Performance of a Liquid Crystal Optical Gate for Suppressing Laser Backscatter in Monostatic Kilohertz SLR Systems

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Abstract

Some of the unique blocking features required by SLR2000 included a large aperture (15 mm), arbitrary polarization returns, a rapid 2 kHz cycle time, long and flexible blocking periods (up to 10% of each 500 microsecond interval between pulses), and adequate switching speeds to minimize data loss. After evaluating numerous potential approaches to optical gating, we determined that the use of a liquid crystal optical gate (LCOG) afforded the best overall protection. We have successfully implemented a 2 kHz LCOG which provides a 50 microsecond "blocked" interval, a 450 microsecond "unblocked" interval, a 10 microsecond rise and fall time on the blocking interval, approximately 90% transmission in "unblocked" mode, and a 659:1 reduction in backscattered radiation in "blocked" mode. Furthermore, the LCOG adapts readily to time shifting of the outgoing pulse.

Introduction

Since SLR2000 operates at a 2 kHz fire rate, multiple pulses are in the air at all times and, at various times within a given satellite pass, reflected signal photons arrive at the SLR2000 telescope at the same time a subsequent transmitted pulse is exiting the system. We refer to these events as "collisions". Since the range gate is open for some period surrounding the expected signal arrival time, the sensitive detector is exposed to backscattered laser radiation from both the instrument and the local atmosphere while in a high gain mode. In principle, backscatter from the atmosphere can be observed for up to 10% of the 500 microsecond laser fire interval. During this time, backscattered photons can cause significant charge transfer from the photocathode to the anode and, since the lifetime of a photocathode is dependent on the number of coulombs transferred, unsuppressed laser backscatter is a potentially life-limiting mechanism. In addition, since SLR2000 is designed to correct telescope pointing by balancing the photon returns in the four ranging detector quadrants, we believe that backscattered photons can interfere with the performance of the pointing correction algorithms by biasing the pointing error in the direction of the transmitter point ahead.

The quadrant segmented anode microchannel plate photomultiplier (MCP/PMT) in SLR2000 has recently been upgraded in order to achieve a factor of 3 to 5 improvement in detection efficiency and sensitivity. The bialkali photocathode tube built by Photek Inc. has been replaced by a significantly more expensive Hamamatsu tube with a less mature but higher efficiency (30% to 40%) GaAsP photocathode. In order to protect the tube from backscattered laser radiation and extend photocathode life, SLR2000 incorporates two design features. The first feature involves periodically changing the laser repetition rate to avoid "collisions" between outgoing pulses and incoming signal photons. This eliminates backscatter during the most critical period when the detector is gated "on", minimizes data loss, and helps to prevent corruption of the quadrant detector pointing correction. We have recently investigated the inclusion of an optical gate which acts as a second layer of defense by

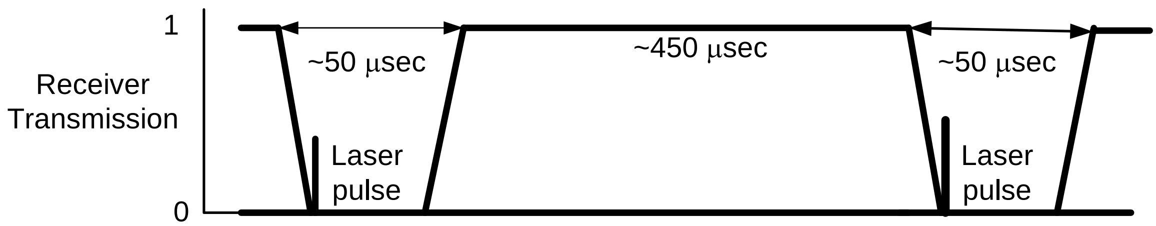


Figure 1. *Performance of the ideal optical gate for suppressing laser backscatter in SLR2000 operating at a 2 kHz rate.*

suppressing backscatter impinging on the photocathode even during less critical times when the detector is gated "off". The ideal performance of the "ideal optical gate" is illustrated in Figure 1. To minimize loss of signal while providing maximum protection, a successful optical gate in SLR2000 must possess the following characteristics:

- Operate at SLR2000 2 kHz laser fire rate,
- Accommodate the 13 mm receiver beam diameter on the optical bench,
- Block atmospheric backscatter for up to 50 microseconds following laser fire,
- Provide high backscatter extinction in blocked mode,
- Provide high signal transmission in unblocked mode,
- Provide a fast transition between blocked and unblocked modes,
- Accommodate variable fire rate used to avoid "pulse collisions",
- Can take advantage of linearly polarized light in two SLR2000 receiver channels if necessary.

We considered various approaches to optical gating including mechanical, electro-optical, acousto-optical, and liquid crystal and rated them with respect to transition speed, aperture, transmission, and ability to provide a long "open" mode. Liquid crystal gates were found to have the best overall performance with electro-optical being deemed less appropriate due to the need to maintain high voltages on the crystals for long periods of time. Our conclusions are summarized in Table 1.

Table 1. *Comparative performance of various optical gating approaches.*

Gating Approach	**Speed**	**Aperture**	**Transmission**	**Gate Duration**
Mechanical	Poor	Poor	Excellent	Poor
Electro-optic	Excellent	Good	Good	Poor (2-3 kV)
Acousto-optic	Good	Poor	Fair	Good
Liquid Crystal	Good	Good	Good	Good (±30V)

Experiment

The Liquid Crystal Optical Gate (LCOG) takes advantage of the fact that, in SLR2000, the received signal is split based on polarization. This is a consequence of our unique passive Transmit/Receive switch which permits the transmitter and receiver to share the entire telescope aperture simultaneously while experiencing low loss in either path [Degnan, 2004]. In a typical configuration, the LCOG normally acts as a time dependent polarization rotator placed between two crossed polarizers. The first polarizer defines the input polarization. Relatively low voltage (< ±30 VDC) waveforms applied to the crystal align the liquid crystals and rotate the propagating light in a time dependent manner. The action of the second polarizer on the rotated light creates the time varying transmission function of the gate.

As will be described later, the current SLR2000 receiver configuration uses uncrossed polarizers in each receiver leg although crossed polarizers could be employed with a relatively minor design change. For this reason, we conducted our laboratory tests with both crossed and uncrossed polarizer pairs. The signs of the waveform voltages were chosen accordingly to approximate the performance of the ideal gate depicted in Figure 1. Figure 2 provides a block diagram and photo of our test setup.

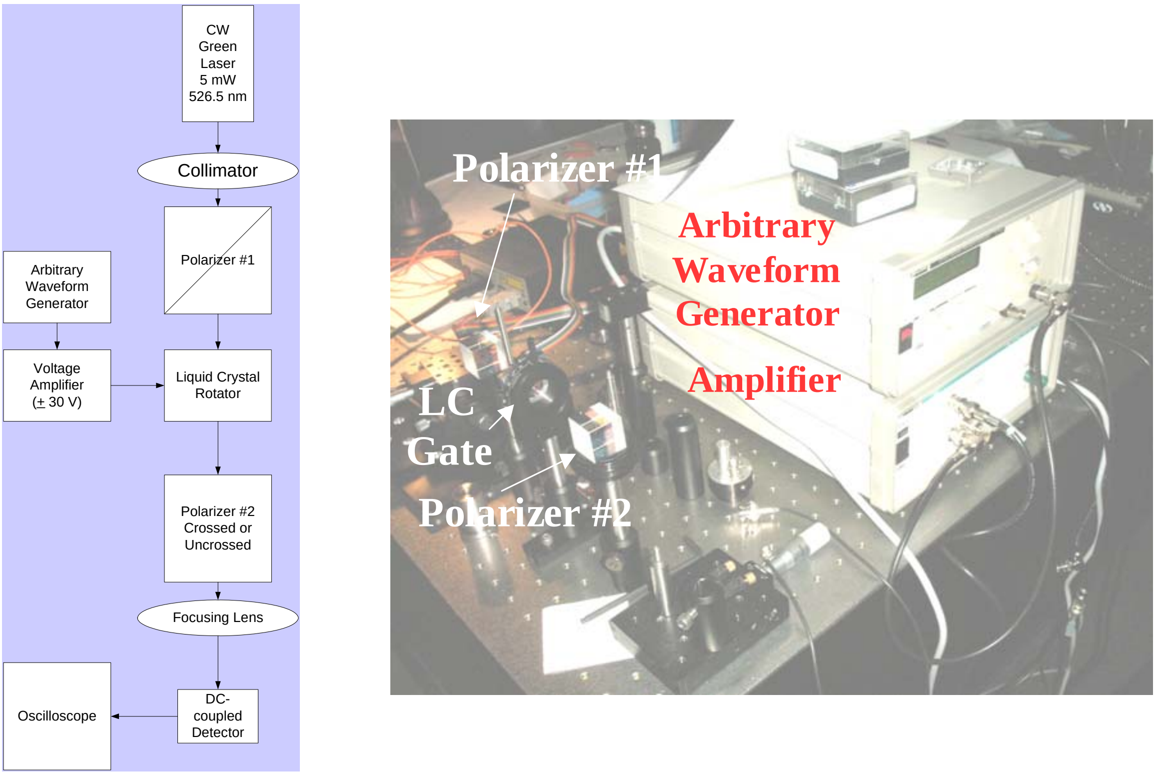


Figure 2: *Block diagram and photo of the laboratory test setup.*

The required waveform was programmed into a high bandwidth Arbitrary Waveform Generator (AWG) and iterated to best approximate the ideal transmission function. The low voltage output of the AWG was amplified to the required ± 30VDC by a separate amplifier module and applied to the flying leads of the Liquid Crystal Rotator manufactured by Boulder Nonlinear Systems, Inc. . Collimated light from a CW green laser was passed through the LCOG and focused onto a DC-coupled detector whose output was displayed on an oscilloscope. Prior to inserting the Liquid Crystal Rotator (LCR), the extinction of the crossed CVI cube polarizers was measured to be 6222:1 in reasonable agreement with the specified value of 10,000:1 and demonstrated the sensitivity of our measurement approach. A summary of the peak optical gate transmissions and extinctions obtained with different polarizer combinations is given in Table 2. Not surprisingly, the best extinction of 659:1 during "closed" periods was obtained with the normal crossed polarizer configuration whereas the P/P and S/S configurations, corresponding to the current SLR2000 receiver configurations (see Figure 4), provided significantly poorer extinctions of 164:1 and 82:1 respectively. The transmission of the gate during "open" periods was comparable in all cases, varying over a narrow range between 89.3% and 92.1%.

Table 2. *Summary of experimental transmissions and extinctions for various configurations of crossed and uncrossed polarizers.*

Polarizer 1	Liquid Crystal Gate	Polarizer 2	Transmission (gate open)	Extinction (gate closed)
P	No	S	NA	6222:1
P	Yes	S	89.3%	659:1
P	Yes	P	91.3%	164:1
S	Yes	S	92.1%	82:1

Temporal waveforms obtained for the gate with crossed polarizers, as registered in different channels of the oscilloscope, are shown in Figure 3. The "optimized" drive voltage waveform to the LCR, corresponding to the orange curve, is being repeated at the 2 kHz rate of SLR2000. The purple curve, corresponding to the optical detector output, is a good approximation to the "ideal" transmission waveform in Figure 1, where the gate is closed for 50 microseconds and open for 450 microseconds and shows a fast transition between the two states (< 10 microseconds). The upper green curve is the purple curve viewed at high resolution and clearly shows the rapid reversal in the transmission trend as the drive waveform voltage to the LCR changes sign.

It is worthwhile to point out certain required characteristics of the drive waveform. The integral of the waveform over one cycle must equal zero, i.e. the positive area under the waveform must equal the negative area. If the average is not zero, any ions present in the liquid crystal will migrate to the surfaces resulting in a build-up of charge. This will effectively keep the liqud crystal pinned in that state [Bauchert, 2004]. Furthermore, during the "open" mode, one must apply a slight residual positive voltage (~2 to 3V) which holds the molecules in their transmissive state and prevents them from becoming randomly oriented and thereby reducing the transmission when the switch is "open". The width of the blocking gate is determined by the combined widths of the positive and negative going pulses. Because of the zero integral condition over the full 500 microsecond cycle, the temporal width of the negative drive pulse is necessarily less than that of the positive pulse.

Integration into SLR2000

Figure 4a shows the current SLR2000 receiver configuration where the incoming light is split into s and p polarizations and then recombined on a final polarizer before impinging on the quadrant MCP/PMT. Note that, without the LCR, the polarization of the light is preserved during recombination at the final polarizer. Thus, using the results in Table 2 for uncrossed polarizers, one can project a mean transmission of 91.7% for the open gate and a mean extinction of 123:1 for unpolarized light entering the receiver. Significantly better performance is obtained if a mirror is placed to the left of the combining polarizer as in Figure 4b and the drive voltages to the LCR are reversed. The expected extinction rises significantly to 659:1, and the transmission decreases only slightly to 89.3% for unpolarized input.

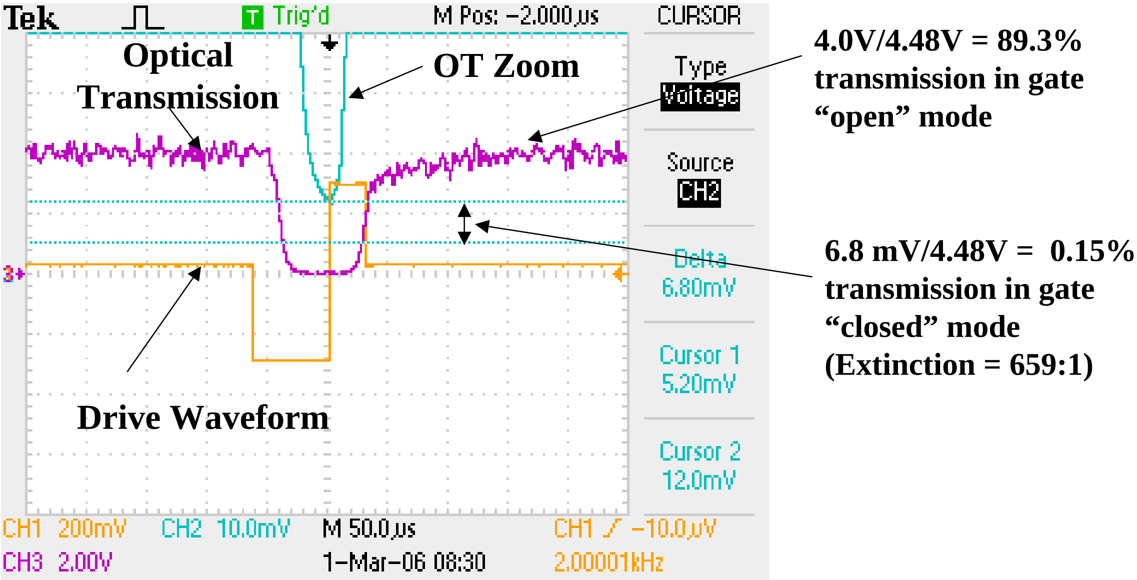
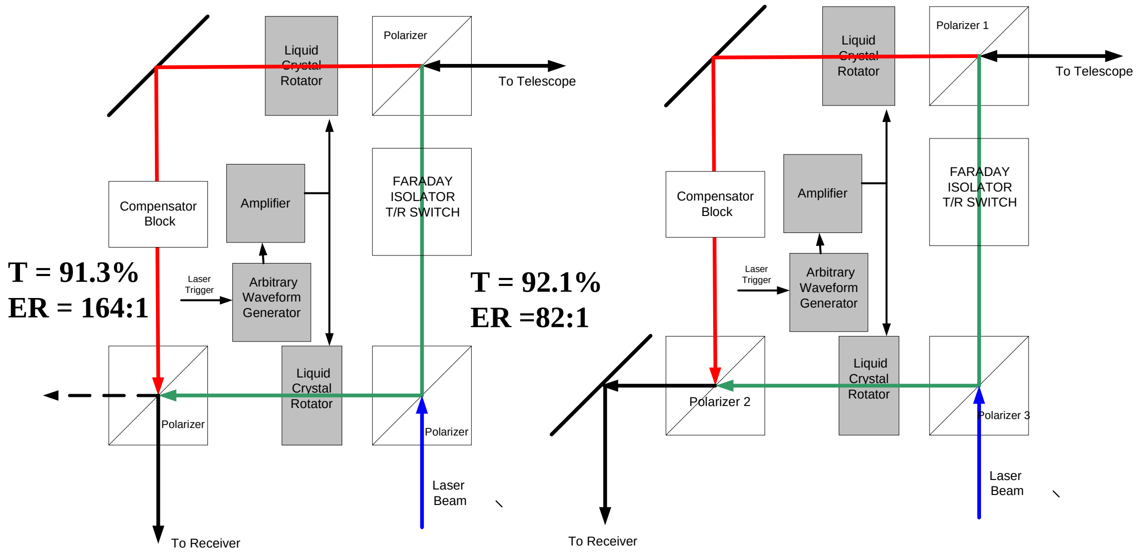


Figure 3: *Oscilloscope traces obtained during transmission/extinction experiments with the normal crossed polarizer configuration. The drive waveform to the LCR is indicated by the orange trace. The purple trace gives the optical transmission from "open" to "closed to "open". The narrow green trace at the top of the figure is a high vertical resolution version of the purple trace and shows the rapid reversal in the optical transmission trend at the point where the sign of the applied LCR voltage is suddenly reversed.*

Summary

We have demonstrated that liquid crystals, when used as a 90^o polarization rotator between two cube polarizers, can:

- reduce the amount of laser backscatter by 2 to 3 orders of magnitude in the "closed" state while exhibiting high transmission (~90%) in the "open" state,
- operate at few kHz rates,
- handle large aperture beams (~15 mm),
- switch states in less than 10 microseconds with low voltage (<±30V),
- produce flexible gate waveforms of arbitrary shape and duration,
- work in tandem with variable laser fire rates to avoid "collisions" between incoming and outgoing pulses.



Current SLR2000 Configuration	Better Configuration
Uncrossed Polarizers (average)	Crossed Polarizers
T = 91.7% ER = 123:1	T= 89.3% ER = 659:1

Figure 4: *(a) With LCR's installed in both legs of the current SLR2000 receiver and unpolarized signal, the mean transmission and extinction would be 91.7% and 123:1 respectively; (b) a minor modification of the SLR2000 receiver configuration would result in 89.3% transmission and 659:1 extinction.*

We close with certain precautions in the use of these devices. The liquid crystal medium is sandwiched between two optical substrates. Care must be taken when mounting the LCR's to avoid stressing the delicate interface. The voltage to the unit must not exceed the ± 30VDC maximum or serious damage to the interface may result. Also, as mentioned previously, in designing the drive waveform, the voltage over one repetition cycle must average to zero.

References

[1] Bauchert, K., Boulder Nonlinear Systems, private communication, 2004.

[2] Degnan, J., "Ray Matrix Approach for the Real Time Control of SLR2000 Optical Elements", Proc. 14th International Workshop on Laser Ranging, San Fernando, Spain, June 6-10, 2004.