Design and Performance of an automated GONG LCVR characterization system

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Summary:

A system was developed for remote characterization of the liquid crystal variable retarders (LCVRs) that are used in the GONG instrument system. This technical report describes the technical design, implementation and performance of this calibration system. GONG LC retarders are used for the full disk longitudinal magnetic field measurement via the Zeeman diagnostics. The goal is to determine two voltage settings of the LCVR which correspond to the ¼ and ¾ wave retardance. These voltages are then used to alternately filter right and left circularly polarized component of the light. By encoding the circular polarization in terms of detector intensities one can measure Zeeman separation between the two circularly polarized sigma components, which is proportional to the line-of-sight magnetic field. The LCVRs drift in their properties over time due to aging and continuous exposure to residual ultra-violet component of the incoming sunlight, thus one often requires recalibration of the LCVR voltage settings. To enable remote calibration of the LCVRs an automated system was designed, and a prototype was demonstrated using off-the-shelf components. This technical report summarizes the design and implementation of this prototype and results of the calibration tests.

Introduction:

A system was developed for remote characterization of the liquid crystal variable retarders (LCVRs) used in the GONG instrument system. This technical report describes the technical design, implementation and performance of this system. The GONG LCVRs are essentially used to switch the polarization state of the incoming circular polarized light to linearly polarized light oriented at 45 degrees. There are two settings of the LCVR which need to be set to correct voltages to alternately allows right and left circularly polarized light into the system. By encoding this polarization in terms of detector intensities one derives the line-of-sight magnetic field. The LCVRs drift in their properties over time due to aging and continuous exposure to residual ultra-violet component of the incoming sunlight, thus one requires a frequent calibration of the LCVR voltage settings. To this purpose a system was designed, and a prototype was developed which can be implemented using off-the-shelf components and allows remote calibration of the GONG LCVRs.

Requirements:

The requirements are as follows:

1. To be able to derive the ¼ and ¾ wave retardance voltages of the LCVR, for the 676.8 nm wavelength corresponding to the Nickel spectral line used in GONG.
2. To be able to map the variation (non-uniformity) of this setting across the clear aperture of the LCVR.
3. To be able to measure the response time of the transitions between ¼ to ¾ wave setting and ¾ to ¼ wave setting.
4. To be able to do these measurements remotely and as quickly as possible to prevent interruptions to the regular observations.

Design Principle:

The design principle is as follows: Feed circularly polarized light through the LCVR and vary the voltage of the LCVR in small increments. At each voltage setting, record the detector (GONG science camera) intensity. The voltage versus intensity profile would resemble a sine wave sampled with unequal steps in phase (this is because equal steps in voltage do not result in equal increments due to the nonlinear response of the LCVR retardance). The best settings for ¼ and ¾ wave retardances correspond to the maxima and minima of this sine wave. By fitting a polynomial function to the peak and bottom of the sine curve one can derive the desired voltages. This fitting can be done on a pixel-by-pixel basis to achieve a map of these voltages across the aperture of the LCVR, which then gives us a measure of the nonuniformity in these values across the aperture of the LCVR. The median value (across the aperture) of the ¼ and ¾ wave voltages are then our optimal LO and HI voltages for the observations. The distribution of the voltages across the aperture also lets us quantify the large anomalies present in the LCVR, if any. Such large anomalies can develop due to aging, failures due to UV radiation (leaking from the GONG entrance window) or just mechanical failure of LC cavity.

For the measurement of the response time or switching time between the LO to HI setting and from HI back to LO setting following design approach is followed: With the same setup as above, let the LCVR switch between the HI and LO states at a low frequency of say 1/2 Hz (same as GONG modulation period) and with a duty cycle of 50%, i.e., 1s in LO state and 1s in HI state. Once this 1/2Hz modulation sequence is started, obtain a burst of images from the detector (GONG science camera) for 10 seconds or so. The time profile of the mean intensity of the images acquired would show a ½ Hz modulation and the transition time HI-LO and LO-HI can be derived by curve fitting. In LCVR switching terminology the transient nematic effect (TNE) is an effect where a high transient voltage (for a very small duration) is applied to LCVR before applying a HI setting voltage and in a similar way voltage is dropped to 0 before bringing it back to LO setting value. This process is used to accelerate the motion of liquid crystals and helps in getting an optimal switching and settling time. In GONG the profile of the transitioning voltage can be tuned to achieve a fast and uniform settling of the LCVR. The tailoring of the switching profiles is possible by looking at the rise and fall time of the intensity on the detector.

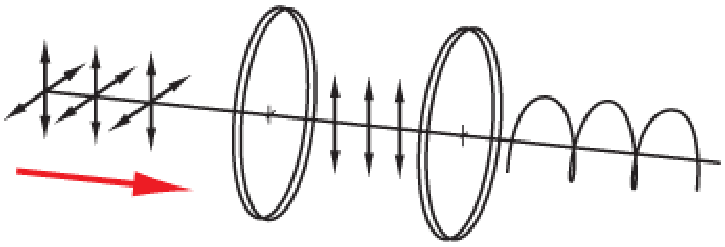
Implementation steps:

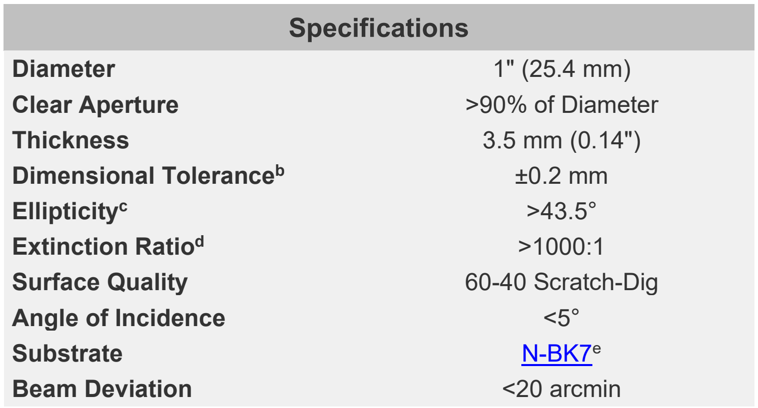
To implement the design philosophy above, following steps are required:

1. Obtain a high quality and uniform circular polarizer optic (it could be either right circular polarizer or left or both for redundancy).
2. Develop a mechanism to allow remote insertion and removal of a circular polarizer in the optical path, before the LCVR module.
3. Develop a system that can perform LCVR voltage tuning.
4. Develop software to control the mechanism for circular polarizer, the LCVR voltage and grab images from the camera.
5. Analyze data and compute best fit HI LO voltages and its nonuniformity across the aperture.
6. Capture of a burst of camera frames (small ROI near disk center) to sample LCVR rise and fall times.
7. Analyze data and find the rise and fall times of the transition.

Hardware/software Components:

1. A Circular Polarizer optic.
   A circular polarizer (CP) is a combination of a linear polarizer sandwiched with a quarter wave plate (QWP). The operation is to feed an unpolarized light at one end and circularly polarized light comes out at the other end. The two faces of the CP are not interchangeable. The linear polarizer side should always face the incoming light beam so that the output on the QWP side is circularly polarized. The purity of the circular polarized output, for a given CP optic, is wavelength dependent due to non-achromatic nature of QWP and the linear polarizer. Hence, we use circular polarizer specifically designed for GONG wavelength and of 1 inch diameter which easily allows integration in front of the prime focus allowing sufficient margin on all sides without causing vignetting. The product was procured from Thorlabs™ Part#CP1L670. The detailed specifications of the CP procured for this project is given in the Table below:





Specifications	
Diameter	1" (25.4 mm)
Clear Aperture	>90% of Diameter
Thickness	3.5 mm (0.14")
Dimensional Tolerance[b]	±0.2 mm
Ellipticity[c]	>43.5°
Extinction Ratio[d]	>1000:1
Surface Quality	60-40 Scratch-Dig
Angle of Incidence	<5°
Substrate	N-BK7[e]
Beam Deviation	<20 arcmin

Figure 1: Top panel shows how an unpolarized incoming beam interacts with the two layers of the circular polarizer to produce circularly polarized light. The specifications of the circular polarizer used are given in the table.

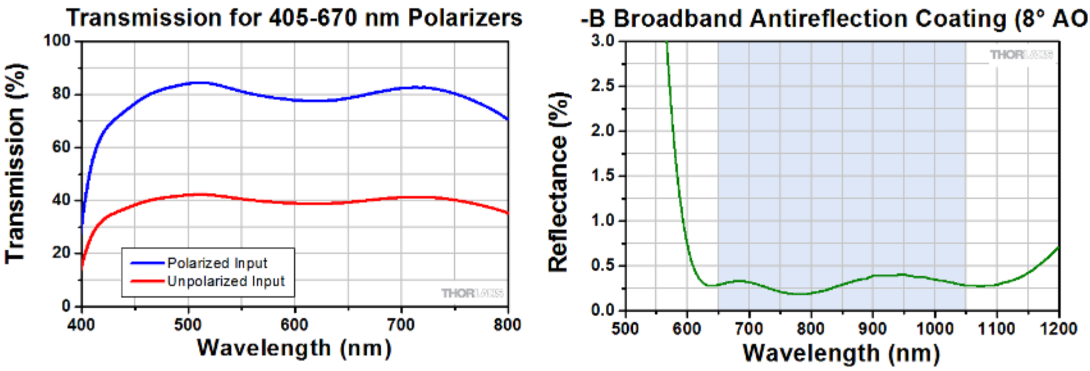


Figure 2: The circular polarizer optic is specified for the 405-670 nm wavelength range. The transmission characteristics (left panel) and the AR coating performance charts (right panel) are shown above.

2. Filter wheel to bring circular polarizer into the beam by computer command. We use six position motorized filter wheel from Thorlabs Part# FW102C. It can hold six one-inch optical filters of maximum thickness 6.35mm. However, in our case we currently need only one for holding the circular polarizer and can use all other positions as OPEN position for normal observations. In addition we can use the stage manually by pressing a feather touch button on the body of the filter wheel or via RS232/USB interface to a Windows PC or laptop. Using vendor provided software libraries one can send commands over RS232 or USB interface to move the filter wheel to one of the defined six positions or read the current value of the filter position. For mounting the wheel has a standard SM1 internal threading for use on optical bench with standard mounting hardware. Additionally, it can also be moved by a trigger signal over a BNC cable. There are two openings of which one can be used and other closed, this gives a choice of selecting the height of the opening above the optical bench.

3. Programmable voltage controller for the LCVR.
   For driving the LCVR with a DC balanced kHZ square wave we use Meadowlark CellDrive™ 5000 controller that can be readily interfaced with the GONG LCVRs which are also manufactured by Meadowlark. The controller can be digitally interfaced to the computer using USB connection.
4. Laptop with interfaces (USB, serial, Ethernet etc.) for the devices listed above and with a remote desktop connection feature enabled.
5. Script to synchronize LCVR voltage and camera acquisition.

Integration of Hardware:

The Thorlabs filter wheel is shown by yellow rectangle in the figure 3 below. It is placed in front of the LCVR (yellow arrow). The filter wheel consists of six positions: one of which is mounted with dark slide to block the beam if required, second position is mounted with circular polarizer (CPL), and third position is OPEN to allow the light to pass the system for regular observations. These positions can be changed/moved and also the current position can be read remotely via computer commands. The commands are simply ASCII commands per user manual, and are passed via RS232 port.

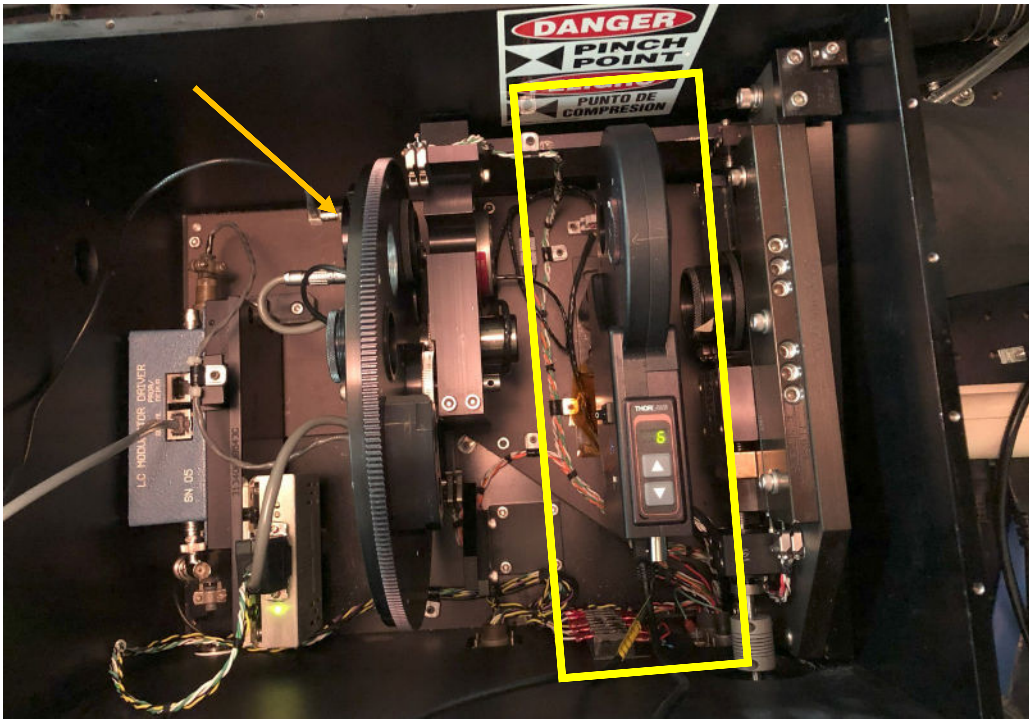


Figure 3: The Thorlabs Filter wheel is located inside the cal-2 box and is indicated by yellow rectangle. Yellow arrow indicated the LCVR.

LCVR Calibration Sequence:

A calibration sequence is initiated by moving the CPL into the beam via commands to the Thorlabs filter wheel. A sequence of voltages from 0 to 20V in increments of 0.1 V is then applied to the LCVR via Meadowlark LC driver. For each voltage an image is grabbed from the camera. Figure 4 below shows an example of full disk intensity map and the voltage response for intensity of the image. The mean intensity of the image inside the black square near the disk center is extracted for the full range of voltages applied to the LCVR, as plotted in the right panel of Figure 4. The vertical dashed lines mark the region where we fit the curve to derive the maximum and minimum intensities, corresponding to the ¼ and ¾ retardance voltages.

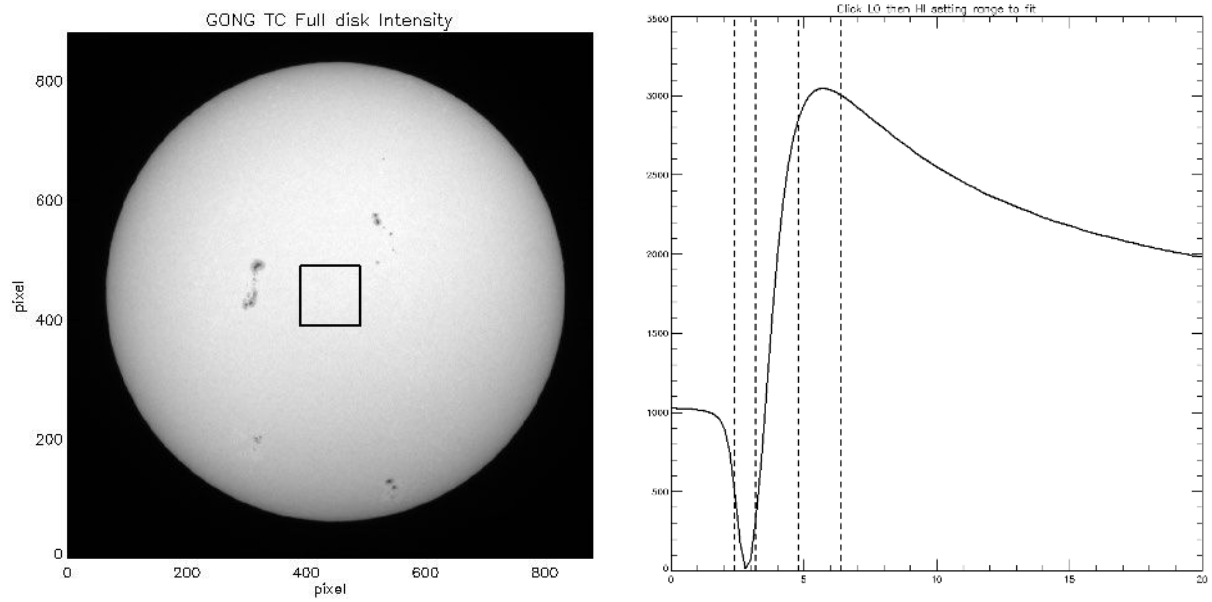


Figure 4: Left panel shows the sample image of the Sun acquired at one of the voltage settings. The mean intensity of the image inside the black square near the disk center, and its voltage response is shown in the right panel.

Aperture nonuniformity of the tuned Voltage:

Each pixel on solar disk exhibits a voltage response which is similar in shape to the curve shown in the right panel of the figure 4. However, quantitatively there are differences due to the nonuniformity in the LCVR retardance across its aperture. This nonuniformity arises primarity due to the nonuniform thickness of the cavity and hence the LC layer. To obtain the map of optimal voltage corresponding to the ¼ and ¾ wave retardance we fit the curve to obtain the minimum and maximum intensities for each pixel. However, to beat down the noise and to overcome seeing induced fluctuations in the periphery of the sunspots and limb we fit the profiles after doing a boxcar average of 5 pixels.

Results: Figure 5 shows the results of the calibration. The top panels show the map of the deviation from the median best fit voltage across the aperture. The median best fit voltage is indicated on the top of the graphs. The blue-red shades as indicated in the colorbar shpw the amount of deviation from median value. As can be seen, the deviation is very small, about 0.05 V for the left panel and 0.1 V for the right panel. Expressed as a percentage these deviations are about ~2% of the median value. If these values deviate significantly than few percent then the magnetograms should be evaluated for loss of magnetic signal in the affected regions. If significant amount of magnetic signal is lost then one should replace the LCVR.

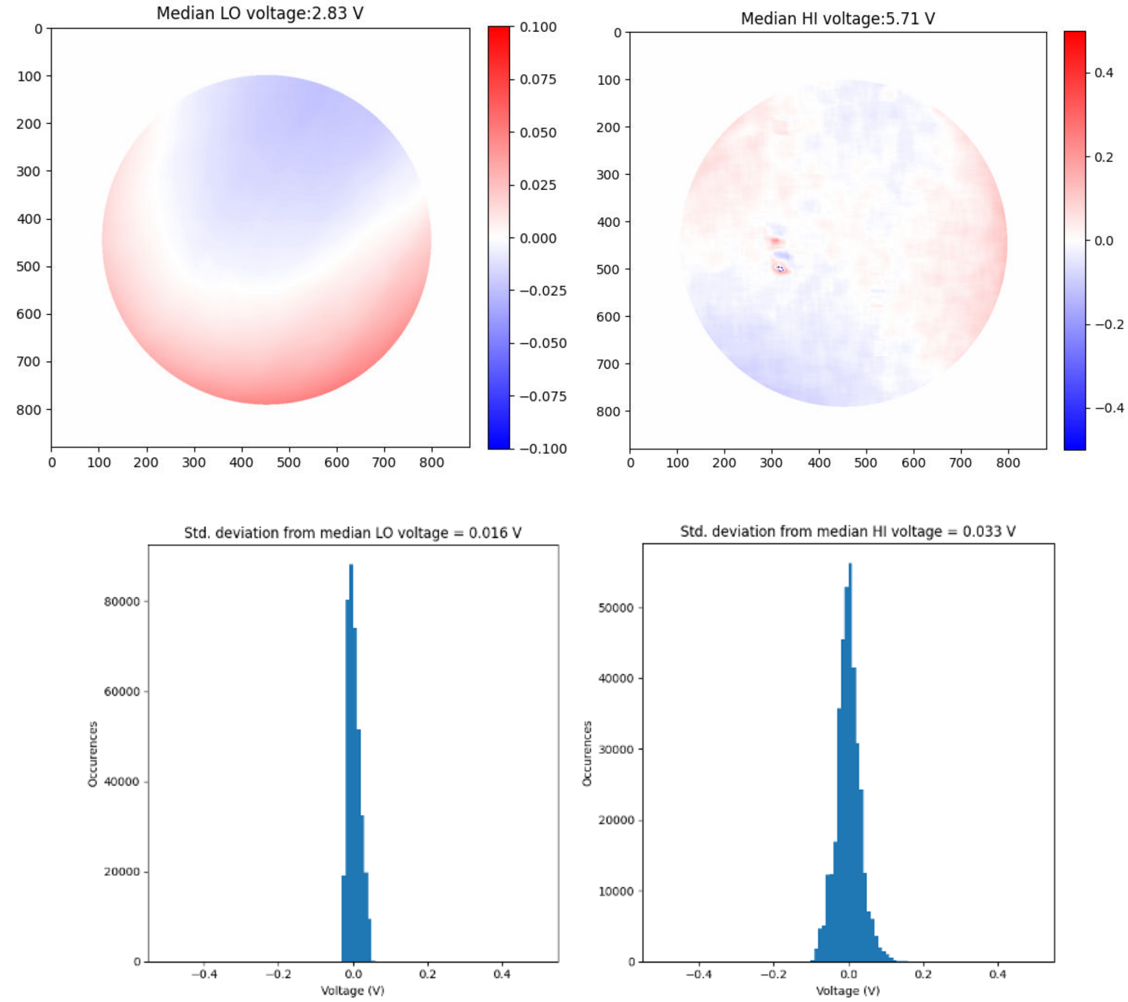


Figure 5: Top panels show the maps of deviations from the median value of the best-fit voltage corresponding to the minimum (left) and maximum (right) intensity across the aperture. The median values of the best fit voltage across the aperture are indicated on the top of the panels. The bottom panels show the corresponding histograms for the deviations in best-fit voltage across the aperture. The standard deviation of the distribution is indicated on the top of the panels.

Response Time of the LCVR:

The LCVRs use nematic liquid crystals for tuning the retardance of the optical element. The response time of the LCVR depends upon many parameters such as layer thickness, viscosity, temperature, variation in the drive voltage and surface treatment. Response time also depends upon the direction of retardance change. For increasing the retardance (i.e., voltage transitioning from High to Low values) the response time is determined by the mechanical relaxation time of the molecules. While for decreasing the retardance (i.e., voltage transitioning from Low to High values) the response time is much faster due to the enhanced electric field applied across the crystal layer. Typical value quoted by Meadowlark Optics™ for the LCVRs is 5ms from low-to-high voltage transition and about 20ms from high-to-low voltage transition.

Running the camera in ROI mode (256x256 region only) the camera can achieve high frame rate of several hundred frames per second, enough to resolve the typical response time of the LCVRs. The figure 6 below shows an example of the mean intensity of the ROI over a 100-millisecond interval while the LCVR is transitioned from low-to-high and then high-to-low. The response time is about 5ms between first two vertical dashed lines which corresponds to the transition from low-to-high voltage, while the high-to-low voltage transition indicated between 3rd and 4th vertical dashed lines shows a response time of about 20ms. These values agree with the typical response time specified by the vendor. This shows that it is possible to measure the response time of the LCVR with the proposed procedure and possibly tweak it using appropriate voltage switching profiles.

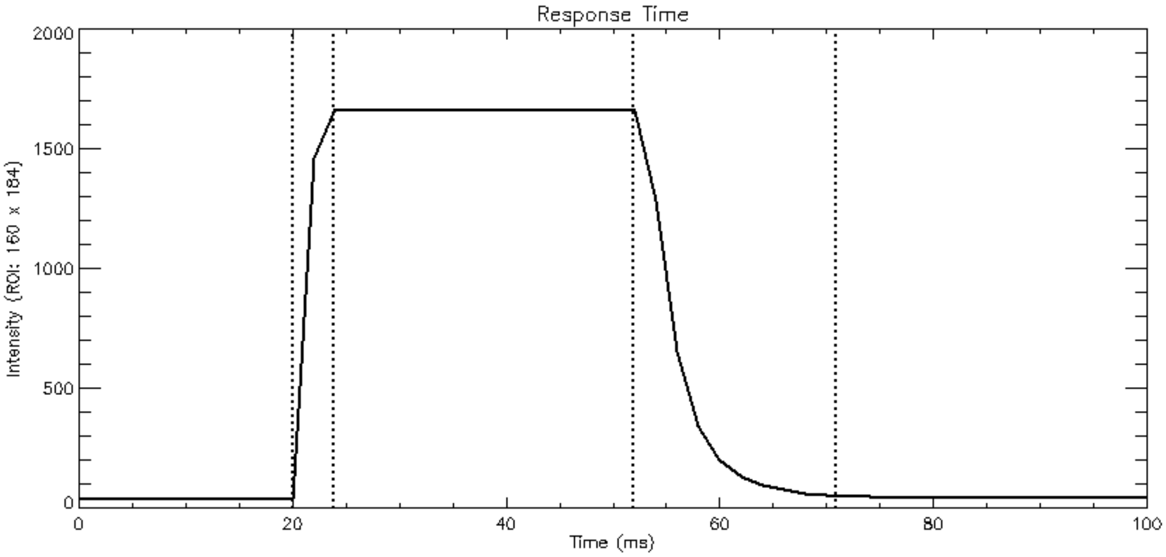


Figure 6: Switching profile of the LCVR captured via fast readout of a small ROI. The response time of low-to-high and high-to-low voltage transition is typical of LCVRs.

References:

1. *LCVRs https://www.meadowlark.com/product/liquid-crystal-variable-retarder/*
2. *Thorlabs six position filter wheel https://www.thorlabs.com/thorproduct.cfm?partnumber=FW102C*
3. *LCVR digital interface https://www.meadowlark.com/product/liquid-crystal-digital-interface-controller-20v-version/*
4. *Circular Polarizer https://www.thorlabs.com/thorproduct.cfm?partnumber=CP1L670*
5. *MATLAB https://www.mathworks.com/products/matlab.html*
6. *High speed camera https://emergentvisiontec.com/products/bolt-hb-25gige-cameras-rdma-area-scan/hb-1800-s/*

Appendix-1

- *Program to control Thorlabs Filter wheel using MATLAB*

```
%Open Serial Port
fw=serial('COM3','Baudrate',115200,'Terminator','CR');
fopen(fw)

%Wait for FW to initialize
pause(2);

% Query the position of the FW
fprintf(fw,'pos?');
c=fscanf(fw);
c=fscanf(fw);
disp('Current filter position is: '+string(c));

%Command to move to desired filter position
x=input('Move to position number: ');
fprintf(fw,'pos='+string(x));
disp('Moving to position '+string(x));
pause(5);

%Verify that the FW reached the desired position
fprintf(fw,'pos?');
c=fscanf(fw);
fprintf(fw,'pos?');
c=fscanf(fw);
disp('Current filter position is: '+string(c));

%Close the Serial Port
fclose(fw)
```

Appendix-2

- *Program to Tune LCVR and Grab Images from the EVT Camera using MATLAB*

```
path='C:\GongTC_ZP\';

USB_PID=hex2dec('139C');
flagsandattrs=hex2dec('40000000');
global flg;
flg=uint32(1);
loadlibrary('usbdrvd.dll','usbdrvd.h');
num_controllers=calllib('usbdrvd', 'USBDRVD_GetDevCount',USB_PID);
global dev1;
dev1=calllib('usbdrvd','USBDRVD_OpenDevice',flg,flagsandattrs,USB_PID);
%*************  initialization of CellDrive
ver_cmd='ver:?\n';
cellwrite(ver_cmd);

%************* Verify initialization of CellDrive


%Initialize camera and grab an image
vid = videoinput('gige', 1, 'Mono12');
src = getselectedsource(vid);
src.LineTime = 658;
src.PacketSize=1984;
flushdata(vid,'all');

xro=880;
yro=880;
vid.ROIPosition=[352 104 xro yro];

nframes=1;
vid.FramesPerTrigger = nframes;
vid.TriggerRepeat=Inf;
triggerconfig(vid,'manual');

src.Gain=256;
src.Offset=0;
 %************ DONE initialization of camera

src.Exposure = 4000;
buff1=int32(zeros(xro,yro,101));

start(vid);
tic

counter=1;

for nv=0:100:10000   %
    disp(counter);
        ver_cmd=char('sqr:1,'+string(nv)+','+string(nv+2)+',200,0,100\n');
```

```
        cellwrite(ver_cmd);
        pause(350/1000);
        trigger(vid);
        buff1(:,:,counter)=int32(getdata(vid,nframes,"uint16"));
        counter=counter+1;
end

fitswrite(buff1,'C:\GongTC_ZP\TC_LCCal_set1.fits');

stop(vid);
delete(vid);
```

Appendix-3

- *Burst of Images from the EVT Camera (small ROI) for Rise/Fall time of LCVR*

```
path='C:\GongTC_ZP\';

%Initialize camera and grab a burst of images
vid = videoinput('gige', 1, 'Mono12');
src = getselectedsource(vid);
src.LineTime = 658;
src.PacketSize=9000;
flushdata(vid,'all');

xro=256;
yro=256;
vid.ROIPosition=[672 470 xro yro];

nframes=5000;
vid.FramesPerTrigger = nframes;
vid.TriggerRepeat=Inf;
triggerconfig(vid,'manual');

src.Gain=256;
src.Offset=0;
 %************ DONE initialization of camera

src.Exposure = 2000;
start(vid);
trigger(vid);
pause(4);

while vid.FramesAvailable >= nframes
       a=0;
end

frames=getdata(vid,nframes,"uint16");
```

```
buff1=int32(frames);

fitswrite(buff1,'C:\GongTC_ZP\TC_LCCal_HILO_timeburst.fits');

stop(vid);
delete(vid);
```