High speed Pockels Cell shutter and the Herstmonceux MCP-PMT detector

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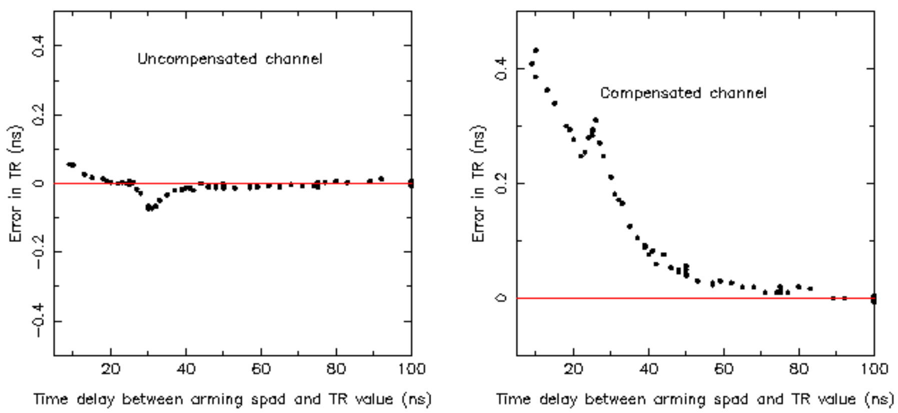
Abstract

Daytime kHz satellite laser ranging at the NERC Space Geodesy Facility in Herstmonceux, UK experiences a large amount of daylight noise. The C-SPAD detector in operation needs a minimum delay of 50ns after gating to avoid any range measurement error and only one detection is made for each laser fire. Therefore a noise point detected in this post-gating time period is a lost opportunity for a satellite laser measurement. An estimate of the loss for Lageos and HEO satellites due to daytime noise varies from 20% to as high as 50% of shots fired.

Introducing a high speed Pockels cell shutter before the C-SPAD allows the detector to be armed in darkness. The shutter then opens ~10ns before the satellite track, resulting in a reduced amount of daytime noise and an increased number of successful return signal detections. The polarisers in the Pockels cell however reduce the return signal intensity by a factor of more than 50%.

Advantages and practical considerations for this application are discussed and compared with an alternative fast gating MCP-PMT detector.

The NSGF SLR system uses a C-SPAD detector and consequently makes only one detection per laser fire. Also the C-SPAD must be armed 50-100ns before an observation to avoid any bias in the range measurement due to characteristics of the detector, as shown in figures 1 and 2.



Figures 1 and 2. Range bias variation of the uncompensated and compensated C-SPAD channels with time of observation after gating.

Once armed, if the C-SPAD detects a noise point before the arrival of the satellite return signal then the opportunity to observe the satellite from that laser shot is lost. Furthermore, in comparison to the Nd:YAG laser, the new kHz laser system has a greatly reduced signal to noise ratio with much more sampling. Therefore, daylight noise is much more apparent in the range gate window and has a more significant impact on daytime observing.

The C-SPAD will make a detection within a few hundreds of nanoseconds during normal daylight operations. To reduce daytime noise the return path includes an oven controlled daylight filter that allows a narrow spectrum of 0.14nm FWHM centred at 532.1nm. Peak Transmission is 68.04%. Nevertheless daytime noise still reaches the detector and figure 3 shows the proportion of lost laser shots due to daylight detections for a Champ. Less than 10% of laser shots result in detected noise in the first 20 nanoseconds after arming the detector. After 100 ns about 40% of shots are lost to daytime nose and about 70% of shots are lost in 250 ns. The drop in percentage lost seen toward the end of the pass is due to the satellite being detected and ND filters being added in front of the C-SPAD.

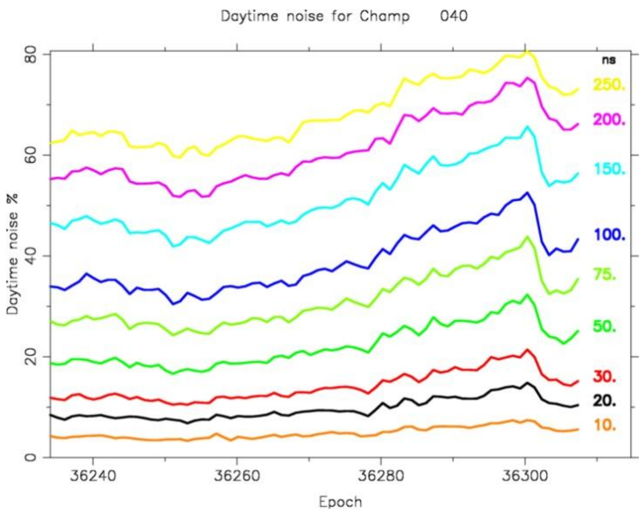


Figure 3. The percentage of lost observation opportunities due to daytime noise detection during a Champ pass during the first 10, 20, 30, 50, 75, 100, 150, 200 and 250 nanoseconds after the gating of the C-SPAD.

Introducing a very fast shutter before the C-SPAD will allow it to fully arm in darkness. The shutter can then be opened much closer to the satellite track (~10ns). This could turn a 50% loss to a 10% loss.

Suitably Fast Shutters

Physical - Spinning disc or resonant forks opening and closing a physical barrier matched in phase. However, it would be demanding to match the kHz frequency and phase of the returning signal.

Liquid Crystal Display - Cell containing long molecules aligned at each surface and 90 degrees apart. Polarised light is rotated through the cell with no applied voltage. Cell becomes opaque when a voltage is applied as the molecules align to the electric field. However, the shutter needs to open in a few nanoseconds and the LCD is too slow with transition times of > 10 μs.

Electro-optic - Pockels cell shutter using fast switching of polarisation to block and transmit light. However, more than 50% of returning signal is lost.

Acousto-optic - A piezoelectric device transmits a sound wave through a quartz crystal to produce a diffraction grating. This grating then deflects light. However, the speed of the shutter is limited to the speed of sound in the crystal and it is only fast enough if the return signal beamwidth is very small ~ 1 micron.

The best option is an electro-optic Pockels cell shutter, which can switch between transmission and blocking very quickly, about 1 ns. Light is polarised before entering the Pockels cell crystal and is blocked by an opposing polariod on the other side. To transmit the light a high voltage is applied to the Pockels cell which rotates the polarisation of the light and allows it to then pass through the second polariod and reach the detector. However, the major disadvantage of introducing a Pockels cell shutter before the C-SPAD is the loss of signal intensity due to Malus's Law. For a perfect polariser aligned by θ to polarised light of intensity I_0, the output intensity equals: $I = I_0\cos^2\theta$. Only the intensity component that is parallel to the polariser's transmission axis is transmitted. Unpolarised light consists of a random mixture of polarisations with an average of $\cos^2\theta$ from 0 to 90°, which equals ½. Therefore the intensity of unpolarised light through a perfect polariser is reduced by half. Polarisers are not perfect and so transmission is less than 50%, although calcite glass polarisers can achieve close to 50% transmission.

Furthermore, the Pockels cell must be electronically switched at high voltage. This reduces gating time to 10-15ns. The Pockels cell will not block all wavelengths of light, but this is not a problem as it would be positioned after the dichroic mirror in the return path and experience mostly green light.

Conclusion

A very fast shutter would benefit Lageos and HEO SLR by reducing daytime noise. The best shutter option is a Pockels cell and all of the obstacles encountered in planning for the installation have been overcome. The disadvantage of this shutter is a 50% loss of return signal. The advantage is the close gating that reduces the number of lost shots due to daytime noise.

An Alternative Detector?

Instead of installing a Pockels cell shutter, an alternative detector option is available that would give the same advantage of close gating. An MCP-PMT detector can be gated even quicker than a Pockels cell shutter. Also this detector has much less dark noise compared to the SPAD.

The choice of the most suitable MCP-PMT detectors lies between two similar but slightly different detector specifications. The first is the Photek PMT210 S2. It has very fast gating, a quantum efficiency of 12% and 30ps jitter. Such a device is on loan from Photek and is undergoing testing at Herstmonceux. Alternatively the Hamamatsu MCP-PMT R5916U-64 has very fast gating, a quantum efficiency of 40% and 110ps jitter. A similar detector was recently installed at the Borowiec SLR station.