Multi Color Satellite Laser Ranging At Czech Technical University

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Abstract

We are reporting on our activity on Satellite Laser Ranging (SLR) using multiple wavelengths. The reasons for simultaneous multi-frequency laser ranging of artificial Earth satellites are discussed. Atmospheric dispersion study and the eye-safe wavelength region are both considered. To detect the returned signal, the Single Photon Avalanche Detector (SPAD) is operated in so-called Geiger mode. The silicon, germanium, and gallium arsenide phosphide based SPAD are used depending on wavelength to cover nearly the entire optical region having the single photon response, temporal resolution better than 120ps FWHM, and quantum efficiency of about 15%. The active area size and the compact design of the detector packages permitted their application in satellite laser ranging yielding sub-centimeter ranging precision in infrared and sub-millimeter precision ranging in the visible region. The active area of the detector used is from 100 to 200 µm. Detectors for the visible region are cooled thermo-electrically and detectors for infrared, based on germanium, are cooled cryogenically with a custom design liquid nitrogen Dewar. The design and diagnostics of a hydrogen Raman-shifted picosecond Nd:YAG laser operated at 10 Hz repetition rate are presented. Both the far-field beam structure and temporal picosecond pulse profile are monitored for different laser configurations. The optimum laser configuration has been implemented to the SLR station in Shanghai for two color ranging. To operate the SLR station in Graz in visible range, three color ranging is accomplished by Nd:YAG SHG 532 nm, the first Stokes Raman at 682 nm and the first anti Stokes at 432 nm using Hydrogen. To operate the eye safe SLR in Tokyo at the 1540 nm wavelength, the laser was operating at 1064 nm to pump the first Stokes at 1540 nm using methane. To operate the SLR in Bern and Wettzell (move to Chile) Titanium-Sapphire based laser has been operating at 852 nm and SHG 426 nm. The color set has been established at the Shanghai observatory since 2004. The ranging has been successfully accomplished for retro-reflector equipped satellites up to a distance 30000 km with one centimeter precision. The results of direct measurements of atmosphere dispersion are presented and compared existing atmosphere models.

Introduction

We have the experience in field of SLR since the seventies of last century. To range satellites or Moon one has to consider several “contributors” to the overall accuracy of the SLR measurement chain: the station itself, satellite retroreflector array, and the atmosphere as well. Current SLR technology aims toward millimeter accuracy. From the point of view of the SLR station, rms of the laser pulse duration, Start and Stop detectors rms and the Event Timer jitter are involved. Related to the atmospheric dispersion, the existing models are not yet explaining the contribution at millimeter accuracy level. The SLR at different wavelengths might help to understand the atmospheric mapping function down to millimeter and consequently sub-millimeter level. In fact, multi-color SLR is a unique method for overall optical path dispersion model direct verification.

Experiment arrangement

Assuming the atmospheric dispersion, to find the right laser for multiple wavelength millimeter SLR, one can consider the Nd:YAG / SHG / THG, Nd:YAG / SHG / Raman First Stokes / First antiStokes in hydrogen, Nd:YAG / SHG / Raman First Stokes in methane and the Titanium Sapphire Fundamental / SHG, all of them at different repetition rates. The basic of Raman conversion is described by eq. 1.

$$\frac{1}{\lambda_{shifted}} = \frac{1}{\lambda_{pump}} + k \cdot \nu_R \text{, where } k \in \left(-\infty, -1\right\rangle \cup \left\langle 1, \infty\right) \qquad (1)$$

Where λ is symbol for the wavelength and ν is material constant describing Raman shift for the selected gas. For hydrogen it is 4155 cm^{-1}, for methane 2914 cm^{-1}, and for deuterium 2987 cm^{-1}.

The selection of the laser transmitter concept is influenced by the required reliability in the routine field operation. Considering that the 6 picoseconds round trip time corresponds to one millimeter range, therefore to reach the millimeter goal, the acceptable laser pulse width within the range of 10 to 50 picoseconds is desirable. The experiment energy budget requires the energy in one pulse in order of several tens of millijoules. The selection of the right wavelength pair is determined by the atmospheric dispersion mentioned above, by atmosphere transparency, and by the availability of high effective frequency shifters. In principle it is difficult to use to independent lasers due to the required picosecond synchronization.

The available detectors have to be considered. Our laboratory has long term experience in the field of picosecond temporal resolution solid state detectors[1]. For the visible range we did examine mainly silicon based SPADs, for the eyesafe SLR Germanium based SPADs. The silicon one can be operated at thermoelectrically cooling temperature. The germanium based cooled detector is suitable for eyesafe wavelengths; however it has to be cooled by liquid nitrogen. Using the Quantel YG580 Laser 30 mJ / 1.06 µm, 35 ps, different Raman tubes filled by Hydrogen at different pressure, different focusing lens, we were getting 8 mJ / 0.68 µm, 1 mJ / 0.45 µm. Considering the eyesafe SLR using Raman shift in methane from fundamental we were getting 3 mJ / 1.54 µm.

Conclusion

We are presenting a review of our activities on multiple color SLR and recent results from Shanghai SLR observatory[2]. The selection of the right wavelength pair is discussed and together with our experience with available and effective frequency shifters selection and tuning. The multiple color laser transmitter based on Nd:YAG picosecond laser generating the second harmonic frequency and the Raman Stokes and anti Stokes frequencies is dedicated for the new Shanghai SLR station, the part of Western Pacific Laser Ranging Network.

References

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