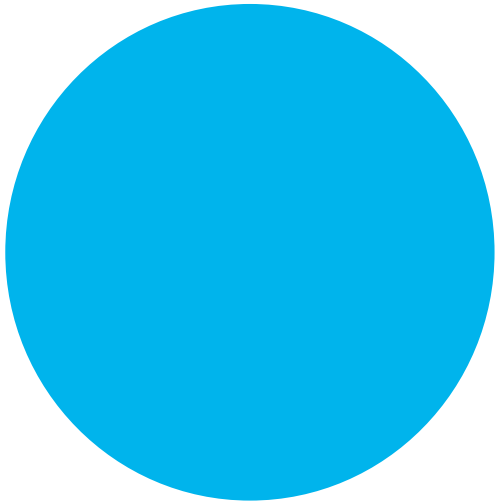

$LiNbO_3$ modulators based Components & Systems for High Energy & High Power Lasers

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Chapter 1

High Energy and High Power Lasers Overview

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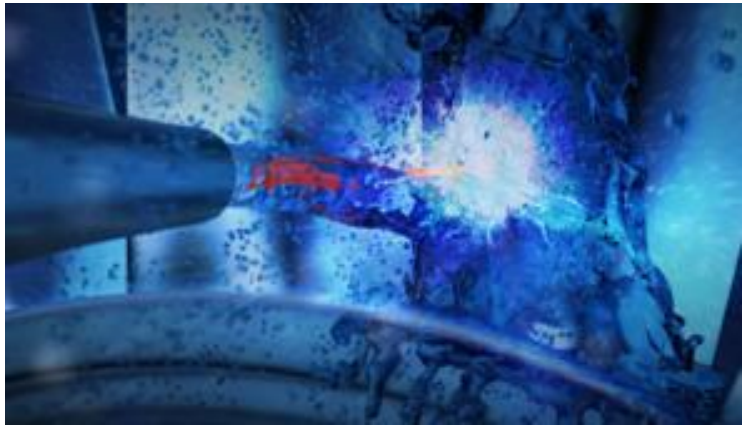
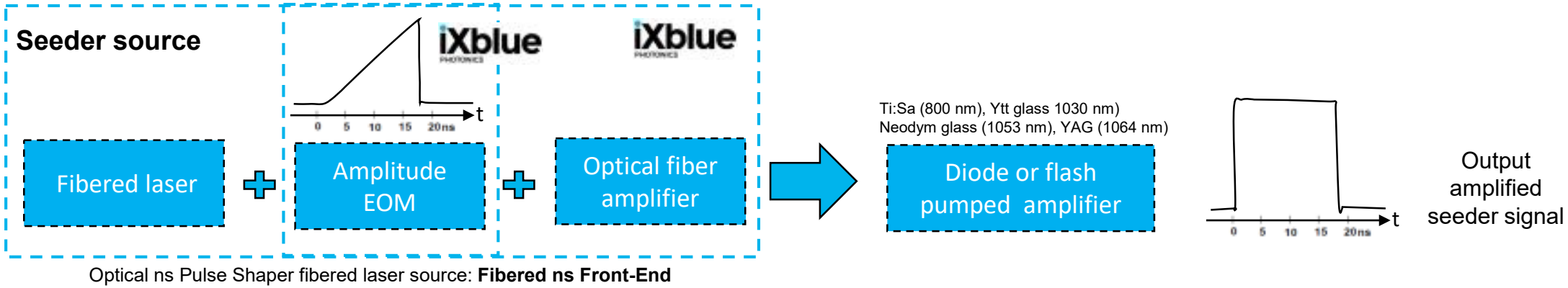
High Energy and High Power Lasers



High Energy Industrial Lasers

- Pulses from 1 - 10 ns, 10 to 100 J
  - Material hardening by laser-induced shock wave (peening)
  - Plasma and shock physics



Optical ns Pulse Shaper fibered laser source: **Fibered ns Front-End**

- Seeder source - key $LiNbO_3$ modulators specification:

  - NIR Modulators with very high optical Extinction Ratio
  - Low Insertion Loss & high Optical Power Handling Capability
  - Wide Electro-Optical bandwidth

- Seeder source - key $LiNbO_3$ modulator based fiber System specification:

  - ns NIR high optical pulse contrast stabilized over time
  - Temporal optical pulse shaping to compensate the amplifiers' distortions
  - Optical fiber amplification to reach pulse energy in the range of nJ

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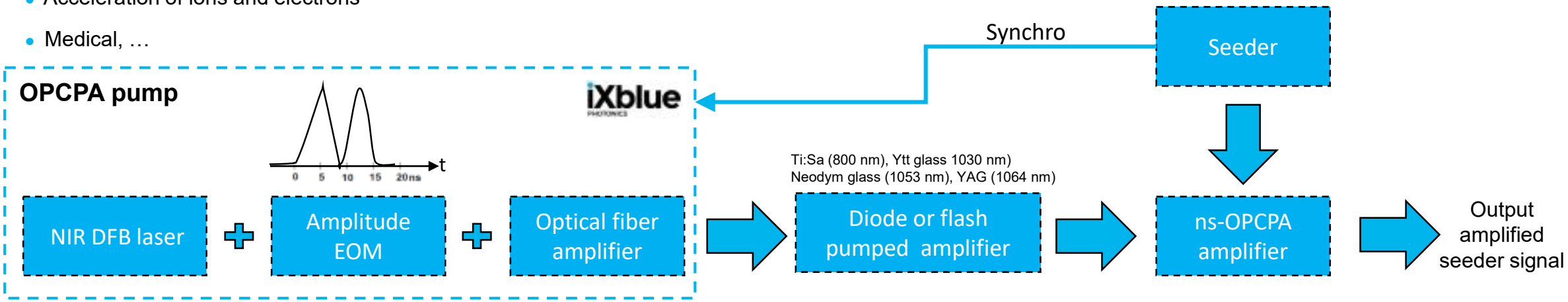
High Energy and High Power Lasers

Scientific High Intensity & Petawatt class lasers based on OPCPA

- Pulses shorter than a picosecond (ELI-Beamlines), up to 10 PW
  - Warm dense matter
  - Plasma physics
  - Acceleration of ions and electrons
  - Medical, …



Optical ns Pulse Shaper fibered laser source: **Fibered ns Front-End**

- OPCPA pump source - key $LiNbO_3$ modulators specification:

  - NIR Modulators with very high optical Extinction Ratio
  - Low Insertion Loss & high Optical Power Handling Capability
  - Wide Electro-Optical bandwidth

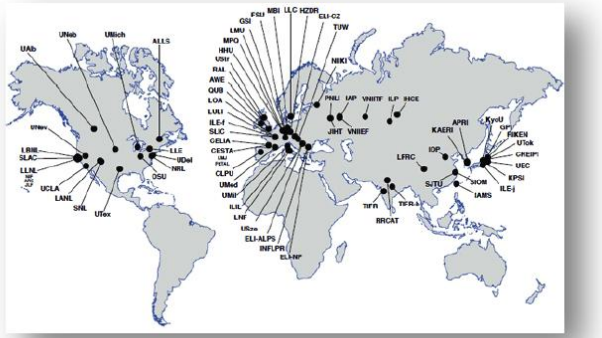
- OPCPA pump source - key $LiNbO_3$ modulator based fiber system specification:

  - ns NIR high optical pulse contrast stabilized over time
  - Temporal optical pulse shaping to compensate the amplifiers' distortion and optimize the overlap between the pump and seeder signals
  - Optical fiber amplification to reach pulse energy in the range of nJ
  - Very low jitter to warrant the best overlap between the pump and seed signals

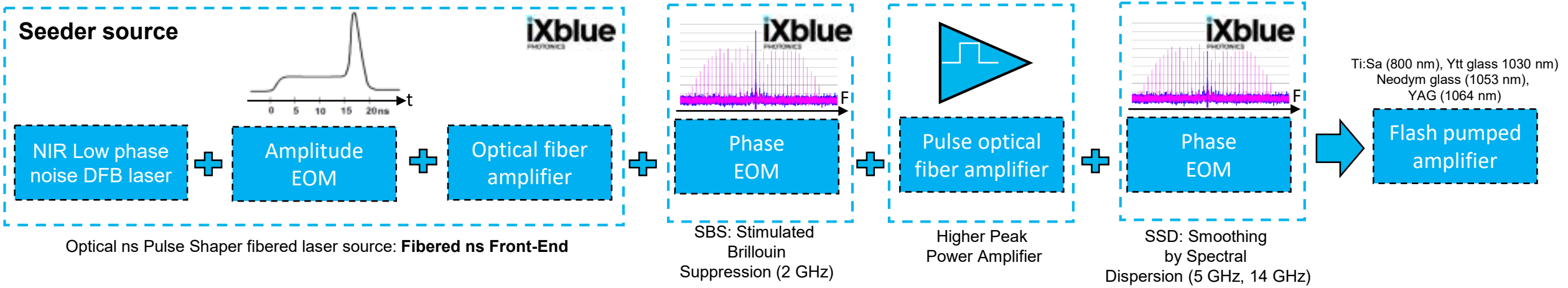
High Energy and High Power Lasers

Scientific High Energy Density (HED) Lasers

- Few nanosecond optical pulse lasers, En > kJ (GSI, RAL, AWE, LULI, LLNL SIOM,,…), En > 1 MJ (LMJ, NIF)
  - Inertial confinement fusion and plasma science
  - Research in nuclear and particle physics,…



Map: source ICUIL web-site



Optical ns Pulse Shaper fibered laser source: **Fibered ns Front-End**

SBS: Stimulated Brillouin Suppression (2 GHz)

Higher Peak Power Amplifier

SSD: Smoothing by Spectral Dispersion (5 GHz, 14 GHz)

- Seeder source - key $LiNbO_3$ modulators specification:
  - High optical Extinction Ratio
  - Low Insertion Loss & high Optical Power Handling Capability
  - Wide Electro-Optical bandwidth
  - High Polarization Extinction Ratio to reduce the FM to AM conversion
  - Low $V\pi$ phase modulator

- Seeder source - key $LiNbO_3$ modulator based ModBox specification:
  - ns NIR high optical pulse contrast stabilized over time, high PER
  - Temporal optical pulse shaping to compensate the amplifiers' distorsion
  - Optical fiber amplification to reach pulse energy in the range of nJ
  - Very low jitter
  - SSB & SSD modulations based on spectrum broadening
  - High Polarization Extinction Ratio

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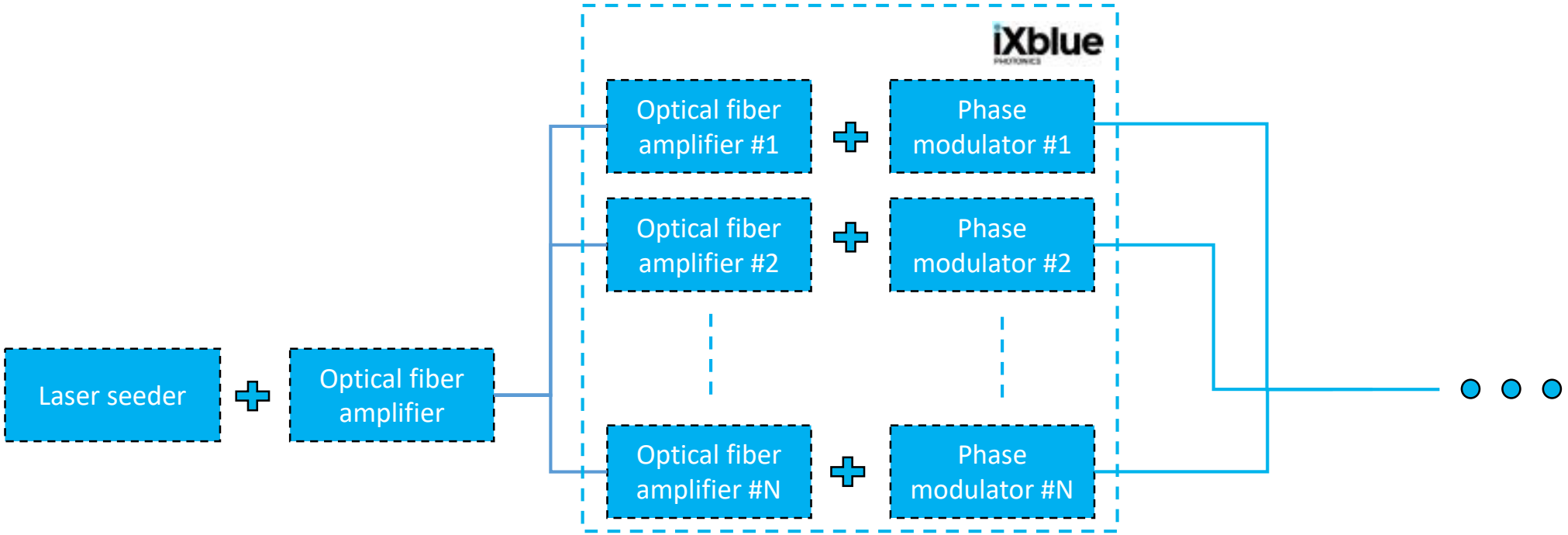
High Energy and High Power Lasers

Industrial and Defense High Energy laser based beams combining

- CW lasers 10 - 100 kW
  - Directed Energy laser weapon (missiles, drones,…)
  - Industrial lasers, heating for hardening (peening), melting for welding and cladding, material removal for drilling,…



- Key $\underline{LiNbO_3}$ Phase modulators specification:

  - Low Insertion Loss & high Optical Power Handling Capability
  - DC to 200 MHz

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Chapter 2

iXblue $LiNbO_3$ modulators for High Energy & High Power Lasers

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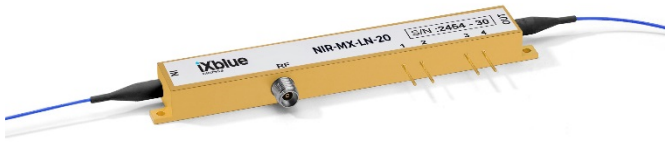
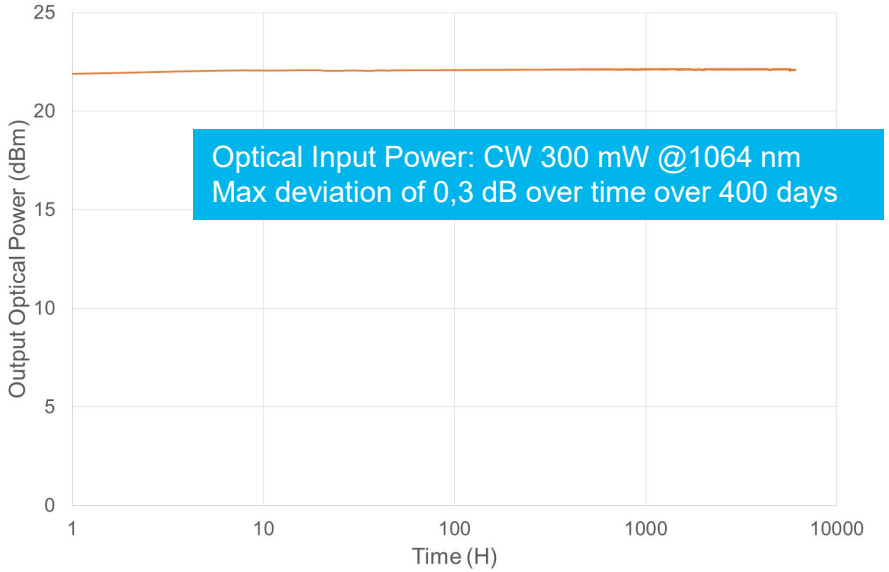
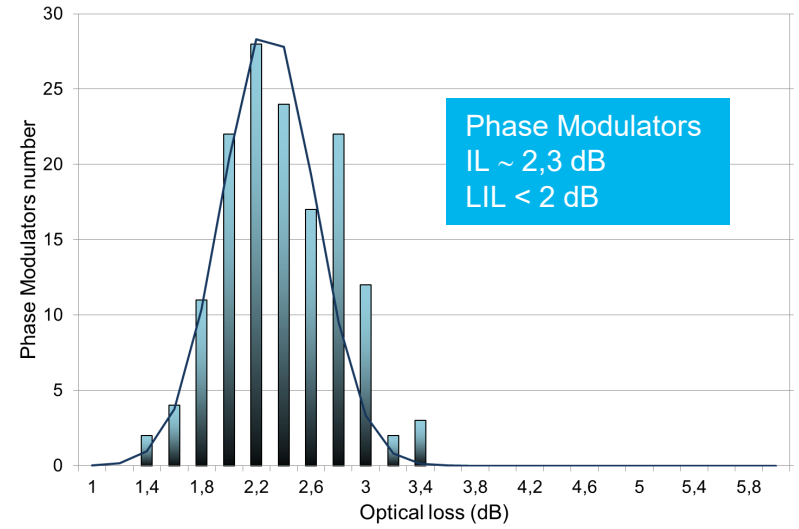
$LiNbO_3$ modulators for High Energy & High Power Lasers

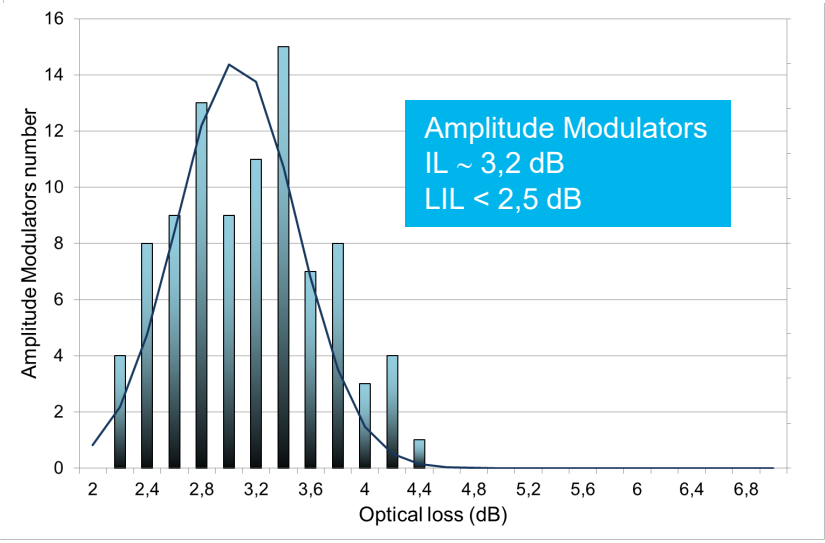
Insertion Loss, optical power handling & PER



- APE technology + co-doped $LiNbO_3$ substrate: makes it possible to increase the modulator optical power handling prior to trigging photo-refractive effects.
- The APE process makes the waveguide polarizing: only TE propagation. High PER by construction.
- Patent to reduce the Insertion Loss based on adapted optical waveguide size







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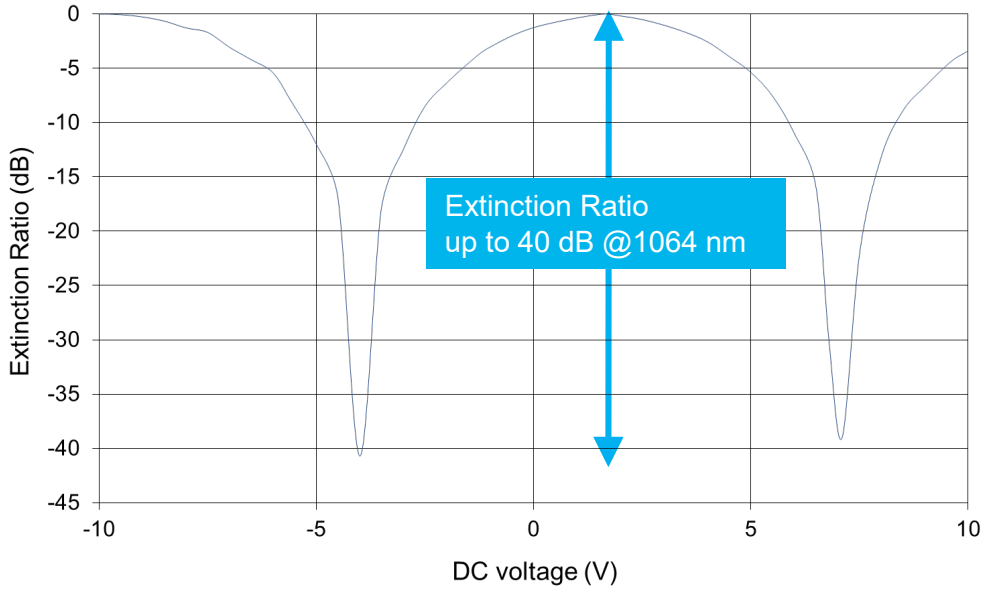
$LiNbO_3$ modulators for High Energy & High Power Lasers

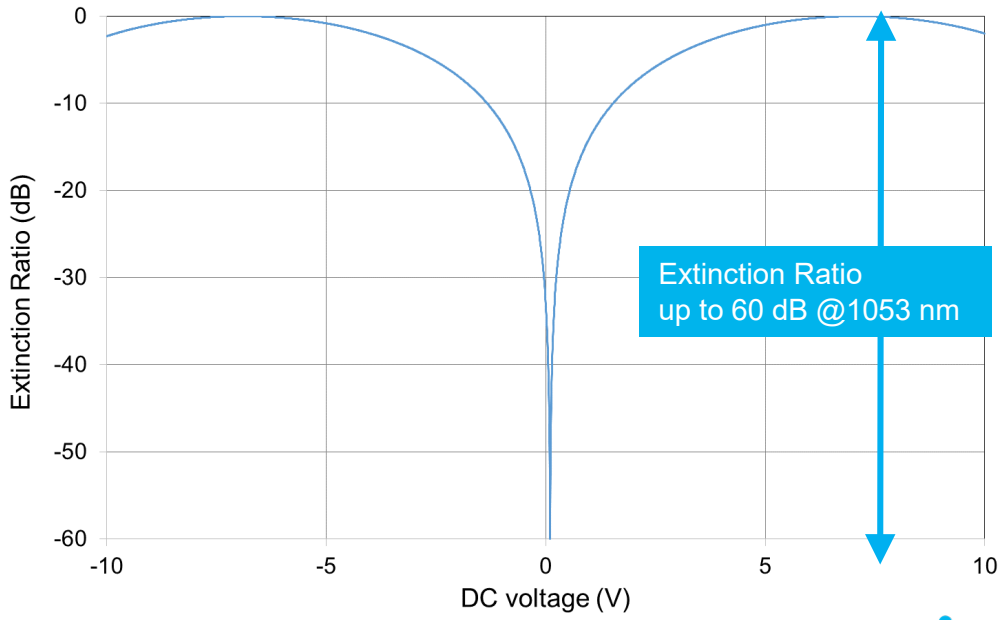
Extinction Ratio for Amplitude Modulators

- Their specific design relies on iXblue “Magic Junction” (patent n° US2008193077).
- From high to very high extinction ratio Mach-Zehnder modulators
- X-Cut amplitude modulator design: to ensure very low modulator drift

Single Stage Mach-Zehnder Amplitude modulator

Dual Stages Mach-Zehnder Amplitude modulator





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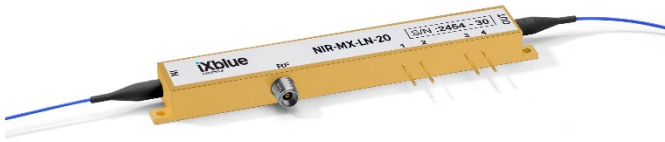
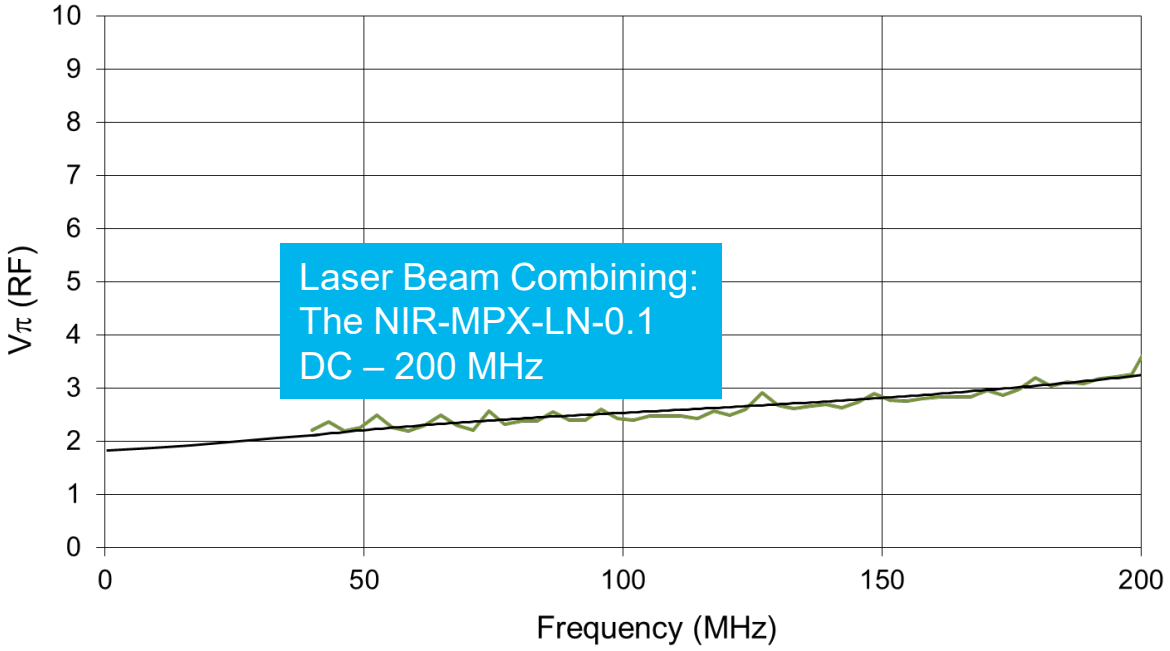
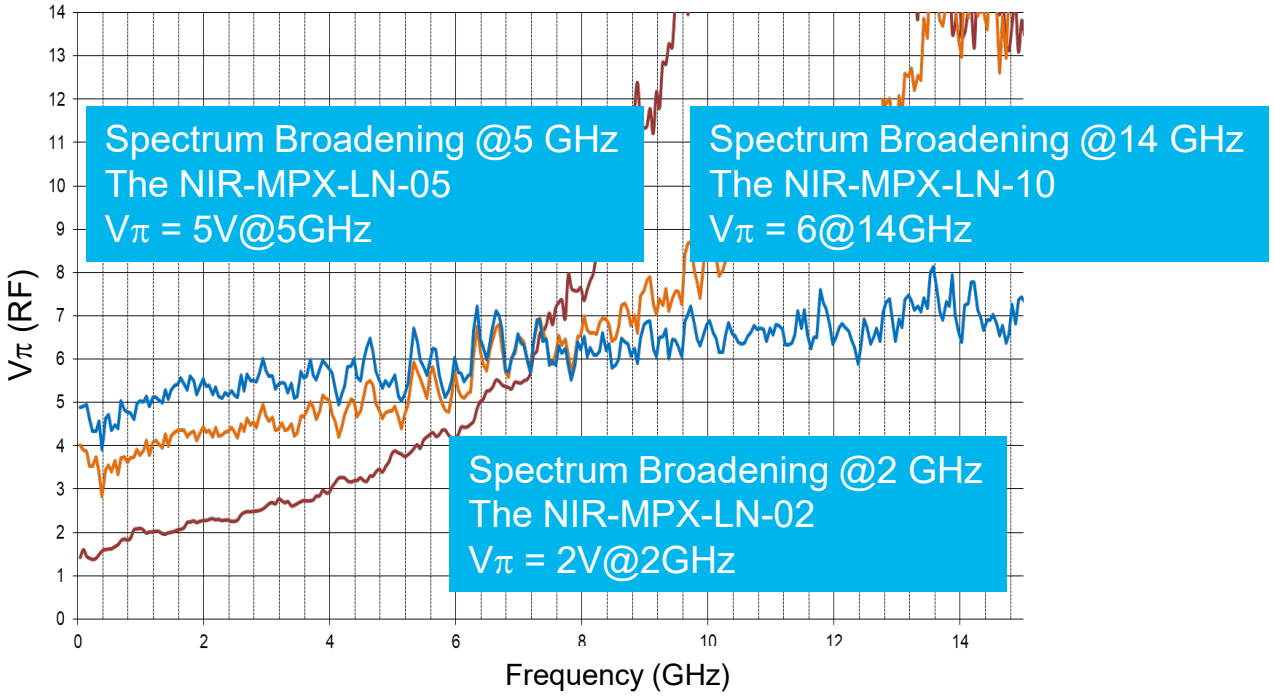
$LiNbO_3$ modulators for High Energy & High Power Lasers

Electro-Optical and RF performances: Vπ, EO-bandwidth, high RF power handling



- Large selection of phase modulator EO-bandwidth in order to minimize Vπ at your frequency of operation
- Specific RF internal load: High RF power handling





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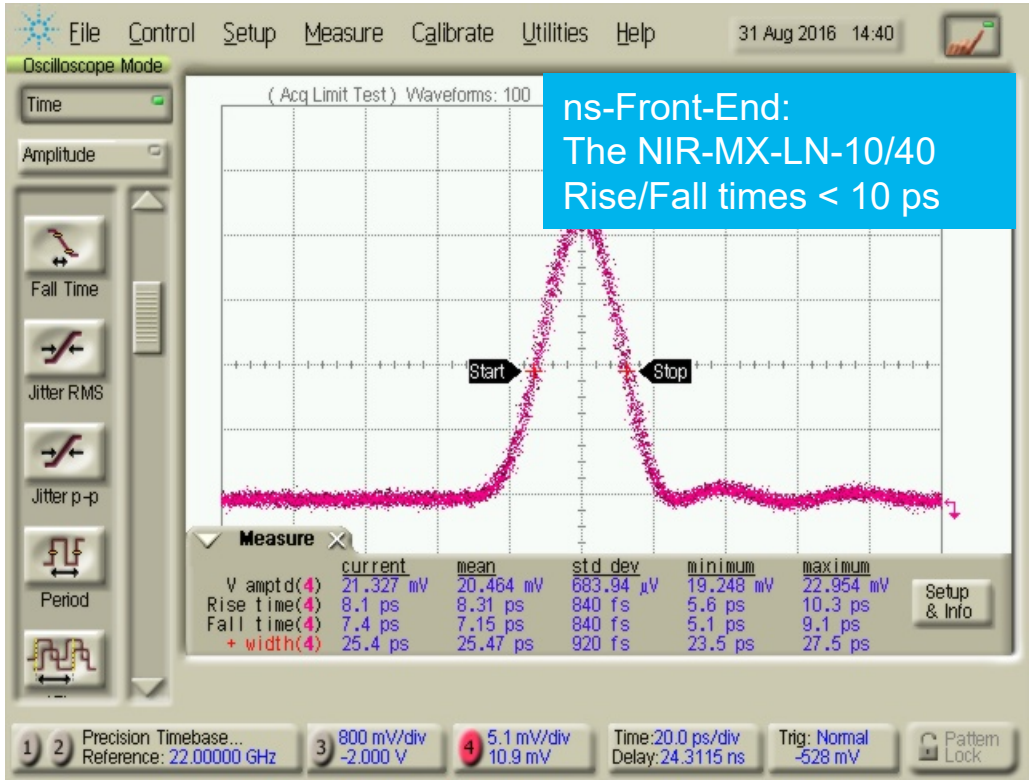
$LiNbO_3$ modulators for High Energy & High Power Lasers

Electro-Optical and RF performances: Vπ, EO-bandwidth, high RF power handling

- Wide EO-bandwidth Amplitude modulators to generate fast rise and fall times optical pulses



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$LiNbO_3$ modulators for High Energy & High Power Lasers

What are the problematics the fibered $LiNbO_3$ modulators have to address?

- High optical Extinction Ratio: to generate high Signal to Noise Ratio optical pulse
  - ➡ Up to 35 dB from a single stage MZ and up to 60 dB with a dual stage Mach-Zehnder
- High Polarization Extinction Ratio: to mitigate the FM to AM conversion
  - ➡ > 25 dB w/o and with optical connectors.
- Low Insertion Loss & high Optical Power Handling Capability: to generate high pulse optical power and energy
  - ➡ Up to 300 mW CW optical input power, IL < 3dB AM, IL < 2 dB PM
- Low frequency & Wide Electro-Optical Bandwidth: to generate optical pulses with fast rise and fall times
  - ➡ DC to 200 MHz, and up to 40 GHz
- Low DC drift & controlled optical non-linearity (refractive index, pyro-electric effects): for long term optical performances stability
  - ➡ APE process and Zero drift (Bias Ready) AM
- Low $V\pi$ and high input RF power handling: to mitigate the SBS and realize SSD
  - ➡ Large modulator choice adapted per modulation frequency, RF input up to 38 dBm

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Chapter 3

iXblue $LiNbO_3$ modulators based systems: the ModBox

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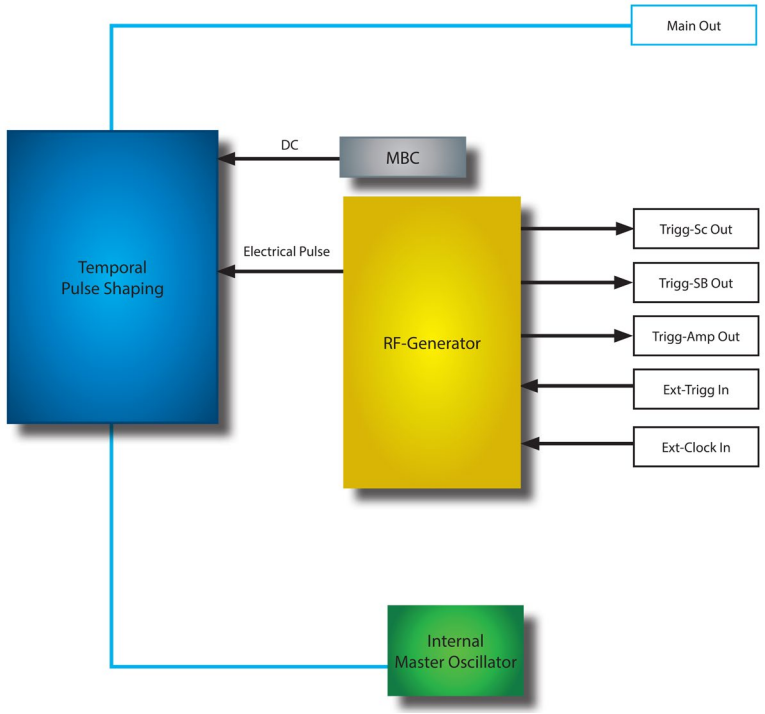
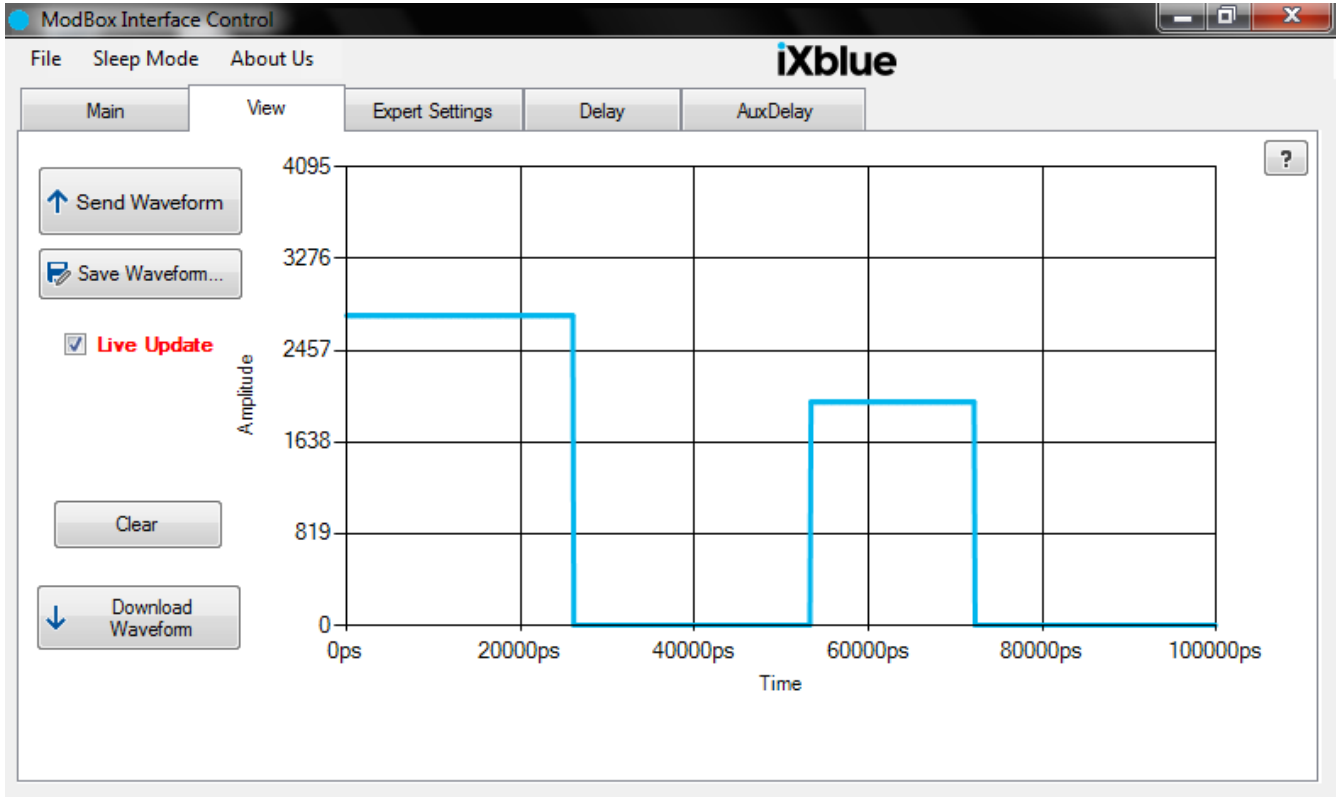
iXblue $LiNbO_3$ modulators based systems: the ModBox

Optical ns Pulse Shaper fibered laser source - Fibered ns Front-End: Schematic & GUI

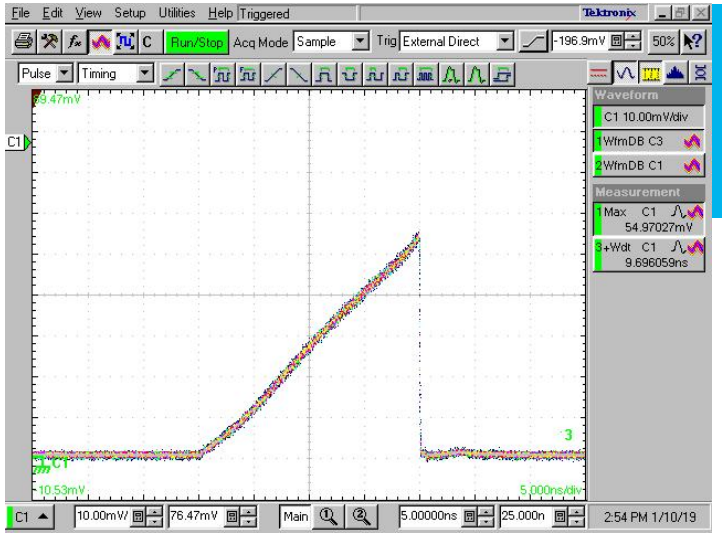




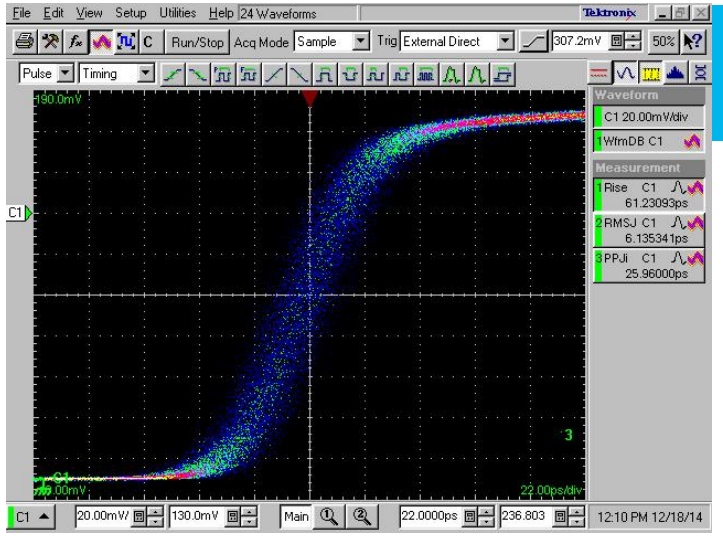
- CW DFB laser source
- Temporal pulse shaping block based on a modulator set to ensure a very high optical pulse extinction ratio
- an automatic Modulator Bias Control circuitry (MBC)
- RF-Generator with an arbitrary waveform capability
- On line video:

iXblue $LiNbO_3$ modulators based systems: the ModBox

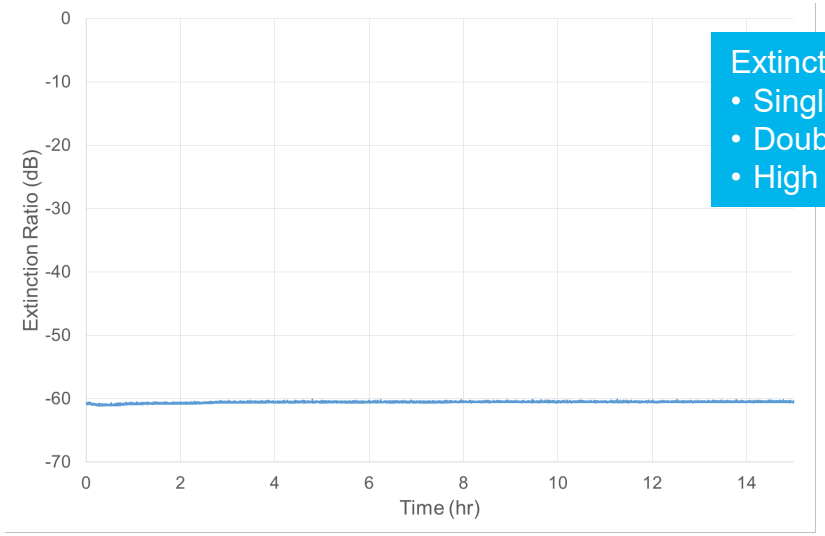
Optical ns Pulse Shaper fibered laser source - Fibered ns Front-End: the main performances



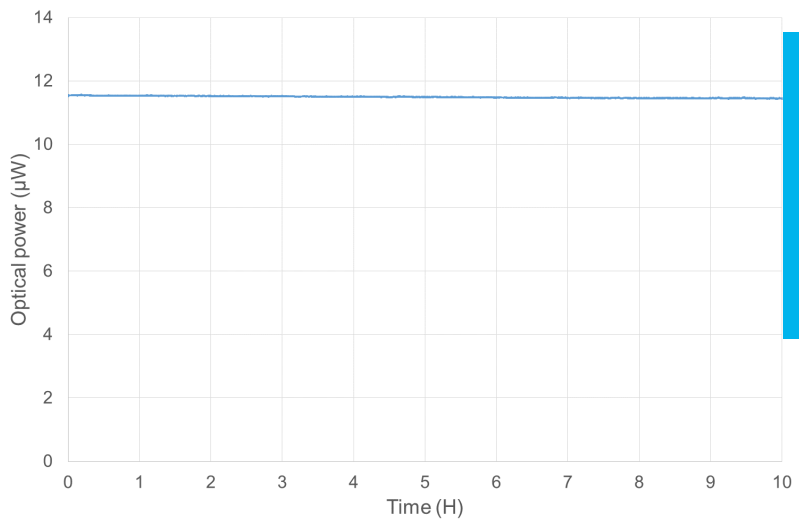
Arbitrary Optical Waveform
- 125 ps to 100 ns Pulse width
- Single Shot to 100 kHz
- 12 bits vertical resolution
- 800 samples



Time jitter:
- Jitter 7 ps RMS
- Low-Jitter option < 7 ps-pp



Extinction Ratio:
- Single MZ: > 35 dB
- Double MZ: > 60 dB
- High stability contrast < 1 %rms



Output optical power:
- 1030 nm, 1053 nm, 1064 nm
- < 1 % RMS.

Energy levels:
- 1 nJ / 1 ns – ER 35 dB
- 300 pJ / 1 ns – ER 60 dB

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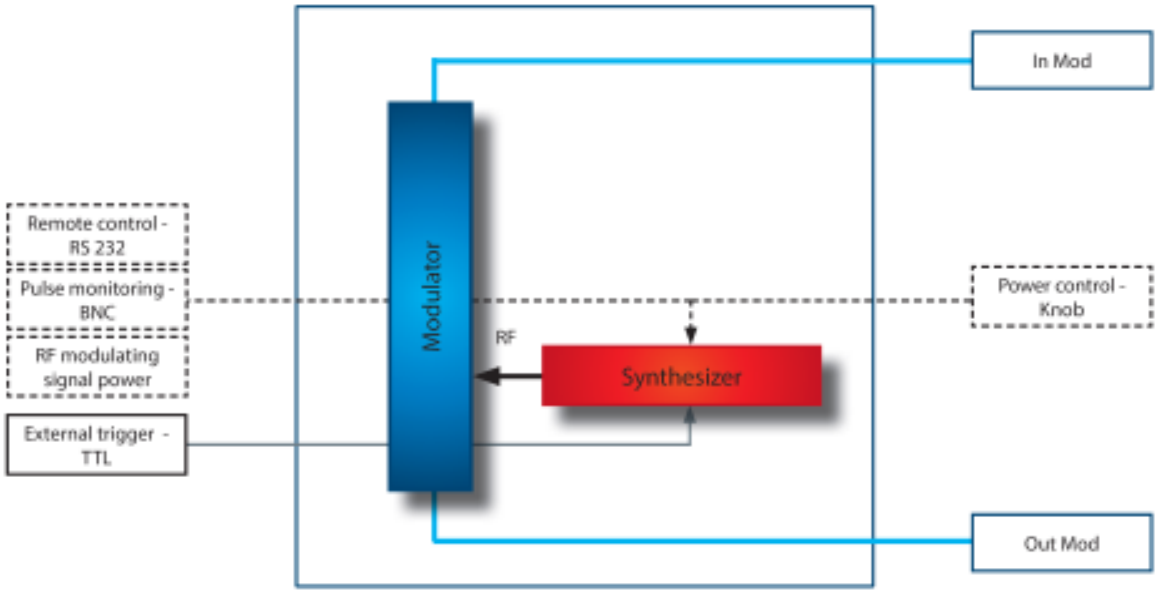
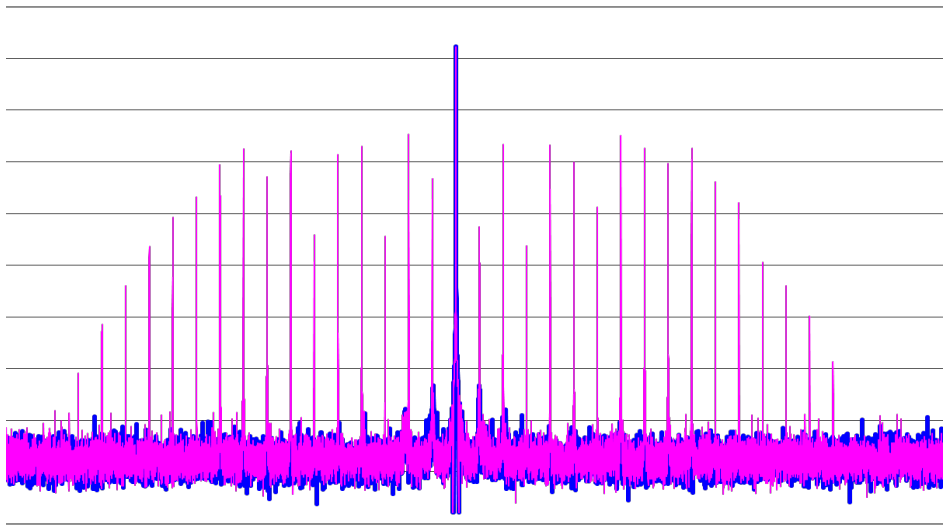
iXblue $LiNbO_3$ modulators based systems: the ModBox

The ModBox Spectrum Broadening – schematic & performances





- High RF power handling $LiNb0_3$ phase modulator
- Pulsed sine wave oscillator with power control

Broadening efficiency
- 0,3 nm (2 GHz) / 0,5 nm (5 GHz) / 1,5 nm (14 GHz)
- Externally triggerable

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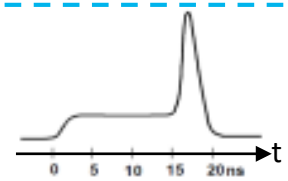
iXblue $LiNbO_3$ modulators based systems: the ModBox

The ModBox MOFA – schematic & performances

Seeder source



NIR Low phase noise DFB laser + Amplitude EOM + Optical fiber amplifier

Optical ns Pulse Shaper fibered laser source: **Fibered ns Front-End**

+ Phase EOM

SBS: Stimulated Brillouin Suppression (2 GHz)

+ Pulse optical fiber amplifier

Higher Peak Power Amplifier

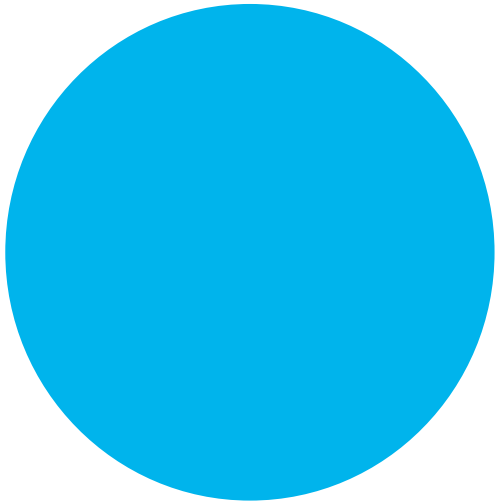
=

ModBox-MOFA
- 1030 nm, 1053 nm, 1064 nm
- ER 60 dB
- Sub-ns Pulse shaping
- 125 ps to 100 ns
- Single Shot to 10 kHz
- Pulse Energy > 10 µJ, 100 µJ
- Output peak power > 100 W

ModBox-FE

ModBox-SB

ModBox-PPA



For any questions and support, please contact:
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