ARCoptix

Variable Phase Retarder

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ARCoptix Phase Retarder

Optical phase shift generated by Liquid Crystal planar cell

Optical retardation is often obtained with piezo-electric mirrors. However this option is not ideal if robust and compact design is necessary. LC variable phase shifter (VPR) offer an interesting alternative especially when working with polarized light (which is often the case when working with lasers). The Arcoptix VPR is a transmissive element causing minimal losses and can be simply placed within the optical path of our system. The more, the optical retardation (or phase shift) of the LC phase shifter is electrically tuneable with a simple laboratory alternative power supply or function generator. It can also be used as optical valve (for a narrow wavelength range) or as polarization State controller.

The liquid crystal VPR (or phase retarder) can be compared to a tuneable waveplate. By addressing it with the right voltage, the LC VPR is able to provide any phase shift from zero to several times the light wavelength. They can be used throughout the visible and the near infrared region (350nm to 1800 nm) without losses higher than 20%. Thanks to the use of thick substrate and a special liquid crystal bend we are capable to offer robust equipment with minimal wavefront distortion (lower than $\lambda/4$).

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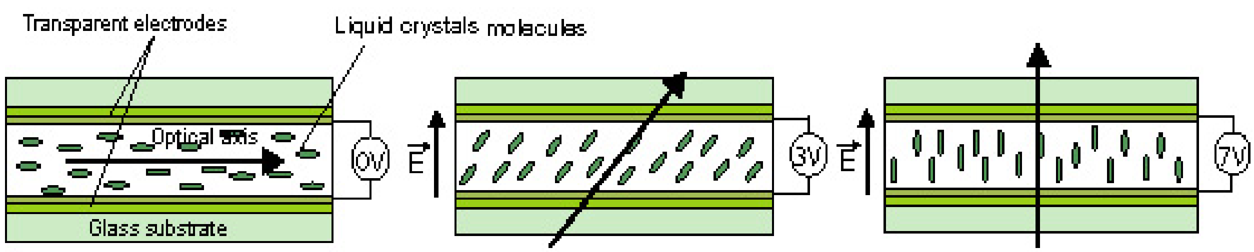
Principle of the liquid crystal phase retarder

The Arcoptix VPR are manufactured with standard liquid crystal technology. As depicted in figure bellow, they are principally made of a liquid crystal layer sandwiched between two flat glass plates coated with a transparent electrode (ITO) and an alignment layer. The two glass plates are precisely spaced apart with a glass fibers at the edges. The cavity formed by these plates is filled with a special blend of liquid crystals optimized for high birefringence, small temperature dependence and high stability. The cell is hermetically sealed with glue. The alignment layer is a gently rubbed polyimide layer necessary for the alignment of the LC molecules. The electric field that can be induced by applying a voltage on the transparent ITO electrodes (0-7V) modifies the alignment of the LC molecules and by the same way the apparent retardance of the cell. Figure (a) shows the alignment of the LC molecules when no voltage is applied. In this case the molecules are aligned along the glass plates and the retardance (along the optical axis) is maximum. Figure (c) shows the other extreme case where a "high" voltage (7V) is applied and the electric field forces the LC molecules to align perpendicularly to the glass plates (parallel to the electric field). Figure (b) shows an intermediate state where we apply a small voltage of about 3V. In this case the molecules have an oblique orientation and the apparent retardation is somewhere in between the maximum retardation (several times the wavelength) and the minimum retardation (almost zero). Notice that a very thin LC layer near the substrate surface will stay with a certain tilt angle which prevent having a perfect zero phase shift without additional compensation plate.



Orientation of the LC molecules (or optical axis) in the phase retarder in function of the applied tension. For 0 V (a), 3 V (b) ,7 V (c).

Retarder type selection

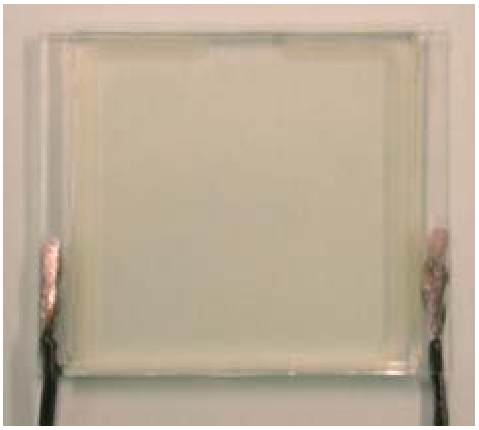
When selecting a phase retarder some key features must be considered such as:

- •Aperture size
- •Position of the phase shifter (in an imaging plane or not?)
- •Size
- •Switching time
- •Wavelength
- •Damage threshold
- •Transmission
- •Phase distortions (eventually compensated by lenses)
- •Beam deviation
- •Maximum phase retardance
- •Retardation stability
- •Optical axis orientation
- •Zero phase shift
- •Precision

In functions of your needs you can select essentially between three categories of products:

Retarder Type	Specificities	Applications	Price
Industrial grade	•Spacer (few microns) over the aperture •Large aperture •Thin substrates •Phase distortions (spherical) • low beam deviation	•Polarization manag. •Polarization vision	**
Scientific grade	•Low phase distortions •No beam deviation •No spacers over the aperture •Aperture 10 mm •Thick substrates •AR Coating	•Interferometry •Metrology •Use in an imaging plane	***
Custom	•Larger apertures. •High switching speeds. •Large quantities/low price. •Zero phase shift	•Custom adapted cells for industrial applications •Specific scientific applications	* / ****

Scientific grade cell with its 1 inch housing



Industrial grade cell without housing

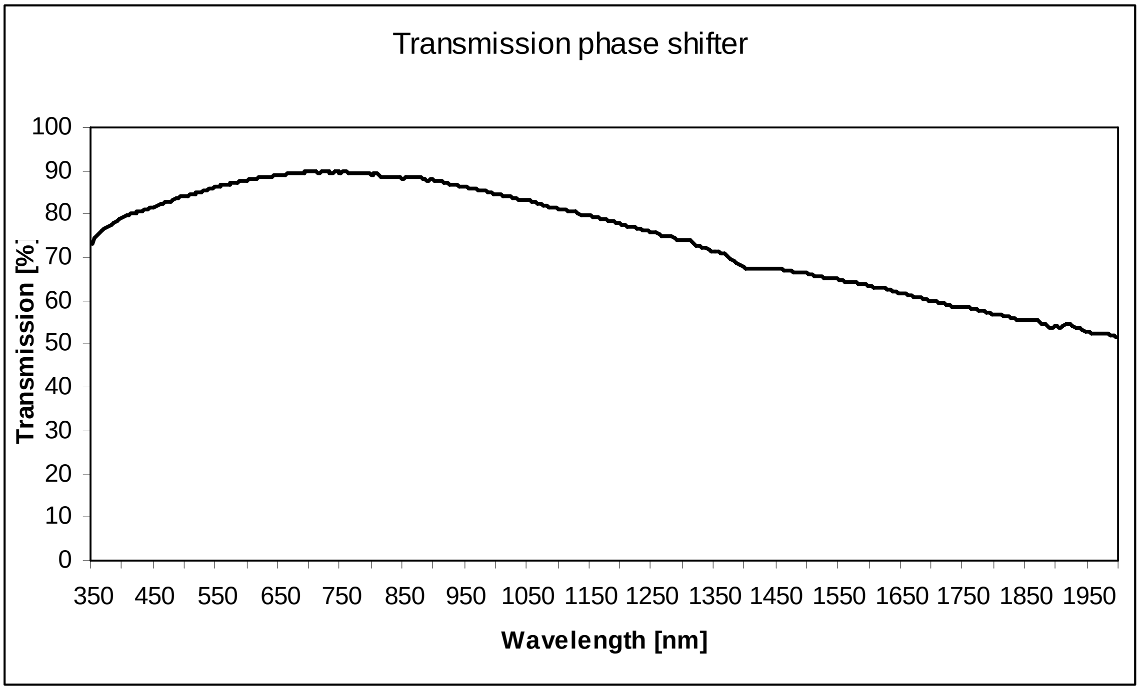
Specifications

The specs (for industrial and scientific grade cells) below are given for a linear input polarization parallel to the optical axis of the liquid crystal layer.

Phase shift range	50-1300 nm (max. 5000nm)
wavelength range	350-1800 nm
Active area	scientific grade: 10 mm 0r 20mm(diam.) Industrial grade: 22 mm (square)
Transmission	About 85% (VIS)
Retarder material	Nematic Liquid-Crystal $\Delta n=0.28$
Substrates	Glass
wavefront distortion	scientific grade: < lamda/4 (over 10 mm) Industrial grade: < 2 lamda (over 23 mm)
temperature range	15°-35°
Retardance temperature dependency	About 0.5%/°C (wavelength dependent)
Phase shift adjustment precision	10nm
Maximum modulation frequency of the phase shift	< 10Hz
Phase shift stability (with arcoptix LC driver and at thermal equilibrium)	Better than 10 nm.
AR Coating (scientific grade only)	Broadband for VIS.
Save operating limit	500 W/cm2 CW 300 mJ/cm2 10 ns, visible 200 mJ/cm2 10 ns, 1064 nm
Total size (with housing)	Scientific grade: 25mm diameter, 16mm long Industrial grade: 31mmx25mmx2.2mm (without housing).

Transmission

Total transmission of the phase shifter (including losses due to reflections) is given by the graph below.



Phase retardance calibration

There is a non-linear relation between the phase retardance and the applied voltage. With each variable phase retarder we provide a calibration curve valid for room temperature which indicated the correspondence between the phase retardance and the applied bias. The graph in the annex shows such a curve.

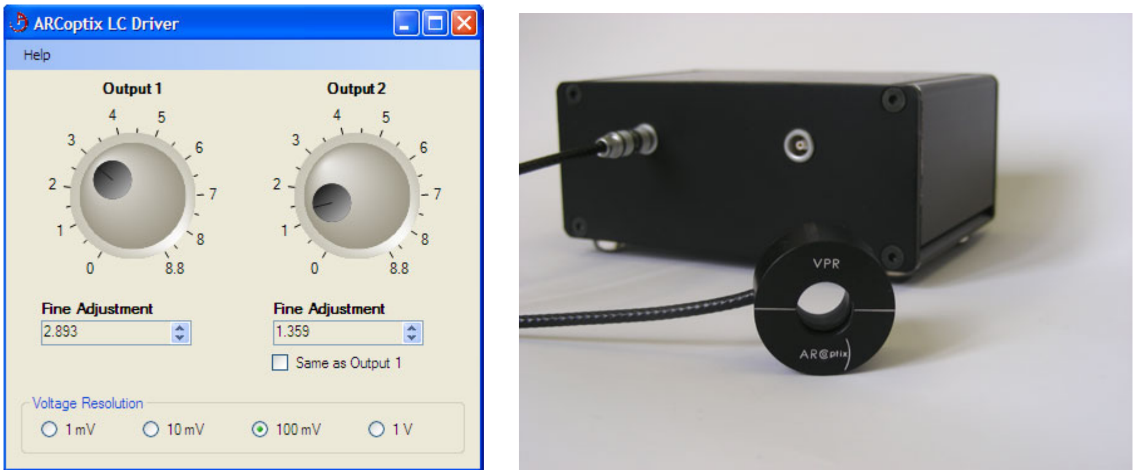
Electrical driving:

The VPR needs to be connected to an alternative (AC) power supply producing a square wave signal with change of polarity (oscillating between positive and negative bias). To drive the VPR there are essentially two options:

1) Use the Arcoptix digital LC Driver that has two independent outputs that are computer controlled via USB and optimized for liquid crystal device driving (see figure 6). It generates a square

signal of 1.6 KHz with variable amplitude between 0V and 9V. The LC driver produces a highly stable signal with a precision of 1mV. An external trigger input can be provided on demand.

2) Use a standard labor generator with square wave signal. The should be somewhere around 0.1-1 kHz and the amplitude should be variable between 0 and 10V (almost no current).



LC Driver with two independent outputs that are computercontrolled via USB.

LC cells are usually driven with AC square-wave voltages of between ±1.0 and ±10 volt whereby the polarity is rapidly switched at speeds of up to 1KHz (the frequency is not very important, typically more than 10Hz) in order to prevent impurity ion migration from occurring. A priory, it may be expected that activation of the LC cell with AC voltage might cause the molecules to rotate. However in practice interactions between the LC molecules themselves hinder this and if the polarity change is rapid enough (which is generally the case for a square wave) the molecules "do not have enough time to react". Polarity reversal (when it is performed quickly) of the driving electronics will therefore have no effect upon the alignment of the molecules and the performance of the device is only dependent upon the root-mean-squared (rms) voltage and not on the polarity of the external field.

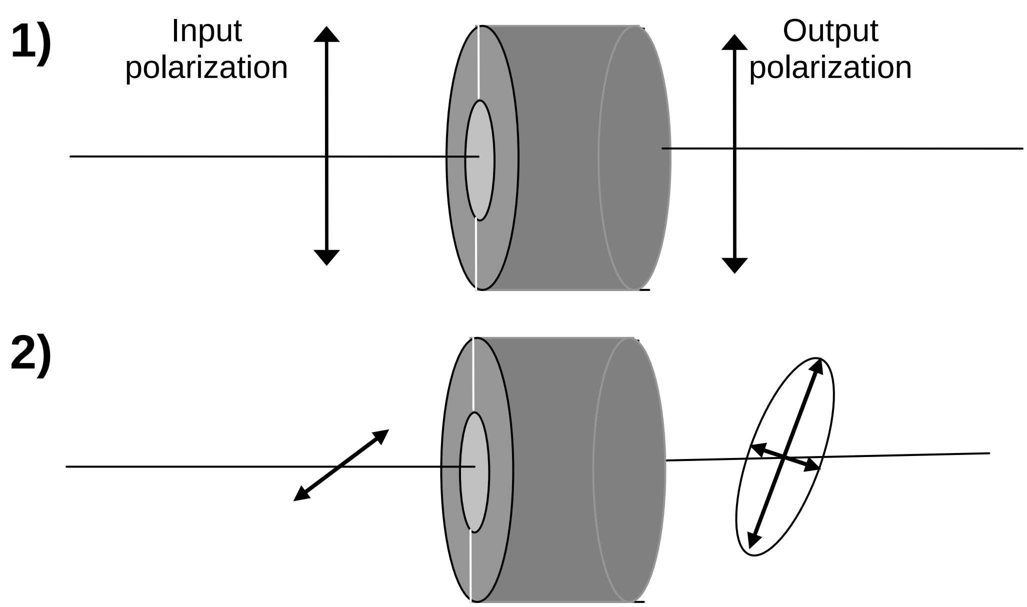
Notice that the phase shift stays constant when applying a square shaped function because of the slow reaction time of the LC molecules. Only slowly varying applied voltages below 50HZ may change the phase shift.

Optical setup

The LC variable phase shifter can only be used when working with polarized light. Totally unpolarized light will not be affected by the phase shifter.
There are mainly two ways to use the phase shifter:

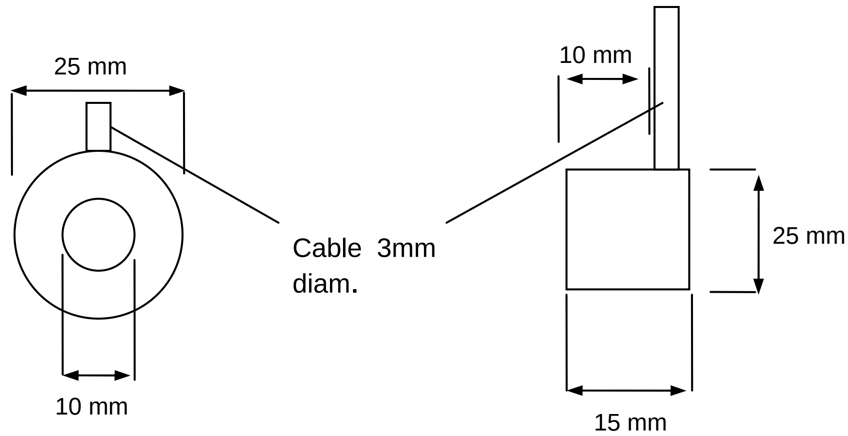
1) The incoming light is polarized parallel with respect to the optical axis of the phase shifter. In this case the beam maintains its polarization and the beam experiences a certain phase retardance inversely proportional to the applied bias on the variable phase shifter.

2) The incoming polarization is oriented by 45° with respect to the optical axis of the phase shifter. In this case the polarization state at the output of the phase shifter will change depending of the applied bias. When placed between two polarizers, this configuration acts as a variable attenuator (see application notes).



Housing:

The Housing (scientific grade) is made of anodized aluminum. It has a diameter of 25mm. The optical axis is indicated by a stripe.



Custom Design

Design and quotes for custom specifications such as switching time, active area, twist angle, total size, 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 warrantied 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 judgement 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.

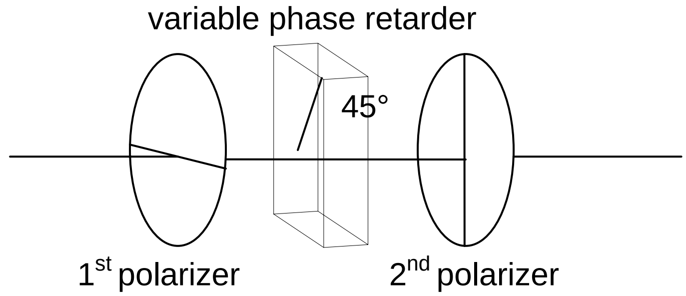
Final order should be placed by sending use a signed fax containing the ordering details.

Applications notes

Beside inducing an uniform phase shift on a polarized beam or modifying the polarization state (phase shift between the polarization component), the variable phase retarder can also be used as variable attenuator or as polarimeter. In this chapter you will find a more detailed description.

Variable attenuator

When placing the variable phase shifter oriented at 45° between crossed polarizers, one obtains a variable attenuator (for one wavelength at a time).



Variable attenuator composed of a variable phase retarder between crossed polarizers.

A maximum transmission is obtained by applying the correct voltage to achieve half-wave retardance. Half-wave operation rotates the incoming light passes by the second polarizer. Minimum transmission is obtained with the variable retarder operating at zero retardance (maximum voltage). Transmission decreases as the the applied AC bias increases. The relationship for crossed polarizers between the transmittance T and the retardance δ (depending on the applied bias) is given by:

$$T(\delta) = \frac{1}{2} T_{\max} (1 - \cos(\delta))$$

where Tmax is the maximum transmittance when retardance is exactly one-half wave .

Phase retarder used for polarization analysis

Several methods exist for computing and analyzing common ways of evaluating a system involve Mueller and Jones thepolarization states of an optical system. Two calculus where the polarization of a light beam and the effects of optical components on that polarization form are represented by simple means.

In the general case, polarizing properties of an optical component are represented by a matrix. A vector describes the polarization form of the incident beam. Multiplying the matrix and vector, the resulting vector represents the polarization characteristics of light that has propagated through the component.

The Stokes vector **S** describes light polarization as:

$$\vec{S} = \begin{pmatrix} I & Q & U & V \end{pmatrix}$$

where:

I total light intensity,

Q intensity difference between horizontal and vertical linearly polarized components,

U intensity difference between linearly polarized components oriented at ±45, and

V intensity difference between right and left circular components.

The Mueller matrix M for a waveplate with retardance δ (in degrees) and arbitrary optical axis orientation φ (measured from the horizontal) is expressed as:

$$M = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & C^2 + S^2\cos\delta & SC(1-\cos\delta) & -S\sin\delta \\ 0 & SC(1-\cos\delta) & S^2 + C^2\cos\delta & C\sin\delta \\ 0 & S\sin\delta & -C\sin\delta & \cos\delta \end{pmatrix}$$

where:

$$C = \cos(2\varphi)$$

$$S = \sin(2\varphi)$$

The stokes vector at the output of the system is given by:

$S' = MS$ or $S = M^{-1}S'$

Analysis of the entrance polarization (stokes polarimetry) can be performed with an optical setup that consist of minimal two variable phase retarders, a polarization beam splitter and two detectors capable to measure the of the two polarization components. Four measurements with different arrangements (δ and φ) of the phase retarders are necessary to determine the four stokes vector components I,Q,U and V.

Similarly with a known entrance polarization muller matrix measurement of samples can be determined by performing at least 16 intensity measurements for various polarization and phase retarder configurations.

Contact arcoptix for more precise description of the measurement procedure.

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) and for a wavelength of 633nm (retardation may have a slight wavelength dependency).