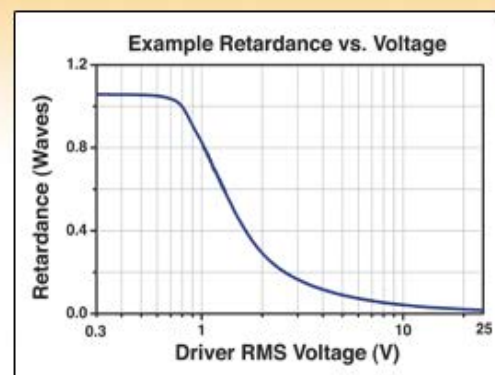


## LCC1222-C - OCT 28, 2019

Item # LCC1222-C was discontinued on Oct. 28, 2019. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

### THREE-QUARTER-WAVE LIQUID CRYSTAL VARIABLE RETARDERS / WAVE PLATES

- ▶ Nematic Liquid Crystal 3/4-Wave Variable Retarder
- ▶ Available with Ø10 mm or Ø20 mm Clear Aperture
- ▶ AR Coated for 1050 to 1620 nm



## OVERVIEW

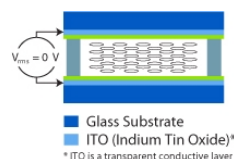
### Features

- Variable Wave Plate to Actively Control the Polarization State of Light
- Retardance Range: ~30 nm to  $3\lambda/4$
- Clear Aperture: Ø10 mm or Ø20 mm
- Surface Quality: 40-20 Scratch-Dig
- Retardance Uniformity:  $< \lambda/50$  Over the Entire Clear Aperture

Thorlabs' Three-Quarter-Wave Liquid Crystal Variable Retarders (LCVR) use a nematic liquid crystal cell to function as a variable wave plate. The absence of moving parts provides quick switching times on the order of milliseconds (see the *Switching Time* tab for details). They are available with an AR coating for 1050 - 1620 nm (see the *Performance* tab for transmission and retardance data). Our Ø10 mm retarders feature a 1" outer diameter, making them compatible with any of our Ø1" optics mounts for 8 mm thick optics. Our Ø20 mm retarder features a 2" outer diameter, making it compatible with any of our Ø2" optics mounts for 13 mm thick optics.

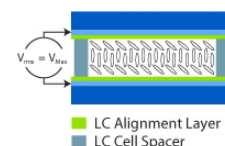
### Performance

### Operating Principle



#### High Retardance

In their nematic phase, liquid crystal molecules have an ordered orientation, which together with the stretched shape of the molecules creates an optical anisotropy. When an electric field is applied, the molecules align to the field and the level of birefringence is controlled by the tilting of the LC molecules.



#### Low Retardance

### Selection Guide for LC Retarders

Type	Clear Aperture
Half Wave	Ø10 mm or Ø20 mm
Half Wave, Thermally Stabilized	Ø10 mm
Three-Quarter Wave	Ø10 mm or Ø20 mm

These liquid crystal variable retarders provide excellent uniformity, low optical losses and low wavefront distortion. Our retarders also provide quick switching time, a broad operating temperature range, and a broad wavelength range. Please see the *Specs*, *Performance*, and *Switching Time* tabs for complete details.

Full Wave	Ø10 mm or Ø20 mm
Full Wave, Thermally Stabilized	Ø20 mm
Multi-Wave	Ø10 mm
Multi-Wave, Integrated Controller	Ø10 mm
Custom LC Retarders	

### Operation

A Liquid Crystal Variable Retarder consists of a transparent cell filled with a solution of Liquid Crystal (LC) molecules and functions as a variable wave plate. The orientation of the LC molecules is determined by the alignment layer in the absence of an applied voltage. The alignment layer is composed of an organic polyimide (PI) coating whose molecules are aligned in the rubbing direction during manufacturing. Due to the birefringence of the LC material, this LC retarder acts as an optically anisotropic wave plate, with its slow axis, marked on the mechanical housing, parallel to the surface of the retarder. Two parallel inner faces of the cell wall are coated with a transparent conductive film so that a voltage can be applied across the cell. When an AC voltage is applied, the LC molecules will reorient from their default alignment according to the applied  $V_{rms}$ .

### Controller

The LCC25 controller, sold below, provides active DC offset compensation, while applying an AC voltage (0 to 25  $V_{rms}$ ). The DC offset compensation automatically zeros the DC bias across the LC device in order to counteract the buildup of charges. It is fully compatible with all of the liquid crystal retarders sold by Thorlabs.

## S P E C S

### Ø10 mm Clear Aperture LC Retarders

Item #	LCC1112-C
Wavelength Range	1050 - 1620 nm
Liquid Crystal Material	Nematic Liquid Crystal
Retardance Range	~30 nm to $>3\lambda/4$
Clear Aperture	Ø10 mm
Surface Quality	40-20 Scratch-Dig
Switching Speed (Rise/Fall, Typical) <sup>a</sup>	20.9 ms / 1190 $\mu$ s @ 25.6 °C
AR Coating	$R_{avg} < 0.5\%$ at all Air-to-Glass Surfaces for Specified Wavelength Range
Wavefront Distortion	$\leq \lambda/4$ (@ 635 nm)
Retardance Uniformity	$< \lambda/50$ over the Entire Clear Aperture
Housing Outer Diameter	Ø1"
Storage Temperature	-30 to 70 °C
Operation Temperature	-20 to 45 °C
Compatible Mounts	RSP1 (RSP1/M), CRM1 (CRM1/M), CRM1P (CRM1P/M), KM100

### Ø20 mm Clear Aperture LC Retarder

Item #	LCC1222-C
Wavelength Range	1050 - 1620 nm
Liquid Crystal Material	Nematic Liquid Crystal
Retardance Range	~30 nm to $>3\lambda/4$
Clear Aperture	Ø20 mm
Surface Quality	40-20 Scratch-Dig
Switching Speed (Rise/Fall, Typical) <sup>a</sup>	20.9 ms / 1190 $\mu$ s @ 25.6 °C
AR Coating	$R_{avg} < 0.5\%$ at all Air-to-Glass Surfaces for Specified Wavelength Range
Wavefront Distortion	$\leq \lambda/4$ (@ 635 nm)
Retardance Uniformity	$< \lambda/50$ over the Entire Clear Aperture
Housing Outer Diameter	Ø2"

<b>Storage Temperature</b>	-30 to 70 °C
<b>Operation Temperature</b>	-20 to 45 °C
<b>Compatible Mounts</b>	RSP2 (RSP2/M), LCRM2, LCRM2/M, KM200

- Switching speed is highly dependent on several factors, including voltage change and cell temperature. See the *Switching Time* tab for more details.

## PERFORMANCE

### LC Retarder Performance

In their nematic phase, liquid crystals molecules have an ordered orientation, which together with the stretched shape of the molecules, creates an optical anisotropy. When an electric field is applied, the molecules align to the field and the level of effective retardance is controlled by the tilting of the LC molecules. To minimize effects due to ions in the material, an LC device must be driven using an alternating voltage. Our LCC25 controller is designed to minimize the DC bias in the driving signal in the operating range of 0 V to 25 V.

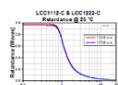
Due to changes in the molecular polarizability, the LC material exhibits higher chromatic dispersion at short wavelengths and comparably small chromatic dispersion at long wavelengths. To account for this, we provide the retardance data at two select wavelengths within the product's wavelength range in the graph below.

Additionally, the LC retardation also depends on the temperature of the device. As temperature increases, the retardation decreases with it. However, as seen in the *Switching Time* tab, the switching speed of the LC improves at higher temperatures. Generally, the LC's refractive indices (both ordinary and extraordinary) change more drastically as temperature nears the LC's clearing temperature. As such, we choose to use materials with a high clearing temperature to minimize the temperature dependence when used at room temperature.

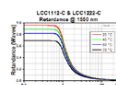
[Click Here to Download Retardance Data](#)

[Click Here to Download Transmission Data](#)

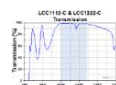
### LCC1112-C & LCC1222-C (1050 - 1620 nm)



[Click to Enlarge](#)



[Click to Enlarge](#)



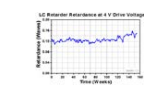
[Click to Enlarge](#)

### Long-Term Stability

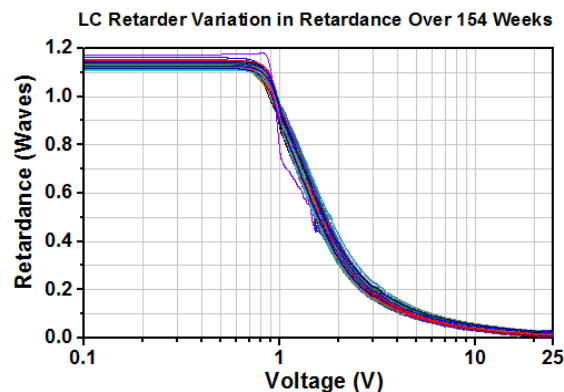
Our liquid crystal retarders exhibit consistent performance over time. The graph to the right shows the retardance vs. voltage for a single three-quarter wave retarder, driven by our LCC25 liquid crystal controller over 154 weeks. The retardance was tested once per week and varied only slightly over the testing period. For the complete set of data from testing each week, please click below to download the full data file.

The graph below to the left shows that the retardance varies only slightly at a constant voltage, while the graph below to the right shows that the voltage varies only slightly at a constant retardance. Similar consistency in performance can also be expected for our other models of retarders. To maximize the long-term stability of our retarders, we recommend always using the LCC25 controller. It is specifically designed to reduce the DC voltage offset, thus minimizing charge buildup and maximizing stability.

[Click Here to Download Long-Term Performance Data](#)



[Click to Enlarge](#)



[Click to Enlarge](#)

Graph shows variation in retardance over a period of 154 weeks.



[Click to Enlarge](#)

## SWITCHING TIME

## LC Retarders Switching Time

Liquid crystal retarders feature a short switching time compared to mechanical variable wave plates due to the lack of moving parts. The switching time of a liquid crystal retarder depends on several variables, some of which are controlled in the manufacturing process, and some by the user.

In general liquid crystal retarders will always switch faster when changing from a high to a low birefringence value. Additionally, the higher the operating temperature is, the faster the retarder will switch from one state to another due to the decreased viscosity at the higher temperature.

For any given retarder, the switching speed will always be faster at higher voltages. The graph to the right depicts examples of switching between different voltages. If trying to achieve faster switching speed, we recommend using the retarder together with a fixed waveplate, to use the variable retarder at a higher voltage.

In addition, the material's viscosity and hence the switching speed also depend on temperature of the LC material. As can be seen below, the switching speed can increase by as much as two times by heating the LC retarder. Our standard LC retarders are designed to work at temperatures of up to 50 °C, where they can still maintain the specified retardation. If additional speed is required, the retarders can work at temperatures up to 70 °C, but the maximum retardation value will be lower.

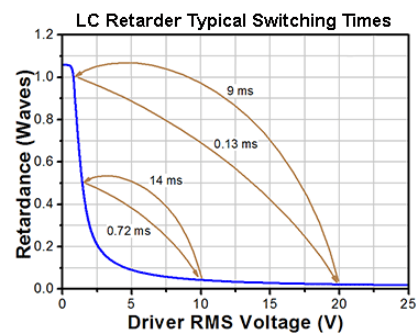
The switching speed also is directly proportional to the thickness of the LC retarder, the rotational viscosity of the LC material, and the dielectric anisotropy of the LC material. However, since each of those variables affects other operating parameters as well, our LC retarders are designed to optimize overall performance, with a special emphasis on switching time. We also offer custom and OEM LC retarders optimized for other parameters, as well as faster liquid crystal retarders. Contact [techsupport@thorlabs.com](mailto:techsupport@thorlabs.com) for details.

## Sample Switching Times at Various Temperatures

Switching times were tested by measuring the rise time from  $V_1$  to  $V_2$  and the fall time from  $V_2$  to  $V_1$  with the liquid crystal retarder being held at the specified temperature.  $V_1$  is fixed at 10 V for all the tests, and  $V_2$  is the voltage at which the retardation is the maximum specified value for the retarder ( $3/4 \lambda$ ). Please note that switching times at lower voltages (for instance, if  $V_1=5$  V) are longer than the switching times specified below.

### LCC1222-C/LCC1112-C

Temperature	$V_1$	$V_2$	Rise Time	Fall Time
25.6 °C	10	1.4	20.925 ms	1190 $\mu$ s
45 °C	10	1.4	8.122 ms	579 $\mu$ s
60 °C	10	1.4	5.140 ms	260 $\mu$ s
70 °C	10	1.4	4.060 ms	210 $\mu$ s



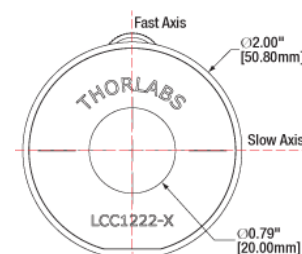
Click to Enlarge  
Switching Time Decreases with Higher Voltage Changes

## APPLICATIONS

## Alignment

In order to precisely align the axis of the liquid crystal cell, mount the retarder in an appropriate rotation mount (e.g. the RSP1 or the CRM1P for our  $\varnothing 10$  mm clear aperture retarders and RSP2 or the LCRM2 for our  $\varnothing 20$  mm clear aperture retarders). Then set up a detector or power meter to monitor the transmission of a beam through a pair of crossed linear polarizers. Next place the LC retarder between two crossed polarizers with the slow axis aligned with the transmission axis of the first polarizer. Then slowly rotate it until the transmitted intensity is minimized. In this configuration, the LC retarder is ready for phase modulation applications.

To operate as a light intensity modulator or shutter, again find the minimum transmitted intensity as prescribed above. Once the minimum is found, rotate the retarder by  $\pm 45^\circ$ . This will maximize the transmitted intensity through the crossed polarizers for most LC retarders (e.g., zero-order quarter- or half-wave plates). However, this rule of



Drawing indicates the slow and fast axes

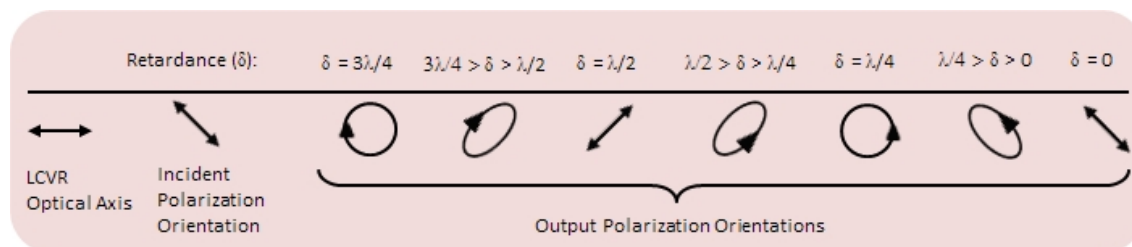
thumb does not rigidly hold for multi-wave phase retarders using broadband sources due to the wavelength dependency of the retardation.

The slow (extraordinary) axis of the liquid crystal retarder corresponds to the orientation of the long axis of the liquid crystal molecules when no voltage is being applied. Applying a voltage will cause the orientation direction of the liquid crystal molecules to rotate out of the plane of the drawing, changing the retardation. Thorlabs LC retarders are nematic liquid crystal devices, which must be driven with an AC voltage in order to prevent the accumulation of ions and free charges, which degrades performance and can cause the device to burn out.

## Applications

### Polarization Control with a Liquid Crystal Variable Retarder

The LCVR can be effectively used as a variable zero-order wave plate over a broad spectrum of wavelengths. The optical axis of the LCVR is defined as the major axis of the liquid crystal molecules when no voltage is being applied to the cell, which are all aligned due to the LC alignment layer. When using the LCVR to control the polarization of a beam, the linearly polarized input beam should be aligned so that its polarization axis is oriented at an angle of 45° with respect to the optical axis of the LCVR in order to maximize the dynamic range of the optic. The schematic below shows how the output state of polarization will change as retardance is decreased (RMS voltage increased).



### Pure Phase Retarder with Liquid Crystal Variable Retarder

In order to only effect the phase of the incident beam, the linearly polarized input beam must have its polarization axis aligned with the optical axis of the liquid crystal retarder. As  $V_{rms}$  is increased, the phase offset in the beam is decreased. Pure phase retarders are often used in interferometers to alter the optical path length of one arm of the interferometer with respect to the other. With an LCVR, this can be done actively.

## LC CONTROLLER

The LCC25 liquid crystal variable retarder and polarization rotator controller produces a 2000 Hz square wave output with an amplitude that can be varied from 0 to 25  $V_{rms}$ . The output amplitude can be set via the front panel controls, the USB interface, and the external input. Both the front panel and USB interface allow the user to select two voltage levels, Voltage 1 and Voltage 2. When the LCC25 is operated in the constant voltage mode, the output of the controller will be a 2000 Hz square wave with an amplitude equal to either of the two set voltage levels (Figure A). If the LCC25 controller is operating in the modulation mode, the output 2000 Hz square wave will be modulated in amplitude between the two voltage settings with a modulation frequency that can be set by the user to be between 0.5 and 150 Hz (Figure B).

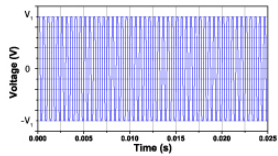
The modulated mode can be used to measure the response time of the LC retarder.

External or remote control of the LCC25 is possible using the external input or the USB interface. The external input accepts a 0 to 5 VDC TTL signal that modulates the 0 to 25  $V_{rms}$  output of the LCC25 between the two set voltages. The USB interface can be used to send line commands to the controller so that the LCC25 can be used in automated lab sequences.

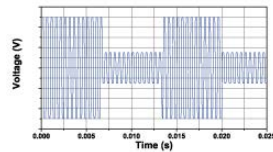
In order to prevent the separation and build up of charges in the liquid crystal layer, the LCC25 will automatically detect and correct any DC offset in real time to within  $\pm 10$  mV.

### LCC25 Specifications

LCC25 Specifications	
<b>Electrical Specs</b>	
Adjustable Output Voltage	$\pm 25$ V
External Input Voltage	0 to 5 VDC Square Wave
Voltage Resolution	1.0 mV
Adjustable Internal Modulation Frequency	0.5 to 150 Hz @ 50% Duty Cycle
Switching Frequency	2,000 $\pm$ 5 Hz, 50% Duty Cycle
Slew Rate	10 V/ $\mu$ s
DC offset	$\pm 10$ mV
Max Output Current	15 mA
AC Power	85 – 264 VAC, 47 – 63 Hz, 25 VA
Fuse Rating	125 mA, 5 x 20 mm SLO-BLO
Warm Up Time	30 Minutes
<b>Physical Specs</b>	



**Figure A.** A plot of the output voltage of the LCC25 Liquid Crystal Controller when it is being operated in the constant voltage mode.



**Figure B.** A plot of the output voltage of the LCC25 Liquid Crystal Controller when the output voltage is being modulated between the two set voltages.

## Software for the LCC25 Controller

### Software

Version 3.2.0

GUI Interface for controlling the Liquid Crystal Retarder Controller via a PC. To download, Click the button below.

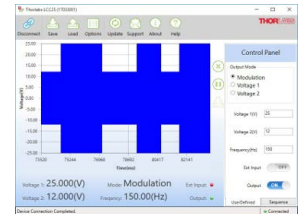


#### GUI Interface

The GUI interface included with the software provides access to all of the settings of the liquid crystal retarder controller. For example, the user can select one of two user-defined voltages or a modulation mode that oscillates between these two voltages at a user-defined frequency. As shown in the above screen shot, the applied voltage is shown in a plot with respect to time. Both the output and external input can be turned on and off via the GUI. In addition, advanced features allow the user to define a custom waveform by specifying the starting voltage, ending voltage, the voltage step size, and the dwell time. The waveform may be previewed on the screen before it is output to the retarder, and it may be saved so that the LCC25 can be restarted quickly in the future. The GUI is available as a stand-alone or LabVIEW based version for flexibility in implementation.

#### Custom Software Development

Users may also use the provided C/C++ and LabVIEW software development kits for implementing the liquid crystal retarder controller with other instruments. Sample C++ code and LabVIEW programs help to illustrate how the C commands and LabVIEW VIs can be utilized. Full documentation on the available commands is provided with the software.



Click to Enlarge  
Screen shot of the GUI interface in Modulation Mode.

## CUSTOM CAPABILITIES

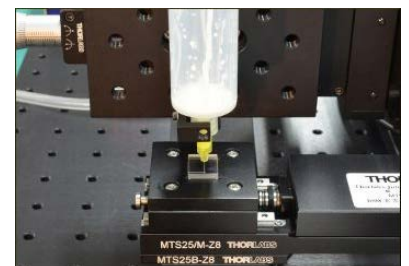
### Thorlabs' Custom Liquid Crystal Capabilities

Thorlabs offers a large variety of liquid crystal retarders from stock, including 1/2-, 3/4-, and full-wave models with a Ø10 mm or Ø20 mm clear aperture as well as 1/2-wave temperature-controlled models. However, we also offer OEM and custom retarders. The retardance range, coating, rubbing angle, temperature stabilization, and size can be customized to meet many unique optical designs. We also offer other custom liquid crystal devices, such as empty LC cells, polarization rotators, and noise eaters. For more information about ordering a custom liquid crystal device, please contact Thorlabs' technical support.

Our engineers work directly with our customers to discuss the specifications and other design aspects of a custom liquid crystal retarder. They will analyze both the design and feasibility to ensure the custom products are manufactured to high-quality standards and in a timely manner.

#### Polyimide (PI) Coating and Rubbing - Custom Alignment Angle

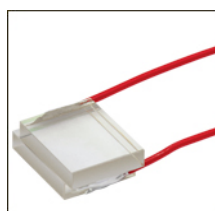
In their nematic phase, liquid crystal molecules naturally align to an average orientation, which together with their stretched shape, creates an optical anisotropy, or direction-dependent optical effect. The orientation of the LC molecules in an LC cell, in the absence of an applied voltage, is determined by the alignment layer, created by the polyimide (PI) coating and rubbing angle. Rubbing creates grooves, which the liquid crystal molecules will align to. Users can



Click to Enlarge  
Liquid Crystal Cell Seal Application



choose any initial orientation of LC molecules by specifying the rubbing angle.



Click to Enlarge  
Custom Liquid Crystal Cell Without Case

### Custom Cell Spacing

The wall spacing inside of the liquid crystal cell, which determines the thickness of LC material, can be customized during the manufacturing process. The retardance range of an LC cell is dependent on the LC material thickness:

$$\delta = \frac{2\pi d \Delta n}{\lambda_v}$$

Here,  $\delta$  is the retardance in waves,  $d$  is the thickness of the LC material,  $\lambda_v$  is the wavelength of light, and  $\Delta n$  is the birefringence of the LC material used. Thus, for a given wavelength, the retardance is determined by the wall spacing inside the LC cell (i.e., the thickness of LC layer). We offer standard retardance ranges of  $\lambda/2$  to 30 nm,  $3\lambda/4$  to 30 nm, and  $\lambda$  to 30 nm, but higher retardance ranges may also be ordered.

### Custom Liquid Crystal Material

Customers can also provide their own liquid crystal material, and Thorlabs will use it to fill the liquid crystal cell. Since different liquid crystal materials have different birefringence values, varying the material enables a different retardance range.

### Temperature Control/Switching Time

A temperature sensor can also be integrated into the LC variable retarder. Using a temperature controller, the temperature of the retarder can be actively stabilized to within  $\pm 0.1$  °C. The viscosity of the liquid crystal material is lowered at higher temperatures, allowing the retarder to switch from one state to another due to the decreased viscosity. An active temperature control system can be used to heat the retarder, allowing it to operate at higher switching speeds.

### Assembly / Housing

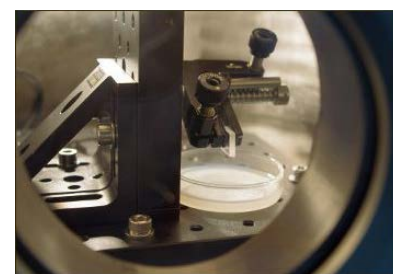
If desired, we can manufacture custom liquid crystal retarders without housings.

### Testing

Each LC retarder is tested for birefringence, uniformity, and fast axis angle, using the measurement setup shown in the photo to the left. The equipment measures the 2-dimensional birefringence distribution using wave plates and a CCD camera. The image to the right shows a sample test result of a liquid crystal retarder, showing excellent uniformity.

### For More Information

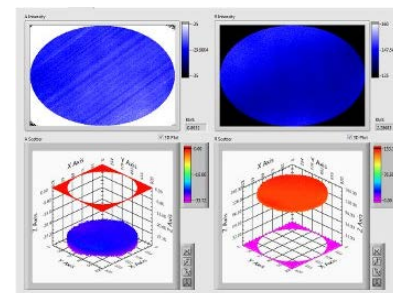
Contact Thorlabs' technical support for more information about our custom liquid crystal device options or to place an order.



Click to Enlarge  
Liquid Crystal Cell Filling in a Vacuum Chamber



Click to Enlarge  
Custom Liquid Crystal Cell Test Setup



Click to Enlarge  
Custom Liquid Crystal Cell Test Result

## PATTERNED RETARDERS

### Features

- Build a Custom Microretarder
- Customize Size, Shape, and Substrate Material
- Retardance Range: 50 - 550 nm
- Fast Axis Resolution:  $<1^\circ$
- Retardance Fluctuations Under 30 nm

### Applications

- 3D Displays
- Polarization Imaging

Custom Capability	Custom Specification
Patterned Retarder Size	$\varnothing 100 \mu\text{m}$ to $\varnothing 2"$
Patterned Retarder Shape	Any
Microretarder Size	$\geq \varnothing 30 \mu\text{m}$
Microretarder Shape	Round or Square
Retardance Range @ 632.8 nm	50 to 550 nm
Substrate	N-BK7, UV Fused Silica, or Other Glass
Substrate Size	$\varnothing 5 \text{ mm}$ to $\varnothing 2"$
	-A: 350 - 700 nm

- Diffractive Optical Applications: Polarization Gratings, Polarimetry, and Beam Steering

AR Coating

-B: 650 - 1050 nm  
-C: 1050 - 1700 nm

Thorlabs offers customizable patterned retarders, available in any pattern size from Ø100 µm to Ø2" and any substrate size from Ø5 mm to Ø2". These custom retarders are composed of an array of microretarders, each of which has a fast axis aligned to a different angle than its neighbor. The size and shape of the microretarders are also customizable. They can be as small as 30 µm and in shapes including circles and squares. This control over size and shape of the individual microretarders allows us to construct a large array of various patterned retarders to meet nearly any experimental or device need.

These patterned retarders are constructed from our liquid crystals and liquid crystal polymers. Using photo alignment technology, we can secure the fast axis of each microretarder to any angle within a resolution of <1°. Figures 1 - 3 show examples of our patterned retarders. The figures represent measured results of the patterned retarder captured on an imaging polarimeter and demonstrate that the fast axis orientation of any one individual microretarder can be controlled deterministically and separately from its neighbors.

The manufacturing process for our patterned retarders is controlled completely in house. It begins by preparing the substrate, which is typically N-BK7 or UV fused silica (although other glass substrates may be compatible as well). The substrate is then coated with a layer of photoalignment material and placed in our patterned retarder system where sections are exposed to linearly polarized light to set the fast axis of a microretarder. The area of the exposed sections depends on the desired size of the microretarder; the fast axis can be set between 0° and 180° with a resolution <1°. Once set, the liquid crystal cell is constructed by coating the device with a liquid crystal polymer and curing it with UV light.

Thorlabs' LCP depolarizers provide one example of these patterned retarders. In principle, a truly randomized pattern may be used as a depolarizer, since it scrambles the input polarization spatially. However, such a pattern will also introduce a large amount of diffraction. For our depolarizers, we designed a linearly ramping fast axis angle and retardance that can depolarize both broadband and monochromatic beams down to diameters of 0.5 mm without introducing additional diffraction. For more details, see the webpage for our LCP depolarizers.

By supplying Thorlabs with a drawing of the desired patterned retarder or an excel file of the fast axis distribution, we can construct almost any patterned retarder. For more information on creating a patterned retarder, please contact Tech Support.

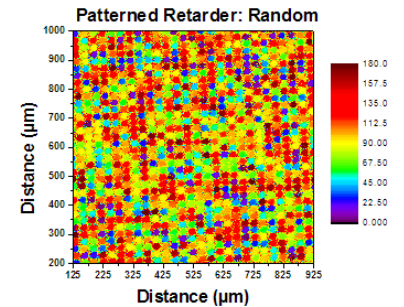


Figure 1: Patterned Retarder with Random Distribution

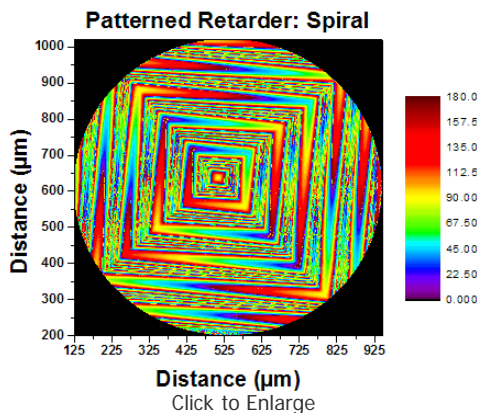


Figure 2: Patterned Retarder with a Spiral Distribution

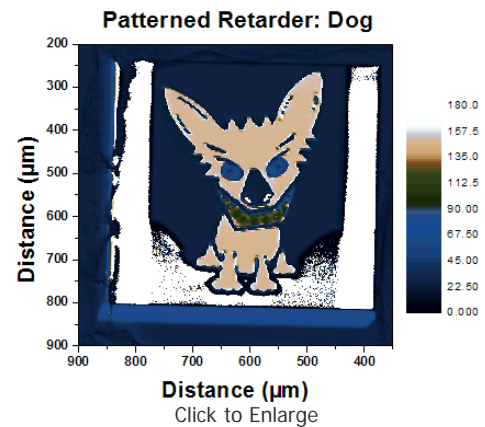


Figure 3: Patterned Retarder with a Pictorial Distribution

## DAMAGE THRESHOLDS

### Damage Threshold Data for Thorlabs' Liquid Crystal Polarization Rotators

The specifications to the right are measured data for Thorlabs' Three-Quarter-Wave Liquid Crystal Variable Retarders.

Damage Threshold Specifications		
Item #	Laser Type	Damage Threshold
LCC1112-C	Pulsed (ns)	1.25 J/cm <sup>2</sup> (1542 nm, 10 Hz, 10 ns, Ø0.458 mm)
LCC1222-C		

## Laser Induced Damage Threshold Tutorial



The following is a general overview of how laser induced damage thresholds are measured and how the values may be utilized in determining the appropriateness of an optic for a given application. When choosing optics, it is important to understand the Laser Induced Damage Threshold (LIDT) of the optics being used. The LIDT for an optic greatly depends on the type of laser you are using. Continuous wave (CW) lasers typically cause damage from thermal effects (absorption either in the coating or in the substrate). Pulsed lasers, on the other hand, often strip electrons from the lattice structure of an optic before causing thermal damage. Note that the guideline presented here assumes room temperature operation and optics in new condition (i.e., within scratch-dig spec, surface free of contamination, etc.). Because dust or other particles on the surface of an optic can cause damage at lower thresholds, we recommend keeping surfaces clean and free of debris. For more information on cleaning optics, please see our [Optics Cleaning](#) tutorial.

## Testing Method

Thorlabs' LIDT testing is done in compliance with ISO/DIS 11254 and ISO 21254 specifications.

First, a low-power/energy beam is directed to the optic under test. The optic is exposed in 10 locations to this laser beam for 30 seconds (CW) or for a number of pulses (pulse repetition frequency specified). After exposure, the optic is examined by a microscope (~100X magnification) for any visible damage. The number of locations that are damaged at a particular power/energy level is recorded. Next, the power/energy is either increased or decreased and the optic is exposed at 10 new locations. This process is repeated until damage is observed. The damage threshold is then assigned to be the highest power/energy that the optic can withstand without causing damage. A histogram such as that below represents the testing of one BB1-E02 mirror.



The photograph above is a protected aluminum-coated mirror after LIDT testing. In this particular test, it handled  $0.43 \text{ J/cm}^2$  (1064 nm, 10 ns pulse, 10 Hz,  $\text{Ø}1.000 \text{ mm}$ ) before damage.

According to the test, the damage threshold of the mirror was  $2.00 \text{ J/cm}^2$  (532 nm, 10 ns pulse, 10 Hz,  $\text{Ø}0.803 \text{ mm}$ ). Please keep in mind that these tests are performed on clean optics, as dirt and contamination can significantly lower the damage threshold of a component. While the test results are only representative of one coating run, Thorlabs specifies damage threshold values that account for coating variances.

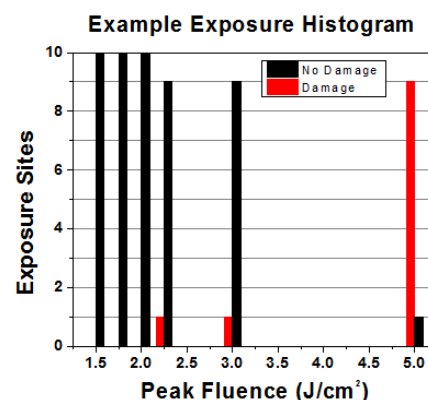
## Continuous Wave and Long-Pulse Lasers

When an optic is damaged by a continuous wave (CW) laser, it is usually due to the melting of the surface as a result of absorbing the laser's energy or damage to the optical coating (antireflection) [1]. Pulsed lasers with pulse lengths longer than  $1 \mu\text{s}$  can be treated as CW lasers for LIDT discussions.

When pulse lengths are between 1 ns and  $1 \mu\text{s}$ , laser-induced damage can occur either because of absorption or a dielectric breakdown (therefore, a user must check both CW and pulsed LIDT). Absorption is either due to an intrinsic property of the optic or due to surface irregularities; thus LIDT values are only valid for optics meeting or exceeding the surface quality specifications given by a manufacturer. While many optics can handle high power CW lasers, cemented (e.g., achromatic doublets) or highly absorptive (e.g., ND filters) optics tend to have lower CW damage thresholds. These lower thresholds are due to absorption or scattering in the cement or metal coating.

Pulsed lasers with high pulse repetition frequencies (PRF) may behave similarly to CW beams. Unfortunately, this is highly dependent on factors such as absorption and thermal diffusivity, so there is no reliable method for determining when a high PRF laser will damage an optic due to thermal effects. For beams with a high PRF both the average and peak powers must be compared to the equivalent CW power. Additionally, for highly transparent materials, there is little to no drop in the LIDT with increasing PRF.

In order to use the specified CW damage threshold of an optic, it is necessary to



Example Test Data			
Fluence	# of Tested Locations	Locations with Damage	Locations Without Damage
$1.50 \text{ J/cm}^2$	10	0	10
$1.75 \text{ J/cm}^2$	10	0	10
$2.00 \text{ J/cm}^2$	10	0	10
$2.25 \text{ J/cm}^2$	10	1	9
$3.00 \text{ J/cm}^2$	10	1	9
$5.00 \text{ J/cm}^2$	10	9	1

know the following:

1. Wavelength of your laser
2. Beam diameter of your beam (1/e<sup>2</sup>)
3. Approximate intensity profile of your beam (e.g., Gaussian)
4. Linear power density of your beam (total power divided by 1/e<sup>2</sup> beam diameter)

Thorlabs expresses LIDT for CW lasers as a linear power density measured in W/cm. In this regime, the LIDT given as a linear power density can be applied to any beam diameter; one does not need to compute an adjusted LIDT to adjust for changes in spot size, as demonstrated by the graph to the right. Average linear power density can be calculated using the equation below.

$$\text{Linear Power Density} = \frac{\text{Power}}{\text{Beam Diameter}}$$

The calculation above assumes a uniform beam intensity profile. You must now consider hotspots in the beam or other non-uniform intensity profiles and roughly calculate a maximum power density. For reference, a Gaussian beam typically has a maximum power density that is twice that of the uniform beam (see lower right).

Now compare the maximum power density to that which is specified as the LIDT for the optic. If the optic was tested at a wavelength other than your operating wavelength, the damage threshold must be scaled appropriately. A good rule of thumb is that the damage threshold has a linear relationship with wavelength such that as you move to shorter wavelengths, the damage threshold decreases (i.e., a LIDT of 10 W/cm at 1310 nm scales to 5 W/cm at 655 nm):

$$\text{Adjusted LIDT} = \text{LIDT Power} \left( \frac{\text{Your Wavelength}}{\text{LIDT Wavelength}} \right)$$

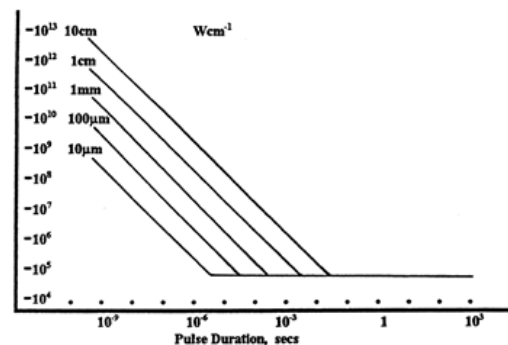
While this rule of thumb provides a general trend, it is not a quantitative analysis of LIDT vs wavelength. In CW applications, for instance, damage scales more strongly with absorption in the coating and substrate, which does not necessarily scale well with wavelength. While the above procedure provides a good rule of thumb for LIDT values, please contact Tech Support if your wavelength is different from the specified LIDT wavelength. If your power density is less than the adjusted LIDT of the optic, then the optic should work for your application.

Please note that we have a buffer built in between the specified damage thresholds online and the tests which we have done, which accommodates variation between batches. Upon request, we can provide individual test information and a testing certificate. The damage analysis will be carried out on a similar optic (customer's optic will not be damaged). Testing may result in additional costs or lead times. Contact Tech Support for more information.

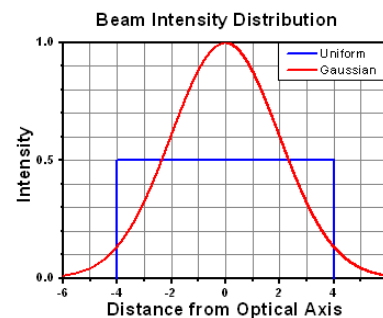
### Pulsed Lasers

As previously stated, pulsed lasers typically induce a different type of damage to the optic than CW lasers. Pulsed lasers often do not heat the optic enough to damage it; instead, pulsed lasers produce strong electric fields capable of inducing dielectric breakdown in the material. Unfortunately, it can be very difficult to compare the LIDT specification of an optic to your laser. There are multiple regimes in which a pulsed laser can damage an optic and this is based on the laser's pulse length. The highlighted columns in the table below outline the relevant pulse lengths for our specified LIDT values.

Pulses shorter than 10<sup>-9</sup> s cannot be compared to our specified LIDT values with much reliability. In this ultra-short-pulse regime various mechanics, such as multiphoton-avalanche ionization, take over as the predominate damage mechanism [2]. In contrast, pulses between 10<sup>-7</sup> s and 10<sup>-4</sup> s may cause damage to an optic either because of dielectric breakdown or thermal effects. This means that both CW and pulsed damage thresholds must be compared to the laser beam to determine whether the optic is suitable for your application.



LIDT in linear power density vs. pulse length and spot size. For long pulses to CW, linear power density becomes a constant with spot size. This graph was obtained from [1].

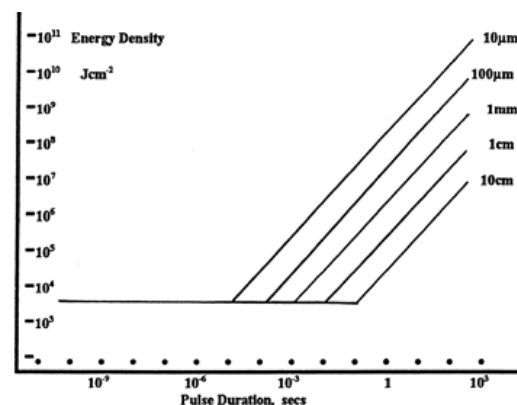


Pulse Duration	$t < 10^{-9}$ s	$10^{-9} < t < 10^{-6}$ s	$10^{-6} < t < 10^{-3}$ s	$t > 10^{-3}$ s
Damage Mechanism	Avalanche Ionization	Dielectric Breakdown	Dielectric Breakdown or Thermal	Thermal
Relevant Damage Specification	No Comparison (See Above)	Pulsed	Pulsed and CW	CW

When comparing an LIDT specified for a pulsed laser to your laser, it is essential to know the following:

1. Wavelength of your laser
2. Energy density of your beam (total energy divided by  $1/e^2$  area)
3. Pulse length of your laser
4. Pulse repetition frequency (prf) of your laser
5. Beam diameter of your laser ( $1/e^2$ )
6. Approximate intensity profile of your beam (e.g., Gaussian)

The energy density of your beam should be calculated in terms of  $J/cm^2$ . The graph to the right shows why expressing the LIDT as an energy density provides the best metric for short pulse sources. In this regime, the LIDT given as an energy density can be applied to any beam diameter; one does not need to compute an adjusted LIDT to adjust for changes in spot size. This calculation assumes a uniform beam intensity profile. You must now adjust this energy density to account for hotspots or other nonuniform intensity profiles and roughly calculate a maximum energy density. For reference a Gaussian beam typically has a maximum energy density that is twice that of the  $1/e^2$  beam.



LIDT in energy density vs. pulse length and spot size. For short pulses, energy density becomes a constant with spot size. This graph was obtained from [1].

Now compare the maximum energy density to that which is specified as the LIDT for the optic. If the optic was tested at a wavelength other than your operating wavelength, the damage threshold must be scaled appropriately [3]. A good rule of thumb is that the damage threshold has an inverse square root relationship with wavelength such that as you move to shorter wavelengths, the damage threshold decreases (i.e., a LIDT of  $1 J/cm^2$  at 1064 nm scales to  $0.7 J/cm^2$  at 532 nm):

$$\text{Adjusted LIDT} = \text{LIDT Energy} \sqrt{\frac{\text{Your Wavelength}}{\text{LIDT Wavelength}}}$$

You now have a wavelength-adjusted energy density, which you will use in the following step.

Beam diameter is also important to know when comparing damage thresholds. While the LIDT, when expressed in units of  $J/cm^2$ , scales independently of spot size; large beam sizes are more likely to illuminate a larger number of defects which can lead to greater variances in the LIDT [4]. For data presented here, a  $< 1$  mm beam size was used to measure the LIDT. For beams sizes greater than 5 mm, the LIDT ( $J/cm^2$ ) will not scale independently of beam diameter due to the larger size beam exposing more defects.

The pulse length must now be compensated for. The longer the pulse duration, the more energy the optic can handle. For pulse widths between 1 - 100 ns, an approximation is as follows:

$$\text{Adjusted LIDT} = \text{LIDT Energy} \sqrt{\frac{\text{Your Pulse Length}}{\text{LIDT Pulse Length}}}$$

Use this formula to calculate the Adjusted LIDT for an optic based on your pulse length. If your maximum energy density is less than this adjusted LIDT maximum energy density, then the optic should be suitable for your application. Keep in mind that this calculation is only used for pulses between  $10^{-9}$  s and  $10^{-7}$  s. For pulses between  $10^{-7}$  s and  $10^{-4}$  s, the CW LIDT must also be checked before deeming the optic appropriate for your application.

Please note that we have a buffer built in between the specified damage thresholds online and the tests which we have done, which accommodates variation between batches. Upon request, we can provide individual test information and a testing certificate. Contact Tech Support for more information.

[1] R. M. Wood, Optics and Laser Tech. **29**, 517 (1998).

[2] Roger M. Wood, *Laser-Induced Damage of Optical Materials* (Institute of Physics Publishing, Philadelphia, PA, 2003).

[3] C. W. Carr *et al.*, Phys. Rev. Lett. **91**, 127402 (2003).

[4] N. Bloembergen, Appl. Opt. **12**, 661 (1973).

## LIDT CALCULATIONS

In order to illustrate the process of determining whether a given laser system will damage an optic, a number of example calculations of laser induced damage threshold are given below. For assistance with performing similar calculations, we provide a spreadsheet calculator that can be downloaded by clicking the button to the right. To use the calculator, enter the specified LIDT value of the optic under consideration and the relevant parameters of your laser system in the green boxes. The spreadsheet will then calculate a linear power density for CW and pulsed systems, as well as an energy density value for pulsed systems. These values are used to calculate adjusted, scaled LIDT values for the optics based on accepted scaling laws. This calculator assumes a Gaussian beam profile, so a correction factor must be introduced for other beam shapes (uniform, etc.). The LIDT scaling laws are determined from empirical relationships; their accuracy is not guaranteed. Remember that absorption by optics or coatings can significantly reduce LIDT in some spectral regions. These LIDT values are not valid for ultrashort pulses less than one nanosecond in duration.

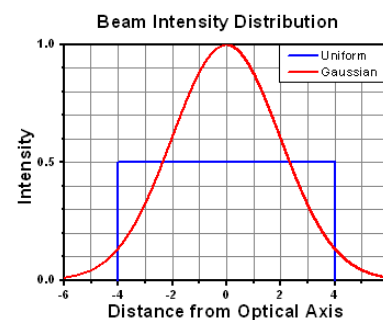
[LIDT Calculator](#)

### CW Laser Example

Suppose that a CW laser system at 1319 nm produces a 0.5 W Gaussian beam that has a  $1/e^2$  diameter of 10 mm. A naive calculation of the average linear power density of this beam would yield a value of 0.5 W/cm, given by the total power divided by the beam diameter:

$$\text{Linear Power Density} = \frac{\text{Power}}{\text{Beam Diameter}}$$

However, the maximum power density of a Gaussian beam is about twice the maximum power density of a uniform beam, as shown in the graph to the right. Therefore, a more accurate determination of the maximum linear power density of the system is 1 W/cm.



A Gaussian beam profile has about twice the maximum intensity of a uniform beam profile.

An AC127-030-C achromatic doublet lens has a specified CW LIDT of 350 W/cm, as tested at 1550 nm. CW damage threshold values typically scale directly with the wavelength of the laser source, so this yields an adjusted LIDT value:

$$\text{Adjusted LIDT} = \text{LIDT Power} \left( \frac{\text{Your Wavelength}}{\text{LIDT Wavelength}} \right)$$

The adjusted LIDT value of 350 W/cm  $\times$  (1319 nm / 1550 nm) = 298 W/cm is significantly higher than the calculated maximum linear power density of the laser system, so it would be safe to use this doublet lens for this application.

### Pulsed Nanosecond Laser Example: Scaling for Different Pulse Durations

Suppose that a pulsed Nd:YAG laser system is frequency tripled to produce a 10 Hz output, consisting of 2 ns output pulses at 355 nm, each with 1 J of energy, in a Gaussian beam with a 1.9 cm beam diameter ( $1/e^2$ ). The average energy density of each pulse is found by dividing the pulse energy by the beam area:

$$\text{Energy Density} = \frac{\text{Pulse Energy}}{\text{Beam Area}}$$

As described above, the maximum energy density of a Gaussian beam is about twice the average energy density. So, the maximum energy density of this beam is  $\sim 0.7 \text{ J/cm}^2$ .

The energy density of the beam can be compared to the LIDT values of 1 J/cm<sup>2</sup> and 3.5 J/cm<sup>2</sup> for a BB1-E01 broadband dielectric mirror and an NB1-K08 Nd:YAG laser line mirror, respectively. Both of these LIDT values, while measured at 355 nm, were determined with a 10 ns pulsed laser at 10 Hz. Therefore, an adjustment must be applied for the shorter pulse duration of the system under consideration. As described on the previous tab, LIDT values in the nanosecond pulse regime scale with the square root of the laser pulse duration:

$$\text{Adjusted LIDT} = \text{LIDT Energy} \sqrt{\frac{\text{Your Pulse Length}}{\text{LIDT Pulse Length}}}$$

This adjustment factor results in LIDT values of 0.45 J/cm<sup>2</sup> for the BB1-E01 broadband mirror and 1.6 J/cm<sup>2</sup> for the Nd:YAG laser line mirror, which are to be compared with the 0.7 J/cm<sup>2</sup> maximum energy density of the beam. While the broadband mirror would likely be damaged by the laser, the more specialized laser line mirror is appropriate for use with this system.

#### Pulsed Nanosecond Laser Example: Scaling for Different Wavelengths

Suppose that a pulsed laser system emits 10 ns pulses at 2.5 Hz, each with 100 mJ of energy at 1064 nm in a 16 mm diameter beam (1/e<sup>2</sup>) that must be attenuated with a neutral density filter. For a Gaussian output, these specifications result in a maximum energy density of 0.1 J/cm<sup>2</sup>. The damage threshold of an NDUV10A Ø25 mm, OD 1.0, reflective neutral density filter is 0.05 J/cm<sup>2</sup> for 10 ns pulses at 355 nm, while the damage threshold of the similar NE10A absorptive filter is 10 J/cm<sup>2</sup> for 10 ns pulses at 532 nm. As described on the previous tab, the LIDT value of an optic scales with the square root of the wavelength in the nanosecond pulse regime:

$$\text{Adjusted LIDT} = \text{LIDT Energy} \sqrt{\frac{\text{Your Wavelength}}{\text{LIDT Wavelength}}}$$

This scaling gives adjusted LIDT values of 0.08 J/cm<sup>2</sup> for the reflective filter and 14 J/cm<sup>2</sup> for the absorptive filter. In this case, the absorptive filter is the best choice in order to avoid optical damage.

#### Pulsed Microsecond Laser Example

Consider a laser system that produces 1 µs pulses, each containing 150 µJ of energy at a repetition rate of 50 kHz, resulting in a relatively high duty cycle of 5%. This system falls somewhere between the regimes of CW and pulsed laser induced damage, and could potentially damage an optic by mechanisms associated with either regime. As a result, both CW and pulsed LIDT values must be compared to the properties of the laser system to ensure safe operation.

If this relatively long-pulse laser emits a Gaussian 12.7 mm diameter beam (1/e<sup>2</sup>) at 980 nm, then the resulting output has a linear power density of 5.9 W/cm and an energy density of 1.2 x 10<sup>-4</sup> J/cm<sup>2</sup> per pulse. This can be compared to the LIDT values for a WPQ10E-980 polymer zero-order quarter-wave plate, which are 5 W/cm for CW radiation at 810 nm and 5 J/cm<sup>2</sup> for a 10 ns pulse at 810 nm. As before, the CW LIDT of the optic scales linearly with the laser wavelength, resulting in an adjusted CW value of 6 W/cm at 980 nm. On the other hand, the pulsed LIDT scales with the square root of the laser wavelength and the square root of the pulse duration, resulting in an adjusted value of 55 J/cm<sup>2</sup> for a 1 µs pulse at 980 nm. The pulsed LIDT of the optic is significantly greater than the energy density of the laser pulse, so individual pulses will not damage the wave plate. However, the large average linear power density of the laser system may cause thermal damage to the optic, much like a high-power CW beam.

### Ø10 mm Three-Quarter-Wave Liquid Crystal Retarders

- ▶ Ø10 mm Clear Aperture
- ▶ 1" Outer Diameter
- ▶ 1050 - 1620 nm AR Coating

Thorlabs' Ø10 mm clear aperture, 3/4-wave liquid crystal retarder features an AR coating for 1050 - 1620 nm light. It has an outer diameter of 1", making it compatible with any of our Ø1" optic mounts for 8 mm thick optics. The RSP1 mount provides precise rotational adjustment and post mounting capability, while the CRM1P adds 30 mm cage-mounting versatility.

This item **Limited STOCK** will be retired without replacement when stock is depleted. If you require this part for line production, please contact our OEM Team.

Part Number	Description	Price	Availability
LCC1112-C	3/4-Wave Liquid Crystal Retarder, Ø10 mm CA, ARC 1050 - 1620 nm	\$827.82	Today

## Ø20 mm Three-Quarter-Wave Liquid Crystal Retarder

- ▶ Ø20 mm Large Clear Aperture
- ▶ 2" Outer Diameter
- ▶ 1050 - 1620 nm AR Coating

Thorlabs' Ø20 mm clear aperture, 3/4-wave liquid crystal retarder is available with a 1050 - 1620 nm AR coating. It has an outer diameter of 2", making it compatible with any of our Ø2" optic mounts for 13 mm thick optics. The RSP2 mount provides precise rotational adjustment and post mounting capability, while the LCRM2 adds 60 mm cage-mounting versatility.

This **Limited STOCK** item will be retired without replacement when stock is depleted. If you require this part for line production, please contact our OEM Team.

Part Number	Description	Price	Availability
LCC1222-C	3/4-Wave Liquid Crystal Retarder, Ø20 mm CA, ARC 1050 - 1620 nm	\$1,071.29	Lead Time

## Liquid Crystal Controller

- ▶ Output Voltage Adjustment Range:  $\pm 25$  VAC ( $f = 2000 \pm 5$  Hz)
- ▶ Max Output Current: 15 mA
- ▶ Output Connector: BNC
- ▶ AC Power Requirements: 85 - 264 VAC, 47 - 63 Hz, 25 VA
- ▶ See the *LC Controller* Tab Above for More Information



Click to Enlarge  
Back Panel of the LCC25 Liquid  
Crystal Controller

The LCC25 is a liquid crystal controller compatible with all Thorlabs LC Variable Retarders and Polarization Rotators, as well as being ideal for driving most other nematic liquid crystal devices. Nematic LC retarders must be driven with an AC voltage in order to prevent the separation and build up of charge, which can cause the device to burn out. In addition to the 2000 Hz AC drive voltage, the LCC25 controller automatically zeros the DC bias across the LC device in order to counteract the buildup of charges. The AC output voltage of the LCC25 controller can be adjusted using the front panel controls, an external 0 - 5 VDC TTL input, and via the USB interface. For more information about the LCC25 controller and for a complete list of its specifications, please see the *LC Controller* tab.

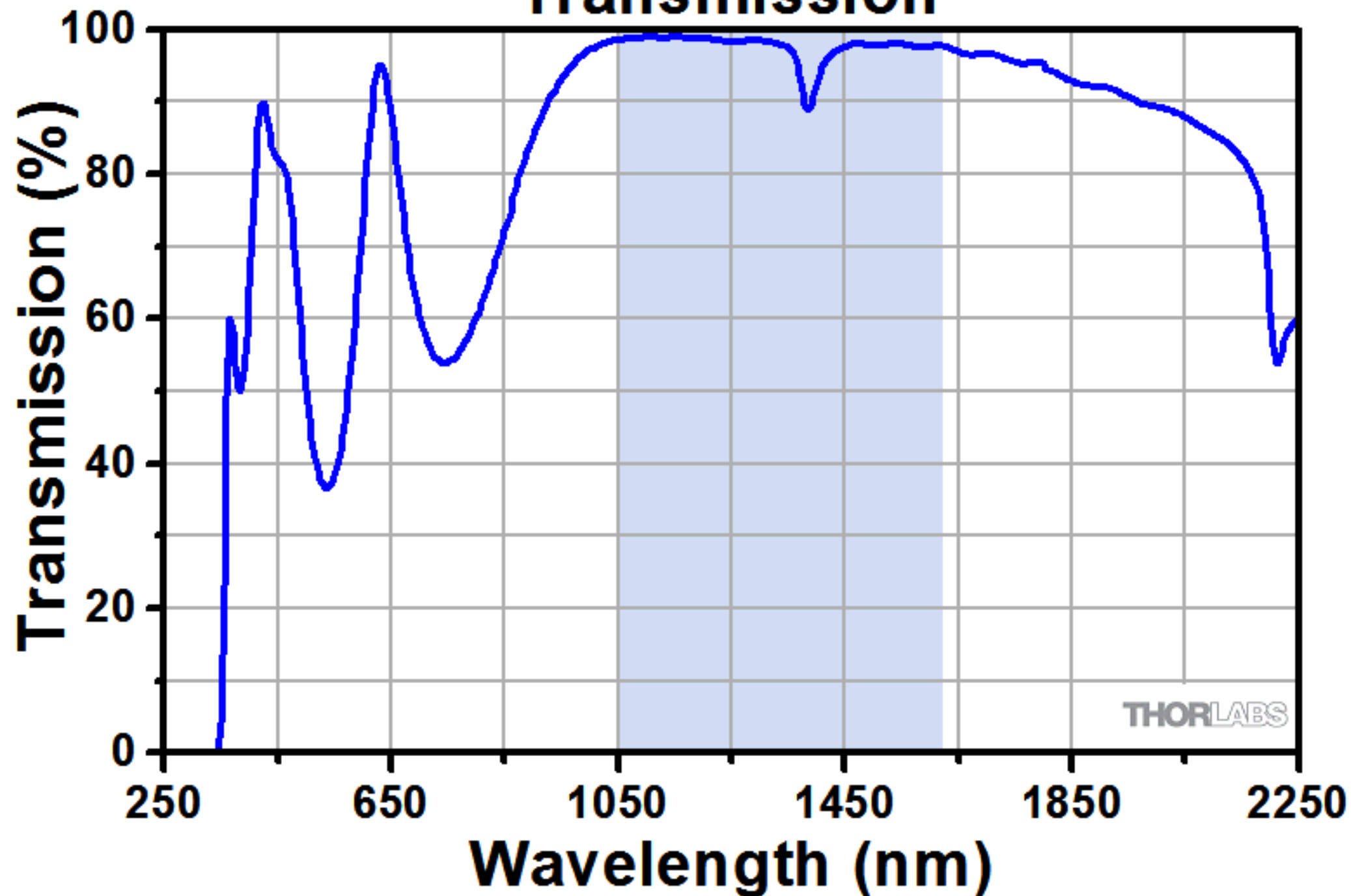
Part Number	Description	Price	Availability
LCC25	Liquid Crystal Controller, 0-25 VAC, Square Wave, 50% Duty Cycle	\$1,405.67	Today





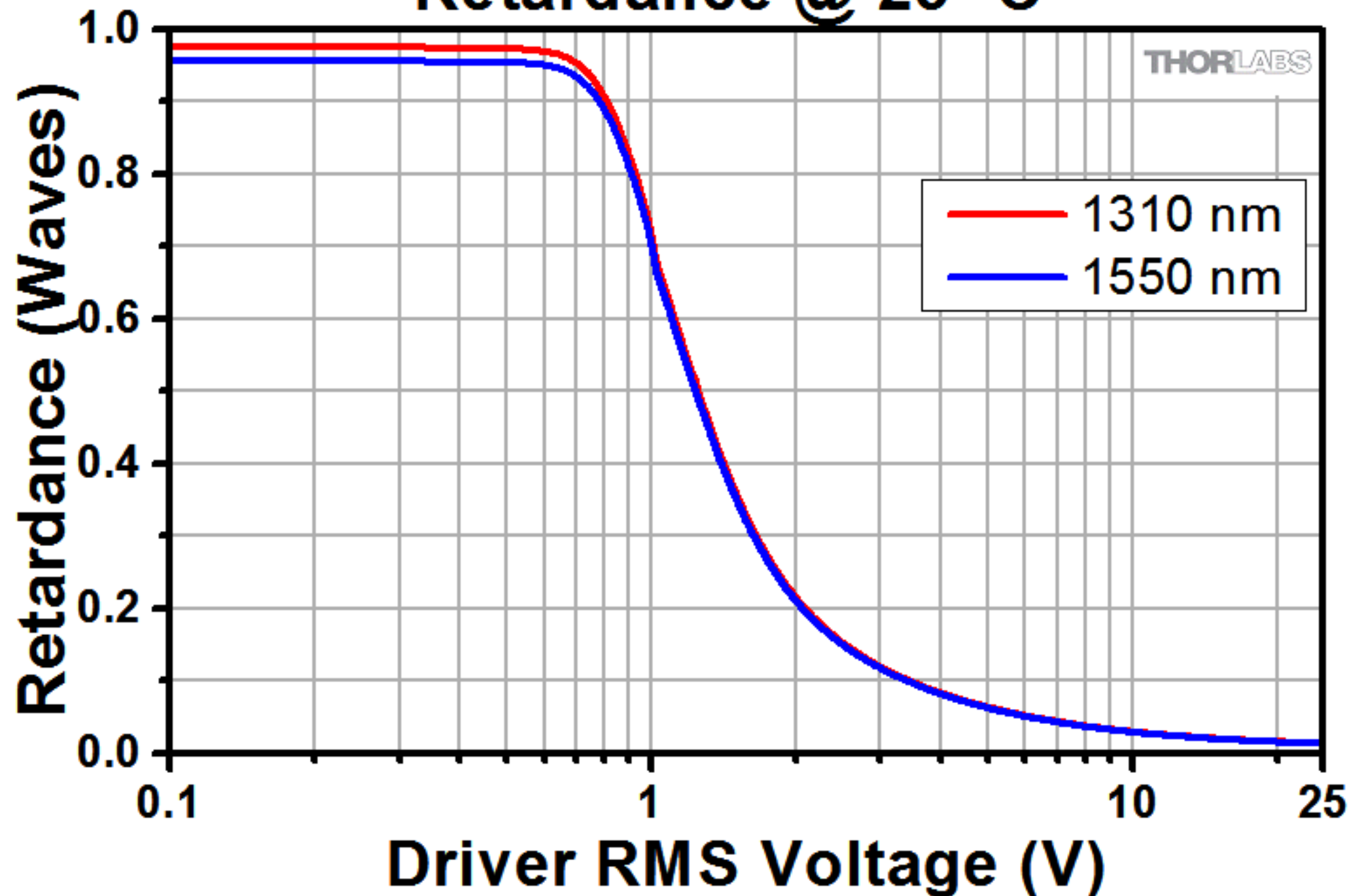
# LCC1112-C & LCC1222-C

## Transmission



# LCC1112-C & LCC1222-C

## Retardance @ 25 °C



# LCC1112-C & LCC1222-C

## Retardance @ 1550 nm

