Two-Color Calibration of The Zimmerwald SLR System

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Abstract

The current and the preceding Zimmerwald SLR systems have used internal, near-realtime calibration with apparently good success. The addition of the second wavelength (infrared) to our system revealed, after some time of routine operation, differences between the calibrated ranges of the two colors that could not be explained with errors in the applied refraction models. It turned out that the internal calibration values of the infrared chain showed variations that had not much to do with system calibration. The source of these variations could not be identified. In June 2006 we switched to external calibration by necessity.

Introduction

The 1-meter Zimmerwald satellite laser ranging system, installed in 1997, has been designed for two-color ranging right from the beginning. In order to have two wavelengths with suitable sensors and reasonable reception signal power at our disposal we chose a Titanium-Sapphire laser with the primary wavelength at 846 nm (near infrared) and the second harmonic at 423 nm (blue).

As receivers we are currently using a compensated SPAD at 423 nm and a Hamamatsu H7422P-50 photomultiplier at 846 nm. The time walk of the latter is compensated using an empirical correction table in function of the measured return pulse energy.

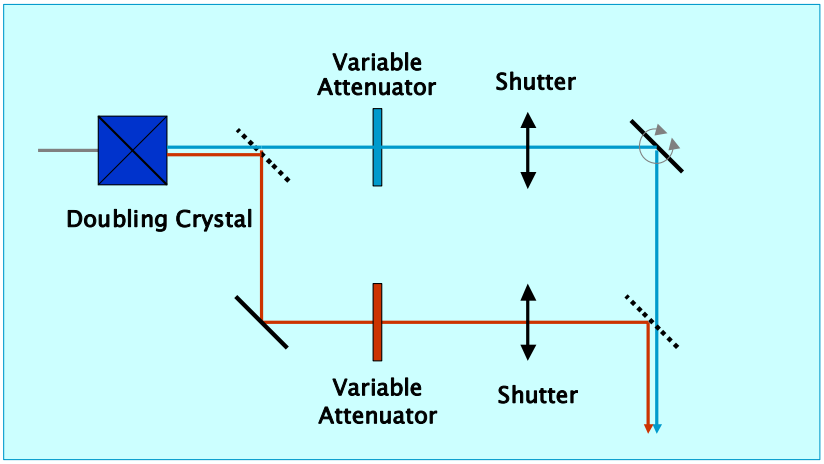

Figure 1: *Transmit path: Individual attenuation*

Single-shot precision is of the order of 60 ps in blue and 150 ps in infrared.
The optical paths to and from the telescope have been optimized for transmission for the two wavelengths. The two beams can be individually attenuated, both in the transmit as well as in the receiving path.

At the International Laser Ranging Workshop 2002 in Washington we reported (Gurtner, 2002) first results of dual-wavelength operation. We concluded;

- *The average difference between infrared and blue residuals per pulse is between 0 and 0.05 ns after a Marini-Murray refraction correction using onsite surface met values.*
- *Apart from the above mentioned tendency we could not yet detect any systematic behavior of the differences so far.*
- *The differential Marini-Murray refraction corrections between 423 and 846 nm seem to be better than < 10 mm.*
- *However, there could still be range biases between the two reception channels of the same order of magnitude.*

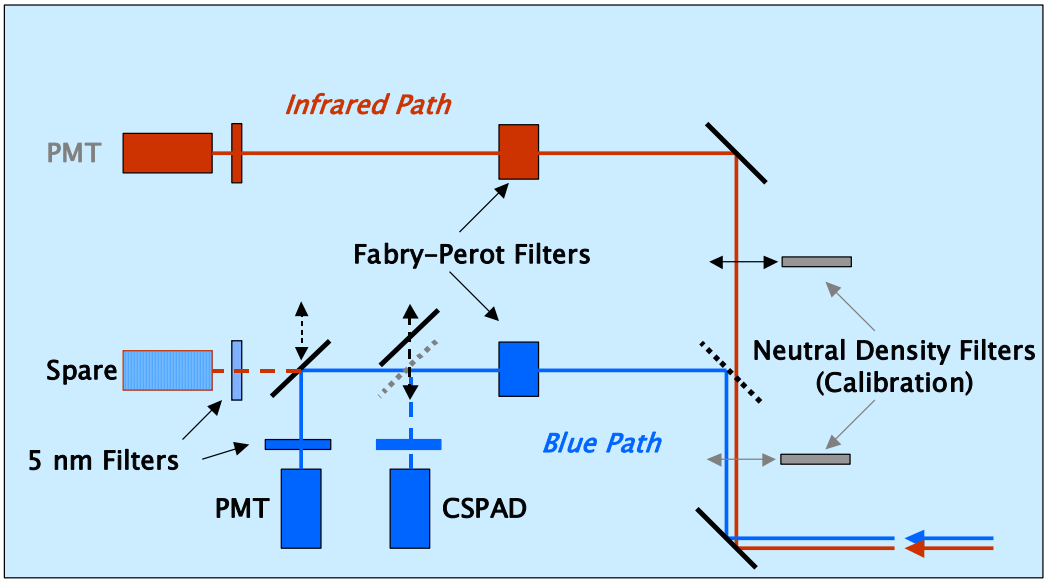

Figure 2: *Receiving path: Separation of the two colors*

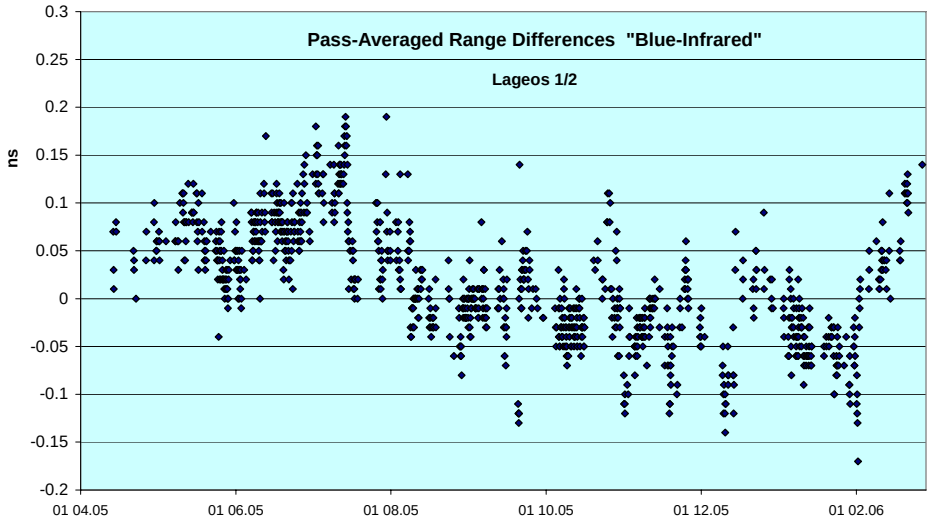

Figure 3: *On-site-determined differences blue-infrared*

Slowly Varying Systematic Differences

In the meantime, however, the refraction-corrected pass-average differences between the two colors showed slowly varying systematic effects that have nothing to do with remaining errors in the applied refraction corrections. These variations could be seen

in on-site generated differences (Figure 3) as well as in the pass-averaged residuals of global analyses performed by ILRS analysis centers (Figure 4). These variations were as large as plus and minus 2 cm!

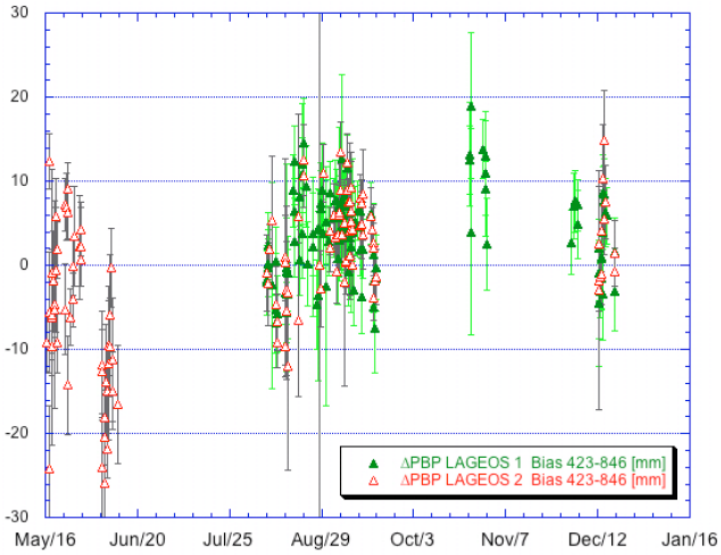

Figure 4: *Pass-averaged biases between blue and infrared (JCET analysis center, 2004)*

A closer investigation showed that these inter-color bias variations highly correlated with the calibration values used to correct the infrared ranges to the satellites (Fig. 5).

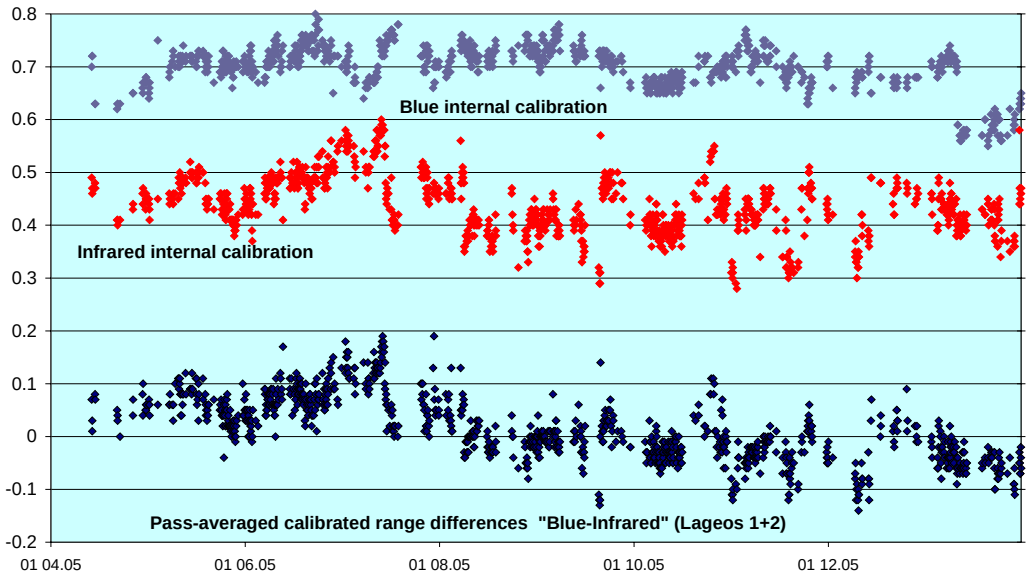

Figure 5 : *Time series of internal calibration values and inter-color biases*

It can be clearly seen that the time series of the infrared calibration values (middle series, covering about 10 months from April 2005 to February 2006) shows the same features as the pass-averaged calibrated range differences between blue and infrared.

The standard calibration procedure used so-called internal calibrations: During the satellite passes, interleaved with the ranging to the satellites, flight time measurements of a weak calibration beam extracted from the main laser pulse and sent through an internal path of known length are performed to keep track of small changes in the

system behavior (e.g. temperature changes) leading to errors in the measured satellite ranges.

The differences between the calibrated ranges (corrected for tropospheric refraction) to the satellites in the two colors should then only contain biases from residual errors in the tropospheric corrections and the applied calibration values, and various random errors from the measurement procedures. The fact that we see slowly varying inter-color biases correlated with the infrared calibration lets us assume that there is a problem with the respective calibration procedure.

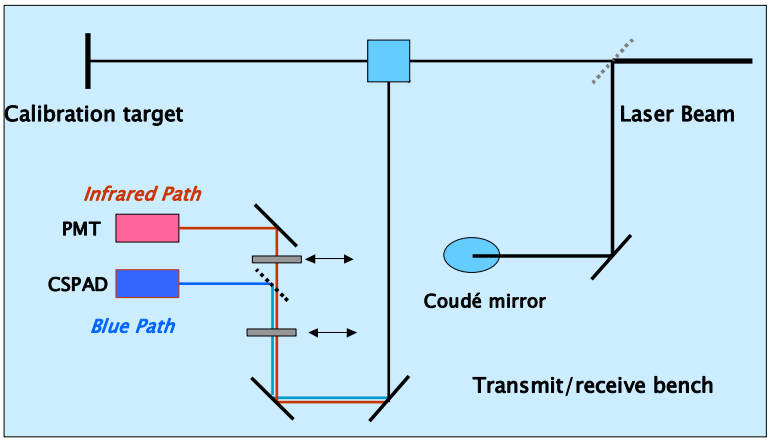

Figure 6: *Internal Calibration*

Occasionally we also perform calibration observations to an external target at about 600 m distance. Figure 7 shows time series of separate internal and external calibration sessions for infrared over the same 10 months and again the pass-averaged differences of calibrated blue-infrared satellite ranges. It is obvious that the external calibrations do not show the same variations.

A possible reason for the problem with the internal calibration (in infrared) could be the behavior of the respective Stanford counter at the very short time of flight (a few tens of nanoseconds). However, a comparison between the two counters used in the two receiver chains (blue and infrared) and the newly purchased A032ET event timers

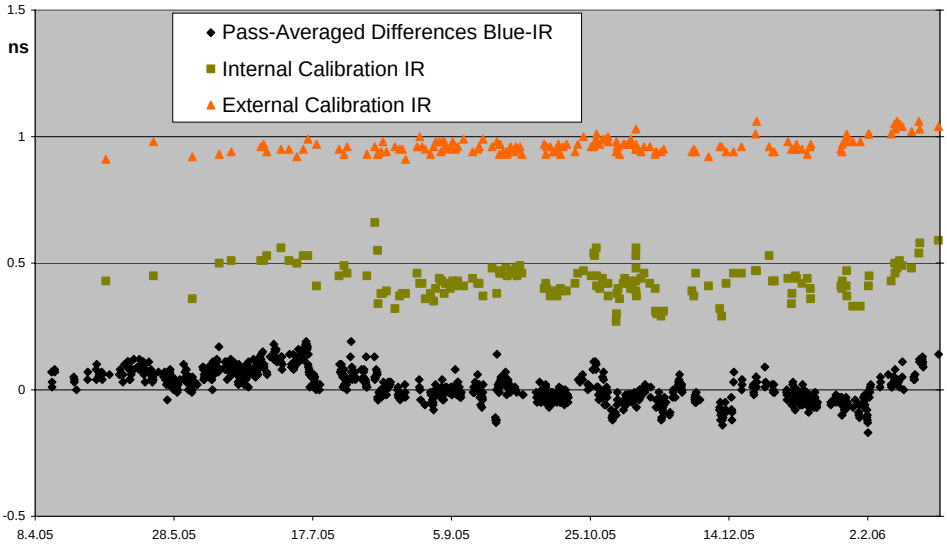

Figure 7: *Internal/external calibration, inter-color biases*

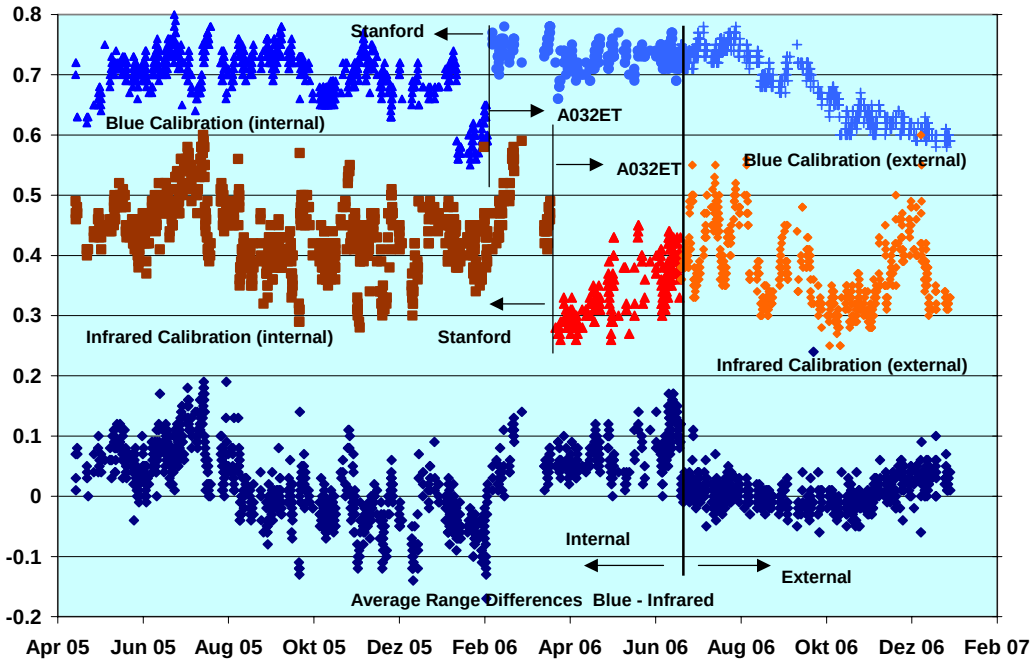

Figure 8: *Calibrations, inter-range biases*

did not reveal anything suspicious. The later replacement of the Stanford counters by the event timers in spring 2006 did not solve the problem either.

Consequently we decided to replace the internal calibration procedure by calibrations to the external target. We modified the observation procedures accordingly: The scheduler inserts now approximately every half hour a short calibration session into the satellite passes.

Figure 8 shows now the behavior of the inter-color biases before and after the modification of the calibration procedures on June 21, 2006. The variations (bottom time series in the Figure) became significantly smaller. There still seems to be a small signature in the time series. We will have to closely monitor these differences and hopefully be able to later correlate these variations with some system parameters.

References

[1] Gurtner, W., E. Pop, J. Utzinger, “Zimmerwald Dual-Wavelength Observations: First Experiences”, 13th International Workshop on Laser Ranging, Washington D.C, October 7-11, 2002