Liquid Crystal Operating Principles

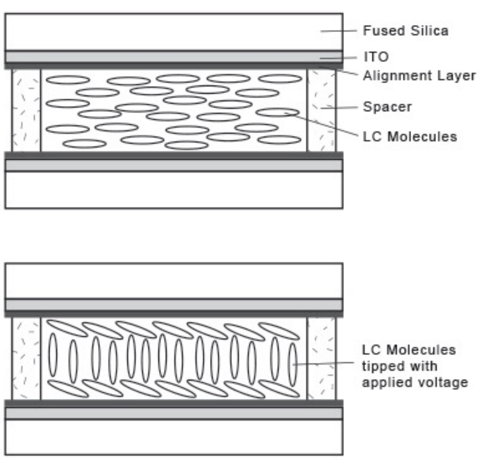
Liquid Crystal Variable Retarders are solid state, real-time, continuously tunable waveplates. Nematic liquid crystals are birefringent materials whose effective birefringence can be changed by varying an applied voltage.

Meadowlark Optics Liquid Crystal Retarders are constructed using precision polished, optically flat fused silica windows spaced a few microns apart. The cavity is filled with nematic liquid crystal material and sealed. This assembly ensures excellent transmitted wavefront quality and low beam deviation required for many demanding applications.

The long axis of the liquid crystal molecules defines the extraordinary (or slow) index. With no voltage present, the molecules lie parallel to the windows and maximum retardance is obtained. When voltage is applied across the liquid crystal layer, the molecules tip toward the direction of the applied electric field. As voltage increases, the effective birefringence decreases, causing a reduction in retardance.

Retardances greater than half-wave can be achieved by using high birefringent materials and/or increased liquid crystal layer thickness. Birefringence of liquid crystal materials decreases at longer wavelengths, requiring proper evaluation and design for optimum performance.

Phase control or modulation is possible for light linearly polarized 45° to the fast axis. Electrical control of the effective extraordinary index allows precision tuning of an optical phase delay in the propagating beam.



Liquid Crystal Variable Retarder construction showing molecular alignment (a) without and (b) with applied voltage

A Liquid Crystal Variable Retarder is the fundamental component used in the following devices and systems:

- Variable Attenuators and Rotators
- Variable Beamsplitters
- Spatial Light Modulators
- Non-Mechanical Shutters
- Beam Steerers
- Optical Compensators
- Polarimeters
- Tunable Filters

Liquid Crystal Variable Retarders

A basic building block of Meadowlark Optics line of liquid crystal products is the Liquid Crystal Variable Retarder (LCVR). Just one of these devices can replace an entire series of polymer and standard crystalline retarders. They are electronically adjustable from nearly zero waves (or less than with an optional compensator) to over half- wave in the order of 10 milliseconds. The switching speeds are symmetric and approximately 150 microseconds. An advanced use of LCVRs is described in the application note "Stokes Polarimetry Using Liquid Crystal Retarders," which is available on our website at www.meadowlark.com.

Meadowlark Optics High Speed Liquid Crystal Variable Retarder

Meadowlark Optics Liquid Crystal Variable Retarders are used throughout the visible and near infrared region. While these liquid crystal retarders are affected by temperature and wavelength changes, they can be calibrated to accommodate those differences. The resulting Variable Retarder is versatile across a considerable thermal environment and significant wavelength range.

Liquid crystal retarders can offer outstanding performance over large incidence angles. Material type, cavity thickness, and especially operating voltage play a large role in determining the acceptable input angle.

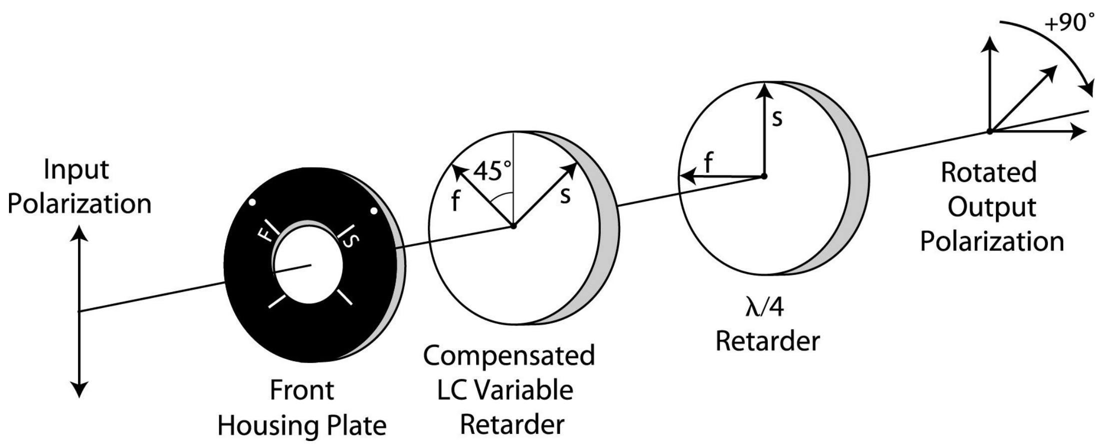
Meadowlark Optics Liquid Crystal Variable Retarders provide precise solid-state retardance tunability. These true zero-order devices are precision engineered, offering excellent performance in the visible to near infrared wavelength ranges. When combined with other optical components, **our Liquid Crystal Variable Retarders produce electrically controllable attenuation, linear polarization rotation, or phase modulation**.

Continuous tuning of retarders over a broad wavelength range is required for many applications. This added versatility makes real-time polarization conversion possible with a single Liquid Crystal Variable Retarder and electronic controller. A variety of output polarization forms can be achieved with a single device. Pure phase modulation is accomplished by aligning the optic axis of the liquid crystal retarder parallel to a linearly polarized input beam..

Variable attenuators with no mechanical rotation are configured by placing a Liquid Crystal Variable Retarder between crossed polarizers. Full 180° linear polarization rotation can easily be achieved by combining the Liquid Crystal Variable Retarder with a fixed quarter waveplate.

Spatial Light Modulators consist of individually controllable pixels. These devices are used in a variety of intensity and/or phase control applications where spatial variation is required. Please refer to the Spatial Light Modulator section for details and specifications on these innovative products.

While we typically list our standard products as the Liquid Crystal Variable Retarder, Attenuator and Polarization Rotator, we also have the ability to utilize Liquid Crystals in other ways that are extremely useful. The Twisted Nematic Liquid Crystal Device (TN) provides our customers with potential for custom applications where a standard LCVR might not be appropriate. At Meadowlark Optics we never cease working on polarization solutions for our customers. We hope the information below will provide our customers with new ideas that will challenge us to create new, exciting solutions for polarization control.



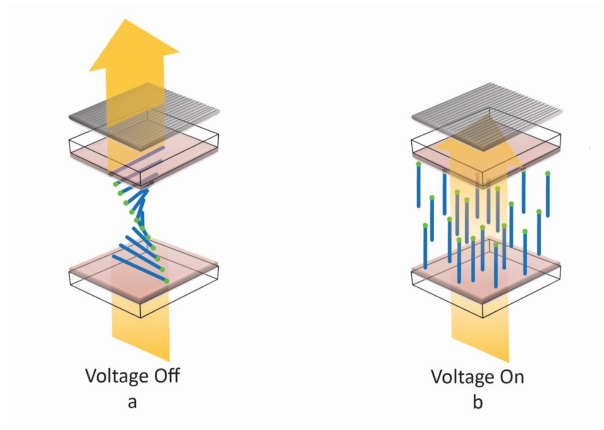
Exploded view of Meadowlark Optics Liquid Crystal Variable Rotator showing LCVR

Twisted Nematic Liquid Crystal Cell

One is often only interested in producing two orthogonal linear polarization states of an optical system, or, in the case of a digital optical switch, only two states are frequently required. If you desire to switch the polarization state between only two angles, for example 0° and 90°, a twisted-nematic device is an excellent solution. A big advantage of the twisted nematic device over an LCVR is the simplicity of the driving scheme. High voltage (above ~ 10 V) gives 0° rotation and low voltage (below ~ 1 V) gives 90° rotation, so you need not concern yourself with exact voltages or tight tolerances. Also, the field of view is wide when compared to an LCVR because the cell is being used in a situation where the optical axis of the liquid crystal molecules is not at an arbitrary angle to the light but is either parallel or perpendicular to it.

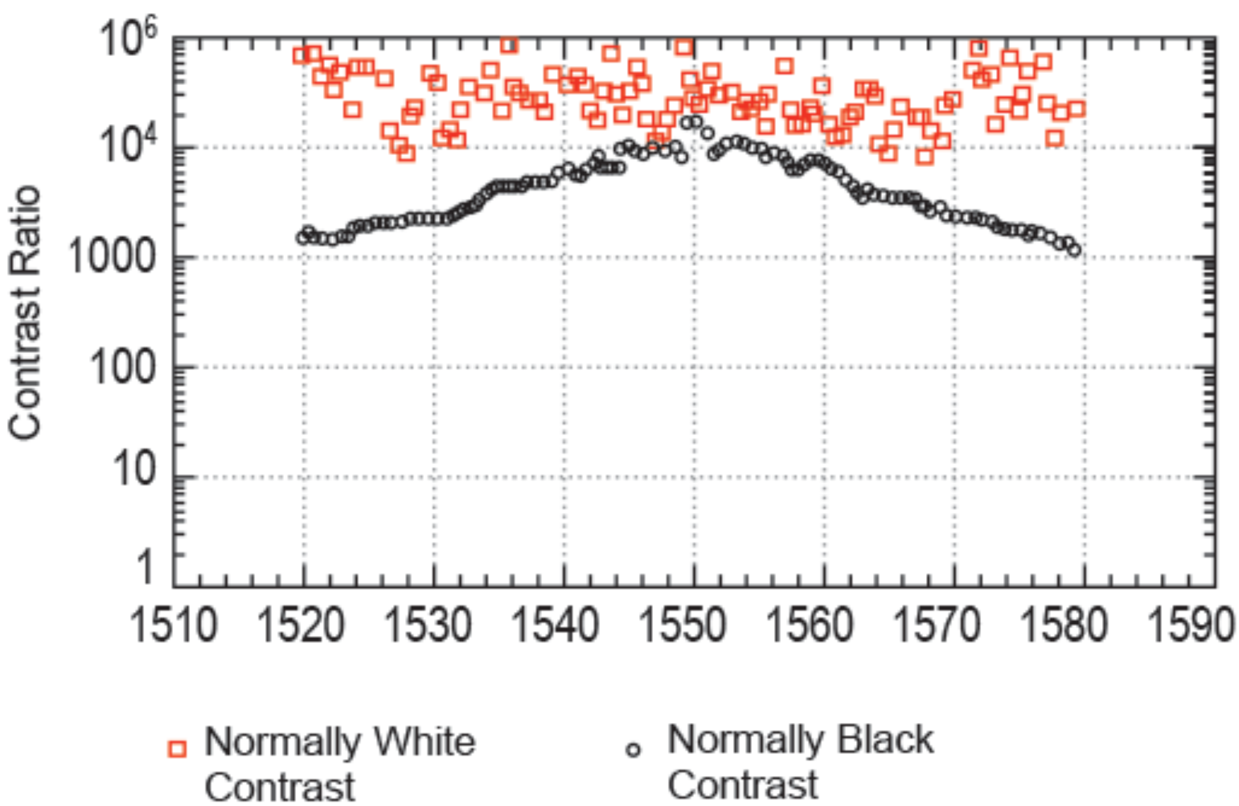
A twisted nematic liquid crystal cell is constructed in the same manner as a standard LCVR except the alignment of the liquid crystal molecules is twisted 90°. As in an LCVR, high voltage (~ 10 V) aligns the molecules with the field and removes the birefringence and therefore does not affect the light. At low voltage, however, the twist does affect the light, causing rotation of the polarization.

If the twist is gentle when compared to the wavelength of the light, the polarization will simply follow the twist of the liquid crystal molecules. Such a cell is said to be operating in the "Mauguin limit" and its rotation is quite achromatic. The polarization rotation angle is equal to the twist angle for all wavelengths, which are short enough for the twist to be viewed as sufficiently gentle. When this is not the case, the cell will no longer act as a pure rotator. The result of inputting linearly polarized light is no longer an output of rotated linearly polarized light but rotated elliptically polarized light. However, for certain discrete wavelengths, depending on the birefringence of the liquid crystal and the thickness of the cell, the pure rotation characteristic is retained.

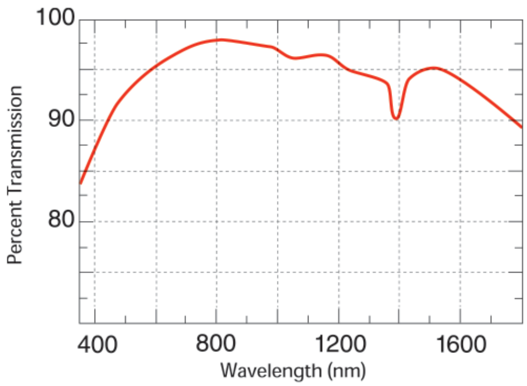


Exploded view of Meadowlark Optics Liquid Crystal Variable Rotator showing LCVR

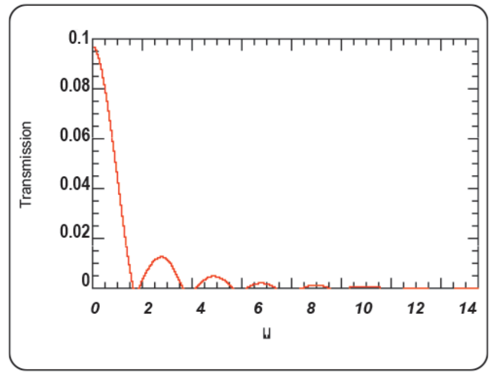
High contrasts of several thousands to one can be achieved in practice with twisted nematic cells. Below, the curve termed "Normally Black Contrast" was taken between parallel polarizers where low voltage gives a dark state and high voltage yields a bright state. The curve termed "Normally White Contrast" was taken between perpendicular polarizers where the dark state occurs at high voltage.



Contrast ratio for a twisted nematic liquid crystal cell



Typical transmission through a liquid crystal device



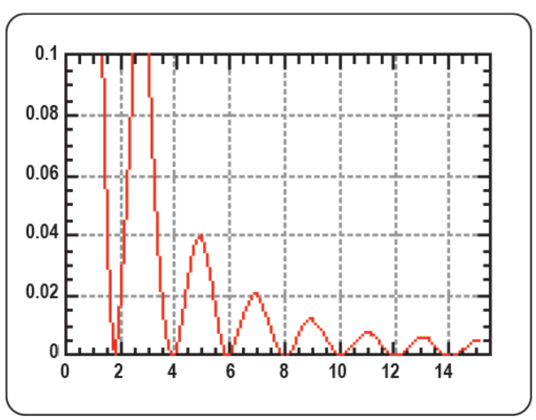
Transmission of a twisted-nematic cell between parallel polarizers as a function of thickness and/or wavelength

The transmission graph above, (normalized to 1), of a 90° twisted nematic cell between parallel polarizers is a function of the variable,

$U = 2d(b/\lambda)$,

where d is the thickness of the cell, b is the birefringence and λ is the wavelength. Where the curve first goes to zero is termed the "first minimum" and this position is typically used. The next highest transmission minimum is called the "second minimum" and so on. In this plot, moving along the horizontal axis can be viewed as increasing thickness or decreasing wavelength.

One might ask, given the achromaticity of thicker cells "why use the first minimum?" The simple answer is speed. The switching speed of an LC is a strong function of the cell thickness; generally, speed drops quadratically with the thickness. Thus, while a cell operating at a particular wavelength in the first minimum condition might switch in 10 to 50 ms, one designed to operate achromatically (for example to transmit < 1 % between parallel polarizers) over the entire visible range can take several seconds to switch.



Liquid crystal cell thickness changes