

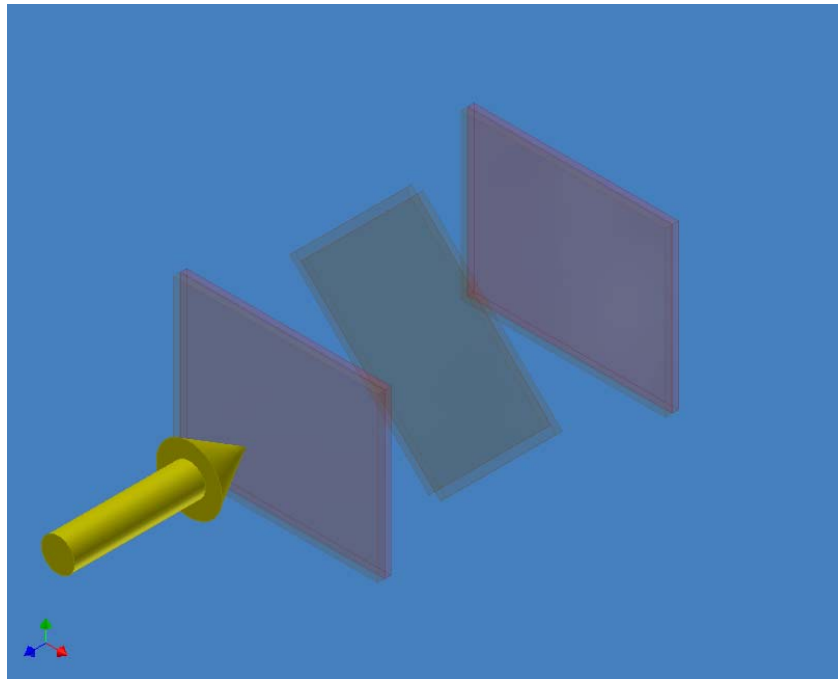
LCTF Introduction

Meadowlark Optics' Liquid Crystal Tunable Filters facilitate spectral analysis of not only a collimated beam, but more importantly of an entire object. The Tunable Filter passes only a narrow bandwidth of light while blocking all others with the spectral range. The pass band can be shifted to a new color in the blink of an eye. This combination of pass band and speed is equivalent to literally thousands of dichroic or interference filters on hundreds of filter wheels. This enables the user to acquire images at thousands of different wavelengths in a short amount of time. Applications of Liquid Crystal Tunable Filters include fluorescence microscopy, absorption microscopy, Raman microscopy, and solar astronomy.

LCTF Basics

A Liquid Crystal Tunable Filter works on the principle of polarization dispersion. Simply stated, when light passes through a waveplate (e.g. a liquid crystal variable retarder), it will be retarded by a certain amount. When light of a different wavelength passes through the same waveplate, it will be retarded by a different amount.

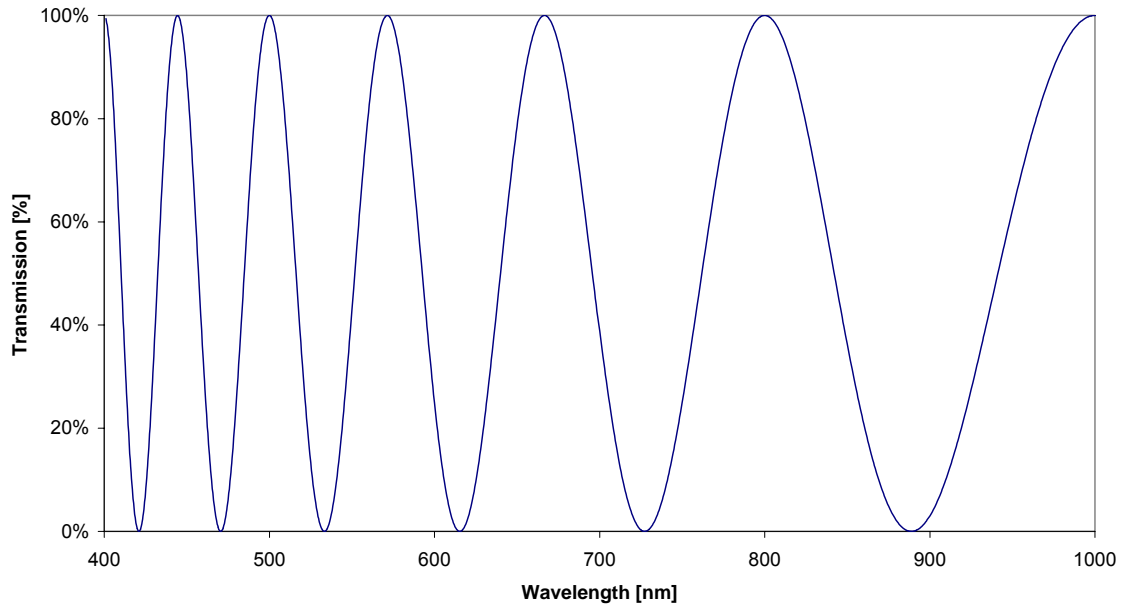
To illustrate this effect, consider a Lyot Stage. This Lyot Stage consists of two parallel (or crossed) polarizers placed around a waveplate, which is oriented at 45 degrees to the polarizers as shown below.



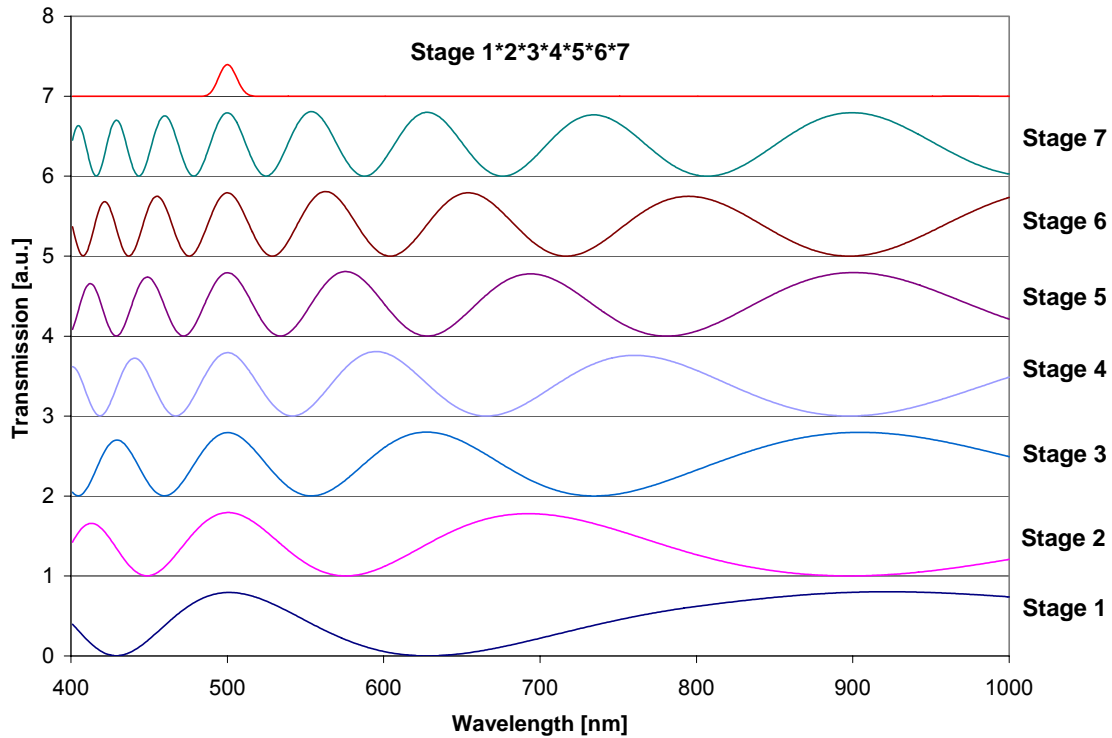
Transmission through the Lyot Stage obeys the following equation,

$$\frac{T(\lambda)}{T_{\max}} = \cos^2\left(\frac{\pi \cdot \beta \cdot t}{\lambda}\right)$$

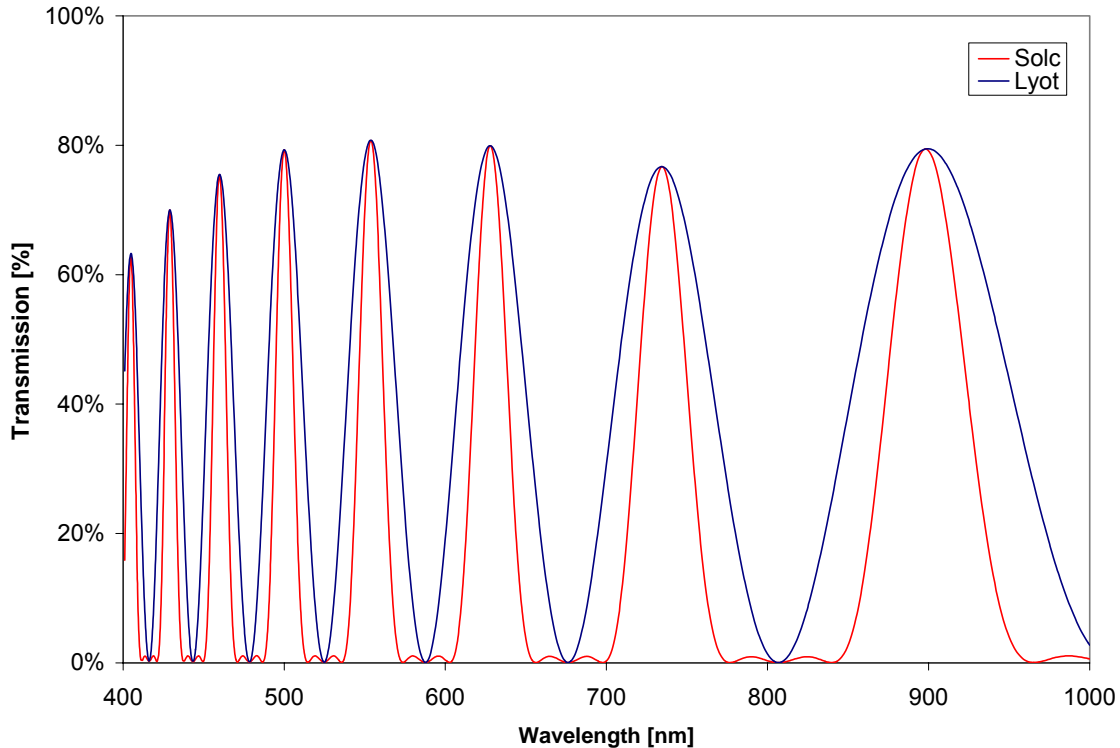
where $T(\lambda)$ is the transmission at wavelength, λ , and β is the birefringence of the waveplate, and t is the thickness of the waveplate. The spectral response is shown below. By using a liquid crystal variable retarder as the waveplate enables β to be a function of the applied voltage. Thus by applying a different voltage, the location of the peaks can be moved, and a filter can be tuned.



A single Lyot Stage is generally not particularly useful, but if many of them are stacked together, the free spectral range can be increased, while the pass band remains about the same. The following figure shows how many Lyot Stages can work in concert to diminish every peak except for the one of interest (top line).



Solc Stages, like Lyot Stages, are also useful in building Tunable Filters. A Solc Stage consists of multiple waveplates at prescribed angles between parallel (or crossed) polarizers. The prescribed angles depend on the number of waveplates within a stage, e.g. a 3-waveplate Solc Stage would have optic axis angles for the three waveplates at 15° , 45° , and 75° . One advantage of using a Solc Stage over a Lyot Stage is that Solcs have a wider null and a narrower peak than a comparable Lyot, as shown below. Therefore, when using stacks of Solc Stages to build a Tunable Filter, it is possible to reduce the total number of stages needed as compared to one built with Lyot Stages. Reducing the number of stages and thus the number of polarizers allows for a higher peak transmission, since the polarizers are generally responsible for most of the attenuation.



Meadowlark Optics uses Lyot Stages, Solc Stages, and other proprietary types of stages to make Tunable Filters. This permits a Tunable Filter to have optimum peak transmission with a minimum of leaks.

LCTF Standard Design

A Liquid Crystal Tunable Filter consists of multiple liquid crystal variable retarders, invariant retarders and polarizers all protected in a temperature-controlled housing.

Temperature control is important since the birefringence of the liquid crystal variable retarders is a function of temperature as well as voltage. For this reason, the entire housing is kept warm at 40C, so that ambient conditions do not affect the calibration or the switching speed.

Each liquid crystal cell that goes into the Tunable Filter is made to be highly uniform in retardance using our propriety manufacturing processes. This produces the best uniformity of color across the clear aperture.

The polarizers used are generally Versalight wire grid polarizers, which have remarkably low losses, producing a final filter with very high transmission. Additionally the polarizers have very wide fields of view and can accommodate much higher fluences than standard dichroic polarizers.

The electronics controller supplies the appropriate voltages to each of the liquid crystal variable retarders and maintains the temperature of the housing. All of the calibration

data for each variable retarder is stored into memory on the electronics controller. When commands are issued to the controller via USB, serial port, or the manual dial, the calibration data are accessed and new voltages to each of the variable retarders are initiated simultaneously.

To issue commands via USB or serial port from a computer, FilterDRIVE™ software is provided. This software allows a user to input a desired wavelength value using a keyboard or mouse. Firmware commands are provided in the user's manual for those wishing to have control using their own custom software.

Our standard tunable filters are shown below, but custom filters can also be easily obtained.

Show table of our standard filters here

LCTF Customization

Meadowlark excels at providing customized Tunable Filters for all kinds of applications. Whether you are doing astronomy, microscopy, or remote imaging, we can find a solution that meets your needs. Since all components are made in-house, a wide range of customization is possible. Whether you would like a larger clear aperture, a narrower pass band, a wider field of view, a variable pass band, or more, we can do it.

When deciding on specs for a custom filter, it is important to remember that not all specs can be chosen completely independently. The most important spec to consider is the finesse, f , which is defined as

$$f = \frac{FSR}{FWHM}$$

where FSR is the free spectral range of the filter and FWHM is the full width at half maximum. Higher finesses are achieved by adding more stages and thus more optics, which leads to a more expensive filter

Another important spec is the peak transmission. This is defined as the maximum transmission of the pass band curve. Additionally peak transmission is generally reported for light that is polarized along the transmission axis of the first polarizer in the Tunable Filter. If unpolarized light is incident on the filter then the peak transmission will be half of the polarized peak transmission. The peak transmission is a function of the center wavelength of the pass band as well as the number of optics in the Tunable Filter. This means that the peak transmission is highly dependent on the optical finesse, since higher finesses have more optics and hence more absorptive elements.

Other specs include field of view, which defines the applicable half-cone angle from the optical axis for which the filter performance is guaranteed. Thus the rays entering the Tunable Filter should be kept less than this angle. If this is not possible, the main result will be an increase in the out-of-band rejection.

The out-of-band rejection is the measure of how much light, which is not within the pass band, gets through the filter. It is most desirable to have the out-of-band rejection as high as possible.

The accuracy of the peak location is better than 20% of the FWHM.

Meadowlark Optics has several proprietary and patent-pending designs for Tunable Filters. If you are interested in a Tunable Filter with a very wide fields-of-view or with a variable FWHM (i.e. several different FWHMs possible at a particular wavelength), please call us to discuss it.