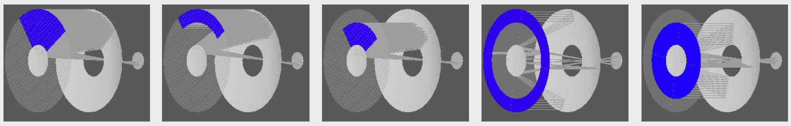
The telecover test:
A quality assurance tool for the optical part of a lidar system

Volker Freudenthaler
Ludwig-Maximilians-Universität, Theresienstrasse 37,
D- 80333 München, Germany, uni@freudenthaler.de

EARLINET

ILRC 24 40TH ANNIVERSARY

The problem: We don't have a calibration method for a lidar system in the near range, where almost never clean air conditions can be assumed. But shortcomings of the optical and opto-mechanical design or misalignments have their greatest effect in the near range. **Telecover test principle:** Lidar signals taken with different parts of the telescope aperture (see Fig. 1) are compared to each other. If the receiver optics is designed and aligned correctly, the normalized signals don't show any differences apart from the overlap range ☺. Range dependent telecover signal differences ☹ indicate range dependent transmission changes in the optics, which cause signal distortions in the total signal. A comparison with ray tracing simulations of the laser-receiver setup, including apertures and optical coatings, can reveal the sources of such problems. Examples are shown below. Ray tracing was performed with ZEMAX-EE including polarization.



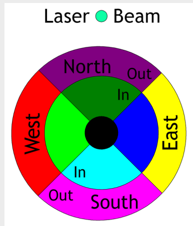


Figure 1: **Nomenclature** of the telecover parts (plot at right) with respect to the laser position at North (biaxial systems) or any prominent orientation of the receiver optics (monoaxial systems). Using the four quarters N,E,S, and W in the left picture is called the quadrant test. Using the outer and inner parts of the quadrants is called the octant test. The pictures above show (from left to right) the sectors North (**N**), North-Out (**NO**), North-In (**NI**), Full-Out (**FO**), and Full-In (**FI**) on a Cassegrain telescope, assuming the laser on top.

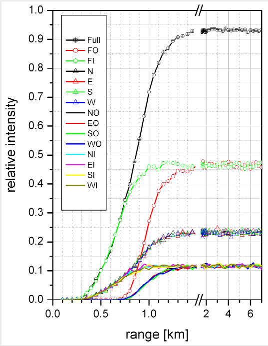


Figure 2: Simulated telecover lidar signal intensities relative to the full intensity at the telescope aperture of a monoaxial lidar system with a Cassegrain telescope with 9 m focal length, 0.6 mrad field of view, and a laser beam divergence of 0.13 mrad fwhm. Without any misalignments all octant Out-sectors show the same signals, as well as all octant In-sectors and all quadrant sectors. In case of a laser misalignment, the quadrant and octant signals split up, and the differences show the direction of the laser tilt. The Out-sectors exhibit a later full overlap than the In-sectors, and the full telescopes overlap is not complete before the outer and inner signals merge. The FI/FO-test can be used to check the distance of full overlap.

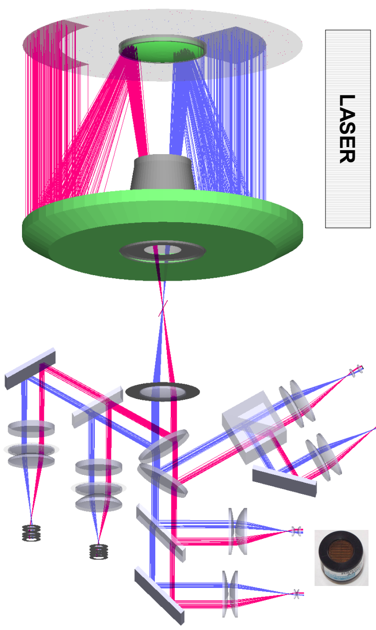
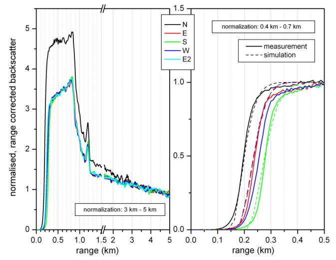


Figure 3: Optical setup of the biaxial lidar system MULIS of the University of Munich with a 300 mm diameter Cassegrain telescope with 0.94 m focal length. The laser, having a beam divergence of 0.6 mrad fwhm, is placed 0.4 m to the right of the telescopes optical axis. The blue rays from the NI-sector and the red rays from the SO-sector have different paths through the optics. Some lens apertures are shown as gray annuli. In front of each detector eyepieces are placed to accurately image the telescope aperture onto the detectors.



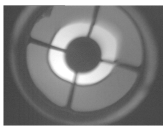


Figure 4: The left plot shows normalized telecover measurements with a strong deviation of the N-signal from the other sectors. But normalizing the same signals in the near range, the mid plot shows a very good agreement between the measured and the simulated overlap regions for all sectors. Considering all additional information, the telescope had been inspected. The right plot shows an image of the telescope aperture through the receiver optics, which indeed shows enhanced **image distortions** in the N-sector, probably due to stress of the secondary mirror. This probably leads to the decrease of signal intensity from the near to the far range in the N-signal. A preliminary solution was to mask the N-sector permanently. The second signal from the E-sector (E2, cyan) conincides with the first signal (E, red) and shows that **atmospheric changes** didn't influence the test.

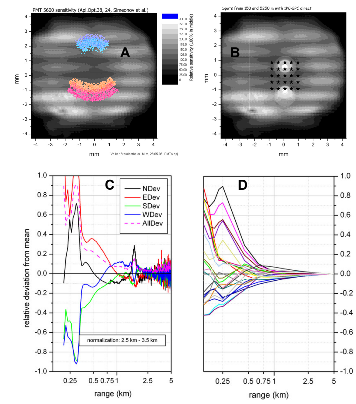


Fig. 5: The telecover test of another lidar system shows irregular deviations in the near range (plot C) of all sectors (NDev etc.), which can be explained by the **inhomogeneity of the photomultiplier sensitivity** (as shown in the plots above for a Hamamatsu 5600 PMT) and the movement of the laser spot over the detector surface with the change of the lidar range. The movement of the NI- (blue) and SO-sectors (red) over different sensitive parts of the PMT are indicated in image A for 0.25 and 5 km lidar range. Plot D shows the possible signal deviations from a set of simulations with various PMT alignments as indicated in plot B (Freudenthaler, 2004), which are very similar to the measurements. An additional eyepiece in front of the PMT could possibly solve this problem.

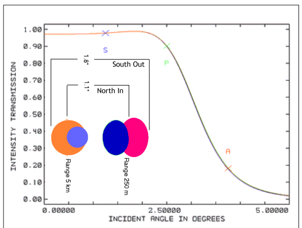


Figure 6: **Interference filters** have limited acceptance angles as shown for a typical filter with 0.5 nm fwhm-bandwidth at 607 nm. The inlay in the plot shows about the angle distribution of the parallel beam of MULIS before the interference filters for the SO- (reddish) and NI-(bluish) sectors for lidar ranges of 5 km and 250 m. Small tilts of the interference filter in the order of 1° cause range dependent transmission effects, different for different telecover sectors, which can be detected with the telecover test as shown in figure 7, right plot.

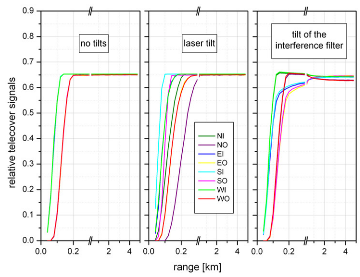


Figure 7: Simulation of octant-test signals for a monoaxial lidar system. The left plot shows the ideal relative intensities, and the middle plot shows the changes when the laser is misaligned (tilted). The direction of the **laser tilt** can be determined from the relative shifts of the overlap functions of the different telecover sectors. The right plot shows typical deviations for a **tilted interference filter**, with effects in the near range and also in the far range.

Together with other tests, the telecover test is implemented as a quality assurance tool in the frame of EARLINET-ASOS (Bösenberg et al., 2003). The first internal quality check of all EARLINET lidar systems is currently ongoing.

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ACKNOWLEDGeMENT: The financial support for the improvement of the EARLINET infrastructure by the European Commission under grant RICA-025991 is gratefully acknowledged.