ARCoptix

Variable Phase Retarder
USER MANUAL

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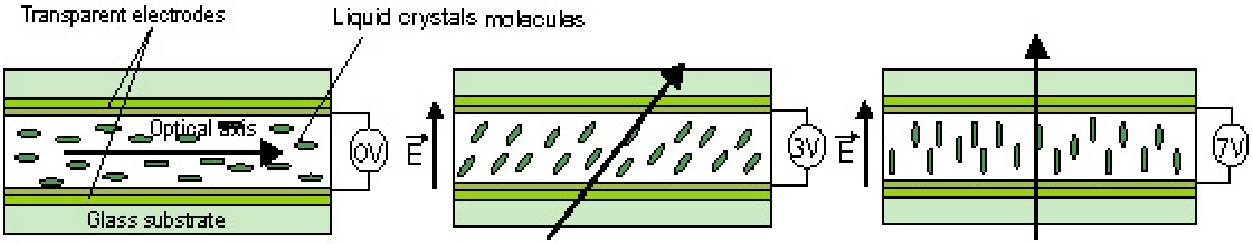
Principle of the liquid crystal phase retarder

The Arcoptix variable phase retarders 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).

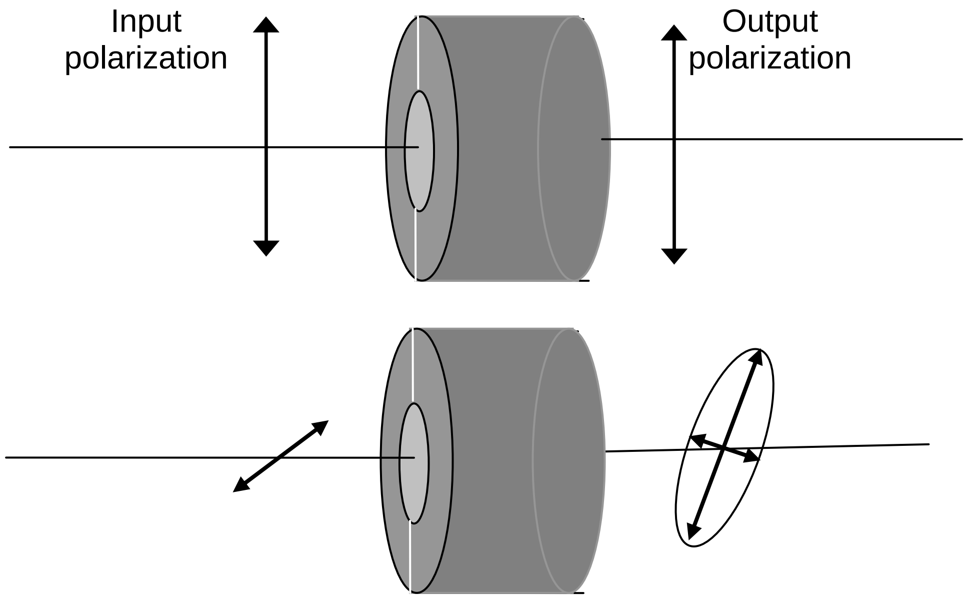
Optical setup

The housing has a diameter of exactly 25 mm and can be inserted in any standard opto-mechanical holder dedicated for this diameter. The optical axis of the phase shifter is indicated by a white stripe on the front of the housing can be oriented in any wanted direction.

There are mainly two ways to use the phase retarder:

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).



Phase retardance calibration

The graph on next page shows the phase retardance induced by the phase shifter (at 633nm and 23°C) when the entrance polarization is parallel to the optical axis. The voltage corresponds to a Square amplitude at 1.6 KHz.

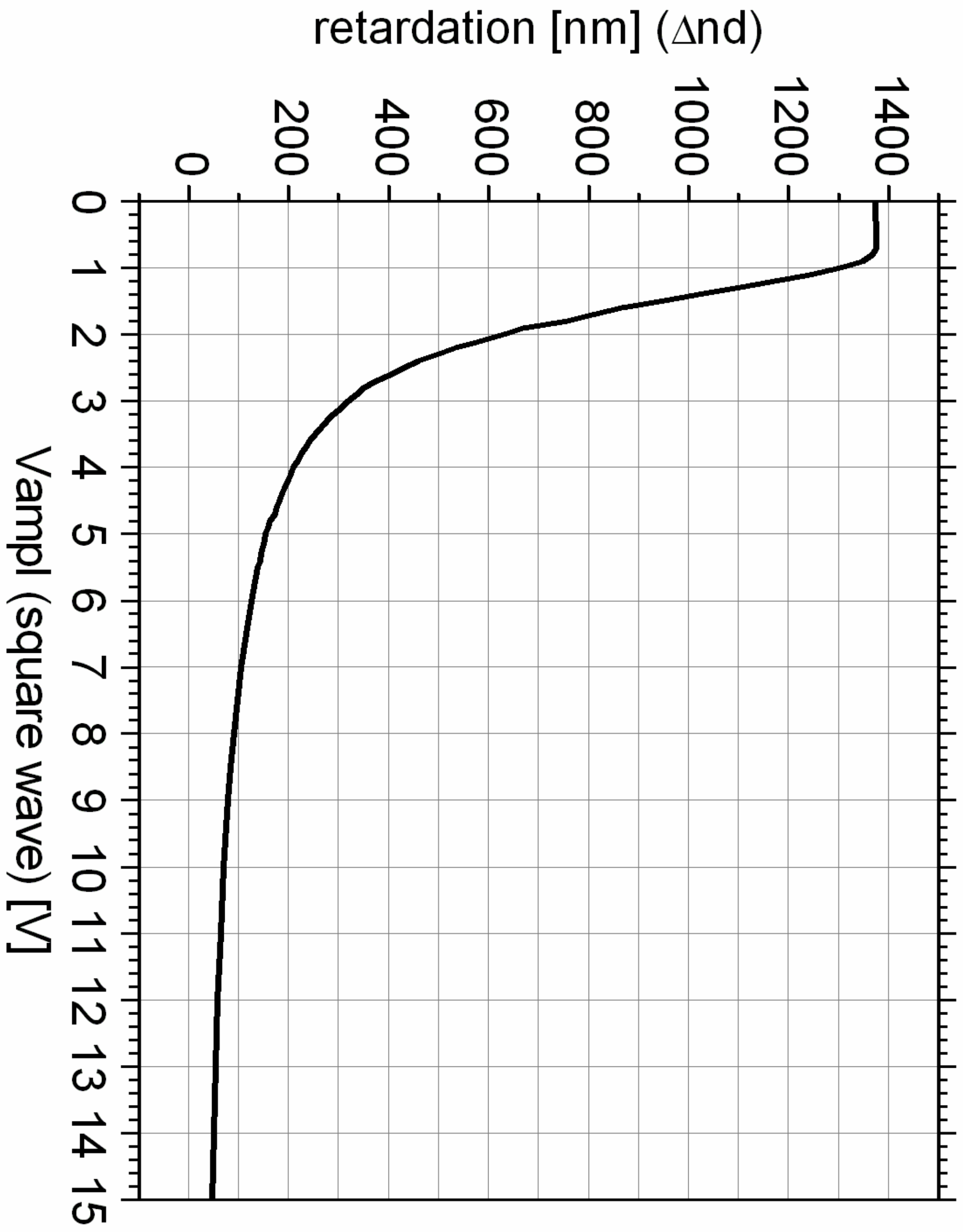
Notice that are several parameters that influences the phase retardance:

- Temperature fluctuations: the phase retardance changes by about 0.5% per °K.
- Wavelength: the birefringence slightly changes with the wavelength.
- Heating due to the illumination: the phase shifter may slightly heat when it is illuminated with a strong laser, this may affect the phase retardance as mentioned above.

In any case the characterization curve shown on the next page must be considered with care and additional bias adjustments are recommended for any specific laser. The easiest way to determine the phase retardance curve for your specific laser is to place the phase shifter between polarizers oriented at 45° and measure the intensity at the output with a photodiode. The phase δ is then given by:

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

Phase retardance characterization curve (633nm):



Electrical connection

With the LC USB Driver:

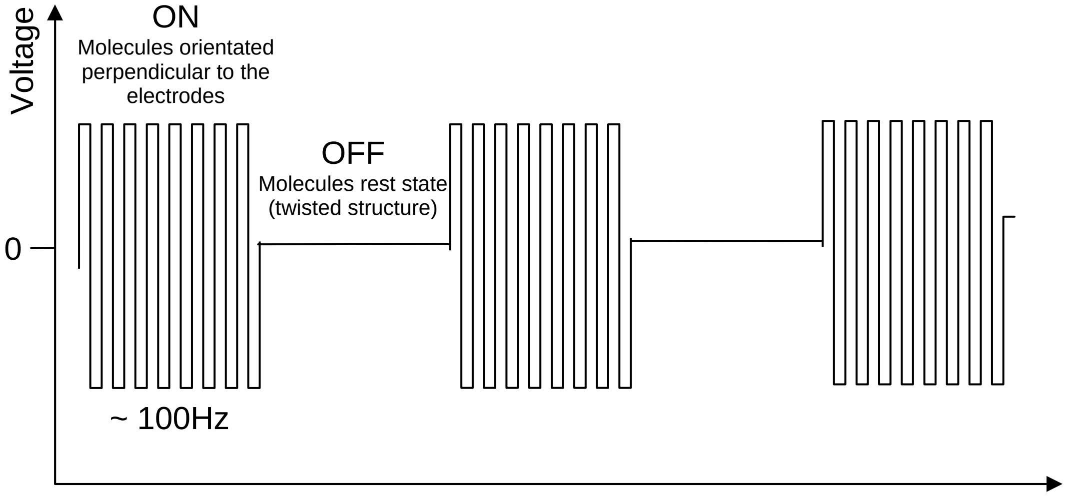
First before using the LC Driver you must install the LC driver software and drivers with its installation CD.
Ones you have installed the LC driver software and connected the driver to the computer, you can connect directly the “Lemo” connector to one of the two outputs of the LC Driver.
The voltage applied to the retarder is directly set in the LC Driver program with the corresponding output knob. The phase retadance decreases with the voltage. A conversion table (for 632nm) is given on page 4 which gives the non-linear relation between phase retardation between the two polarization components and the applied voltage. Notice that the precision of the LC driver is 1mV. As already explained in the previous chapter the calibration graph is only valid for a particular measurement condition (room temperature and 632nm): For other experimental conditions (other light source for example) it is recommended to make its own characterization.
Since there are two outputs the LC driver can drive two phase retarders simultaneously if necessary.

Some explanations about driving the phase retarder:

This chapter is not absolutely necessary to read for using the phase retarder. It is just written for general understanding of the system.

In principle the phase shifter can be adjusted by simply applying a DC bias on both sides of the cell. Unfortunately this will in practice not work very well. Impurity ions present in the LC material such as alkaline-earth metals cause a leakage current to flow across the cell gap when a voltage is applied to the cell. This ion migration may destroy the helical stacking structure and initiate irreversible degradation chemical reactions. If driven with a DC voltage, impurity ions present may migrate towards the alignment layers under the action of the electric field and become embedded at the cell surfaces. Upon removal of the applied voltage thereafter, an electrical field across the liquid crystal may persist due to the captured charges and hence hinder cell switching.
For this reason, LC cells are usually (as it is the case for the LC driver) driven with AC square-wave voltages of between ±0.0 and ±8 volt whereby the polarity is rapidly switched at speeds of up to 1KHz 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.



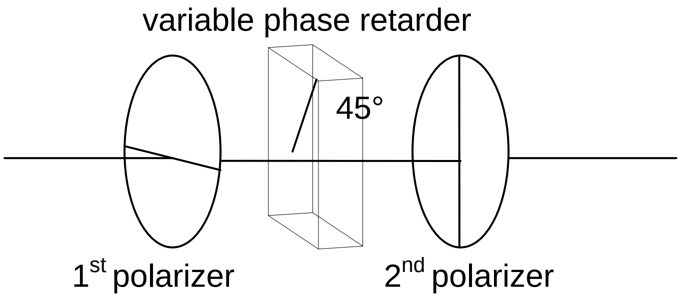
The user may eventually use a sinus wave function it is recommended to use a higher frequency (at least 10 KHz) in order to decrease the rise and fall time of the voltage so that it is far below the reaction time of the LC molecules.

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.