iXblue Photonics

iXblue Polarization SCrambler
PSC-LN
Introduction

The Lithium Niobate Integrated Optical Polarization Scrambler (PSC-LN) modulator is based on:

- A modified phase modulator on X-cut (low speed) or Z-cut (high speed) LiNbO$_3$.
- An optical waveguide made by titanium in-diffusion and supporting both TE- and TM-polarization states.
- An optical waveguide with a low Polarization Dependent Loss (PDL).
- An input polarization maintaining (PM) fiber whose slow axis is set at 45° from the TE and TM axis of the LiNbO$_3$ crystal.
- An output standard single mode fiber.
- Lumped electrodes for low frequency applications (up to 200 MHz).
- Travelling wave electrodes for high frequency applications (up to 30 GHz).
Principle

- The PSC-LN are based on a birefringent LiNbO$_3$ phase modulator whose waveguide is illuminated at 45° of its main axis. The input state of polarization (SOP) is thus equally split up in two orthogonal TE and TM polarization states.

- Due to the birefringence properties of the LiNbO3 crystal (extraordinary and ordinary main axes) and the configuration of the modulator, the TE-polarized wave propagates at a different speed compared to the TM-polarized wave.

- When a voltage is applied via the control electrodes, an additional optical path difference between the TE and TM components is produced by the electro-optical effect, resulting in a new adjustable SOP for the output light (linear, circular or elliptic).
**Principle:**

- **Phase shift on the extraordinary fast axis:**
  \[
  \phi_e = \frac{2\pi}{\lambda} \left[ n_e L + \frac{1}{2} n_e^3 r_{33} \eta \frac{V_0}{g} \right]
  \]

- **Phase shift on the ordinary slow axis:**
  \[
  \phi_o = \frac{2\pi}{\lambda} \left[ n_o L + \frac{1}{2} n_o^3 r_{13} \eta \frac{V_0}{g} \right]
  \]

- **Differential phase shift:**
  \[
  \Delta\phi = \frac{2\pi}{\lambda} \left[ (n_e - n_o) L + \frac{1}{2} (n_e^3 r_{33} - n_o^3 r_{13}) \eta \frac{V_0}{g} \right]
  \]

- **Half-wave voltage** $V_\pi$ : voltage applied for a $\pi$ radians phase shift between the fast and slow axes.
  \[
  V_\pi = \frac{\lambda g}{(n_e^3 r_{33} - n_o^3 r_{13}) \eta}
  \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Glossary</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_e$</td>
<td>Extraordinary refractive index</td>
</tr>
<tr>
<td>$n_o$</td>
<td>Ordinary refractive index</td>
</tr>
<tr>
<td>$r_{13}$, $r_{33}$</td>
<td>LiNbO$_3$ Electro-optic coefficients</td>
</tr>
<tr>
<td>$L$</td>
<td>Crystal length</td>
</tr>
<tr>
<td>$l$</td>
<td>Electrode length</td>
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<td>$g$</td>
<td>Electrodes gap</td>
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<tr>
<td>$\lambda$</td>
<td>Optical Wavelength</td>
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<tr>
<td>$V_0$</td>
<td>Applied Voltage</td>
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<tr>
<td>$\eta$</td>
<td>Electro-optic overlap</td>
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Polarization on the Poincaré Sphere vs applied voltage

- When a variable voltage is applied on the electrodes, the output SOP follow a circle (red curve) whose trajectory crosses the states of right and left circular polarization and the two states of linear polarizations at +/- 45°.

- Exemple of an experimental Poincaré sphere trace of the output SOP for a continuous voltage of 10 Vpp applied to the modulator.
  PL denotes the linear polarisation states.
Degree Of Polarization (DOP)

- On Lithium niobate modulators, the polarization scrambling method is based on applying a periodically voltage at a speed equal or higher than the bit rate.
- The degree of polarization (DOP) describes the portion of polarized light during the detection time frame.
- For the specific case of a periodically sinusoidal voltage applied on the electrodes:
  \[ V(t) = V_0 \sin(\Omega t) \]
  \[ \text{DOP} = |J_0(\gamma)| \]
  with  \[ \gamma = \pi \frac{V_0 M(\Omega)}{V_\pi} \]
  \[ M(\Omega) \], the electro-optic response of the modulator
- The DOP tends to zero at specific modulation indexes.
- For the first root:  \[ V_0 = 0.7655 \, V_\pi M(\Omega) \]
Configuration: Low frequency Polarisation Scrambler PSC-LN-0.1

- X-cut: better stability against environmental perturbations (temperature variations).
- Lumped electrodes: well adapted to the low frequency range (kHz, MHz).

Simulated degree of polarization vs applied voltage

![Diagram of X-cut LiNbO3 with labeled parts: Lumped electrodes, X(n_e), Z(n_e)]
Configuration: High frequency Polarisation Scrambler

PSC-LN-10

- Z-cut: high efficiency (low driving voltage).
- Travelling wave electrodes: very wide bandwidth (up to 30 GHz).
- Low electrical reflections ($S_{11}$) thanks to travelling wave electrodes matched close to 50 $\Omega$.

Simulated degree of polarization vs electrical power
LiNbO$_3$ Integrated Optical Polarization Scrambler PSC-LN modulator features:

- Adjustable scrambling speed over a very wide range of frequencies.
- Compactness.
- Low electrical power consumption.
- Wide operating wavelength range.