Retroreflector complexes to determinate the coordinates of SC moving parts

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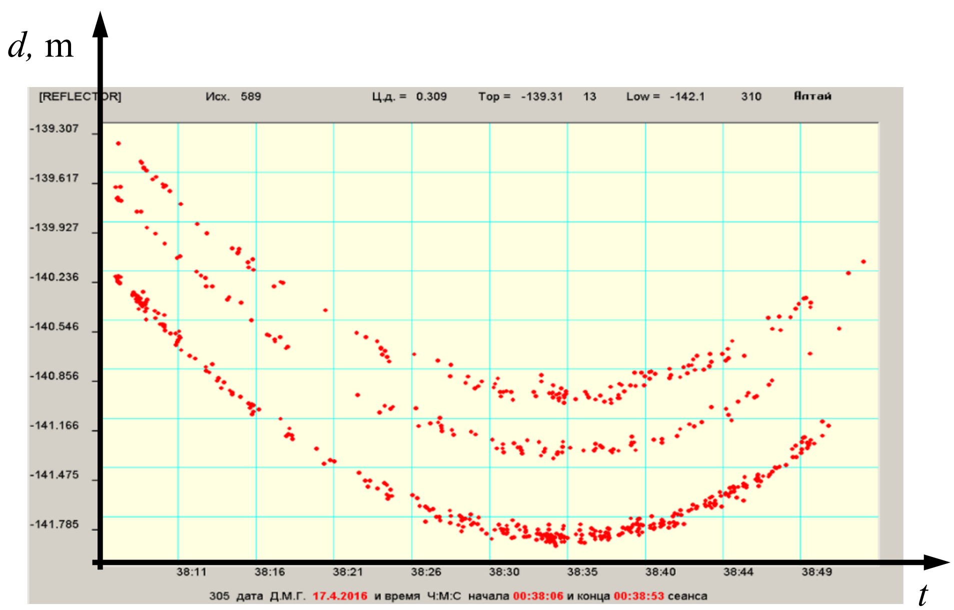
To understand the definition of the retroreflector complex, we introduce the following terminology: a compact set of the corner cube reflectors (CCR) will be called the retroreflector system (RRS), and several systems that are located in different places of the spacecraft (SC) will be called the retroreflector complex (RRC).

One of the first RRC was installed on the “Reflector” satellite (see fig. 1a), which was launched in 2001 as a piggyback payload on board of the SC “Meteor-3M”. The orbit altitude is 1000 km. The satellite was used for analyzing and investigating the return signal structure for determination of the spatial (angular) resolution and testing. Despite the fact that the satellite is not included in the list of active missions, it has retained an ranging ability. We recently have had several sessions to check laser station equipment. The result of ranging is showed on fig. 1b.

a)

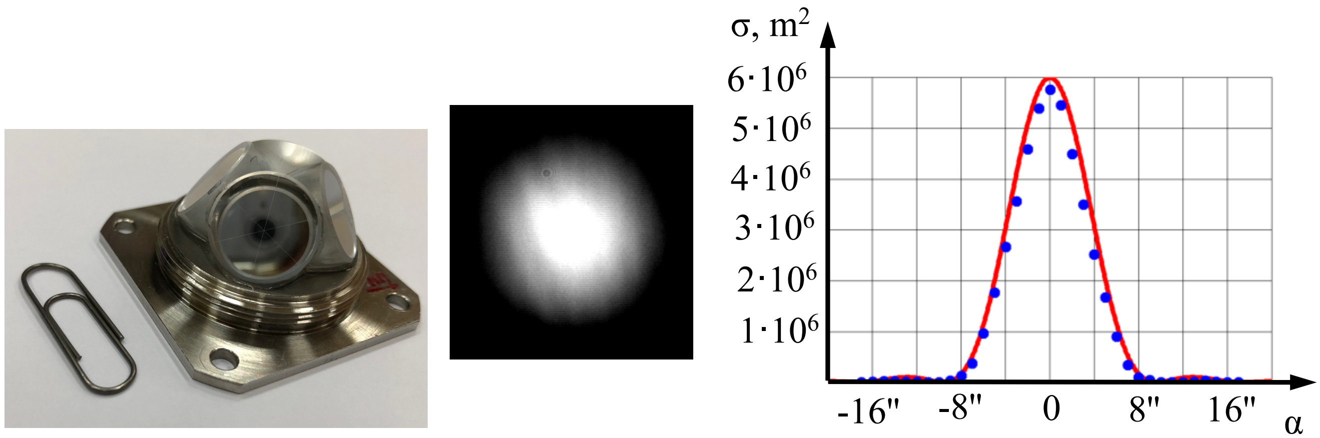


b)

Fig. 1 – SC “Reflector” (*a*) and the results of the SLR session at the ALTAY station on April 17th 2016 (*b*): *d* – range residual; *t* – time from the beginning of the SLR session

Fig. 2a shows one of the RRSs, which we offer to use as a component of the RRC. This is the RRS “Pyramid”. The RRS mass is 41 grams, and the value of the target error, which is determined by the signature of the impulses, reflected from the RRS “Pyramid”, is less than 0.5 mm.

The far-field diffraction pattern (FFDP) of the CCR in this case consists of one central spot and weak peripheral rings (fig. 2,b). The light diameter of the CCR is 14 mm and we have a sufficient reflected signal in the region of the velocity aberration (6'' – 10'') taking into account pulling out of the spot with oblique incidence of light [1].



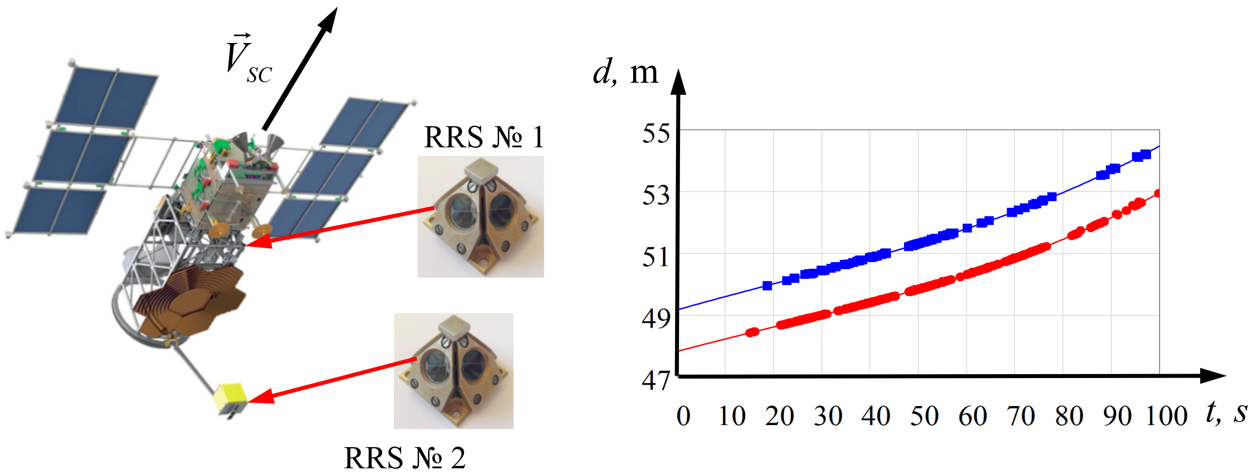
a) *b*)

Fig 2 – The RRS "Pyramid" (*a*) and FFDP (*b*) of reflected radiation from the CCR of the RRS "Pyramid"

The presented RRS can be installed on different parts of the SC in order to determine the spatial orientation of the SC axes or its movable object (for example a rod, an antenna or a solar panel). The amount of the RRS depends on the goal of the SC spatial orientation determination and its movable object.

The RRC of two RRSs “Pyramid” was used on the SC “Lomonosov” for the purpose of additional control of the photodetector rod disclosure by calculating the difference range between the RRS. Fig. 3 shows the results of the satellite laser ranging session, which was carried out by the GRAZ station [2].

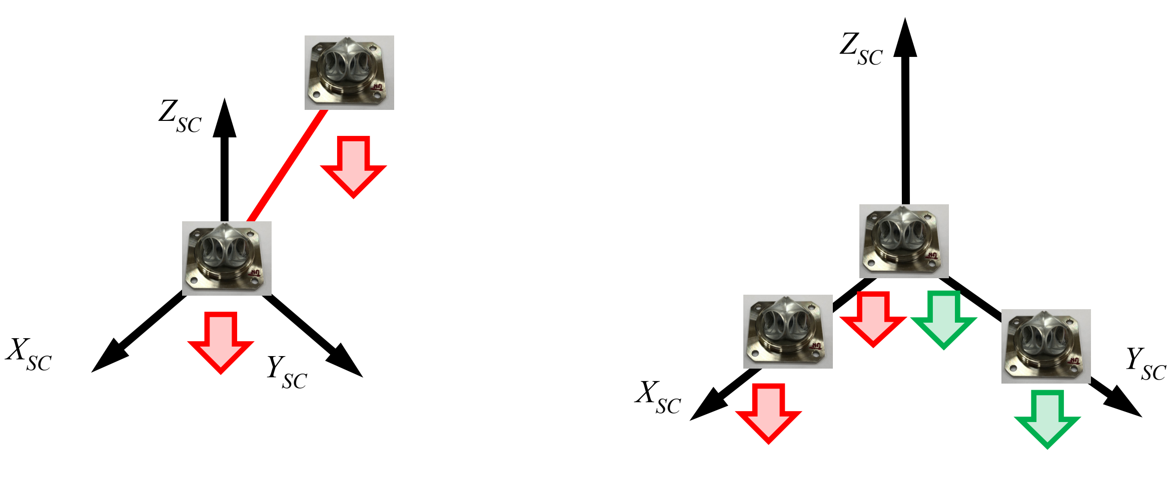
So in simple cases, only two systems are sufficient, for example, if it is necessary to control the opening (extension) of some part of the SC (see fig. 4,a). The first RRS is mounted on the SC unmovable body. The second RRS is mounted on the SC movable object. Another task is determination of the movable object location, if it deviates along the known trajectory.



a) *b*)

Fig. 3 – The RRC of the SC "Lomonosov" (*a*) and the results of the satellite laser ranging session (*b*) for the SC "Lomonosov" by the GRAZ station (10.11.2016): *d* – range residual; *t* – time from the beginning of the SLR session

Determination of the SC spatial orientation is based on the laser ranging measurements of 3 RRS (fig.4b). Wherein it is necessary to know the direction one of the SC coordinate axes, the SC precise orbit must be determined by calculation from the satellite laser ranging results



a) b)

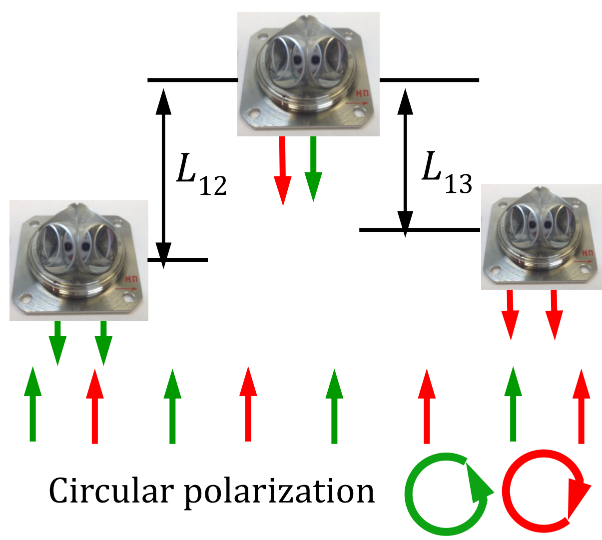
Fig. 4 – The RRC for determination of the spatial orientation:

a – The RRC for determination of the SC movable objects, *b* – the RRC for determination of the SC spatial orientation

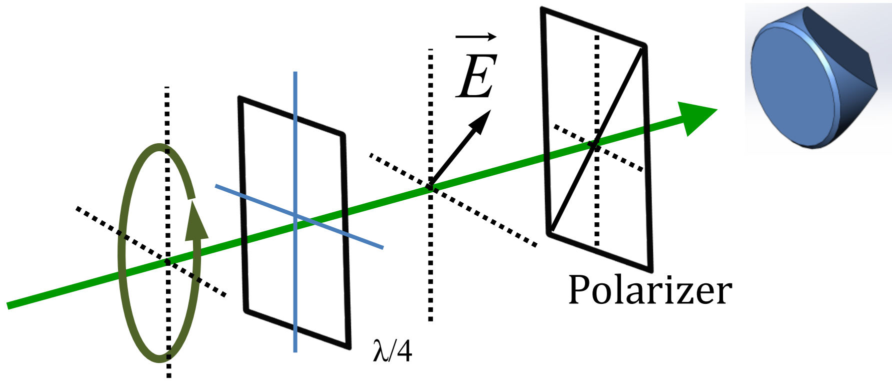
But the question arises: how to distinguish the separation of the signals coming from different RRSs, if there are more than two RRSs? There are several ways to distinguish this separation: one of them is used to determine the pictures of RRS location on different sides of SC.

The mode of switching two circular polarizations from right to left (fig.4) provides the signals separation. To separate the signals from the different RRSs, special polarizing filters should be placed on the CCR entrance faces on two of three RRSs (see fig. 5). One of RRSs does not have any polarizing filter.

It is a combination of the quarter-wave plate and the polarizer. The laser ranging session should be accompanied by a change of the polarization state of the radiation from the *right* circular to the *left* circular to separate the signals from the RRS. RRS 1 reflects both beams. RRS 2 reflects only the beam with the left circular polarization and RRS 3 reflects only the beam with right circular polarization.



a)



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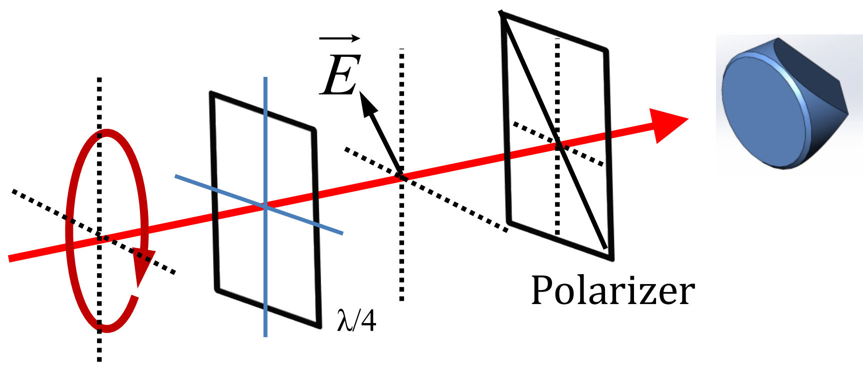


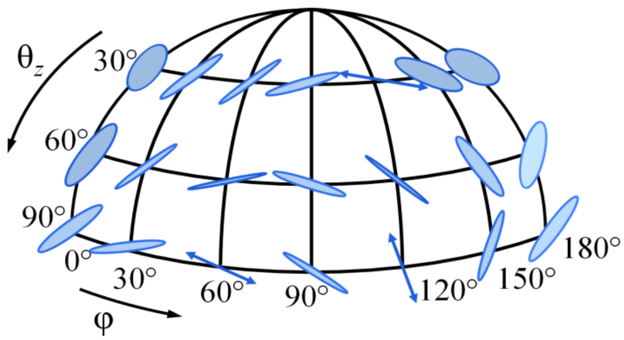
c)

Fig. 5 – Separation of the signals from the RRSs: *a* – RRC for the SC spatial orientation determination, *b* – the optical system for the reflection of the radiation with the *right* circular polarization, *c* – the optical system for the reflection of the radiation with the *left* circular polarization, L_{12} (L_{13}) – the difference ranges between RRS1 and RRS 2 (RRS 1 and RRS 3)

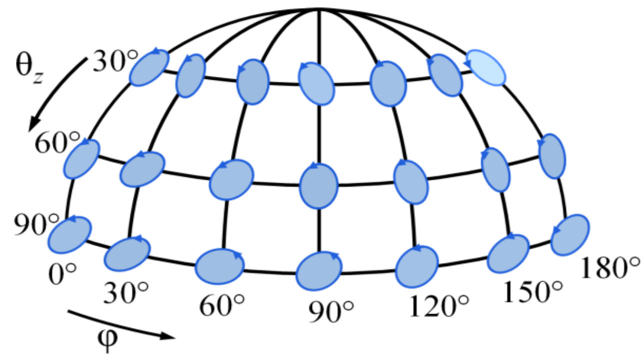
Along the way, we have solved the problem of determining the polarization state of a laser beam at the output of the guidance system of a laser station.

It turns out that even in the case of ideal interference mirrors, the azimuth of the linear polarization state changes substantially when the laser beam is directed to different points in the celestial hemisphere (see fig. 6).

The best result is to use laser radiation with the circular polarization. Then the state of polarization of the output beam ideally does not depend on the orientation. In practice, the amplitude-phase anisotropy of the mirrors distorts this pattern [3].



a)



b)

Fig. 6 – The results of the beam-steering device polarization analysis for the linear polarization (*a*) and for the circular polarization (*b*): θ_z – zenith angle, φ – azimuth angle

Summary:

1. The retroreflector complexes of the SC make it possible to determine the coordinates of the SC movable parts and to clarify its orientation, in particular, during an emergency operation.

2. The results of the laser ranging session of the SC "Lomonosov" allow us to recommend the installation of the RRS "Pyramid" on the LEO spacecraft as a part of the RRC for different tasks. Such non-expensive RRC allows to identify the SC, which may be defined as space debris.

3. Three RRSs with different polarization characteristics should be installed on the SC for the clarification and monitoring of the spatial orientation. In order to divide the range differences between the RRSs, the polarization state of the laser radiation should change alternately from the *right* to the *left* circular during the laser ranging session.

References

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3. A.S. Akentyev, A.L. Sokolov, M.A. Sadovnikov, G.V. Simonov. Polarization Analysis of the Beam-Steering Device of Quantum Optical Systems// *Optics and Spectroscopy*, June 2017, Vol. 122, № 6, pp. 1044–1050.