Navigating to the quantum world

Electro-optic modulation solutions and polarizing fibers for cold atom and quantum applications

iXblue June 2020
contact.photonics@ixblue.com
1- iXblue : navigating to the quantum world
   - Who is iXblue
   - iXblue Photonics
   - Quantum Optic Market Opportunities
   - Improving / Enabling lasers for quantum optics with EOMs

2- Electro-optic modulation solutions for the quantum world
   - What is an EOM
   - Technical choices for modulation in the NIR
   - Relevant EOMs for quantum optic applications

3- 780nm cold atom laser source $^{87}$Rb
   - iXatom
   - Laser Source used in Cold atom accelerometer setup

4- Polarizing Fiber and FBGs
   - PM vs PZ fiber
   - Narrow linewidth filters

5- Conclusion
iXblue: navigating to the quantum world
iXblue: navigating to the quantum world

Who is iXblue

- 700+ employees
- 130+ M€ turnover
- 80% export
- 40 years' experience
- 100% independent
iXblue: navigating to the quantum world

Photonics Division

Modulation

Modulators, RF Drivers, MBC & ModBox

Fibers

Specialty Fibers & Photonic Components
The practical realization of Quantum Mechanics theories has led to an explosion of new frontiers in R&D. Many different areas use the same fundamental tools such as Magneto-Optical Traps (MOT), laser cooling and optical frequency combs, which in turn apply Electro-Optic Modulators in similar methods.
Quantum physic needs lasers: example of atomic manipulation by lasers

The laser quality and performance are very important:

- Wavelength is related to the atomic transition used
- Laser power
- Laser stability and linewidth
- Agility
- Tunability
- ...

LiNbO$_3$ modulators and special fibers are used....
iXblue: navigating to the quantum world

Improving / Enabling lasers with LiNbO$_3$ modulators in quantum physics

- **Stabilizing Laser sources: Pound-Drever-Hall (PDH) locking technique**
  
  A very stable laser frequency is most welcome.
  
  - Low frequency (MHz range) phase modulator

- **Multi Line Laser**
  
  The carrier frequency (0 order modulation) and the first sideband (+1 order modulation) can be used as the cooling and re-pumping lines during magneto-optical trapping
  
  - Dedicated phase and amplitude modulators for operating frequency and wavelength

- **Frequency Combs**
  
  Metrology and short optical pulses
  
  - phase modulators

- **Single Line Laser tuning**
  
  In order to minimize parasitic wavelengths, CS-DSB, CS-SSB or FC-SSB and side bands generation:
  
  - Mach-Zehnder modulator (CS-DSB) combined with an FBG (CS-SSB)
  - Dual-Parallel modulator (CS-SSB or FC-SSB)

- **Laser pulses**
  
  Single photon sources to deliver very short optical pulses
  
  - Mach-Zehnder modulator
Electro-optic modulation solutions for the quantum world
What is an electro-optic modulators and what does it do?
Electro-optic modulation solutions for the quantum world

Intensity, phase and IQ modulators

LiNbO$_3$ chips

- Modulation of a guided light (amplitude, phase and polarization).
- Planar integrated technology: waveguide + electrodes on a LiNbO$_3$ substrate
- Electro-optical effect: change of a material refractive index in the presence of an electrical field
Electro-optic modulation solutions for the quantum world

Intensity, phase and IQ modulators

- **Phase modulator**
  \[ \vec{E} = E_0 e^{j\phi} \]

- **Amplitude modulator**
  \[ \vec{E} = E_0 e^{j\phi} \]

- **IQ modulator**
  \[ \vec{E} = E_0 e^{j\phi} \]

**Phase shift**

- CS-DSB, Comb generation

**Sub-ns pulse**

- CS-DSB
  - Optical carrier
  - Side-bands
  - 43dB
  - 32dB
  - 10.7GHz

- CS-SSB
  - Optical carrier
  - 43dB
  - 32dB
  - 10.7GHz
Electro-optic modulation solutions for the quantum world

Intensity, phase and IQ modulators

Technological choices for high stability and optical power handling in the light in the near-infrared
Electro-optic modulation solutions for the quantum world

Intensity and phase modulators

Atom physics typically requires wavelength in the NIR to visible region.

Unfortunately LiNbO$_3$ is susceptible to photorefractive effect at lower wavelength.
   ➔ This prevents us from proving a solution in the visible and for wavelengths shorter than 760 nm.

Even though, iXblue has acquired a unique and extensive know-how in the technique used for producing near infrared modulators - typically for the 760 nm up to 1150 nm wavelength range.

In the next slides we will present our technological choices and their positive impact on the performance of the amplitude NIR-MX800 and phase NIR-MPX800 modulators.

Technology choices include:

- Choice of manufacturing process
- Choice of LiNbO$_3$ substrate
- Choice of crystal cut to minimize pyroelectric effect
Electro-optic modulation solutions for the quantum world

Manufacturing process on Lithium Niobate substrates

- Titanium In-Diffusion
  - Widely used
  - Reliable process, easy to implement
  - Susceptible to photorefractive effect at shorter wavelength
  ➔ Instability of the Insertion Loss and Extinction Ratio curves only with few mW @780 nm optical power

- Annealed Proton Exchange (APE)
  - More complex to implement
  - Very few manufacturers
  - Technology of choice for all modulators in the NIR (760 nm to 1150 nm)
  - APE process helps mitigate photorefractive effect in the NIR
  ➔ Stable Insertion Loss and Extinction Ratio curves only up to 20 mW @780 nm / 60 mW 850 mW / 300 mW 1064 nm optical power
Electro-optic modulation solutions for the quantum world

Custom Lithium Niobate substrate

- The photorefractive effect threshold can be increased further by a specially designed LiNbO$_3$ substrate.

- The choice of the APE technology, combined with the custom LiNbO$_3$ substrate, makes it possible to increase the modulator optical power handling prior to triggering photo-refractive effects.
Electro-optic modulation solutions for the quantum world

Crystal Cut: the X factor

<table>
<thead>
<tr>
<th></th>
<th>Z-cut modulator</th>
<th>X-cut modulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric fields</td>
<td>Z axis</td>
<td>X axis</td>
</tr>
<tr>
<td>EO Efficiency</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
</tr>
<tr>
<td>Insertion loss</td>
<td>😊😊😊</td>
<td>😊😊😊</td>
</tr>
<tr>
<td>Pyroelectric effect</td>
<td>😞😞😞</td>
<td>😊😊😊</td>
</tr>
<tr>
<td>Stability</td>
<td>😞😞😞</td>
<td>😊😊😊</td>
</tr>
</tbody>
</table>

- Most of iXblue LiNbO₃ modulators are based on an X-cut design.
- We believe the benefit of this configuration – stable insertion loss, low drift – outweighs the slight hit on performance.
Electro-optic modulation solutions for the quantum world

Intensity, phase and IQ modulators

Relevant EOMs for quantum optic applications
Electro-optic modulation solutions for the quantum world
Phase modulators – Laser frequency locking, PDH

- PDH: Pound Drever Hall = stabilization of the wavelength / optical frequency of a laser source thanks to an absolute reference (Etalon, spectroscopic gas cell, …).

- Phase modulation at $\Omega$ is applied to the source to generate frequency modulation on a range $\delta \Omega$.

- Frequency modulation is converted into amplitude modulation by discrimination on the slopes of the reference Etalon.

- Feedback loop locks the laser at the absolute reference thanks to harmonics optimization.
Electro-optic modulation solutions for the quantum world

Phase modulators – Laser frequency locking, PDH

- RAM = Residual Amplitude Modulation = ratio between the voltage dependent power modulation and the total average power transmitted by the phase modulator.

- In case of use in PDH application, the amplitude harmonics can be combined with harmonics issued from PDH frequency to amplitude discrimination.

- Consequence: wavelength lock-in occurs with an error value \( \omega_e \) proportional to the modulation range \( \delta \omega \) and to the RAM = \( \epsilon V/P_0 \).

- Residual amplitude modulation results from coupling with a deep electrical induced waveguide.

- Low permanent DC voltage (5 - 15 V) is enough to reduce RAM by more than 10 dB, compared to an unbiased modulator.

- Resulting RAM > 30 dB fits the requirements of PDH where sensitivity limitations is related to shot and thermal noise.

\[
RAM_{dB} = 10 \log_{10} \frac{\epsilon V_{pp}}{P_0}
\]

\[
P(t) = P_0 + \epsilon V(t)
\]
Electro-optic modulation solutions for the quantum world

Phase modulators – Laser frequency locking, PDH

- MPX-LN-0.1 product family
- Operating wavelength: 780 nm to 1560 nm
- DC coupled and low frequencies phase modulators
- Low Residual Amplitude Modulation (LRAM)
Electro-optic modulation solutions for the quantum world

On-board Phase modulators – Laser frequency locking, PDH

- **Application**
  Laser cavity stabilization

- **Technology:**
  Each Laser uses a Phase LiNbO$_3$ modulator
  LiNbO$_3$ Crystal oriental X-cut
  APE (Annealed Proton Exchange) process
  Wavelength: 1064 nm
  Medium frequency < 100 MHz
  Pound–Drever–Hall (PDH) technique

- **The reality - Commercial project:**
  GRACE FO: Gravity Recovery and Climate Experiment Follow-On:
  tracking Earth’s water movement to monitor changes in underground water storage

(Twin satellites « Tom et Jerry »)

(GrACE-FO) mission launched onboard a SpaceX Falcon 9 rocket,
Tuesday, May 22, 2018,
Electro-optic modulation solutions for the quantum world

Phase Modulators

- Using a mathematical identity, the output modulated optical field can be expanded as a sum of harmonics $\pm \omega, \pm 2\omega, \ldots$ around the optical carrier:

$$E(t) = E_0 e^{j\omega t} \sum_{k=-\infty}^{k=\infty} J_k(\gamma) e^{jk\Omega t}$$

- Each amplitude of the generated kth sideband is weighted by the kth Bessel function of the first order.

- Each sideband weight depends on the modulation index $\gamma$. 

---

Comb generation
Multi-lane
Electro-optic modulation solutions for the quantum world

Phase modulators – Sides bands generation

- Operating wavelength: 760 nm – 1560 nm
- Low insertion loss
- Unparalleled high-power handling capability
- High Electrical Power (HEP) handling for multiple sides bands generation
- Choice of bandwidth 5 /10 GHz for low $V_{\pi}$

Combiner generation

Multi-lane

NIR-MPX800-LN-10
Low $V_{\pi}$ @ 9.2 GHz

NIR-MPX800-LN-05
Low $V_{\pi}$ @ 6.83 GHz
Electro-optic modulation solutions for the quantum world

800 nm Intensity modulators - NIR-MX800-LN-10/20

- Operating wavelength: 780 nm – 890 nm
- Wide EO Bandwidth up to 40 GHz
- Low insertion loss ~ 4.5 dB
- Low EO-drift
- Unparalleled high-power handling capability
- High extinction ratio: 30 dB
Electro-optic modulation solutions for the quantum world

High Extinction ratio modulators at 1560nm, 800 nm band

- Wide bandwidth 18 GHz or 25 GHz
- Low insertion loss
- High extinction ratio > 40dB
- Low DC drift
Electro-optic modulation solutions for the quantum world

ModBox-Pulse Generation – Sub-ns optical pulse generation

- Pulse Generation: Single photon / QKD
- Sub-ns pulses from 30 ps to several hundreds ns
- Very high optical pulse contrast, from 30 dB to 100 dB
- Square pulse, arbitrary waveform
- High contrast stability over time
- Low time jitter
**Electro-optic modulation solutions for the quantum world**

**IQ modulators – Carrier Suppression Single Side Band (CS-SSB)**

- The structure of an I&Q is constituted by 2 sub- Mach-Zehnder Interferometers nested inside a third one, it is used as spectral shaper when properly driven by an RF signal.

- To generate CS-SSB, the IQ modulator is coupled with an RF coupler that splits the RF signal toward the I and Q sub-Mach-Zehnders RF input, tunable delay lines and RF driver.

- The carrier attenuation and the side band attenuation are depending on several factors including the RF power driven to the modulator, the RF power balance between the two sub-Mach-Zehnders, the wavelength of the optical signal, the frequency of the RF modulation signal and the I/Q phase shift.
Electro-optic modulation solutions for the quantum world

IQ modulators – Carrier Suppression Single Side Band (CS-SSB)

- The MXIQER is designed for CS-SSB application – high ER
  Carrier attenuation > 30dB
  Sideband attenuation > 30dB

- Low insertion loss

- Matching MBC-IQ, design to lock the three operating bias points of IQ Modulator
Electro-optic modulation solutions for the quantum world
IQ Based ModBox – Carrier Suppression / Residual / Full Single Side Band

- The ModBox-CBand-CS-RC-SSB is a versatile SSB transmitter allowing the control of the carrier level by an original mean.

- The ModBox-CBand-CS-RC-SSB is coming with 3 preset modes, for each of these modes, the remaining side band is frequency adjustable from the RF generator:

  - **CS-SSB**: Carrier Suppression Single Side band. This mode generates only one side band.
  - **FC-SSB**: Full Carrier Single Side band. This mode generates one side band and the carrier.
  - **RC-SSB**: Residual Carrier Single Side band. This mode generates one side band and the carrier with equal amplitude.
780nm cold atom laser source - $^{87}$Rb
iXatom is a joint laboratory between iXblue and LP2N in Bordeaux France specialized in atom interferometry.

The focus is on the development of a three-axis accelerometer based on atom interferometry.
ModBox Cold Rubidium Atoms Laser Source

Presentation

- Agile and reconfigurable dual bands emitter dedicated to cold atoms applications.

- Able to help the user during the difference sequences of rubidium cold atoms operations. Switching time between each frequency sequence can be as short as 50µs, thanks to the agile microwave pilot source.

- Original and proprietary design (*Patent WO2018 FR52959 20181122, FR3074371 (A1)*)

- Based on the use of a 1560 nm CS-SSB modulation and second harmonic generation.

- Allows to deliver two simultaneous optical lines at 780 nm with a high rejection of parasitic lines.

- high rejection of parasitic lines improves significantly the performances of the instrument in particular regarding atoms interferometry metrology.
Turnkey Laser Transmitter
Laser Source used in Cold atom accelerometer setup

- Our laser architecture combines an all-fibered IQ modulator operating at 1560 nm and a wavelength conversion module to 780 nm.

- Using carrier-suppressed dual single-sideband (CS-DSSB) modulation, the IQ modulator generates two optical sidebands that can be independently controlled in frequency, phase and power.

- Compared to standard phase modulators, this architecture presents strong attenuation of lines that generates parasitic Raman transitions and avoids additional acceleration bias.
ModBox Cold Rubidium Atoms Laser Source

Features

- Dual independent side bands generation at the 780 nm Rubidium transitions
- Agile side bands tunability
- Agile side band power level
- High accuracy of the frequency tuning
- High rejection of the undesired parasitic side bands and harmonics
- Fast switching between frequency states
- High output optical power level
- Proven solution
- Remote control
- High stability
# ModBox Cold Rubidium Atoms Laser Source

## Specifications

<table>
<thead>
<tr>
<th>specifications</th>
<th>unit</th>
<th>value 1</th>
<th>value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total output signal power</strong></td>
<td>dBm</td>
<td>@ 780 nm</td>
<td>27</td>
</tr>
<tr>
<td><strong>SSB #1 &amp; SSB #2 output signal optical power</strong></td>
<td>dBm</td>
<td>@ 780 nm</td>
<td>20</td>
</tr>
<tr>
<td><strong>SSB #1 &amp; SSB #2 output signal optical linewidth</strong></td>
<td>kHz</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td><strong>SSB #1 &amp; SSB #2 frequency detuning</strong></td>
<td>GHz</td>
<td>reference to slave laser @780 nm</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Polarization extinction ratio</strong></td>
<td>PER</td>
<td>dB</td>
<td>20</td>
</tr>
<tr>
<td><strong>Side parasitic lines rejection</strong></td>
<td>dB</td>
<td>6.8 GHz spacing</td>
<td>20</td>
</tr>
<tr>
<td><strong>RF Switching time between channels</strong></td>
<td>µs</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td><strong>Acousto-optic shutter switching time</strong></td>
<td>ns</td>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>
3 Polarizing Fiber and FBGs
Polarizing Fiber
Patch cable for cold atom experiments

Why? use a polarizing fiber as patch cable for cold atom experiments?

➔ A polarization-maintaining (PM) fiber can maintain a linear polarization state on one of the two principal axes (fast or slow axis).

➔ A polarizing (PZ) fiber can only maintain a state of linear polarization on one of the two principal axes (slow axis). There is no propagation on the fast axis.
A PM fiber behaves like a polarimeter that is similar to an interferometer.

When the path difference becomes longer than the decoherence length $L_{dc} = \frac{\lambda^2}{\Delta \lambda_{\text{FWHM}}}$, both eigen polarizations cannot interfere: light becomes depolarized.

Depolarization is reached for a distance longer than the so-called depolarization length: $L_d = L_{dc} / B \approx 2000 L_{dc}$, where $B$ is the birefringence of the PM fiber.

Can be viewed as wave trains which do not overlap anymore.
Polarizing Fiber

Depolarization in a PM fiber

Example 1: erbium-doped fiber source for fiber-optic gyroscope

\[ \lambda = 1550 \text{ nm} \]
\[ \Delta \lambda_{\text{FWHM}} = 15 \text{ nm} \rightarrow L_{dc} = 160 \mu\text{m} \]

A $5 \times 10^{-4}$ birefringence index difference yields a depolarization length $L_d = 30 \text{ cm}$

Example 2: Cold Atom source

EYLSA 780 (Single Frequency Benchtop) - Quantel

\[ \lambda = 780 \text{ nm} \]
\[ \Delta \lambda_{\text{FWHM}} < 2500 \text{ kHz} \rightarrow L_{dc} = 120 \text{ m} \]

A $5 \times 10^{-4}$ birefringence index difference yields a depolarization length $L_d = 240 \text{ km}$

→ To not have interference requires that the length of fiber used is superior to 240 km!
Polarizing Fiber

Patch cable for cold atom experiments

Why?

use a polarizing fiber as patch cable for cold atom experiments

Because with

→ PM Fiber: both eigen polarizations will interfere! → power instability
→ PZ Fiber: there is no interference!
Polarizing Fiber

Patch cable for cold atom experiments

How?

use a polarizing fiber as patch cable for cold atom experiments

To have a robust solution (insensitivity to curvatures and vibrations) the fiber must have a coiled part to increase the leakage mechanism (by design; for short lengths of fiber less than 20 meters).

Our polarizing solutions can be sold packaged in a box.
Example: All-Fiber Polarizer IXS-POL-780-10-BOX (10 meters)
  Coil diameter: 70 mm; coil length: 8 meters; fiber length deployed: 2x1 meter
A polarizing fiber - PZ - is a birefringent fiber designed for only one of the two polarization modes is guided.

One is able to polarize and/or maintain the polarization state with a very good extinction ratio (> 50 dB).
Polarizing Fiber

How it works

- Operated far above the higher-mode cut-off wavelength (λ > 1.5 λc), the mode profile widens and its equivalent index decreases.
- The equivalent index of the slow (high-index) polarization mode remains above the index of the cladding, and then guided.
- The equivalent index of the fast (low-index) polarization mode gets below the index of the cladding which induces leakage, and yields some polarization dependent loss (PDL) of the PM fiber.
Polarizing Fiber for applications at 780 nm

**Specifications**

<table>
<thead>
<tr>
<th>Typical Polarization Performance</th>
<th>Other Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Wavelength (nm)</td>
<td>Design</td>
</tr>
<tr>
<td>780</td>
<td>Tiger</td>
</tr>
<tr>
<td>Polarizing Bandwidth (nm)</td>
<td>MFD (μm) @1064 nm</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>5.5 ±1</td>
</tr>
<tr>
<td>Extinction Ratio (dB) @1064 nm</td>
<td>Cladding Diameter (μm)</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>125 ±1</td>
</tr>
<tr>
<td>Attenuation (dB/m) @1064 nm</td>
<td>Minimum Bend Diameter (cm)</td>
</tr>
<tr>
<td>&lt; 0.02</td>
<td>&gt; 2</td>
</tr>
</tbody>
</table>

The deployment of the PZG fiber is key to its performance. **Usage example:** Single-Frequency Laser Transmission

**Configuration example:**
- Deport lengths: 3 m one side, 1 m other side
- Protective jacket: Ø3 mm cable with Kevlar strain-relief
- Connectors FC/APC at both ends

> According to your needs and your constraints, we have a Polarizing Solution!

Available on request: Connectorization FC/APC & SC/APC (PER>30 dB); LSZH Up-jacketing 2.5 mm; Coil Packaging

**Other Polarizing Wavelengths Available**

- Cs (770 & 767 nm)
- K (555 & 852 nm)
- Li (1064 nm)
- 795 nm
- 830 nm
- 1310 nm
- 1550 nm
FBGs
UV Bragg grating technologies

1. Interferometric method
   - Short gratings (max 10mm)
   - Bragg wavelength $\lambda_B$, flexibility (300nm – 2100nm)
   - Customizable grating shapes (phase & amplitude)

2. Photolithography method
   - $\lambda_B$ fixed by the pitch of the phase mask ($$$)
   - Low coherent sources can be used
   - Customizable grating shape (phase & amplitude)
   - Repeatability
Polarizing Fiber & FBGs

Narrow linewidth filter @ 795nm

<table>
<thead>
<tr>
<th>Optical parameters (in transmission configuration)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>iXblue part number</td>
<td>IXC-FBG-PS-795-OPP-31100</td>
</tr>
<tr>
<td>Center Wavelength of bandpass</td>
<td>795 +/- 0.5 nm</td>
</tr>
<tr>
<td>CW referenced to</td>
<td>vacuum, slow axis</td>
</tr>
<tr>
<td>Rejection bandwidths $\Delta \nu$, $\Delta \nu_0$ (transmission)</td>
<td>$&gt; 6$ GHz</td>
</tr>
<tr>
<td>Bandpass linewidth $BP_{3\text{dB}}$ (^1)</td>
<td>$&lt; 1$ GHz</td>
</tr>
<tr>
<td>Rejection loss (transmission)</td>
<td>$&gt; 15$ dB</td>
</tr>
<tr>
<td>Bandpass Insertion loss $IL$ (^1)</td>
<td>$&lt; 1$ dB</td>
</tr>
</tbody>
</table>

Other specifications

| Fiber type                                      | PM780-HP |
| Grating type                                    | \(\pi\)-shift grating |
| FBG recoat                                      | acrylate, diameter 280\(\mu\)m |
| Pigtail length A/B                             | 1 meter, each side of FBG |

Typical spectrum (in transmission configuration)

\(^1\) by design
Polarizing Fiber & FBGs
DFB Fiber Laser at 1908nm -> 954nm

ixblue solutions (IXC-CLFO-LN-2) – Typical characteristics

- Bragg grating inscribed in customized ixblue Thulium active fiber
- Ultra-short cavity length (20 to 40 mm)
- Narrow-linewidth < 10 kHz
- Single longitudinal mode fiber laser and single frequency operation
- Mode-hop-free

Other products (IXC-CLFO-LN-1.5) for C-band applications

Conclusion
Key iXblue solutions for the quantum world

- Relevant understanding of the lasers related to the quantum physics markets
- Identified and dedicated LiNbO$_3$ modulators for each laser
- iXatom lab
- The best performances available for the Near Infra Red window
- Original and innovative solutions (MXIQER, PZ, ModBox)
- Ultimate modulation performances based on the ModBox solution
Key Electro-optic modulation solutions for the quantum world

The need for EOMs in functional sub-system: expected optical performance

Wavelength selected modulator

- High Static Extinction Ratio (HSER)
- High Polarization Extinction Ratio (HPER)
- Low insertion Loss (LIL)
- Optical Power handling Capability (HOP)
- Low Residual Amplitude Modulation (LRAM)
- Optical performance Stability vs optical power (IL, PER, ER)

LiNbO$_3$ Modulators

760 nm | 850 nm | 960 nm | 1150 nm | 1270 nm | 1330 nm | 1625 nm | 2050 nm

NIR-MPX800 | NIR-MPX950 | NIR-MPX | MX1300 | MX, MXER, MXAN | MX200 | MPX2000

NIR-MX800 | NIR-MX950 | NIR-MX | MPX1300 | MPZ, MPX | MPX1300 | MPX1300 | MPX1300

850 nm | 960 nm | 1150 nm | 1270 nm | 1330 nm | 1625 nm | 2050 nm

960 nm | 1150 nm | 1270 nm | 1330 nm | 1625 nm | 2050 nm

NIR-MPX | NIR-MX | MX1300 | MX, MXER, MXAN | MX200 | MPX2000

850 nm | 960 nm | 1150 nm | 1270 nm | 1330 nm | 1625 nm | 2050 nm

NIR-MPX | NIR-MX | MX1300 | MX, MXER, MXAN | MX200 | MPX2000

960 nm | 1150 nm | 1270 nm | 1330 nm | 1625 nm | 2050 nm

NIR-MPX | NIR-MX | MX1300 | MX, MXER, MXAN | MX200 | MPX2000

1150 nm | 1270 nm | 1330 nm | 1625 nm | 2050 nm

NIR-MPX | NIR-MX | MX1300 | MX, MXER, MXAN | MX200 | MPX2000

1270 nm | 1330 nm | 1625 nm | 2050 nm

NIR-MPX | NIR-MX | MX1300 | MX, MXER, MXAN | MX200 | MPX2000

1330 nm | 1625 nm | 2050 nm

NIR-MPX | NIR-MX | MX1300 | MX, MXER, MXAN | MX200 | MPX2000

1625 nm | 2050 nm
Key Electro-optic modulation solutions for the quantum world

The need for EOM in functional sub-systems: expected electrical and electro-optical performance

- High Polarization Extinction Ratio (HPER)
- EO-stability: low drift over time
- Matching RF amplifier
- Matching Modulator Bias Controllers
- Dedicated modulator EO-Bandwidth for Low $V_\pi$ (LVPI)
- Wide EO-bandwidth for fast rise and fall times (WEO)
- Space graded packaging
Key Electro-optic modulation solutions for the quantum world
The ModBox systems are Optical Transmitter solutions based on external LiNbO$_3$ modulation means

30 ps to several 100 ns optical pulse widths
Square Pulses, Arbitrary waveforms
780 nm SSB #1 & SSB #2
Turn key and agile optical transmitter

1560 nm CS-DSB, CS-SSB, RC-SSB, FC-SSB

Strong background and High competences quantum physics field

Selected LiNbO$_3$ modulator for ultimate performance