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Laser Ranging to Nano-Satellites

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Abstract: *Several small satellites in the class of pico- and nano-satellites will be equipped with multiple small corner cubes: OPS-SAT (ESA), S-Net and TechnoSat (8 kg resp. 15 kg; Technical University Berlin), and CubETH (ETH Zuerich). The size of these satellites is in the range from 10x10x30 cm up to about 40x40x30 cm; the planned circular orbits are in the 450 – 620 km range. Commercially available 10 mm and 0.5" corner cubes will be used for SLR; a single corner cube of this size will be sufficient for SLR to the planned LEO orbits. Placing several of these corner cubes on each side of the satellites will not only allow for standard SLR and POD, but also for an independent attitude determination with < 1° accuracy, even after the end of the satellites lifetime, or in case of problems or satellite failure. For multiple satellites flying in close formation, it will be possible to distinguish the sequence of single satellites within the formation.*

1. Introduction

Numerous small satellites, called cube-sats, pico-satellites, nano-satellites, etc. – typically designed and built by Universities – have been launched during the past years, and are planned for launch within the next years. Usually, low Earth orbits (LEO; below e.g. 800 km) are selected for this type of satellites. Mounting small, cheap COTS (Commercial Off-The-Shelf) corner cube retro-reflectors (CCR) on such satellites allows to use Satellite Laser Ranging (SLR) for POD (precise orbit determination, and – using multiple CCR per surface – also for precise attitude determination, even after end of lifetime, in case of failure etc., down to short before re-entry into atmosphere.

The satellites considered here will be launched within the next 2 or 3 years, into circular orbits, in altitudes between 450 and 620 km. All of them will be equipped with several COTS CCR of 10 mm or 1.27 mm (0.5") diameter.

2. Satellites to be equipped with COTS corner cube reflectors

2.1 OPS-SAT

OPS-SAT is the first ESA satellite in this class of small satellites (Fig.1); at a planned orbit of 600 km altitude, it will be mainly a platform for software experiments. The FPGAs on board are re-programmable in orbit, and will allow for various tests, changing software configuration, testing various operating systems, file transfer capabilities etc.

Its size of 10x10x30 cm will allow to mount several CCR, possibly on several sides, allowing not only POD with SLR, but also precise attitude determination (see below).

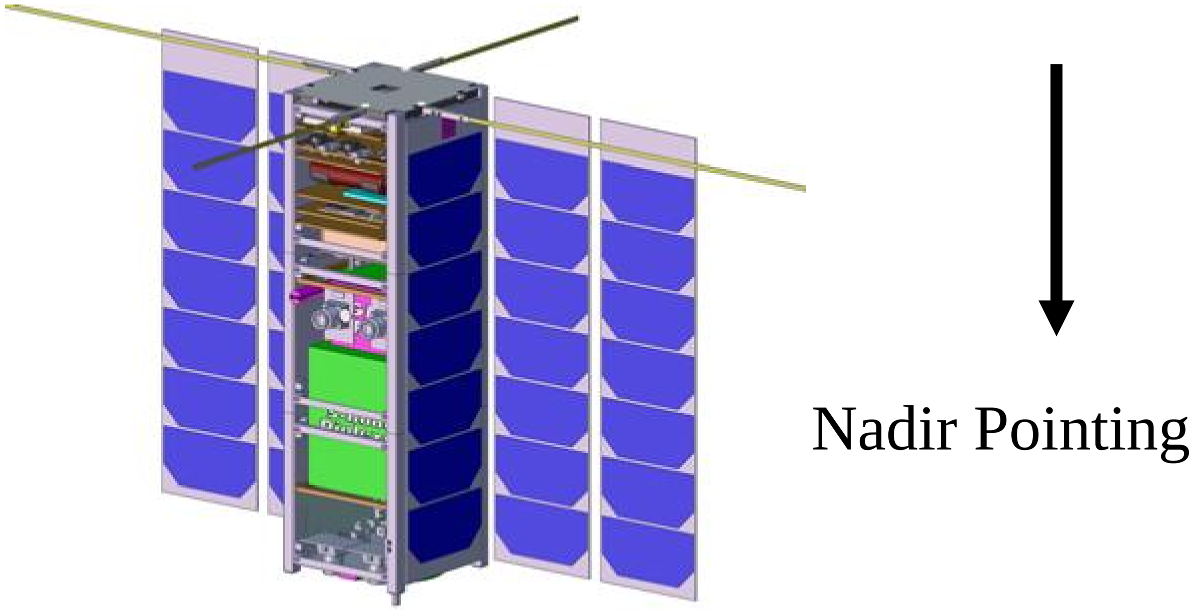


Fig. 1: OPS-SAT: 10 x 10 x 30 cm; 600 km orbit; stabilized; launch planned for 2015

Placing multiple CCR on several sides is planned, but faces some problems due to surface needed for solar cells, and dimension constraints due to normalized launch containers. The present compromise solution places a ring of CCR around a camera at the nadir side.

2.2 TechnoSat Mission

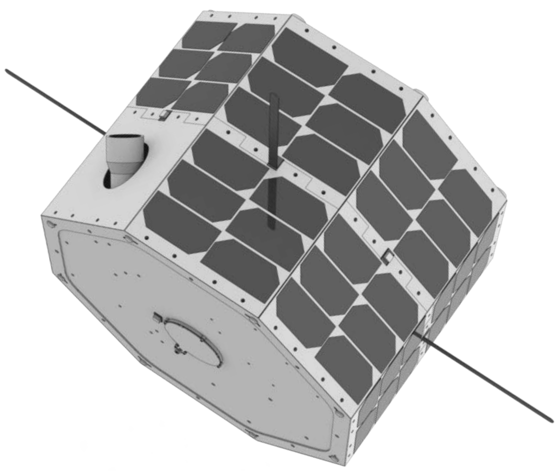


Fig. 2: TechnoSat: 400 x 400 x 300 mm, Technical University Berlin; technology demonstrator

This mission is planned for launch in 2015, into a 600 km orbit (tbd); its dimensions and geometry allow placing several CCR at least on top and bottom side, and will be ideal for attitude determination via kHz SLR.

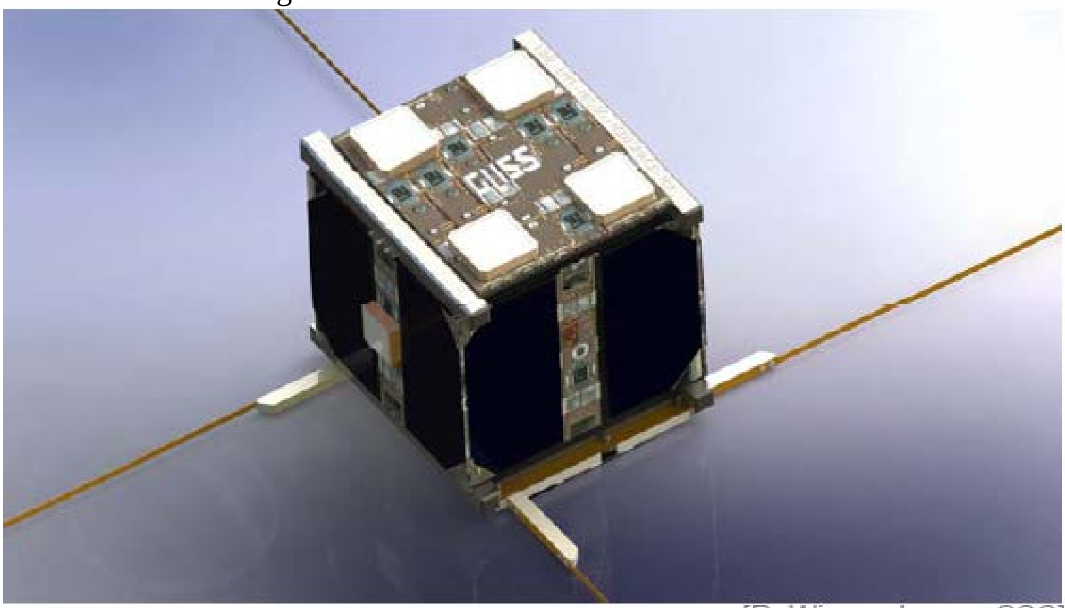
2.3 S-Net: A communication network of 4 satellites using S-Band

Fig.3: S-Net: 4 satellites with S-Band Transceivers, each 240 x 240 x 240 mm, TU Berlin

The 4 satellites – launched together, and ejected in very short intervals – will use SLR data from CCR on their surfaces not only for POD and attitude determination, but also for identification of single satellites, especially during begin of the mission, when satellites are still close together.

2.4 CubeETH: A Swiss project (ETH Zuerich), mainly for GNSS experiments

This satellite is planned for launch in 2016, into an orbit of about 450 km; the main goals will be GNSS experiments, using GPS, GLONASS, QZSS, GALILEO and COMPASS data in orbit. An additional science goal is attitude determination, using single-frequency GNSS (post-processing and real-time; proof-of-concept); this coincides nicely with the planned CCR, which also will allow such attitude determination using SLR.

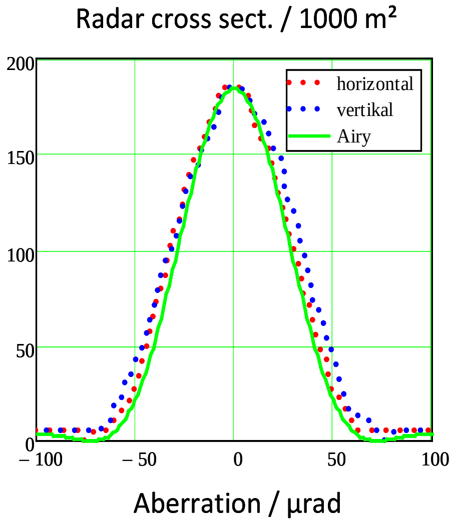


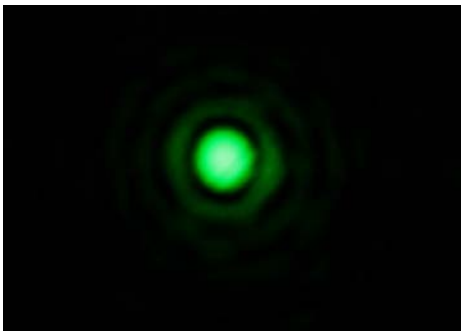
[R. Wiesendanger, SSC]

Fig. 4: CubeETH: 450 km orbit, GNSS Experiments

3. Single corner cubes for circular orbits of up to 620 km altitude

The main goal here is to use a single, small and cheap COTS CCR on these satellites, to allow standard laser ranging to their orbits of up to 620 km, independent of CCR orientation. The velocity aberration at such orbits is in the range of 25 to 50 µrad; the CCR have to be big enough to deliver a return signal which should be at least comparable to the LAGEOS signals, allowing ALL SLR stations to range to these satellites.





0.5“ CCR (OTS optics)

Fig. 5: Radar cross section of a 0.5” COTS CCR, at a 620 km orbit, 45° incidence angle; the velocity aberration for such an orbit is between 25 and 50 µrad, and the expected return signal is about 2 x the LAGEOS signal. Right: Far Field Diffraction Pattern of 0.5” COTS CCR

The 0.5” fused silica CCR used for these calculations are COTS parts with aluminium coating and protective painting of their back sides, and are available for less than 150 EUR per piece.

4. Attitude Determination

Placing several CCR on EACH side of a satellite, allows precise attitude determination using kHz SLR data. This has been demonstrated already several years ago, using SLR to the Russian satellite ‘Reflector’ (Fig. 6). This kHz SLR data set demonstrates nicely the possible high resolution for attitude determination; distance differences of less than 10 mm can be determined easily.

To simulate attitude measurements and to determine the resolution, we used our far target at Graz SLR, a single 50 mm diameter retro-reflector mounted in a distance of about 4.3 km. The attenuated 2-kHz laser pulses (10 ps pulse width, 532 nm wavelength) were reflected at this CCR back to a test bar in front of transmit and receive telescope: a simple bar with 2 CCR mounted (fig. 7); this bar was rotated by ± 20° in 1°-steps from normal incidence. The photons reflected here made the trip back to our far target, and back again into our receive telescope. The total round trip time of single photons was measured with about 2.5 mm RMS. Using this data, the tilt angle of the bar was calculated, and compared with the tilt angle of the bar as set for each measurement (fig. 8).

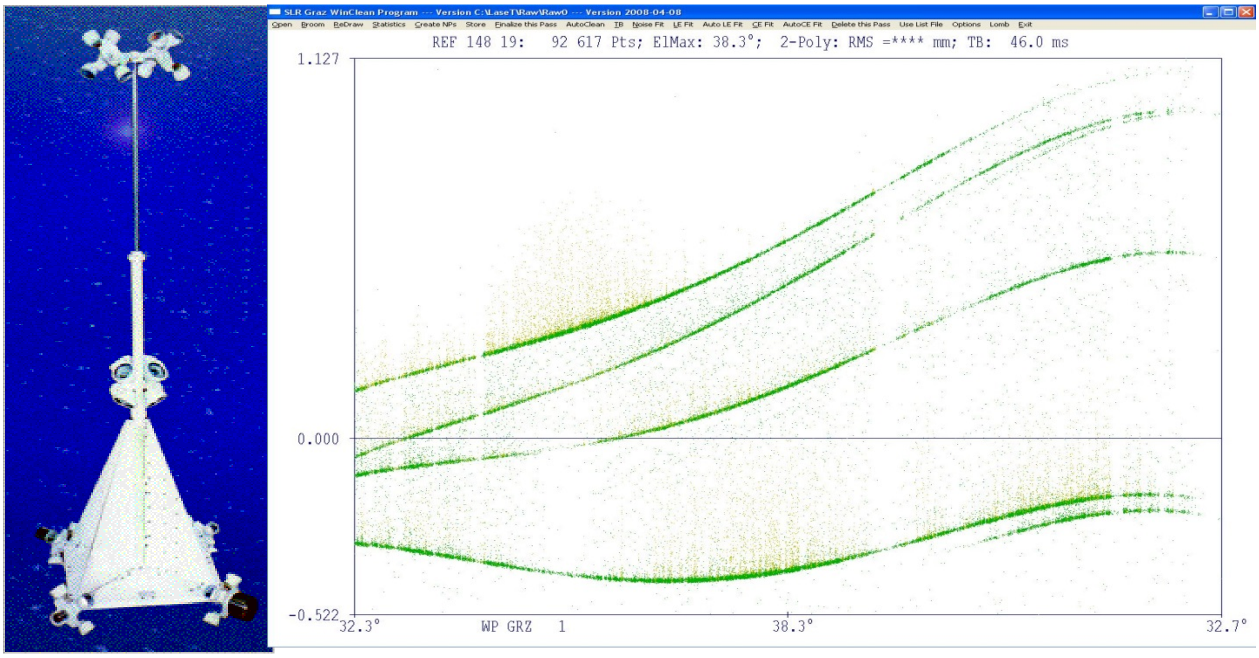


Fig. 6: The Russian satellite 'Reflector' (left): Graz 2-kHz SLR data shows the attitude during the pass with high resolution (right)

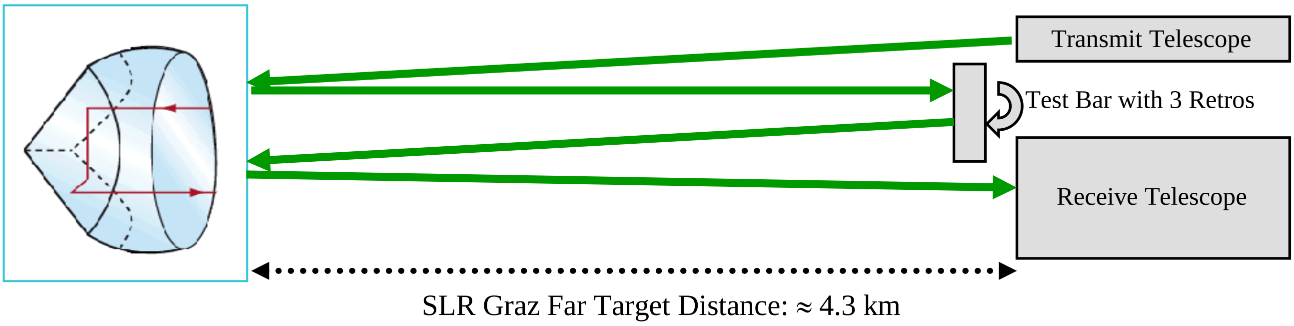


Fig. 7: Setup to simulate and measure attitude determination

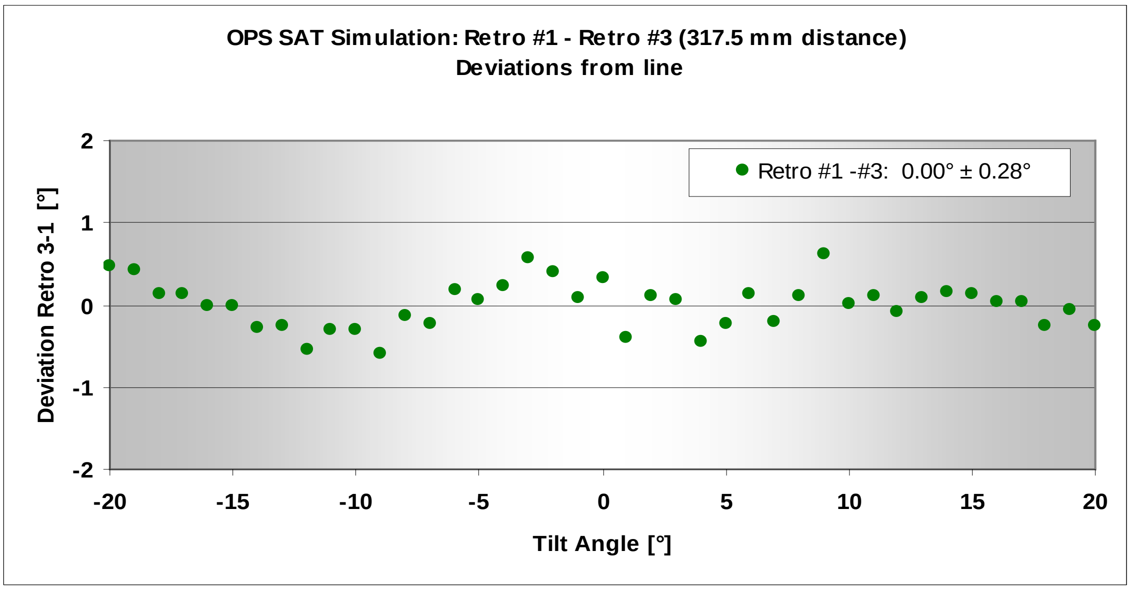


Fig. 8: Test bar tilt angle: Measured (via SLR to far target) vs. set tilt angle

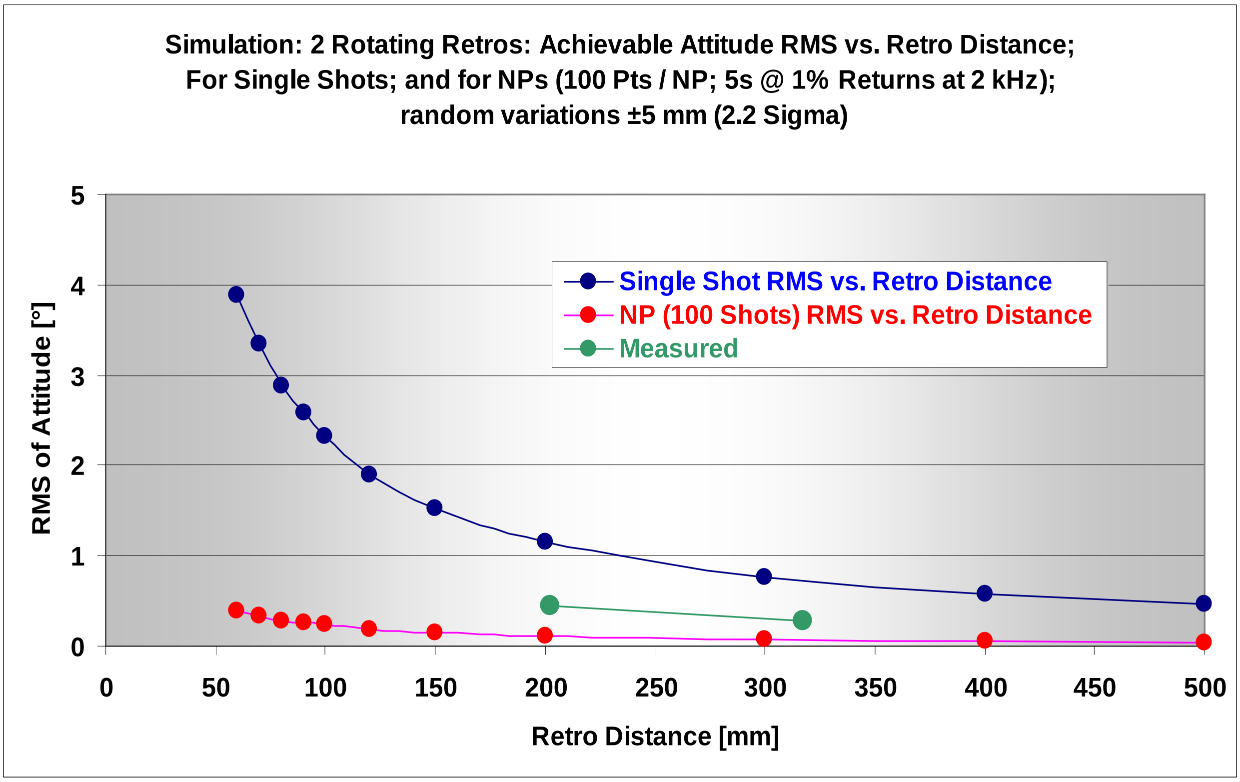


Fig. 9: Simulated achievable accuracy of tilt angle determination, depending on spacing of 2 CCR: Using single shot (blue dots) or normal point (red dots) data; measured accuracy for 2 selected spacings (200 mm and 315 mm): Green dots.

Spacing of CCR, mounted on small satellites like CubeSats, is limited due the size of these satellites; hence we simulated such measurements for different spacing, taking the specifications of the kHz laser ranging station Graz, and the available geometry on a small satellite into account. The results are shown in fig. 9: Using simulated single shot (blue dots) and normal point (red dots) data, it can be seen that down to a spacing of 50 mm of 2 CCR the attitude can be determined with a precision of less than 1°; at smaller spacing of the 2 CCR, the returns from the 2 CCR cannot be distinguished anymore. For a CCR spacing of 200 mm and 315 mm resp. the tilt angles were measured with a precision of less than 0.5° (green dots).

5. Conclusion

Several small satellites – to be launched in the next years – will be equipped with COTS corner cube reflectors; these fused silica CCR will be small: 0.5" or 10 mm diameter. They will allow SLR up to orbits of 620 km, with expected return signal strength of at least that from LAGEOS. Using more than 1 CCR per surface, it will be possible to determine the attitude of the satellites with a precision of better than 1°, independent of operational status of the satellite. In case of multiple satellites – flying in close configuration at least during mission start – it will allow to determine the positions or sequence of the individual satellites.

References: The major part of this work is the result of several meetings of the small group of proponents, as stated in the authors list. Several more project meetings are proposed in the near future, to finalize details about CCR arrangements etc; anybody interested to participate in these project meetings, or with plans to launch similar satellites, is welcomed to participate.