iXblue Polarization SCrambler
PSC-LN

Introduction

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

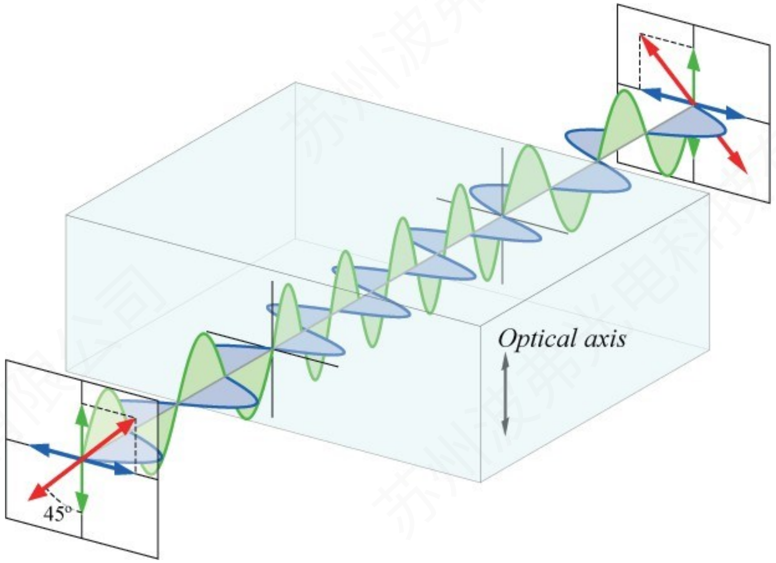
- A modified phase modulator on X-cut (low speed) or Z-cut (high speed) $LiNbO_3$.
- An optical waveguide made by titanium in-diffusion and supporting both TE- and TM-polarization states.
- An optical waveguide with a low Polarization Dependent Loss (PDL).
- An input polarization maintaining (PM) fiber 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 cristal (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 additionnal optical path difference between the TE and TM components is produced by the electro-optical effect, resulting in a new ajustable SOP for the output light (linear, circular or elliptic).



Principle:

- Phase shift on the extraordinary fast axis:

$$\phi_e = \frac{2\pi}{\lambda}\left[n_e L + \frac{1}{2} n_e^3 r_{33} l\eta \frac{V_0}{g}\right]$$

- Phase shift on the ordinary slow axis:

$$\phi_o = \frac{2\pi}{\lambda}\left[n_o L + \frac{1}{2} n_o^3 r_{13} l\eta \frac{V_0}{g}\right]$$

- Differential phase shift:

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

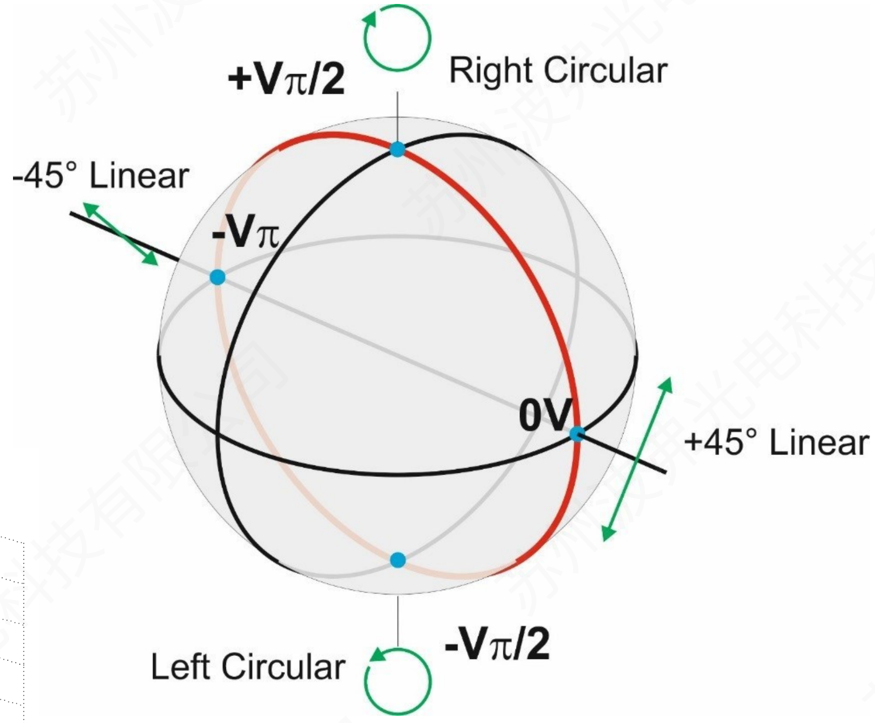
Symbol	Glossary
n_e	Extraordinary refractive index
n_o	Ordinary refractive index
r_{13}, r_{33}	$LiNbO_3$ Electro-optic coefficients
L	Crystal length
l	Electrode length
g	Electrodes gap
λ	Optical Wavelength
V_0	Applied Voltage
η	Electro-optic overlap

- Half-wave voltage V_π : voltage applied for a π radians phase shift between the fast and slow axes.

$$V_\pi = \frac{\lambda g}{(n_e^3 r_{33} - n_o^3 r_{13}) l\eta}$$

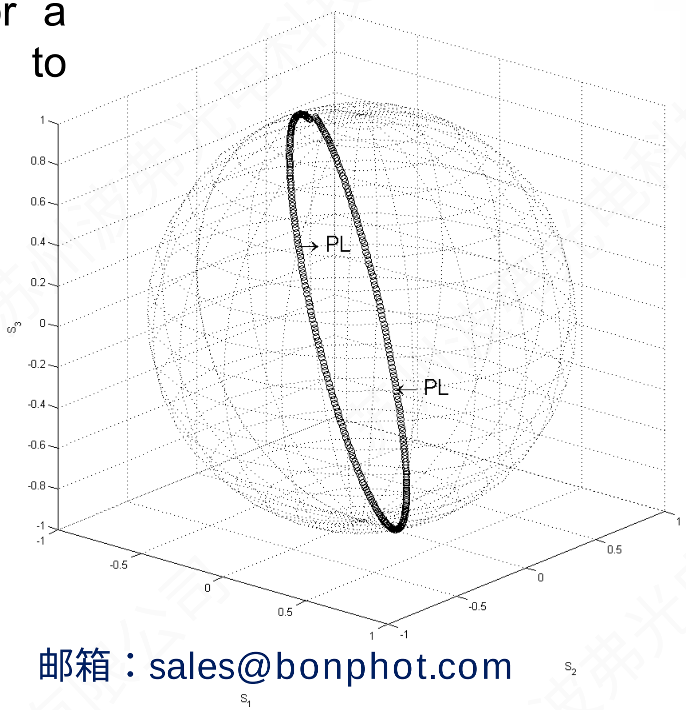
Polarization on the Poincaré Sphere vs applied voltage

- 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 V_{pp} applied to the modulator.

  PL denotes the linear polarisation states.



Degree Of Polarization (DOP)

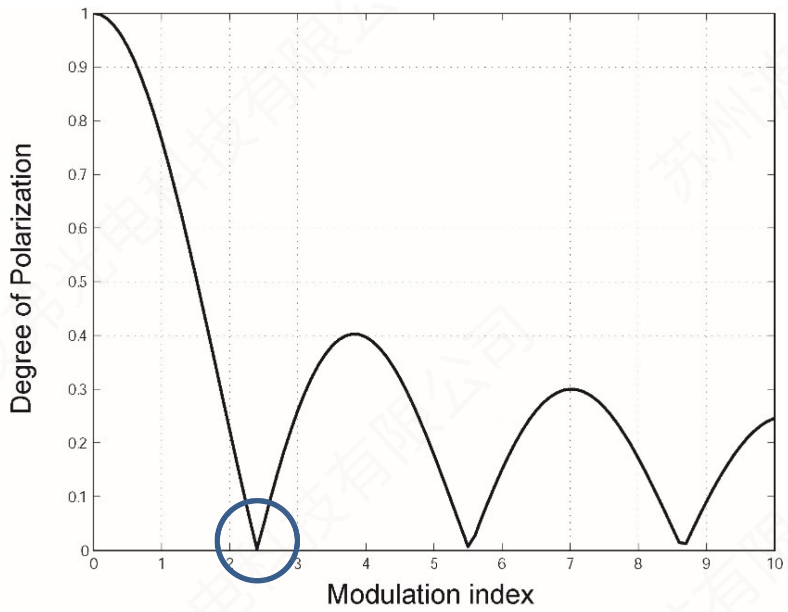
- On Lithium niobate modulators, the polarization scrambling method is based on applying a periodically voltage at a speed equal or higher than the bit rate.
- The degree of polarization (DOP) describes the portion of polarized light during the detection time frame.
- For the specific case of a periodically sinusoidal voltage applied on the electrodes:

$V(t) = V_0 sin(\Omega t)$

DOP= $|J_0(\gamma)|$

with $\gamma = \pi \frac{V_0 M(\Omega)}{V_\pi}$, the modulation index.

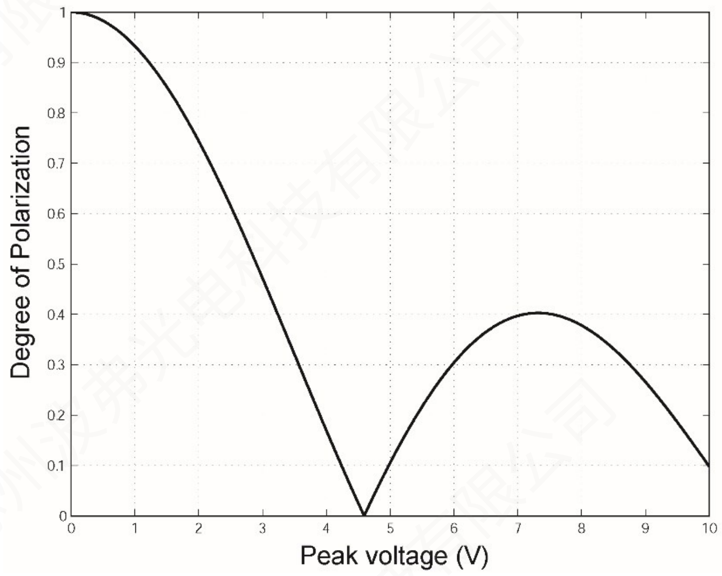
$M(\Omega)$, the electro-optic response of the modulator



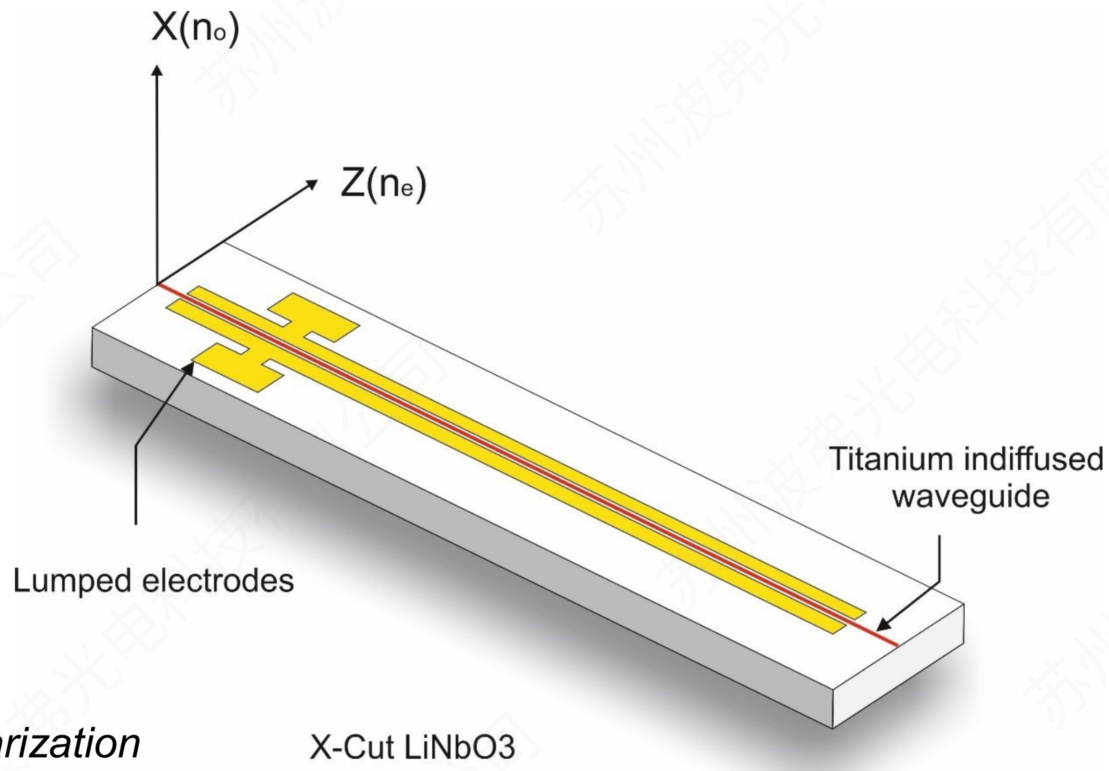
- The DOP tends to zero at specific modulation indexes.
- For the first root: V_0 =0,7655 $V_\pi M(\Omega)$

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).

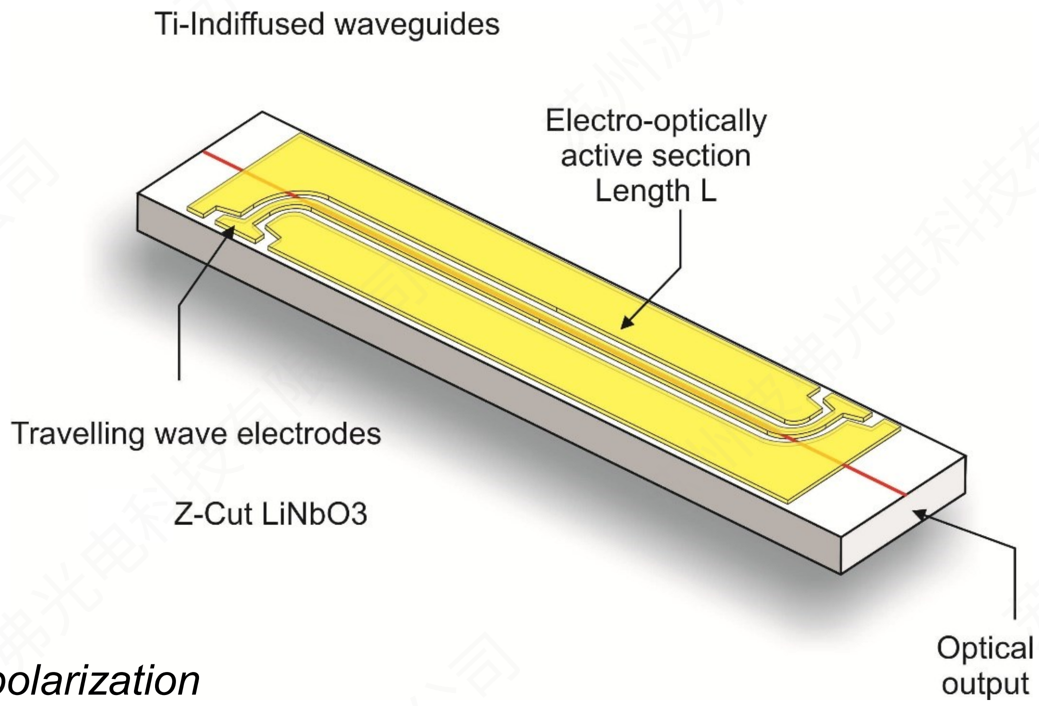


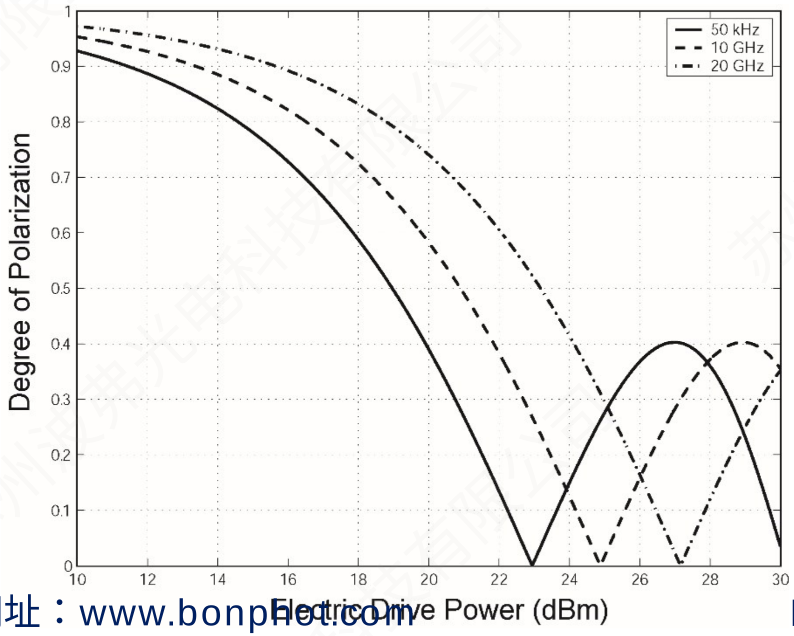
Simulated degree of polarization vs applied voltage



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 Ω.





Simulated degree of polarization vs electrical power

Conclusion

$LiNbO_3$ Integrated Optical Polarization Scrambler PSC-LN modulator features:

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