Retroreflector Studies

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Abstract

This paper discusses studies being done on retroreflectors. Complete reports are available for some, and others are ongoing projects. The studies include a preliminary transfer function for the LARES retroreflector array; computation of the wavelength correction for LAGEOS 850–425 nm; the cross-section of the Apollo lunar retroreflector arrays; parametric thermal analysis of a hollow beryllium retroreflector; retroreflector arrays for high-altitude satellites; measured diffraction patterns of retroreflectors; thermal simulations of coated and uncoated solid cube corners; and modelling of the response of a SPAD detector to various retroreflector arrays.

Introduction

This is an abbreviated version of the paper. The full paper in PDF format is available at http://www.ilrscanberraworkshop2006.com.au/workshop/day6/overview.asp or on the SPWG website in WORD format at http://nercslr.nmt.ac.uk/sig/signature.html.

LARES preliminary transfer function

The variations in range are reduced by the square root of the number of cube corners. Since LAGEOS has 4 times as many cubes as LARES the averaging is better by about a factor of 2. Because the radius of LARES is about half the size of LAGEOS the range correction is smaller. The two effects cancel each other approximately so the variation in the range correction is about the same for both satellites.

Wavelength correction for LAGEOS 850nm-425nm

Table 1 shows the wavelength correction (mm) vs velocity aberration (microradians). The average wavelength correction between 32 and 38 microradians is 2.806 ±.2 mm. The input polarization is circular.

***Table 1**: Range correction as a function of velocity aberration*

30	32	34	36	38	40
2.615000	2.773500	2.891750	2.865250	2.696250	2.465750

Cross section of the APOLLO Lunar retroreflector arrays

The APOLLO Lunar retroreflector arrays use a 1.5 inch diameter uncoated fused silica retroreflector with no intentional dihedral angle offset. The front face is recessed by half the diameter in a cavity with a 1.5 degree flare on the first APOLLO array and a 6 degree flare on the two later arrays. The cutoff angle with no flare would be 27.7 degrees. With the 1.5 degree flare it is 28.3 degrees. With the 6 degrees flare it is 30.3 degrees. Since the APOLLO retroreflectors are uncoated, there is loss of total internal reflection at certain incidence angles. The cross section has been computed vs incidence angle.

Parametric thermal analysis of hollow cubes

Equations have been derived for making order of magnitude estimates of the thermal gradients in a hollow Beryllium retroreflector due to absorption of solar radiation. The performance of the retroreflector can be degraded by thermal warping of the plates or changes in the dihedral angles between the reflecting plates as a result of differential expansion and contraction. The equations consider the case of conduction through the plate and along the plate.

Putting numbers into the equations shows that conduction through the plate is not a problem because the conduction path is wide and the path length short. Conduction along the plate can be a problem because the path length is long and the conduction path is narrow. Thermal distortion of the plates is acceptable as long as the cube corner is not larger than about 2 inches and the plate has a low solar absorptivity such as 7 percent.

Retroreflector arrays for high altitude satellites

Tables 2 and 3 show the area and mass of the cube corners needed to obtain a cross section of 100 million sq meters at the altitude of the GNSS satellites and a cross section of one billion sq meters at geosynchronous altitude.

***Table 2**: GNSS*

Design	# of cubes	Diam. in	Area sq cm	Mass g
uncoated	50	1.3	428	1000
coated	400	0.5	508	460
hollow	400	0.5	508	201
hollow	36	1.4	356	400
GPS	160	1.06	1008	1760

***Table 3**: Geosynchronous*

Design	# of cubes	Diam. In.	Area sq cm	Mass g
Uncoated	165	1.7	2415	7457
Coated	1153	.7	2863	3638
Hollow	1153	.7	2863	1590
Hollow	122	1.8	2003	2863
Single dihedral	22	2.0	446	708

Measurements of Russian cube corners

The data used in this analysis were kindly provided by Vladimir Vasiliev. A measurement of a reference mirror the same size as the cube corner is used for absolute calibration of the cross section of the cube corner. The first cube corner is a very high quality diffraction limited cube and the second is a typical cube corner. The cross section of the typical cube is larger than that of a diffraction limited cube corner past about 20 microradians.

Thermal simulations of Russian cube corner

These simulations were done using a very simple thermal simulation program that has been used only to give order of magnitude effects. The cube corners have no intentional beam spread. The isothermal diffraction does not show sufficient cross section at 26 microradians to account for the nominal cross section of the GPS array. The simulations with solar illumination show that thermal gradients could spread the beam sufficiently to increase the cross section of the GPS array to 20 million sq meters that is the nominal cross section. The simulations show that the thermal gradients disappear quickly when the solar illumination stops. This could make it difficult to study the effect of thermal gradients in the laboratory. In the absence of a detailed engineering data on the cube corners the only way to know how the Russian cube corners behave is by laboratory testing.

Laboratory tests of cube corners

The space climactic facility at LNF in Frascati, Italy presently has a section of the LAGEOS retroreflector array, a section of LARES cube corners, and the third GPS array that contains Russian cube corners. The plan is to take diffraction patterns similar to those described in section 7 of this report and do thermal vacuum tests to measure the response of the cube corners to solar radiation. These test results can be compared to the simulations given in section 8 of this report. There will probably be significant differences between the simulations and the laboratory tests because of the limitations in the modelling.

Modelling of the response of a SPAD detector to a distributed signal

My analysis programs compute the range correction of a retroreflector array for centroid and constant fraction discriminator detection systems. All single photoelectron systems measure the centroid. For multi-photoelectron signals the range correction for a SPAD detector requires modelling the current vs time as a function of the time of arrival of each photoelectron. The exponential model of a SPAD assumes the number of charge carriers increases exponentially after a photon is detected until the available charge carriers are depleted. Tom Murphy has suggested modelling the number of charger carriers as a quadratic function of time on the assumption that the region of charge carriers is a thin disc whose radius increases linearly with time. The actual behaviour is complex. The rise time of a SPAD detector is a function of the number of photoelectrons. The CSPAD detector compensates for the number of photoelectrons for a point reflector. In the exponential model the rise time is independent of the number of photoelectrons. The exponential model does not explain the observed dependence of the rise time on the number of photoelectrons.

Simulations with the exponential model indicate that the measured range decreases if additional photoelectrons arrive before the current from the first photoelectron has increased to a large value.

***Table 4**: Two-photon bias*

x	0.0	2..6	5.2	10.4	15.6	20.8	26.0	52.0
Δr	3.60	2.66	1.77	0.72	0.28	0.10	0.04	0.00

In Table 4, 'x' is the one-way distance between the reflection points of two photoelectrons. Δr is the decrease in the measured one-way range due to the second photoelectron. For millimeter accuracy ranging the effect is significant for the first centimeter.

The modelling of a SPAD is complex. Unless one has a good model the only way to study the effect of a photoelectron that arrives a short time after the first is to do an experiment. For example, the target calibration vs signal strength could be done with a flat target and with a target where half the area is at position zero and the other half is a few millimeters farther away.