Introducing Exail Polarization Scramblers

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Principle

Exail Polarization Scramblers are based on a birefringent $LiNbO_3$ phase modulator. The principle of the polarization switch is to illuminate the waveguide at 45 ° of its main axis in order to obtain another polarization depending on the applied voltage.

Due to the birefringence properties of the $LiNbO_3$ 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).

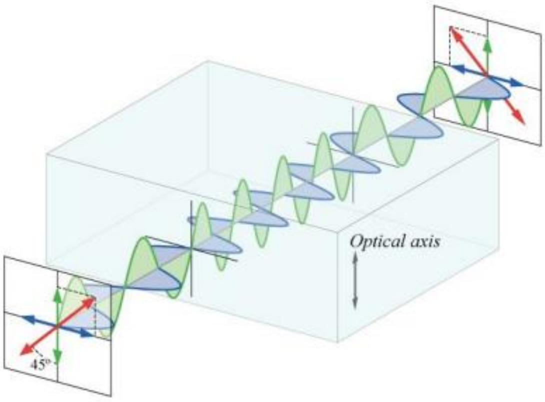


Figure 1 : Polarization change principles

Mathematically it can be expressed as follow:

- Phase shift on 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 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:

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

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

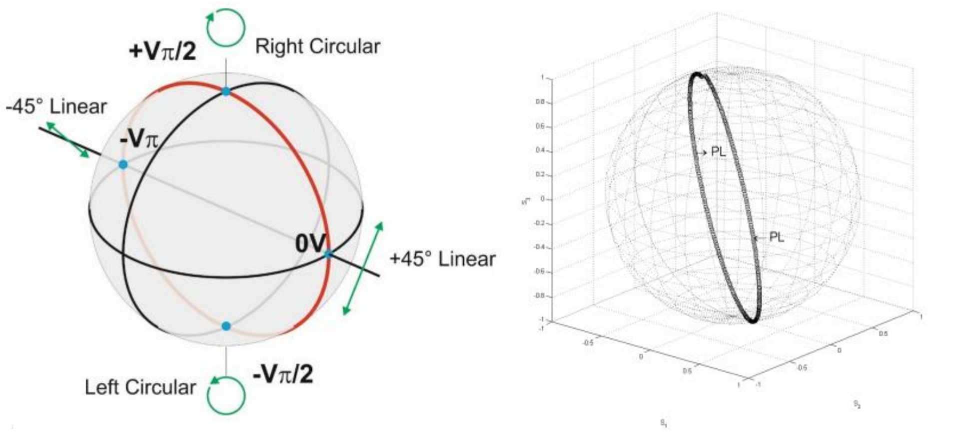
$$V_\pi = \frac{\lambda g}{(n_e^3 r_{33} - n_o^3 r_{13}) l\eta}$$

Where:

- 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

Polarization on the Poincare 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°. Example of an experimental Poincare sphere trace of the output SOP for a continuous voltage of 10 V_{pp} applied to the modulator.



Note : PL denotes the linear polarization states.

Figure 2 : Poincare Sphere Vs Applied Voltage

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

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

We can see on the graph below that the DOP tends to zero at specific modulation indexes. The first root is $V_0 = 0{,}7655\ V_\pi M(\Omega)$.

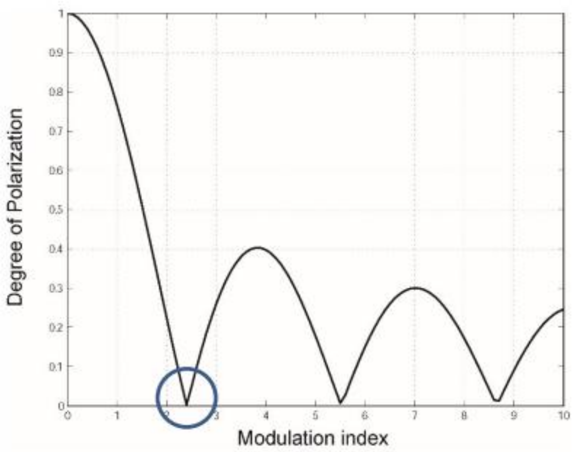


Figure 3 : DOP Vs Modulation index

Exail Polarization Scrambler

The PSC-LN serie is based on a modified phase modulator on X-cut (low speed) or Z-cut (high speed) $LiNbO_3$. An optical waveguide is made by titanium in-diffusion and supporting both TE- and TM-polarization states offers a low Polarization Dependent Loss (PDL). We use an input polarization maintaining (PM) fiber whose slow axis is set at 45° from the TE and TM axis of the $LiNbO_3$ crystal and an output standard single mode fiber.

PSC-LN-0.1

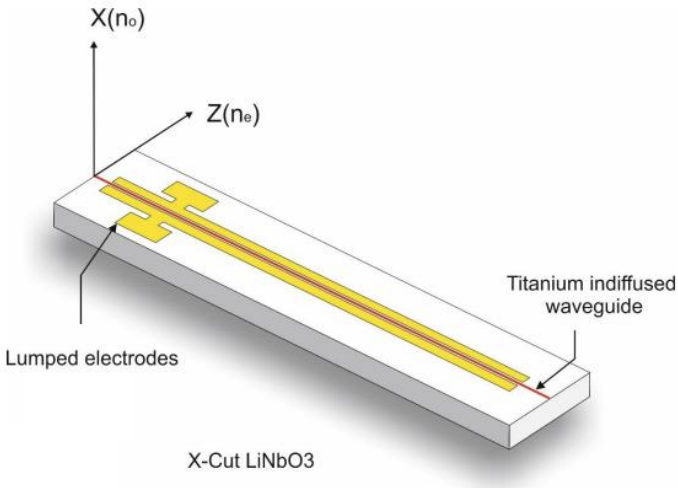


Figure 4 : PSC-LN-0.1

We use a X-cut $LiNbO_3$ modulator to achieve a better stability against environmental perturbations, especially the temperature variations. The use of lumped electrodes is well adapted to the low frequency range (up to 200 MHz).

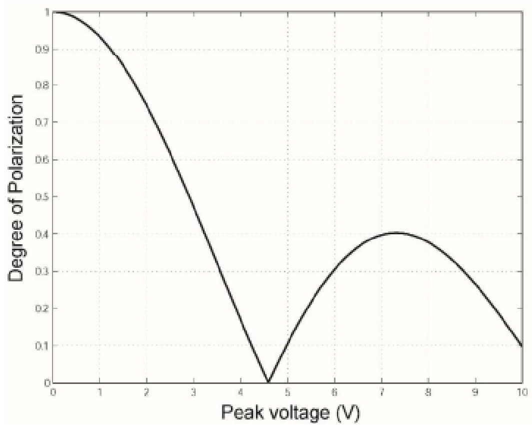


Figure 5: Simulated degree of polarization vs applied voltage

PSC-LN-10

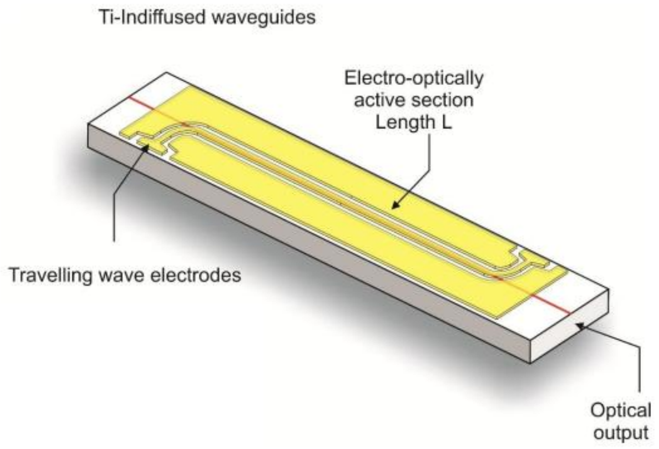


Figure 6: PSC-LN-10

We use a Z-cut $LiNbO_3$ to have a high efficiency thanks to the low driving voltage. The use of travelling wave electrodes allows the user to have a very wide bandwidth (up to 30 GHz) and achieves low electrical reflections (S_{11}) thanks to travelling wave electrodes matched close to 50 Ω.

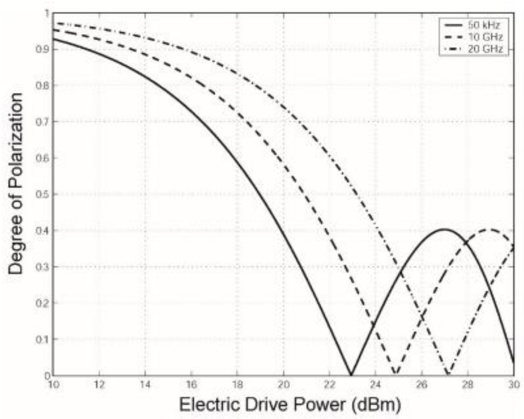


Figure 7: Simulated degree of polarization vs electrical power

Conclusion

$LiNbO_3$ Integrated Optical Polarization Scrambler (PSC-LN) features:

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

For more information, please see the datasheet.

Figure 8: Exail PSC-LN-10