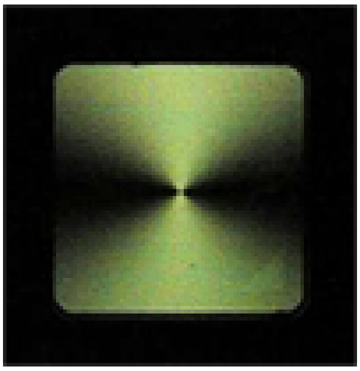
ARCoptix

Radial Polarization Converter



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ARCoptix Polarization Converter

Radially and azimuthally polarized beams generated by Liquid Crystal elements

Arcoptix worldwide unique polarization converter is capable to convert a linear polarized light beam into a beam with a (axially symmetric) perfectly radial or azimuthal polarization distribution. The generation of the axially symmetric beams is described. Our system has the advantage to useable for wavelength from 400 nm up to 1700 nm. If the input polarization is linear, the system presents losses of about 20%-30% (due to reflections and small absorption of the liquid crystal material). It is also compact and can be easily inserted in an optical set-up.

Principle of the radial polarization converter

The most important element is the radial polarization converter described in Stalder et.al. Opt. Lett. 21 (**1996**) 1948. The entrance and the exit plates of the cell are linearly and circularly rubbed, respectively. The direction of the linear rubbing on the entrance plate determines the **cell axis**. Each LC molecule chain is characterized by a twist angle (i.e. the angle between the orientation of the molecules at the entrance and at the exit plates) that is a function of the angular position with respect to the cell axis. When the polarization-guiding conditions are met, a linearly polarized beam incident on the entrance plate, propagating parallel to the polarization converter normal and with electric field vector parallel or perpendicular to the cell axis experiences a rotation of its polarization direction by the twist angle. This phenomenon occurs for a broad range of wavelengths (twisted nematic cell optics in the waveguide limit). Having a closer look to the cell texture in their stable configuration, as drawn in Fig.1, one realizes that there are two parts with different sense of rotation.

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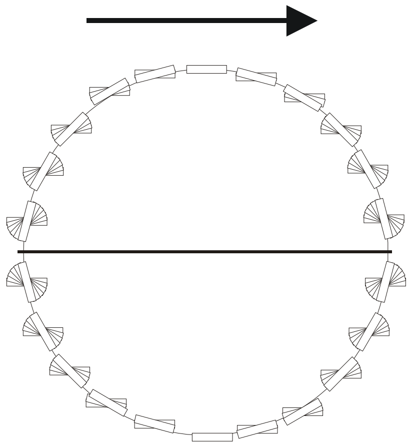
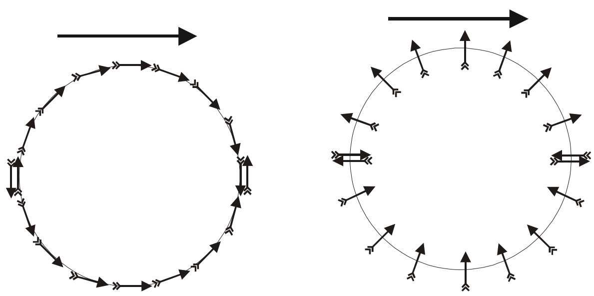


Figure 1. Liquid crystal alignment in the polarization converter for a stable configuration. The line in the center represents a defect line present because of different twist sense of the upper and lower part. The arrow represents the entrance polarization.

While on the top half the rotation is clockwise, the lower part is characterized by counterclockwise rotation. In this case, a defect line running along the diameter parallel to the cell axis arises. A thin defect line is caused by different rotation sense in the two parts of the cell and is for a non-chiral liquid crystal mixture along the rubbing direction (cell axis). The defect line is drawn as black horizontal line in the Fig. 1.

Next the polarization rotation properties are discussed. Linear polarized light is entered from the side with linear rubbing. Two different polarization states are created when linear polarized light enters parallel or perpendicular to the cell axis. Figure 2 visualizes the polarization states. The small arrows are used to indicate the polarization state of light.



A B

Figure 2. Azimuthally and radially polarizations. The double arrows indicate the phase of the beams that has a mismatch at the disclination line. The big arrow represents the entrance polarization.

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Azimuthally polarized light is achieved for light incident parallel to the cell axis (rubbing direction). Radially polarized light is achieved for light incident perpendicular to the cell axis.

In the following, the definitions of azimuthally and radially polarized beams will be used to indicate the two configurations displayed in Fig. 2 (A) and (B), respectively.

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System Options

Option 1

including an additional twisted nematic (TN) cell two switch between radially and azimuthally polarization distributions

If one wants to work with incoherent light for example and the system is insensitive to any phase shift, it may be preferable to use only the theta-cell or eventually the theta cell combined with a switchable twisted nematic cell (without any phase shifter in front of the theta cell as it is the case in option 2).
This additional TN cell (driven with a simple square wave electrically signal with polarity change that can be switched between 0 and 5 V) permits to switch rapidly between radially and azimuthally polarization distributions.
This TN cell can be considered as an achromatic half-wave plate, it rotates every wavelength almost equally by 90°.
Note that one can switch between radial and azimuthal polarization distribution by simply rotating manually the polarization converter or the polarization of the incoming light.
Pay attention that the TN cell is absolutely necessary for switching between the two modes if using option 2 (see below).

Option 2

including an additional liquid crystal phase retarder to compensate inhomogeneous phase distribution over the beam

Although the electric field vector lies along the azimuthal or radial directions, the polarization converter produces a π phase step in the center of the beam. This is due to the opposite rotation of the LC molecules on both sides of the defect line of the theta cell.
For some applications a homogenous phase distribution is needed, the polarization converter alone cannot be used. Thanks to an integrated variable phase retarder this phase step can be compensated. The variable phase retarder is a transparent cell providing a tunable phase delay between the two halves of the beam passing through it. It is integrated in the housing in the front of the polarization rotator cell as seen in Fig. 6. The active area covers half the useful aperture as illustrated in Fig 3. With a thickness of 6µm and filled with the liquid crystal with a birefringence of $\Delta n=0.286$ the cell gives a maximum retardation of 1772 nm at room temperature. If voltage is applied, the retardation can be reduced continuously. (see Annex).
Pay attention that the TN cell is here absolutely necessary if the user wants to switch between radial and azimuthal polarization distribution!!

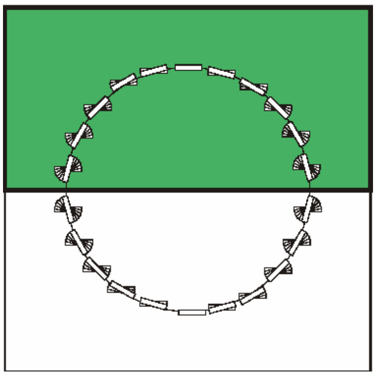

Figure 3. If the upper half is covered with a retarder element of π (green area), the phase can be adapted to achieve the correct relative phase distributions for any wavelength.

General description of the system

The complete system (if ordered with all the options) is shown in figure 3. It consist of the polarization converter (theta-cell) itself, a phase shifter that permits to compensate the $\lambda/2$ phase step between the upper and the lower half of the theta cell and a twisted nematic cell capable to rotate the entrance polarization by 90° and permits to switch between the azimuthal and radial polarization distribution.
One half of the phase shifter (delimited by the black line in figure 3) is provided with an electrode that permits to change the inclination angle of the LC molecules, which changes its extraordinary refraction index. By applying a bias on between the electrodes the retardance is reduced compared to the second half where the retardance stays constant at 1580nm.

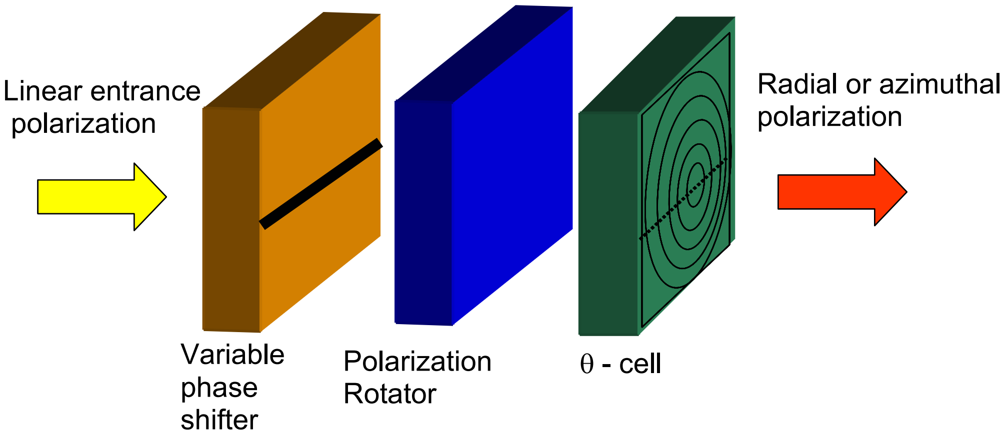

Figure 3. Liquid crystal cell configuration in the converter element. Linear polarized light enters from the left first the phase shifter cell, might be rotated by the polarization rotator and exits either radially or azimuthally polarized from the polarization converter.

The complete system (polarization converter + TN cell+ variable phase retarder) is integrated into aluminum housing as shown in figure 4. The polarization converter can be rotated and translated with respect to the TN cell and the phase shifter with the rotation lever and the x-y adjustment screws. Two wires must be connected to a conventional labor AC power supply (or the Arcoptix LC driver) for stetting the adequate phase retardation depending of the used wavelength and to the two other wires must be connected to a second power supply capable to switch between 0 and (at least) 4V (see electrical connection section) AC square signal with a frequency of at least 50 Hz.

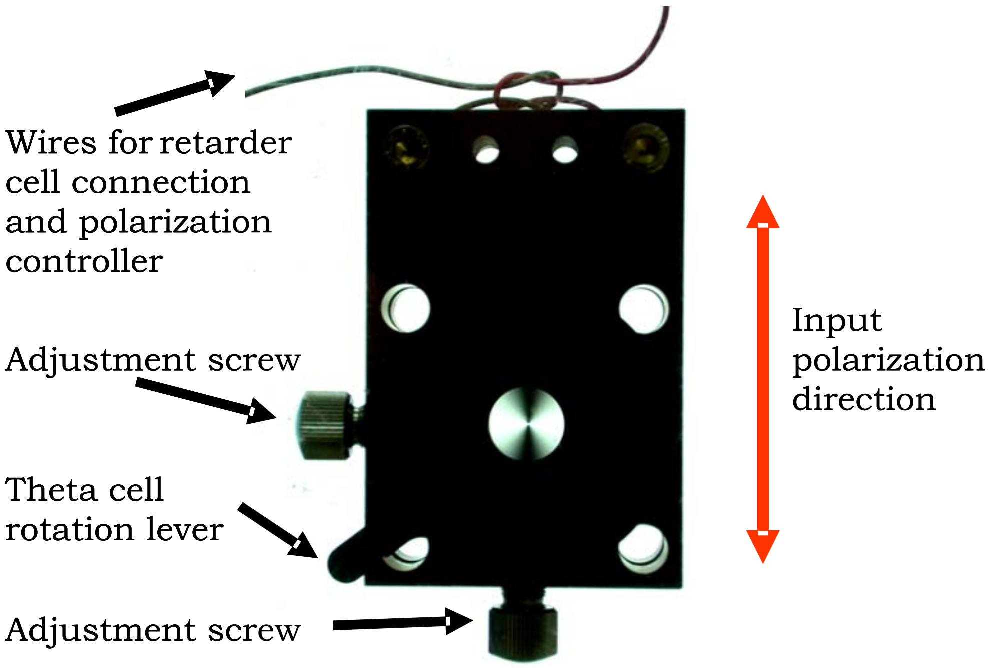

Figure 4: The liquid crystal polarization converter in its final housing. The clear aperture is 10 mm. the upper half of the aperture is covered with the phase shifter (retarder) and the phase shift can be applied.

Notice that in figure 4 the polarization converter (between polarizers) is illuminated with white diffuse light. If the system is illuminated with a collimated coherent laser beam the defect line (pi phase step) of the theta cell produces a diffraction pattern (low intensity line in the

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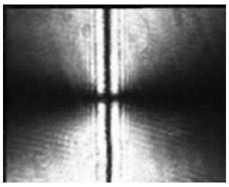
center) that disturb the intensity profile at the output of the system (see figures in the alignment section). As shown in figure 5, this line disappears when an additional phase shifter is inserted in the system to compensate the π phase shift of the theta cell (option 2). A further spatial filter after the polarization converter may be used to clean up some residual inhomogenities in the intensity profile.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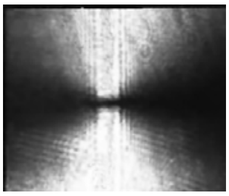
B

Figure 5:Intensity distribution at the output of the polarization converter system when placed between two polarizers oriented at 0°-90°. A: Without compensation we see a diffraction pattern B: When the π phase shift induced by the θ-cell is compensated by the variable phase shifter the diffraction pattern almost disappear.

It is also important to mentioned that right is the center of the theta in a zone of about 100 μm the alignment of the LC molecules is not completely

Electrical driving:

If included in your system (depending of the options) the twisted nematic cell (responsible to rotate the entrance polarization by 0° or 90°) and the phase shifter (responsible to correct the phase step between both sides of the radial polarization converter) needs to by connected to an alternative (AC) power supply producing a square wave signal with change of polarity (oscillating between positive and negative bias). The frequency of the applied bias is not crucial, ideally it should be somewhere around 0.1-1 kHz. The amplitude should be as stable as possible. A standard laboratory function generator may be perfectly adapted as power supply.

- <u>Supplying the TN cell</u>: When a bias of 5 V rms is applied the cell is switched on and the entrance polarization is not rotated. In this case at the output of the system presents a radial polarization distribution.

When the TN cell is switched OFF, one obtains an azimuthal distribution.

- Supplying the phase shifter: When a bias is applied a phase shift between the upper and lower part is produced. The dependency of the phase shift versus the bias (rms) is given in the graphic in the annex.

	Bias (rms)	Frequency	Function
TN cell	0V off Min.5V ON	~ 1kHz	Switch between radial and azimuthal polarization
Phase shifter	0-10V	~ 1kHz	Homogenize the phase

Housing

The Housing is made of anodized aluminum. It has an M4 thread on every side and it is compatible with spidler&hoyer components. The overall size is 6x4x1.5 cm.

Summary of the characteristics

wavelength range	400-1700 nm
active area	10 mm diameter
transmission	better than 70% (in the VIS)
retarder material	Nematic Liquid-Crystal
Substrates material	Glass
temperature range	10°-50°
Total size of the housing	6 cm x 4 cm x 1.5 cm

Custom Design

Design and quotes for custom specifications such as switching time, active area, twist angle, total size, and housing can directly be asked by sending us an email at info@arcoptix.com.

payment Terms

Payment terms are 30 days upon shipment arrival. Prepayment may be occasionally required for international orders (but generally not for universities, research institutes and other governmental institutions). Please ask for a quotation. Arcoptix do in principle not accept credit cards (please ask if this may be a problem).

Specifications
Listed specifications are accurate as of the publication date. Product improvements and design changes may alter product specifications without notice.

Warranty
All products in this catalog are warranted against defects in materials and workmanship for a period of one year from the date of shipment. Liability of Arcoptix is limited to the defective product value only. polarization solution.

Shipping
We will use our best judgment regarding shipping
Method (mostly with DHL), unless a specific carrier is requested.
Freight charges are paid by the receiver.

Ordering information
Quotes can be asked by
e-mail: info@arcoptix.com.
By phone: ++41 (0)32 731 04 66 or 64
By Fax: ++41 (0)32 731 04 63.

Final order should be placed by sending us a signed fax containing the ordering details.

Annex: The Retardation ($d(n_e(V)-n_e)$) between the two halves of the retarder cell measured as a function of $V_{amplitude}$ (1 kHz square wave)

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and for a wavelength of 633nm (retardation may have a slight wavelength dependency). The retardation indicates the phase