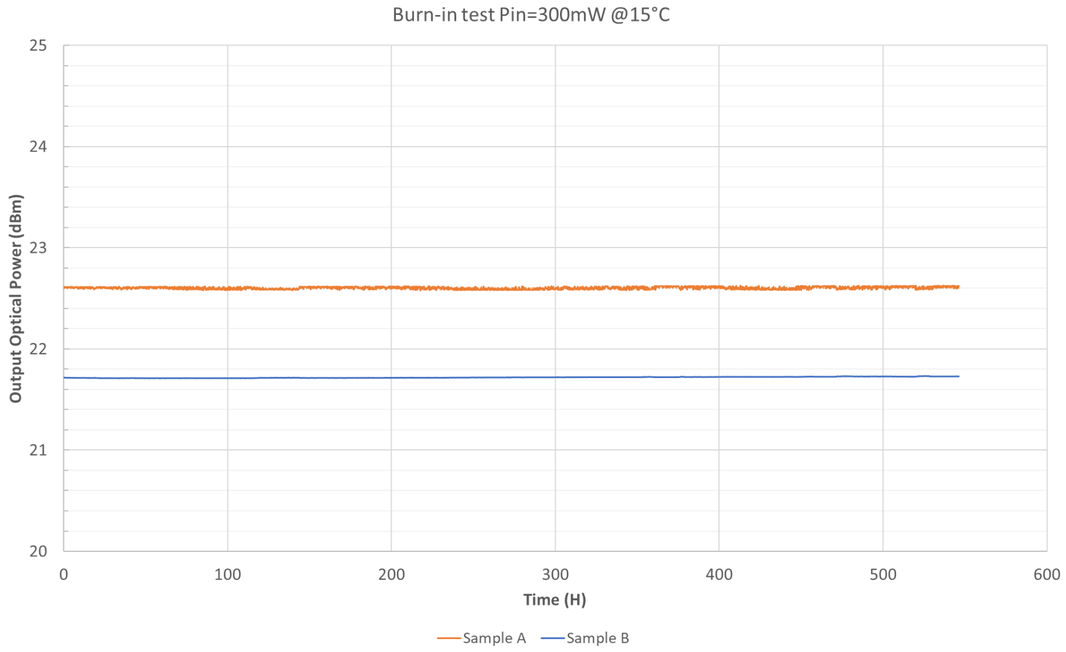


Optical power stability

- **Test n°1:**
  - Temperature: 22°C
  - Input optical power (CW): 300mW
  - Wavelength: 1060 nm
  - Output optical power > +22 dBm.
  - Output optical power variation ~0,1dBm other 280 H.



- **Test n°2:**
  - Temperature: 15°C
  - Input optical power (CW): 300mW
  - Wavelength: 1060 nm
  - Output optical power variation <0,1dBm other 550 H.



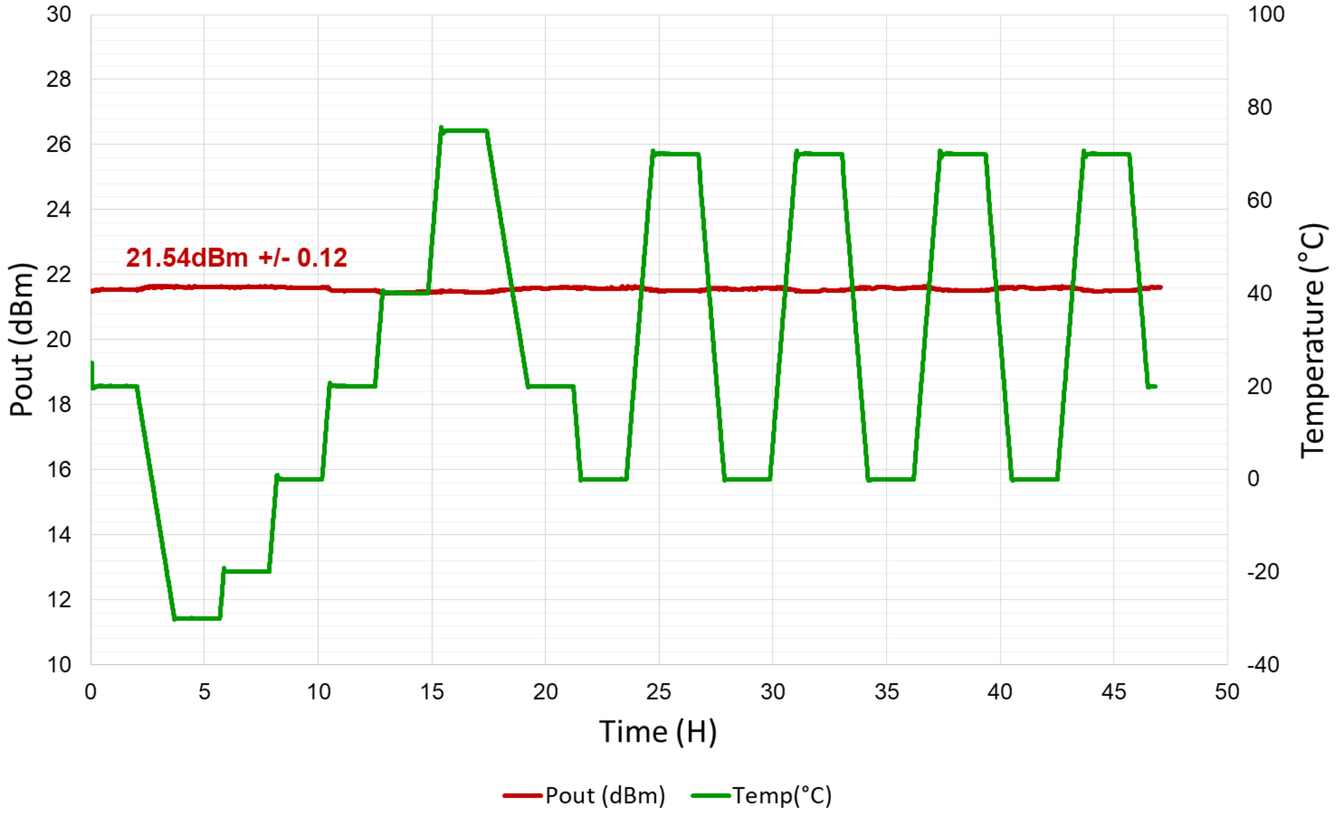
Optical power stability [-30 ; +75] °C

Setup:

- Temperature: [-30 ; +75]°C, ramp < 1°C / min
- Input optical power (CW): 300 mW
- Wavelength: 1064 nm
- RF input Power: +28 dBm @ 2 GHz
- Output optical power measured

Results:

- Output optical power stable > +20 dBm
- No sharp variations with T°.

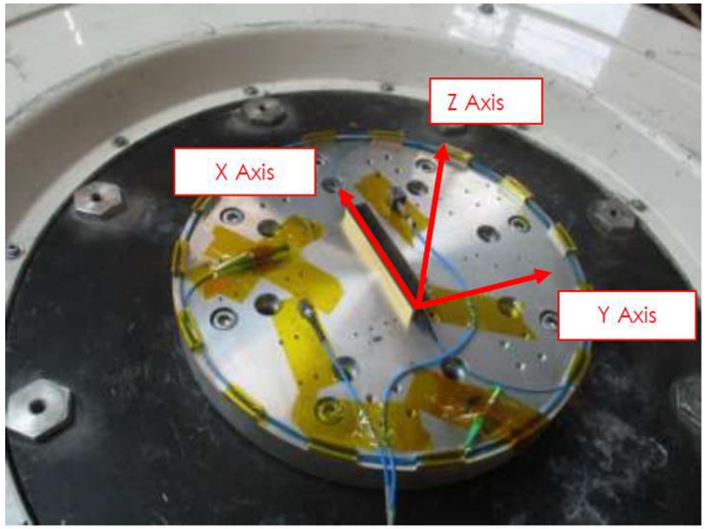


Mechanical qualifications

- **Vibrations MIL-STD-883 J, Method 2007.3, Condition B:**
  - 3 samples.
  - Key characteristics measured before / after.
  - No degradation.
- **Shocks MIL-STD-883 J, Method 2002.5, Condition B:**
  - 3 samples (same as vibrations).
  - Key characteristics measured before / after.
  - No degradation.

Axes	X , Y, Z
Frequency Range	35 – 2000 Hz
Amplitude	50 g
Cycles	4 / direction
Time	4 min / cycle

Axes	X , Y, Z
Wave form	½ sine
G level	1500 g
Duration of pulse	0,5 ms
Shocks	5 / direction



	Initial Functional Test, IFT				Post Vibration Test B (PVTB)				Final Functional Test, FFT			Analysis					
												IL (dB)		VpiRF (V)		S11Max (dB)	
	Optical Insertion Loss: IL (dB)	Half-Wave Voltage: VpiRF @ 50 kHz (V)	Maximum Electrical Return Loss: S11 (dB)	Vibration Test MIL-STD-883, Method 2002.5 Condition B	Optical Insertion Loss: IL (dB)	Half-Wave Voltage: VpiRF @ 50 kHz (V)	Maximum Electrical Return Loss: S11 (dB)	Shock Test MIL-STD-883, Method 2007.3 Condition B	Optical Insertion Loss: IL (dB)	Half-Wave Voltage: VpiRF @ 50 kHz (V)	Maximum Electrical Return Loss: S11 (dB)	Mean Value	Standard Deviation	Mean Value	Standard Deviation	Mean Value	Standard Deviation
Sample A	3,13	3,23	-12,52		3,31	3,49	-12,66		3,06	3,22	-12,53	3,17	0,13	3,31	0,15	-12,57	0,08
Sample B	2,57	3,30	-14,17		2,50	3,43	-14,47		2,60	3,29	-14,54	2,56	0,05	3,34	0,08	-14,39	0,20
Sample C	4,70	3,22	-10,16		4,39	3,52	-10,06		4,36	3,23	-10,05	4,48	0,19	3,32	0,17	-10,09	0,06
	3,47	3,25	-12,28		3,40	3,48	-12,40		3,34	3,25	-12,37						

A dedicated and wide range of $LiNbO_3$ modulators for CBC & SBC laser architectures

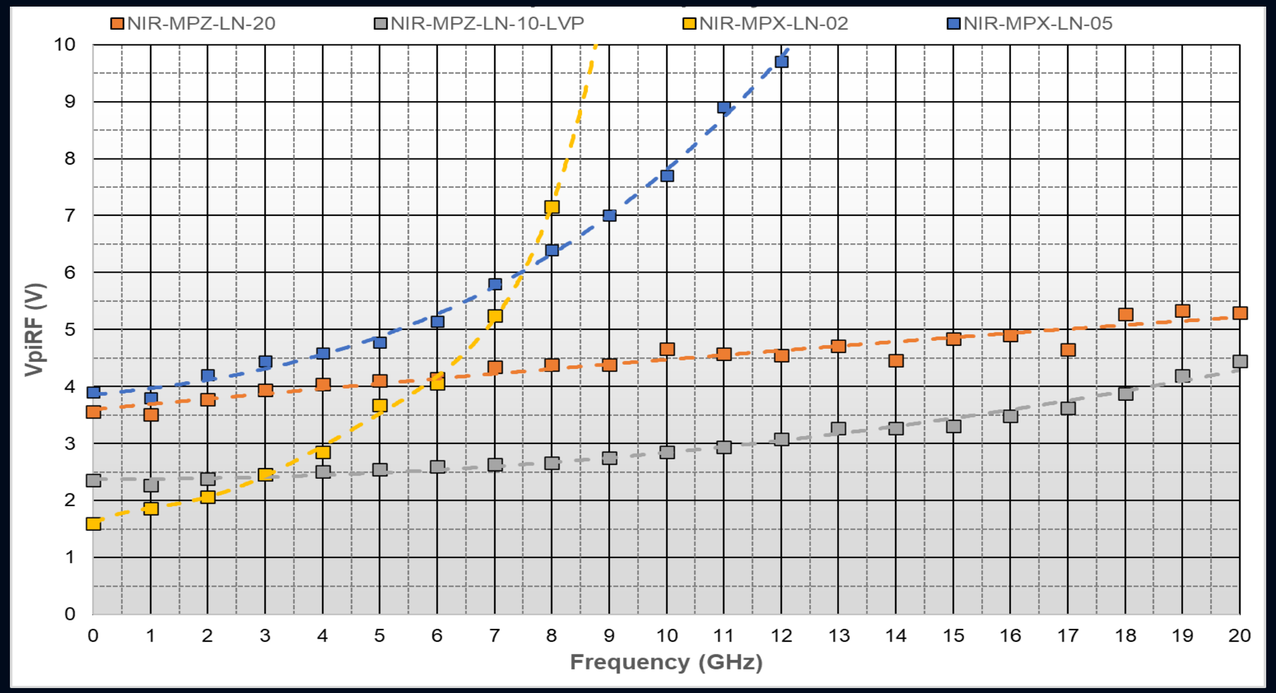
> **Incomparable optical waveguide and the key optical performances reached:**
  - Annealed Proton Exchange process on a selected $LiNbO_3$ doped wafer.
  - High optical power handling capability of up to 300 mW.
  - Optical power stability < ± 0.5 dBm over [-30 ; +75] °C.
  - Optical power stability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

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

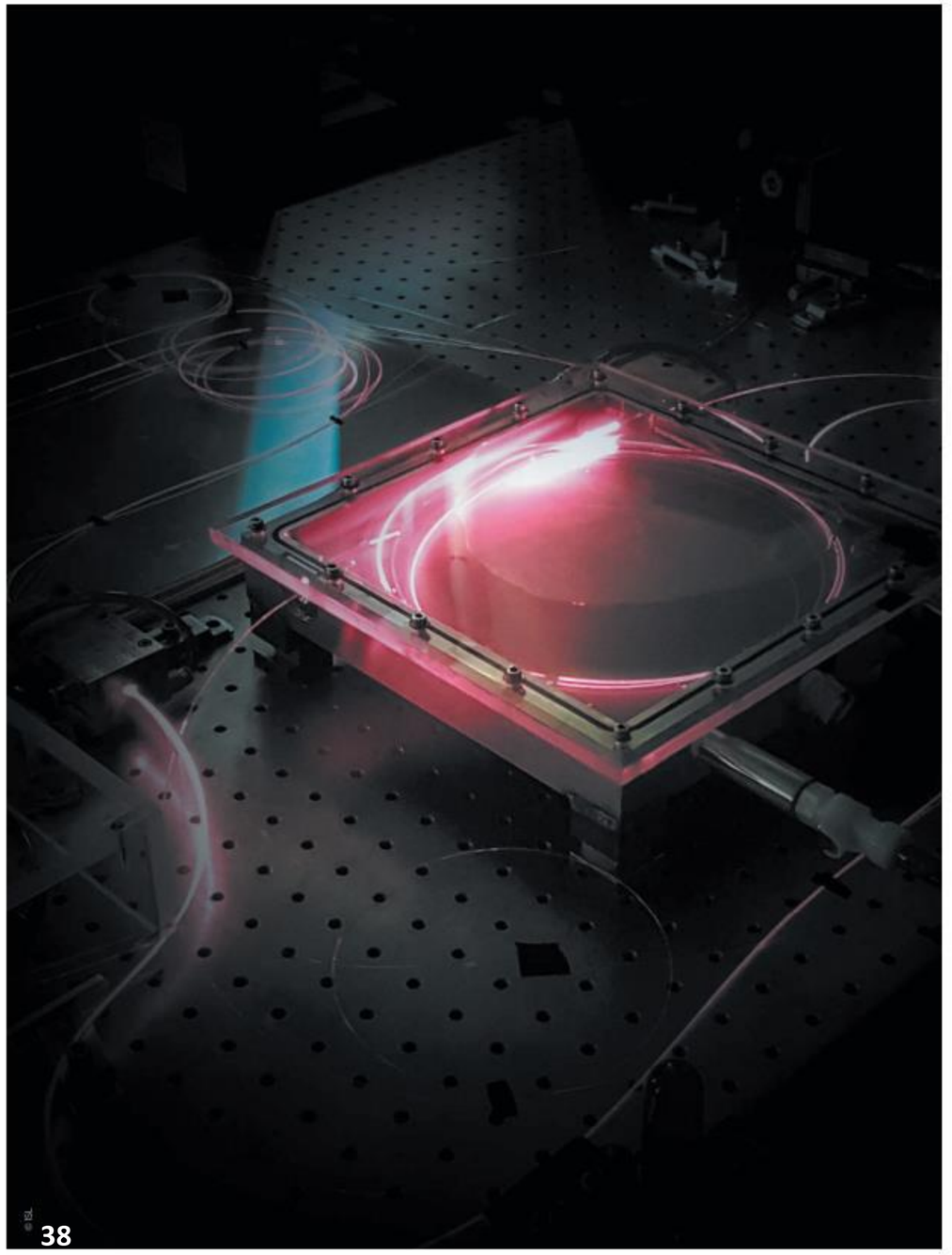
⇒ High optical performances stable over the temperature range and over the time

> **Very low Vπ and very large bandwidth modulators choices:**
  - The NIR-MPX-LN-0.1 features
    - Vπ of only 1,5 V @ 50 MHz / 2,5 V @ 300 MHz
    - EO-Bandwidth @-3 dB 300 MHz / Usable EO-Bandwidth 300 MHz
  - The NIR-MPX-LN-02 features
    - Vπ of only 1,5 V @ 50 MHz / 2,5 V @ 3 GHz
    - Bandwidth @-3 dB 2 GHz/ Usable EO-Bandwidth up to 5 GHz
  - The NIR-MPZ-LN-10-LVP features
    - Vπ of 2,3 V @ 1 GHz / 3 V @ 10 GHz
    - Bandwidth @-3 dB 12 GHz/ Usable EO-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 @-3 dB 20 GHz/ Usable EO-Bandwidth up to 30 GHz

Phase modulators comparison with Vπ versus frequency



⇒ 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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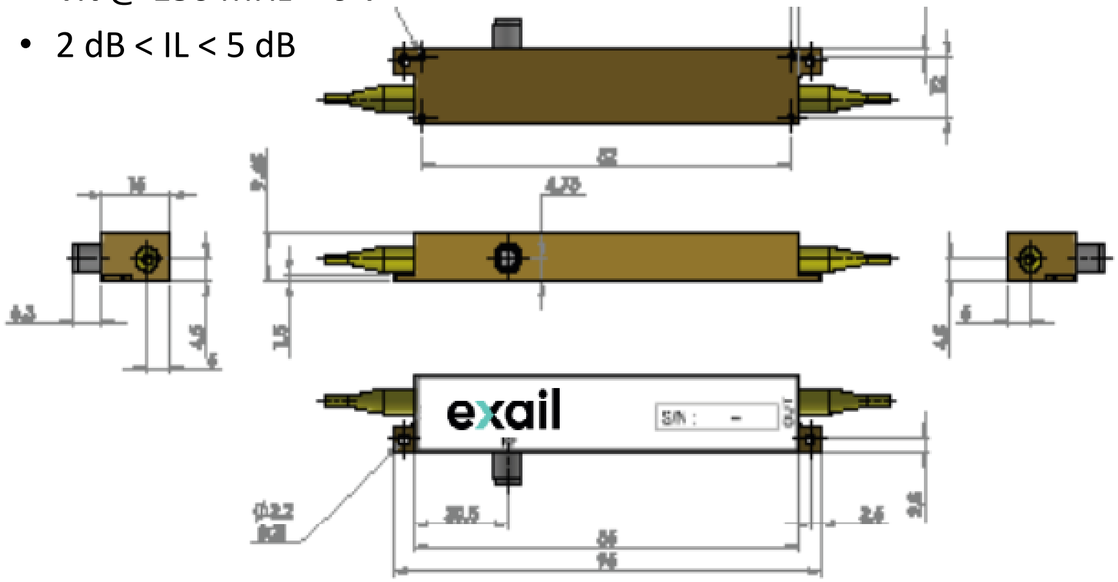
The MPX2000-LN-0.1 general specification

- **MPX2000-LN-0.1:**
  - DC coupled phase modulator with a very low Vπ adapted for low frequencies.
  - Low Insertion Loss (LIL) option (IL < 5 dB)

- **Key parameters:**
  - DC to 300 MHz
  - High impedance RF input
  - Vπ @ 50kHz = 4,5 V
  - Vπ @ 150 MHz = 6 V
  - 2 dB < IL < 5 dB



Housing #A: Standard Modulator housing

MPX2000-LN-0.1

300 MHz Phase Modulator

Electrical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Electro-optical bandwidth	S_{21}	RF electrodes	100	150	-	MHz
Usable electro-optical bandwidth	S_{21}	RF electrodes	-	300	-	MHz
Vπ RF @50 kHz	$V\pi_{RF\ 50\ kHz}$	RF electrodes	-	4.5	6	V
RF input impedance	Z_{in-RF}	-	-	10	-	kΩ

Optical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Crystal	-	-	Lithium Niobate X-Cut Y-Prop			
Waveguide process	-	-	Ti diffusion			
Operating wavelength	λ	-	1900	2000	2200	nm
Insertion loss	IL	Without optical connectors [1]	-	3	5	dB
Optical return loss	ORL	-	-40	-45	-	dB

All specifications given at 25 °C, 2050 nm, unless differently specified.
[1] Consider an extra-loss up to 0.25 dB for each FC/APC optical connector

Absolute Maximum Ratings

Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. These are absolute stress ratings only. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of the data sheet. Exposure to absolute maximum ratings for extended periods can adversely affect device reliability.

Parameter	Symbol	Min	Max	Unit
Modulation voltage range	EV_{in}	-20	20	V
Optical input power	OP_{in}	-	20	dBm
Operating temperature	OT	0	+70	°C
Storage temperature	ST	-40	+85	°C

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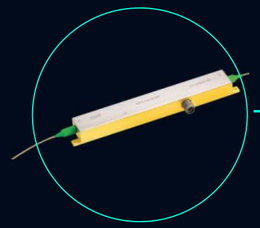
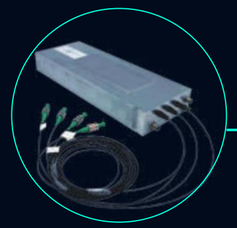
Coherent combination of laser beams: ModBox-CBC-2000nm-8CHannels



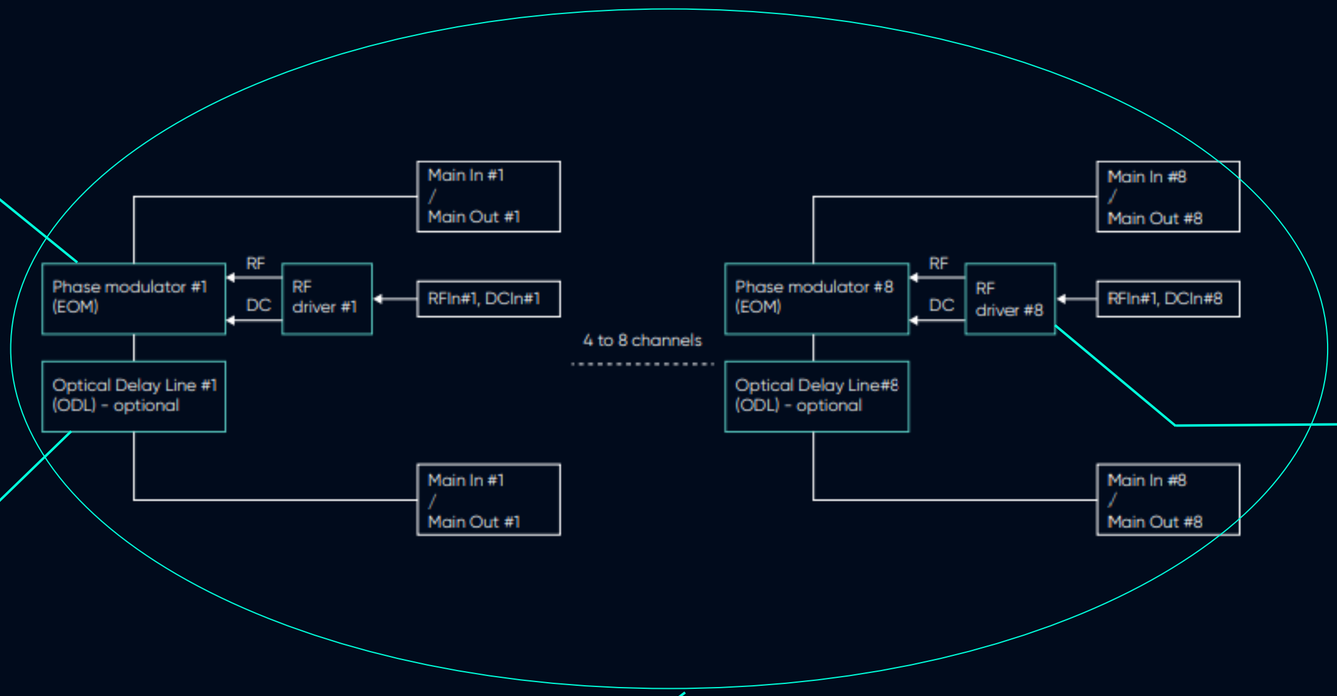
$LiNbO_3$ Phase Modulator Performances Highlight

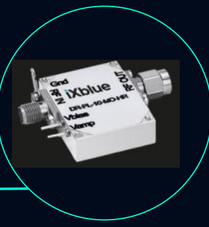
Bandwidth	DC to 300 MHz
Insertion loss	2 dB
Maximum optical power	300 mW

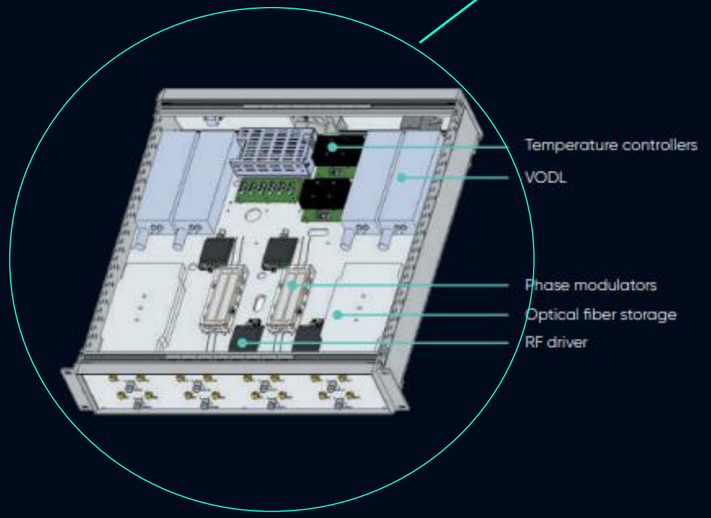


Optical Delay Line Performances Highlight

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







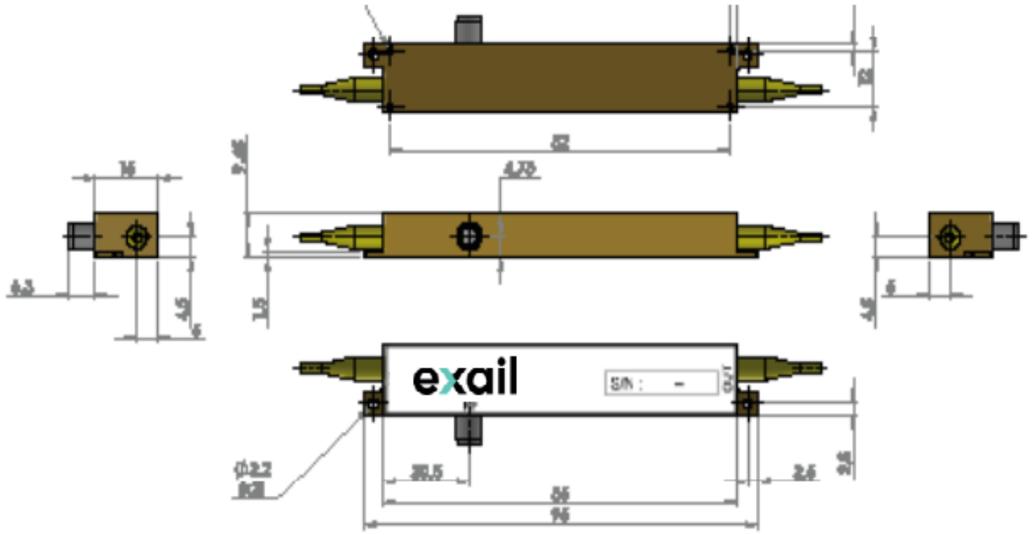
ModBox-CBC Performances Highlight

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

The MPZ2000-LN-10-LVP general specification

- **MPZ2000-LN-10-LVP:**
  - New optical broadband (usuable bandwith up to 20 GHz) phase modulator
  - Very low Vπ phase modulator
  - Low Insertion Loss (LIL) option (IL < 4 dB)

- **Key parameters:**
  - Usable Electro-Optical Bandwidth up to 20 GHz
  - Vπ @ 50kHz = 4,5 V
  - Vπ @ 10 GHz = 5,5 V
  - 2 dB < IL < 4 dB



Housing #A: Standard Modulator housing

MPZ2000-LN-10-LVP

20 GHz Phase Modulator

Electrical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Electro-optical bandwidth	S_{21}	-	10	12	-	GHz
Usable electro-optical bandwidth	S_{21}	-	-	20	-	GHz
Ripple S_{21}	ΔS_{21}	-	-	0.5	1	dB
Electrical return loss	S_{11}	-	-	-16	-13	dB
		HEP option		-13	-10	dB
Vπ RF @50 kHz	$V\pi_{RF\ 50\ kHz}$	-	-	4.5	5	V
Vπ RF @10 GHz	$V\pi_{RF\ 10\ GHz}$		-	5.5	-	V
Impedance matching	Z_{in-RF}	-	-	50	-	Ω

Optical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Crystal	-	-	Lithium Niobate Z-Cut X-Prop			
Waveguide process	-	-	Ti diffusion			
Operating wavelength	λ	-	1900	2050	2200	nm
Insertion loss	IL	Without optical connectors [1]	-	2.5	4	dB
Optical return loss	ORL	-	-40	-45	-	dB

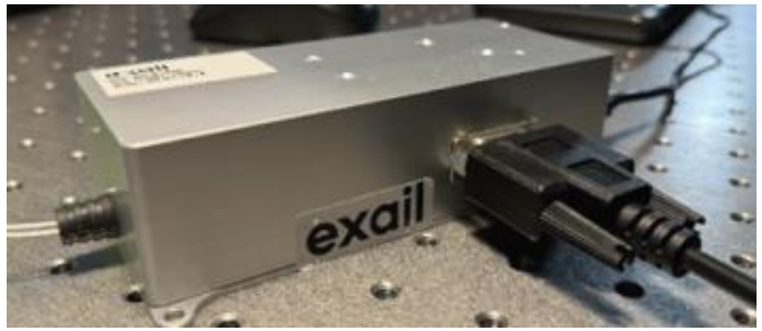
All specifications given at 25 °C, 2050 nm, unless differently specified.
[1] Consider an extra-loss up to 0.25 dB for each FC/APC optical connector

Absolute Maximum Ratings

Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. These are absolute stress ratings only. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of the data sheet. Exposure to absolute maximum ratings for extended periods can adversely affect device reliability.

Parameter	Symbol	Condition	Min	Max	Unit
RF input power	EP_{in}		-	28	dBm
High electrical input power option	HEP_{in}	HEP option	-	33	dBm
Optical input power	OP_{in}		-	20	dBm
Operating temperature	OT		0	+70	°C
Storage temperature	ST		-40	+85	°C

Variable Optical Delay Line also available at 2000 nm !!



Features

- Delays an optical signal
- Enables a very precise and stable control of an optical path length

Our patent

- Offers not only directional invariance, but also positional invariance
- Reduces Insertion Loss
- Allows to compensate for any translation misalignement

Custom products

- Our free-space technology enables us to easily customize our products.

300 ps

- Manual version
- Motorized version

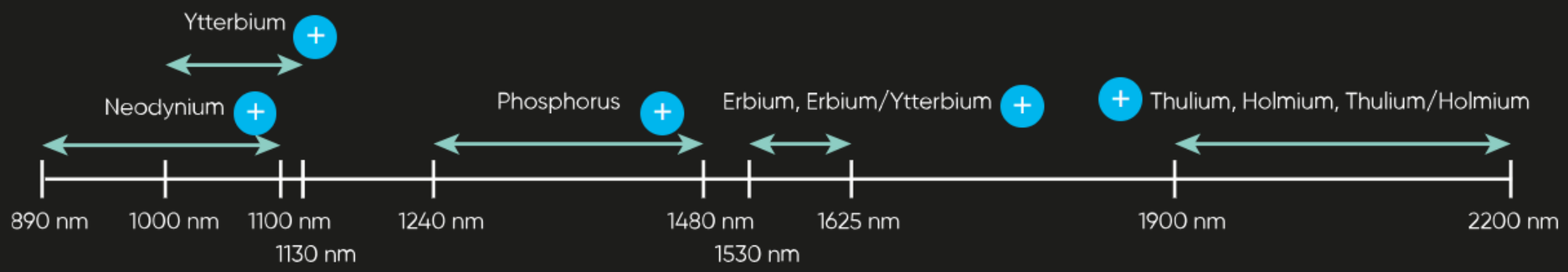
600 ps

- Manual version
- Motorized version

3 ns, 6 ns, 9 ns or 12 ns

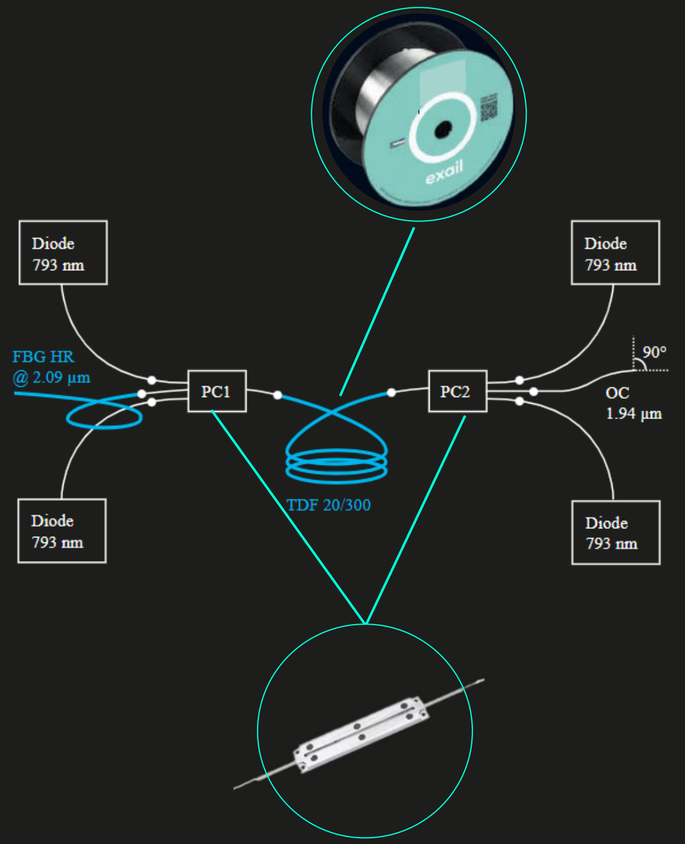
- Motorized version

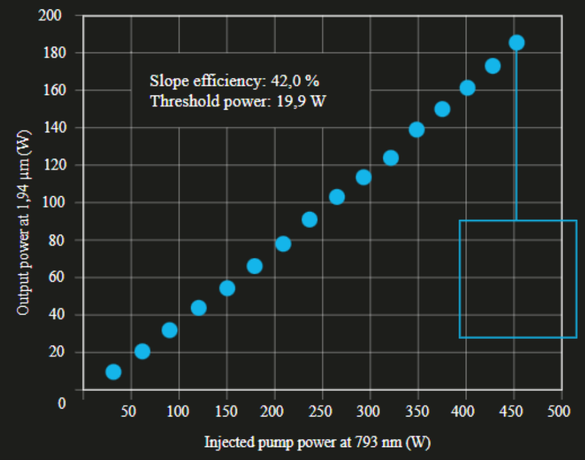
Fiber lasers in the 2 µm range: doped fiber for seeder and amplifier



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



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