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Demonstration Breadboard of a Miniaturized Single Photon Detection Laser Altimeter for Small Satellite Applications

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Laser Altimetry is a powerful technique to create absolutely calibrated digital terrain maps of planetary surfaces, to analyze their surface geology, and to get insight into the interior structure of planetary bodies by measuring tidal elevations and libration amplitudes and frequencies [1]. The recent ESA missions BepiColombo and the Jupiter Icy Moons Explorer (JUICE) carry the first European laser altimeter instruments, i.e. the BepiColombo Laser Altimeter (BELA) [2] and the Ganymede Laser Altimeter (GALA) [3], the latter of which has a strong contribution from JAXA.

The measurement principle of laser altimetry is based on the time-of-flight measurement of an optical pulse. BELA, which is now on its way to orbit Mercury, applies a diode-laser pumped Nd:YAG laser sending pulses with an energy of 50 mJ at a repetition rate of 10 Hz. Over typical ranging distances of 400 km to 1000 km, the BELA telescope collects return pulses with a few hundred photons and the mean topographic altitude of the area illuminated by the 5 to 40 m diameter laser beam is derived from the time of photon arrivals. The return pulse width further gives information on slope and roughness within the area illuminated by the laser. GALA is a similar instrument with 17 mJ pulse energy and 30 Hz repetition rate. It launched in April 2023 to enter the Jovian system after a six-year cruise to fly-by Europa and Callisto and finally orbit the Jovian moon Ganymede at an altitude of about 500 km above its icy surface. BELA and GALA [2,3] are instruments that consume about 50 W of power and have masses of close to 15 kg and 25 kg, respectively. The instrument's physical dimensions are strongly driven by the telescope diameter of about 25 cm. Both of these instruments use Avalanche Photo Diodes (APD) in linear mode for photon detection. In order to enable the use of this type of instruments on small satellites, the size, weight and power budgets need to be drastically reduced.

We present first results from a design study of such a system for use on small satellites applying a newly developed detection scheme using a Single Photon Avalanche Diode (SPAD). The goal of the study is to derive the time-of-flight information from only a few photons, thus reducing the resources needed for the transmitting laser and the receiver telescope. An elegant breadboard of a single photon detection laser altimeter has been built at DLR and the instrument will be tested in the field on ranges of up to 10 km. Measurements are planned to be taken during different illumination conditions and a flight campaign at altitudes of up to 6 km is in preparation for spring 2024. The instrument breadboard design makes use of commercial optical and opto-mechanical components including a 5 µJ microchip laser at a wavelength of 1064 nm with kHz pulse repetition rate. A SPAD module serves as detector and the module has been characterized with respect to dark count rates, quantum efficiency, gain, dead times and after pulsing using a measurement setup at DLR. Temperature stabilization and active quenching are implemented in the SPAD to achieve low dark count rates and short dead times.

High precision time-to-digital conversion (TDC) on nanosecond scales is driving the shot-to-shot ranging accuracy. The major challenge for providing such precision using a single photon detection laser altimeter is the reduction of the background photon rate to acceptable levels. This can be realized by using a high quality laser beam with low divergence, by tightly limiting the field-of-view of the telescope, by good spectral filtering as well as by effective filtering and statistical algorithms. We will present measurement results and compare these with predictions derived from simulations to test our ranging algorithms. Furthermore, the option to use SPAD arrays for efficient background filtering will be discussed. The feasibility of accommodating the instrument on the modular TUBiX20 microsatellite platform [4, 5] developed by Technische Universität Berlin will be explored.

1 References

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