Compact retroreflector array «Pyramid» for LEO satellites

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«RPC «PCI»

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The important task of retroreflector array (RA) improvement is minimizing the target error of range measurement, caused by the reflection of laser radiation from two or more CCRs. In order to obtain the required energy and precision characteristics, it is necessary to ensure the optimal far field diffraction pattern of reflected radiation by design parameters of RA. Since the satellites orbital altitude varies, the task of RA optimization should be solved for each spacecraft separately.

Let us consider the capability of reducing the random error of a single range measurement occurring at the expense of RA in relation to the low-orbit satellites. In this case, the mean value of velocity aberration is about 8" [1]. The compact RA has a pyramidal structure with four CCRs (Fig. 1).

The RA at CHAMP, GRACE-A, GRACE-B, TerraSAR-X, TauDEM-X are the most similar in design to the compact RA. However, these RAs used large-size CCRs with aperture diameter of 38 mm, and the distance between vertexes of neighboring CCRs of these RA is 27 mm [2].

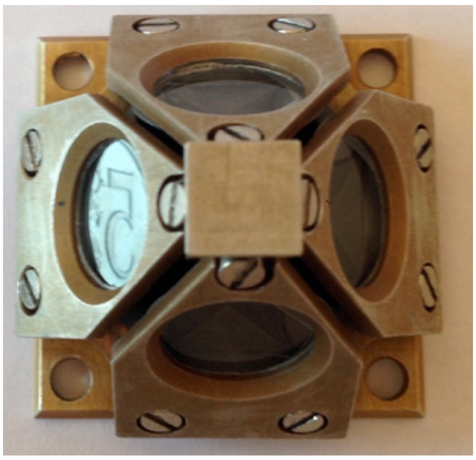


Fig. 1 – Prototype of the «Pyramid» RA

For the determination of the RA characteristics we introduce the following parameters: *A* is the angle between the satellite velocity vector and the laser radiation projection on the pyramid base (Fig. 2a); γ is the angle measured from the direction to the Earth's center to the optical axis of the laser beam (Fig. 2b). Using the introduced parameters, it is possible to specify the direction of laser beam incidence on the RA.

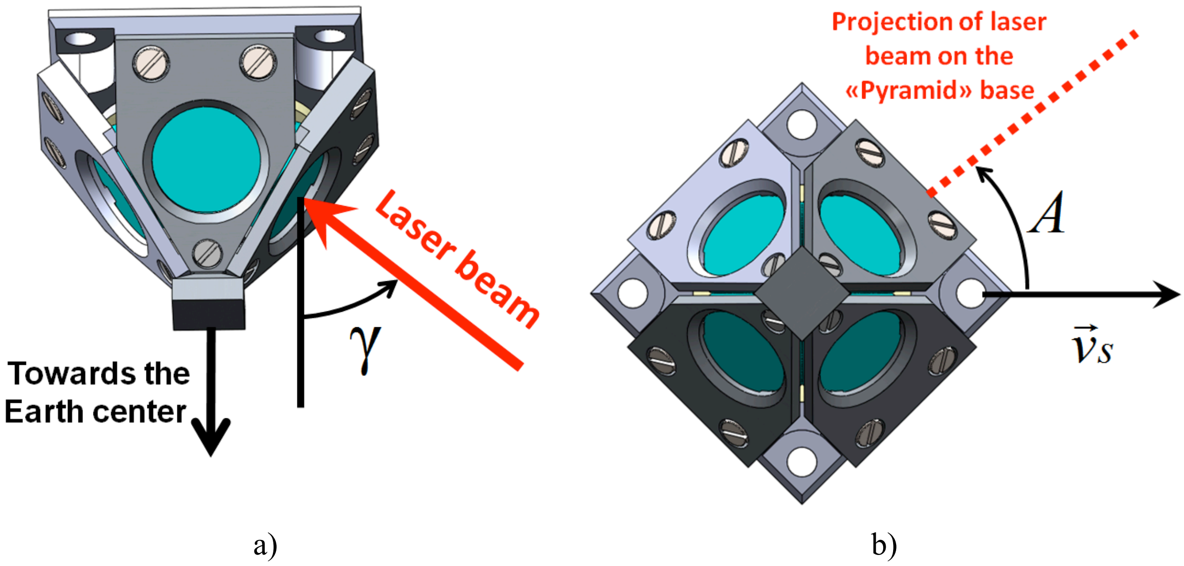


Fig. 2 – Determination of the direction of laser beam incidence on the RA:
a – γ angle, b – A angle

The satellite orbital altitude is characterized by the maximum value of γ angle: γ_{max}. For example, γ_{max} is 60 degrees for the orbital altitude of 1000 km (Fig. 3).

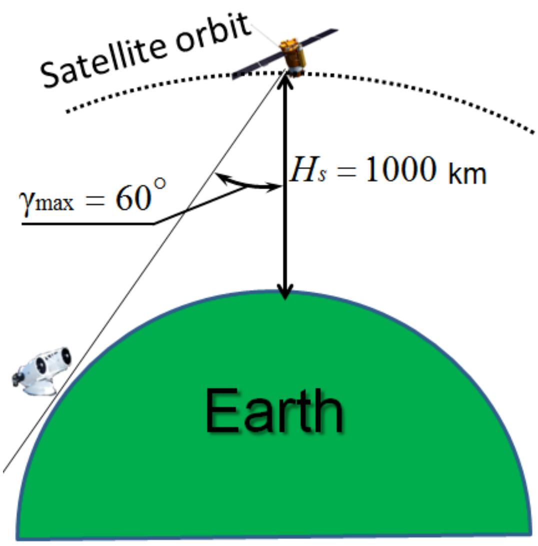
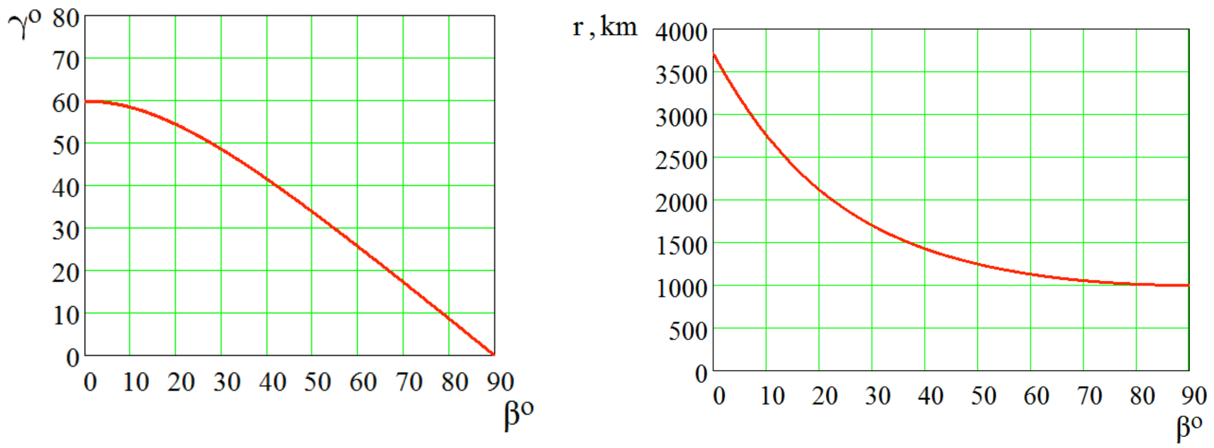


Fig. 3 – Limit of the γ angle

Diagrams of the γ angle and range to the satellite r dependence on the elevation angle β are presented in Fig. 4 (the satellite orbital altitude is 1000 km).

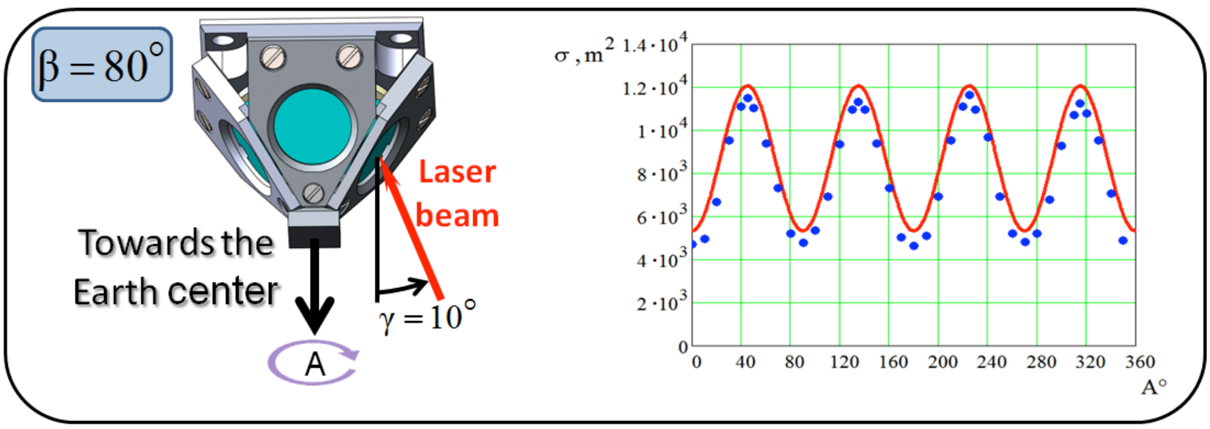


a) b)

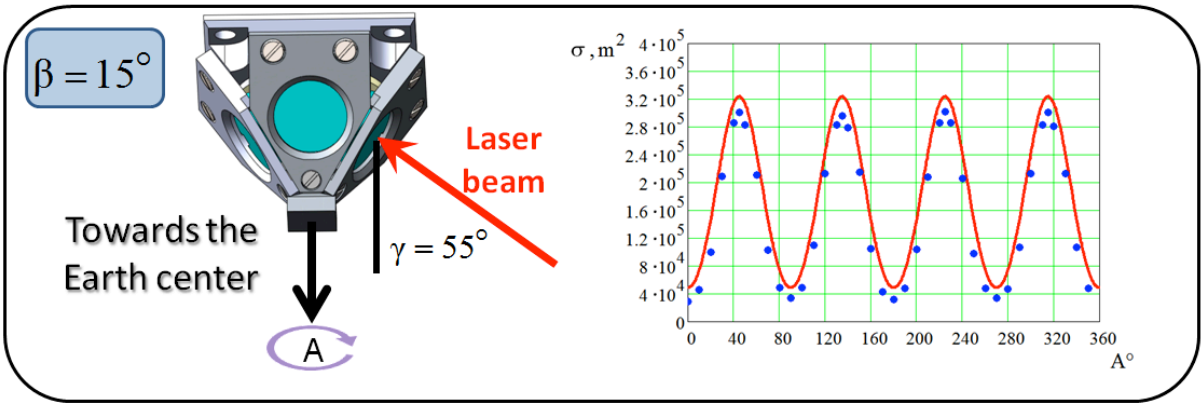
Fig. 4 – Dependence of the γ angle (a) and the satellite distance *r* (b) on the elevation angle β for a satellite orbit altitude of 1000 km.

When the elevation angle is close to zero, the satellite is located near the visible horizon and the γ angle is maximal. When the altitude angle is close to 90°, the satellite is located in the zenithal area and γ approaches zero. The range to the satellite is maximal when the satellite is located slightly above the visible horizon. The increasing of the elevation angle reduces the range to the satellite and around the zenith area the range is approximately equal to the satellite orbit altitude.

In order to determine the energy characteristics of RA, let us consider two extreme cases: location of satellite near the zenith area (Fig. 5a) and slightly above the visible horizon (Fig. 5b).



a)



b)

Fig. 5 – CS of the compact RA «Pyramid» for the satellite position near the zenith area (β = 80°) (a) and slightly above the horizon (β = 15°) (b) (point – experiment, line – theory)

At γ = 10° the total value of CS is approximately constant. In case of the satellite location slightly above the visible horizon the CS varies within the range from $3.2 \cdot 10^5$ m^2 to $4.0 \cdot 10^4$ m^2. Maximums of CS, obtained from each CCR separately, are reached when the radiation is incident only on one CCR normally to the input face. Minimums correspond to the case when the radiation is incident on two CCRs, and CCRs apertures have elliptical shapes. The high laser pulse repetition frequency makes it possible to obtain a sufficient number of return signals even with the minimum CS.

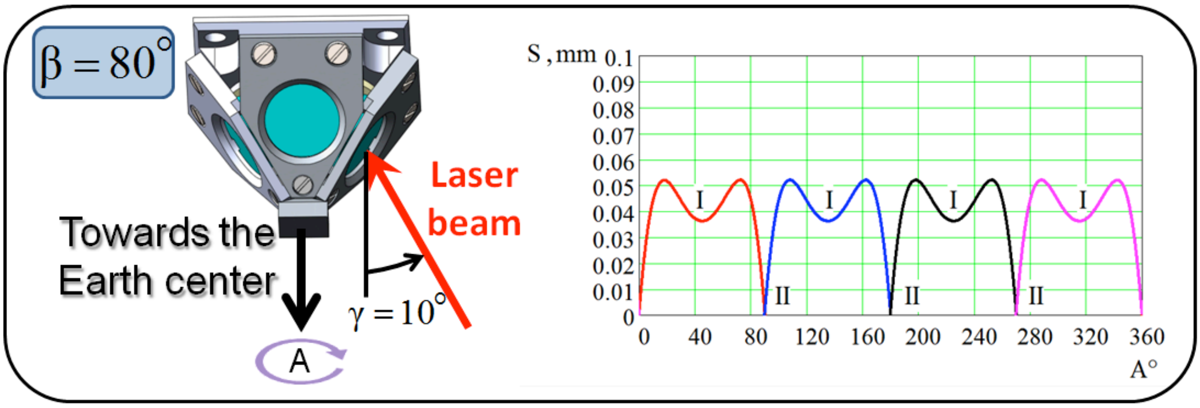
The «Pyramid» retroreflector array range correction

A quite important parameter of the RA is the target error. For its calculation, let us suggest that the range to the spacecraft is measured from the common vertex point of the four CCRs. The range correction can be calculated according to the following formula:

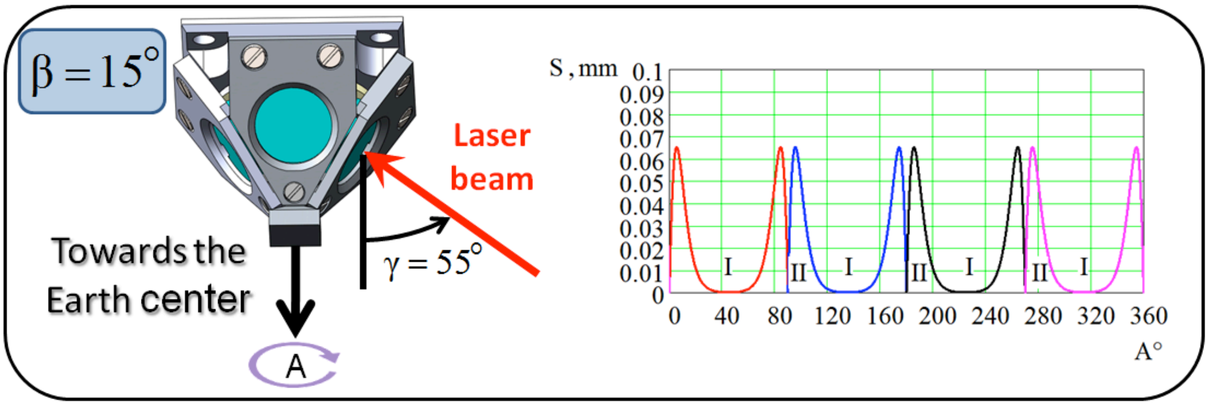
$$S_i = \frac{\sum_{i=1}^{4} \sigma_i \Delta_i}{\sum_{i=1}^{4} \sigma_i} - \Delta_i,$$

where i is the CCR number, σ is the CS, $\Delta = -h\sqrt{n^2 - \sin^2\theta} + h\cos\theta$ is the systematic range measurement error related to the beam propagation inside the CCR (h is the height of CCR, n is the index of glass refraction, θ is the angle of light incidence on the input face of the CCR).

Diagrams of the range correction depending on the direction of laser radiation incidence on the RA are shown in Fig. 9 (a, b).



a)



b)

Fig. 9 – Range correction of the «Pyramid» RA for the satellite position near zenith area (β = 80°) (a) and slightly above the horizon (β = 15°) (b)

The maximum error occurs near zenith, when the radiation is incident on several CCRs. The minimum at γ = 10° corresponds to the case when the radiation is incident on two CCRs, but the optical beam path lengths inside of them are identical. The maximums at γ = 55° are caused by the various optical beam path lengths inside the two CCRs. The minimum I corresponds to the case when the radiation is incident practically on one CCR, and the minimum II is observed when two CCRs “operate” but the optical beam path lengths inside of them is identical. As follows from Fig. 9 a, b, the range correction of distance measurement does not exceed 0.1 mm.

Conclusion

The compact RA «Pyramid» consisting only of four CCRs allows to increase the accuracy of range measurements for low-orbit satellites with a sufficient energy level. The total variations CS (see fig. 5) can be significantly reduced by using for the CCRs optical material with high index of refraction (n = 1,7 – 1,8).

It is planned to test the «Pyramid» prototype (see fig. 1) at the «Mikhailo Lomonosov» spacecraft [3]. The approximate launch date of the spacecraft from the «Vostochni» cosmodrome is December 2015 year.

References

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2. Reinhart Neubert, Ludwig Grunwaldt, Jakob Neubert, «The Retro-Reflector for CHAMP Satellite: Final Design and Realization», internet access: http://ilrs.gsfc.nasa.gov/docs/rra_champ.pdf.

3. «Mikhialo Lomonosov» spacecraft, internet access: [www.lomonosov.sinp.msu.ru/en].