ILRS Meeting on Retroreflector Arrays
Austrian Center Vienna
April 6, 2006

An ILRS meeting on retroreflector arrays was held in Vienna at EGU2006 to begin the process of developing a specification (effective cross section) for satellites in high orbit such as GNSS and synchronous satellites. The meeting also provided an opportunity for discussions on other retroreflector issues not presently being covered by other ILRS working groups.

The charts presented at the meeting and those provided but not used are available on the ILRS Web site at http://ilrs.gsfc.nasa.gov/reports/special_reports/index.html. A list of attendees is included at the end of this report.

Specifications and Options

Dave Arnold examined a number of configurations yielding an effective cross section of 100 million square meter for GPS altitude and 1 billion square meters for synchronous altitude. These are approximately the cross sections necessary for getting daylight returns from a low power system like the SLR2000 with parameters:

Wavelength	532 nm
Pulse repetition rate	2000/sec
Pulse width	200 psec
Output energy (output from the receiver)	60 microjoules
Quantum efficiency of the detector	30 %
Output beam divergence	20 microradians
Telescope diameter	40 cm

The results would scale up or down as these parameters varied. He considered;

- Solid cubes
  - coated and uncoated;
  - varying sizes; and
- Hollow cubes
  - varying sizes;
  - vertex angles offsets adjusted to compensate for velocity aberration

He roughly estimated the area of the arrays by the area of the corner cube faces and the weight of the solid cubes based on their volume and density and of the hollow cubes by the weight of the aluminum forming the cube. These are very rough and do not include the contribution of the structure holding the cubes. For reference on the GPS Array, the cubes occupied about 45% of the front surface area and about 28% of the total array mass.

Simulations at Galileo altitude for Effective Cross Section of 100 million sq. meters.				
Design	# of cubes	Diam. (inch)	Approx. Area of the cornercubes (sq cm)	Approx Mass of the cornercubes (gm)
uncoated	50	1.3	428	1000
coated	400	0.5	508	460
hollow	400	0.5	508	201
hollow	36	1.4	356	400
Present GPS cubes	160	1.06	1008	1760

GIOVE A has the same cubes as those used in GPS. The “present GPS cube” option identified here would have about twice the effective cross section of the GIOVE –A. The computations need to be redone with better estimates of the area and mass, but it is apparent that better selection of cube design would save both area and mass on the spacecraft.

Simulations at synchronous altitude for effective cross section of 1 billion sq. meters.				
Design	# of cubes	Diam. In.	Approx. Area of the cornercubes (sq cm)	Approx Mass of the cornercubes (gm)
Uncoated	165	1.7	2415	7457
Coated	1153	.7	2863	3638
Hollow	1153	.7	2863	1590
Hollow	122	1.8	2003	2863
Hollow cube with one dihedral offset	22	2.0	446	708

At synchronous altitude, all of the multicube options take up considerable space, but the hollow cube arrays may save some weight. If the synchronous satellite was three-axis stabilized, an array of 2.0 inch hollow cubes with one dihedral offset could provide very large savings in both real estate and mass.

Requirements for SLR 2000

Jan McGarry estimated the return signal strengths required for SLR 2000 ranging to satellites over the range from LEO to geosynchronous altitudes. Scaling from the MOBLAS experience, she estimates that daylight ranging with SLR2000 will require 10 pe/sec. for LEO satellites, 6 pe/sec for GNSS, and 3 pe/sec for satellites in synchronous altitude. For the SLR2000 properties, these figures translate into a retroreflector array effective cross section of about 140 million sq. meters at GNSS altitudes and about 1.2 billion sq. meters are synchronous altitudes, which are roughly the values Dave Arnold used in the analyses above.

Retros on the GPS-III Complex

Jan McGarry reported that NASA has briefed the Joint Project Office (JPO) on the rational for including retro on the GPS-III complex. There is general agreement that it would be a good idea, but benefits are mostly indirect and for specialized applications. There are also concerns about the impact on the spacecraft. NASA continues to work with the JPO, understanding the orbital issues, weighing the applications, and examining options for reducing the burden on the spacecraft.

Description of the Galileo Arrays

Graham Appleby showed the drawings of the Galileo configurations aboard GIOVE-A and –B. All dimensions are well defined for extrapolation to the satellite center of mass except the offset between the face of the cubes and a reference point on the array structure. Graham will contact Dr. Vasiliev to see if he can get the needed information for GIOVE-A. The information for GIOVE-B must still be obtained from Surrey Ltd.

Studies of Hollow Cubes at GSFC

Jan McGarry reported that mechanical simulations underway at GSFC show good performance of cubes through thermal gradients and thermal changes up to 80 deg. C. The real issue is the integrity of cube, does it come apart at high temperatures. The vendor has a design for a bolted cube which should be very resilient to thermal changes. A 2.5” cube has been built for testing in a thermal chamber with measurements to be made of wavefront properties, beam deviation and far field patterns over temperature extremes. Performance will then be compared with the simulations.

Measurement Test Bed at INFN-LFN

Giovanni Delle Monache from the Laboratori Nazionali di Frascati dell'INFN reported in their Space Climatic Facility (SCF) for Testing LAGEOS, LARES and GPS-III CCR prototypes. The facility was established to characterize the thermal properties of the retroreflectors on the LARES satellite and to support other projects. Basically the test item in the facility is heated with a sun simulator and examined with a thermometry system (IR camera and a probe system) to measure the temperature distribution. The far-field pattern and the ranging quality of the cubes are measured before and while heated to see how the pattern degrades and how signal link and range stability deteriorate. First tests are being done on a small set of cubes that are identical to LAGEOS to estimate the thermal effects that influence the stability orbit.

The SCF will be used to test the LARES satellites. The LARES satellite is configured to conduct some of the solar energy to the dark side of the satellite. This should reduce the thermal gradients on the cubes and allow the thermal energy to be re-radiated more uniformly over the sphere, thereby reducing thermal thrusts on the spacecraft. Models are being developed to simulate the satellite performance and allow for parametric studies. Simulations indicate that this design will be compatible with the Lense-Thirring and other relativity measurement planned for the LARES mission

The SCF will also be used in a joint program with NASA and the ILRS to test hollow cube designs for possible use on the GPS-III series to be flown starting in 2011. The cubes might also lend themselves to the LARES structure. Beryllium cubes are being considered for weight considerations.

Westpac Satellite

John Ries has made the observation (as have others) that the orbital residuals on the Westpac satellite are larger that those on the Starette, Stella and other spherical satellites at similar altitudes. This is contrary to our intuition since the cubes on Westpac are recessed to prevent overlap in the field of view from the cubes and therefore to avoid multi-cube returns. John Luck gave a rundown on the structure of the Westpac satellite, but there was no resolution.

Optus B Experience from Mt Stromlo

John Luck related the ranging experience on the geostationary satellite OPTUS-B from the Mt. Stromlo station. OPTUSB-B had a flat tray 20 cm x 18 cm with 14 round-faced solid fused silica corner-cubes with inscribed diameter 38 mm. The dihedral angles were offset by 0."8 +/- 0."3 to allow for velocity aberration at the Stromlo SLR/LLR station. The front faces of the cubes were coated with Indium Tin Oxide over an anti-reflection dielectric layer. The rear faces were coated with Indium Tin Oxide. The cubes were mounted to the tray with Vespel O-rings to avoid potentially damaging charge buildup.

John reported that the return rate from the Stromlo SLR on clear nights was greater than 100 returns/minute for extended periods of time using the APD detector. Returns were still being received when the two laser power amplifiers (x 20?) where shut off and some ND's were inserted in the path.

This experienced needs to be scaled to estimate the projected experience on lower powered SLR systems.

Discussion on Satellite Speeds and Point-Ahead

John Luck also presented some computations on velocity aberration and point-ahead angles for a number of SLR satellites as seen at Mt. Stromlo. Point ahead angles range from 10 – 11 arc sec for low satellites to 1.4 arcsec for the moon.

Lunar Lander

Jan McGarry discussed a link analysis for a 2 inch hollow retroreflector at the lunar distance. The application in mind is the RLEP II Lunar Lander which would be at the south pole of the moon. The 2 inch cube, if oriented toward the Earth, could provide about a factor of 2-3 greater effective cross section than an Apollo cornercube. The real benefit would be the reduced weight burden on the spacecraft.

Other Topics

Graham Appleby showed the latest information that we have on the retroreflector array position on GLONASS. Appleby also provided a table of station dependent center-of-mass corrections for LAGEOS.

Although not presented, Dave Arnold provided results from an analysis on LAGEOS showing how wavelength biases depend on velocity aberration and dihedral offset angle. The range correction is most stable for any wavelength if the dihedral offset is optimized for the particular velocity aberration.

Erricos Pavlis presented material provided by Shargorodsky, Vasiliev and Parkhomenko. The Radioastron satellite is a multinational project to place a VLBI antenna in space. The satellite, to be launched into a highly eccentric orbit by the Russian Space Agency in 2007, will carry a retroreflector array and be supported by the ILRS. The Russian SLR network stations at Komsomolsk, Maidanak, Moscow, and Altay Mountain are being upgraded with more powerful, reduced pulsewidth lasers, and improved detectors to support future missions. A light weight mobile SLR system has been built and is now being tested.

A number of satellites have carried retroreflectors provided by the Russians – GPS, Cryosat, Galileo, etc. Work continues on the “zero signature” Luneberg Lens as a replacement for the conventional corner cubes which have limitations at the few cm level. The first test was on the Meteor-3M satellite (launched in December 2001) which was fortuitous since the on-board GPS system failed shortly after launch and the SLR tracking saved the SAGE experiment. However tracking deteriorated over time since the Luneberg lens was not radiation hardened for long term use in space. A new larger lens has been built and is now being tested for launch on a Meteor-3 satellite in 2007. This version will be radiation hardened.

Thank you to all who participated in this very productive meeting on retroreflector technology.

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