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Test Results from LAGEOS-2 Optical Characterization Using Pulsed Lasers

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Abstract

Laser Geodynamic Satellite (LAGEOS-2) has undergone extensive optical testing at NASA Goddard Space Flight Center during 1989. The techniques included measuring the far field diffraction pattern using cw and pulsed lasers. In the pulsed measurement technique, response of the satellite was studied by measuring the FFDP as a function of pulsewidth, wavelength, polarization, position in the FFDP, detector/processing techniques, and satellite orientation. The purpose of the pulsed laser testing was two-fold: (1) Characterize the satellite optical response with the detector and signal processing electronics currently used in most SLR stations using the Portable laser ranging standard, and (2) to characterize the satellite response for various conditions using the highest bandwidth optical detector (streak camera) available for the next generation of SLR technology. The portable ranging standard employed multiple measurement devices and an optical calibration scheme to eliminate range-dependent and amplitude-dependent systematics. These precautions were taken to eliminate/minimize instrumental errors and provide maximum accuracy. For LAGEOS orbit (6000 Km) ground stations are located 34 to 38 μ-radians off the axis of the return signal from the satellite; therefore an optical mask was used to restrict the field of view (FOV) of detection to this annular region of the far-field diffraction pattern (FFDP). The two measurement techniques were implemented using an aperture sharing scheme and complemented each other by providing mutual verification.

The results indicate a variation of range correction as a function of satellite orientation and location within the far-field diffraction pattern. Range correction as a function of wavelength shows a maximum at 532 nm. For other wavelengths, the FFDP of normal-incidence cube-corners is detuned, providing a greater contribution to the integrated response from cube-corners farther away from the observer. Constant-fraction processing of the detected pulse provided more consistent results than peak and leading-edge. Changes in the orientation of the E-vector of the linearly polarized light showed a systematic variation of ≤ 2mm in the polar regions of the satellite. A consistent difference in RC of ≃ 2 mm between linearly polarized light and circularly polarized light was also observed. The test results showed that a range correction of ≃ 251 mm is applicable to the third-generation SLR systems operating at the multi-photoelectron (MPE) level. The use of short (≃15 ps) laser pulses and streak cameras would provide time resolved signature of the satellite allowing improved (1mm accuracy) range correction.

BACKGROUND

- LAGEOS-1 launched on May 4, 1976; 5900km orbit; 110° inclination.
- Prior to launch, the satellite was optically tested (532nm, 60ps) at GSFC.
- Remarkable progress in SLR technology over 15 years and the projections for the future required understanding of LAGEOS-2 LRA better than LAGEOS-1.
- Major emphasis to accurately (submillimeter) determine the range offset to satellite CM from the effective reflection point.
- Elaborate experimental schemes with state of the art instrumentation and expanded parameteric study than LAGEOS-1.
- Satellite manufactured by Aeritalia for ASI.
- LAGEOS-2 scheduled for deployment Oct. 15, 1992; 5900km orbit 52° inclination.

SATELLITE FEATURES:

MECHANICAL

- Spherical satellite with a DIAMETER of 599.87mm.
- Two hemispherical shells with outer skin made of aluminum.
- Core of the satellite has brass to improve mass..
- Cylindrical core for preferred spin axis (N-S).
- Total mass 405.38 kgm.
- Hemispherical shells and the brass core held together by a steel shaft.
- 426 cube corner cavities.
- Center of gravity and center of geometry are nearly coinciden (0.078mm)..

SATELLITE FEATURES:

OPTICAL

- 426 cube corners; fused silica (422), germanium (4).
- UV-near IR supported by FS; Ge for infrared ranging..
- FS cubes distributed with symmetry about the polar axis; Ge cubes distributed as a tetrahedron.
- Special grade of FS (Suprasil 1, Special T19) for material homogenity and isotropy..
- Clear aperture 38.1 mm; face to apex depth 27.84mm..
- Dihedral offset of 1.5 arc sec for FS cubes; no dihedral offset for Ge cubes.
- No metallic coating; only TIR to enhance reflection from CCs close to the incoming laser beam.
- TIR cubes are sensitive to polarization affecting FFDP and therefore range correction.

OPTICAL CHARACTERIZATION

PURPOSE

- Range correction to center of mass from effective reflection point.
- Target spread function.
- Lidar cross section.

APPROACH

- Measure the temporal response of the satellite using mode-locked lasers and fast detectors (streak camera, photodiode, MCP-PMT) as a function of wavelength, pulsewidth, polarization, position in the FFDP, satellite orientation, detection bandwidth and, type of signal processing; Compute and deduce the satellite characteristics.

MEASUREMENT PARAMETERS

LASER

- Wavelength: Pulsed 1064, 532, 355nm
- Polarization: Linear (horizontal, vertical), circular
- Pulsewidth: 60ps (1064nm); 140ps, 45ps, 25ps (532nm), 30ps (355nm)

DETECTOR

- Temporal Resolution: 2.5ps (streak camera); 100ps (photodiode) 500 ps (MCP-PMT)
- Photoelectron Level: 10-100 (MCP-PMT); 1000-10000 (SC); 100000 - (Photodiode)

SIGNAL PROCESSING

- Peak
- Half Max.
- Centroid
- Constant Fraction

SATELLITE ORIENTATION

- Polar
- Equatorial
- Others

Velocity Aberration: Various positions in the annular (34-38 microradian) region of the FFDP.

EXPERIMENTAL APPROACH

PULSE MEASUREMENT

- Mode-locked laser for illumination.
- Temporal detectors in the focal plane.
- Detection limited to useful region in the FFDP.

ADVANTAGES

- Net effect of coherent/incoherent superposition of FFDPs directly measured.
- More direct than cw case since instrumentatiion used is similar to those currently used for SLR; easy to verify spaceborne performance.
- Computationally simple.
- Less sensitive to air currents, vibration, etc.

DISADVANTAGES

- Experimental measurement is complex.
- Allows only discrete measurement of the FFDP.

LAGEOS-2 RESULTS

POLARIZATION EFFECT

- Although LAGEOS-1 testing showed no significant effect on polarization, analysis of LAGEOS-2 RC using pulsed laser measurement showed ± 1.5mm in the polar region
- Pulsed laser measurement showed ≈ 2mm offset between circular and linear polarization consistently for all pulse widths

PULSE LENGTH/DETECTION METHOD

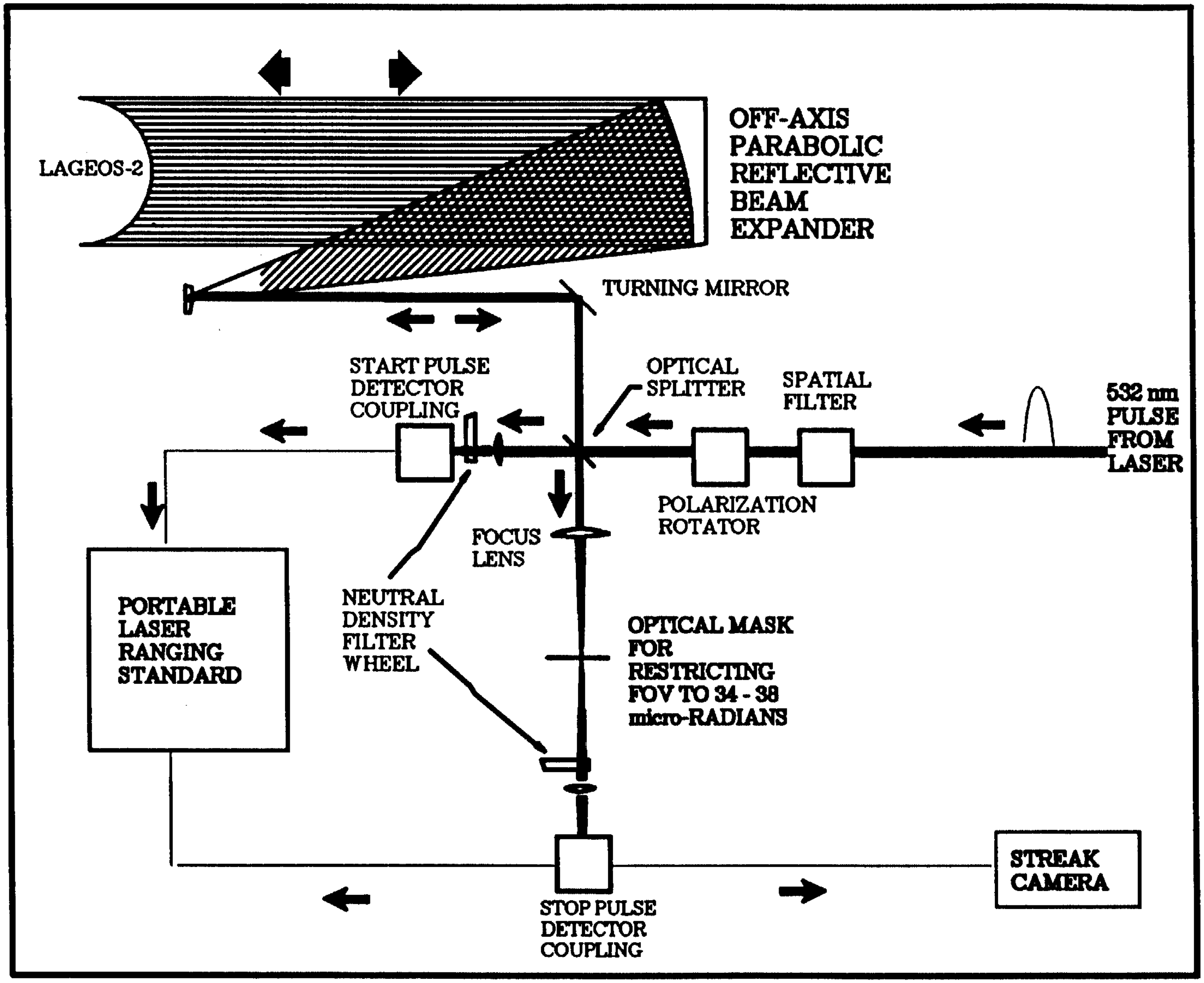
- Peak and half max. detection produced increased range corrections (1-2mm) for shorter pulses; at longer pulsewidths, an asymptotic value of ≈ 251mm is reached.
- Experimental data on constant fraction discrimination showed decreased range correction for shorter pulses in good agreement with theroretical predictions.
- Range correction to center of mass is 250.8mm (gaussian, 200ps pulsewidth, 532 nm, average orientation, plane polarized light, centroid detection/constant fraction detection).
- Range correction is a function of orientation, wavelength, pulse length, detection method, coherent effects, and location within the far field diffraction pattern (FFDP).

WAVELENGTH EFFECT:

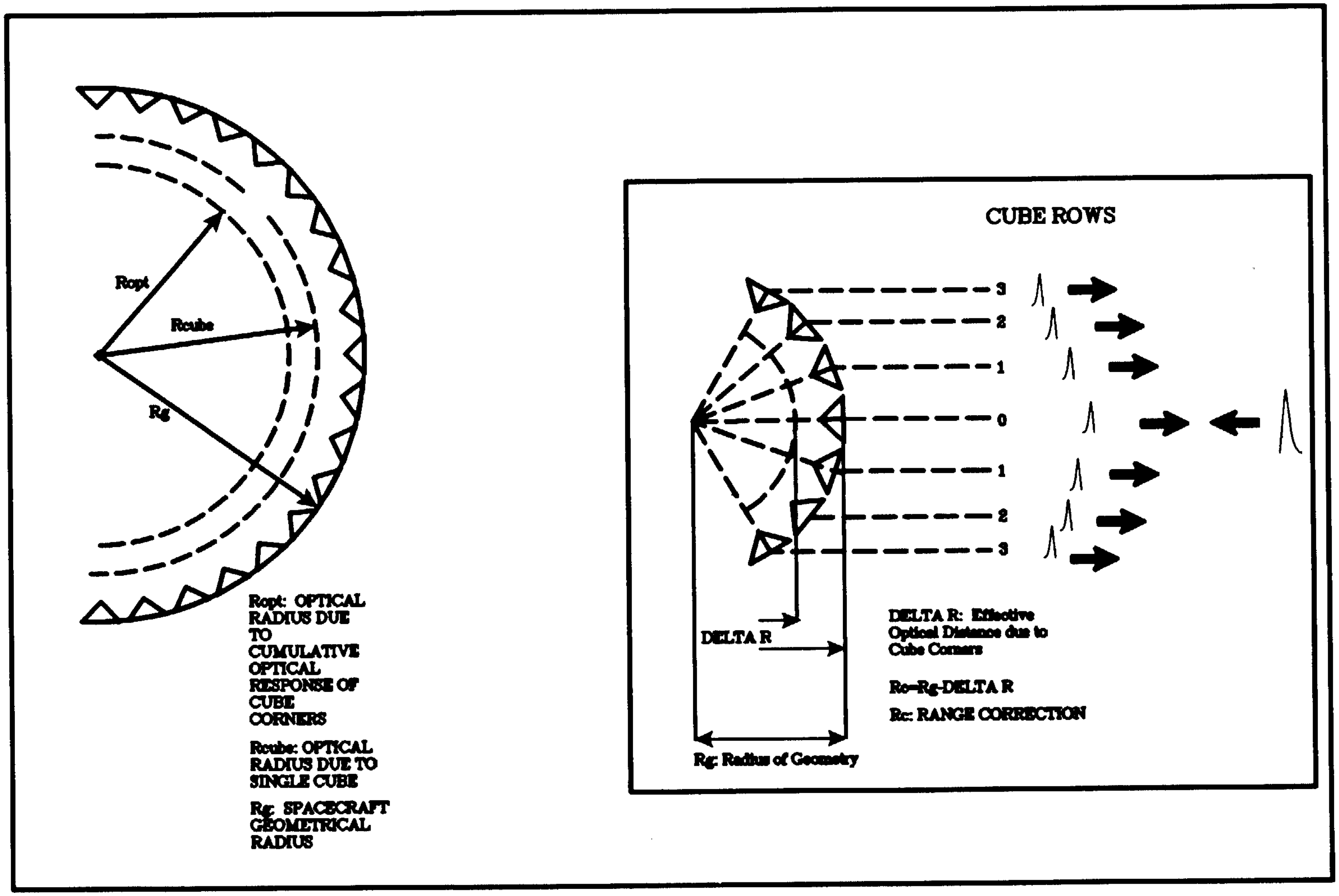
- Range correction is maximum at 532 nm and showed a decrease with increase in wavelength (355 - 1064).
- Detuning of the FFDP which is optimized for 532 nm and near-normal incidence; affects longer and shorter wavelengths; cube corners farther from normal incidence contribute more and shift the range correction towards the center of the satellite.

SUMMARY

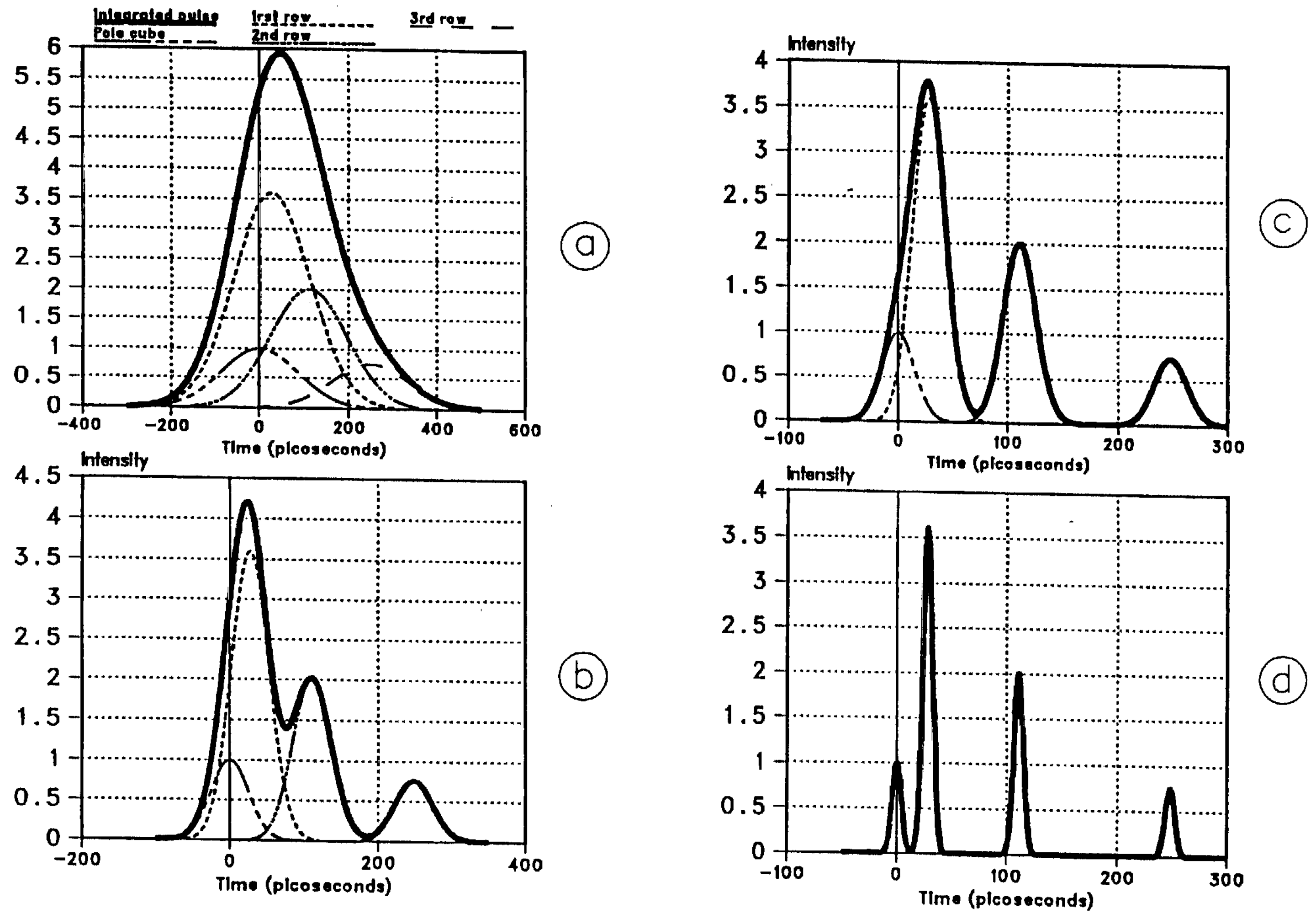
- Detailed investigation of LAGEOS-2 optical characteristics has been completed, algorithms for RC to CM of the satellite have been derived to apply any SLR scenario.
- The small departure of LAGEOS-2 results from LAGEOS-1 is currently believed to be due to calibration/instrumentation errors in LAGEOS-1 measurement.
- Current estimates of the satellite-limited ranging accuracy is estimated to be < 3mm for the best multi-photoelectron (MPE) SLR station; accuracy approaching 1mm can be obtained with shorter pulses (<15ps) and streak cameras.



LAGEOS-2 EXPERIMENT OPTICAL SET-UP

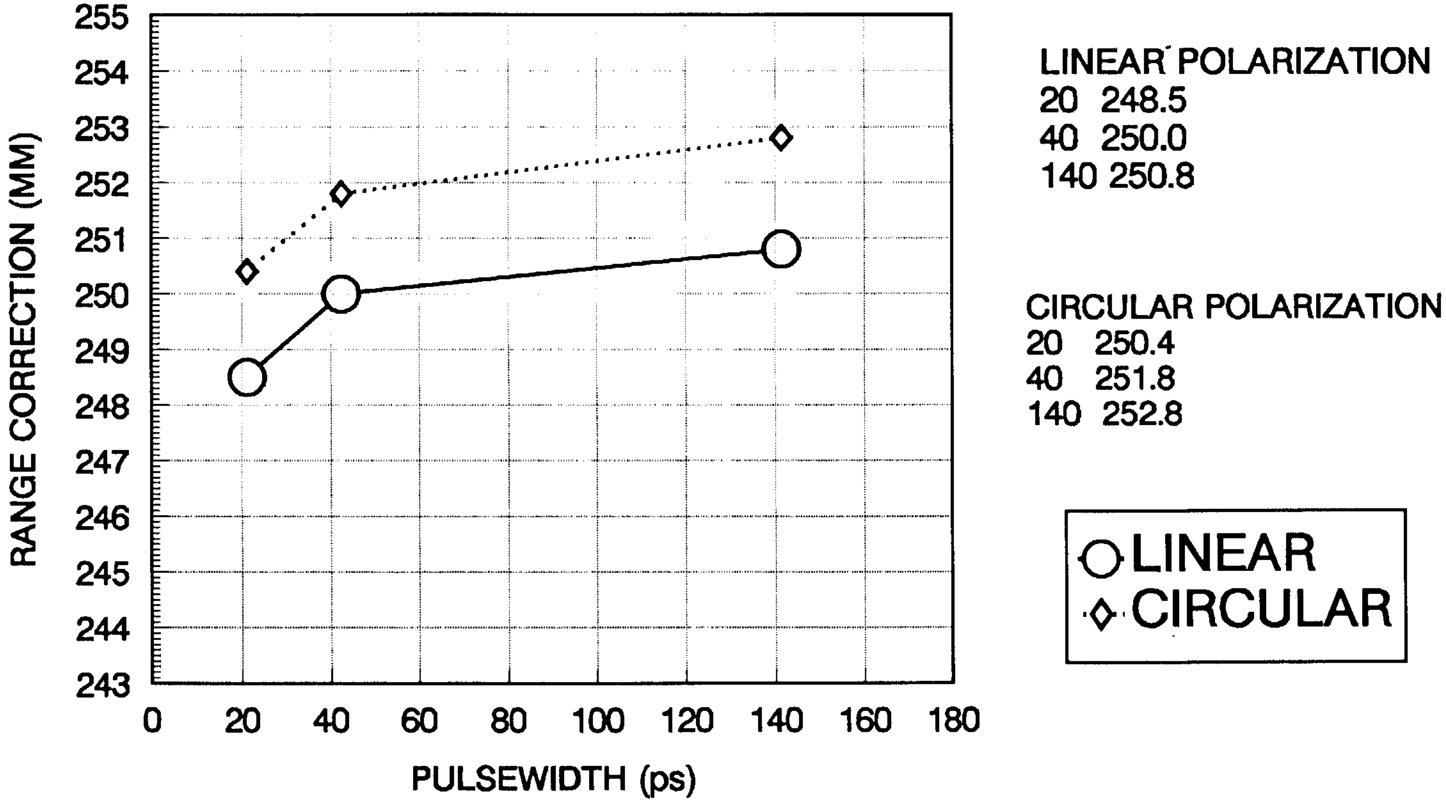


SCHEMATIC OF CUBE CORNER LAYOUT



SIMULATION SHOWING INCOHERENT SUPERPOSITION OF THE CONTRIBUTION FROM INDIVIDUAL CUBES IN THE POLAR REGION OF THE LAGEOS-2 SATELLITE AS A FUNCTION OF PULSEWIDTH. THE SIGNATURE OF THE SATELLITE GETS PROGESSIVELY TIME RESOLVED AS THE PULSEWIDTH IS REDUCED FROM APPROXIMATELY 200 PS (a) TO 10 PS (d).

RC-VS-PULSEWIDTH FOR LINEAR AND CIRCULAR POLARIZATION



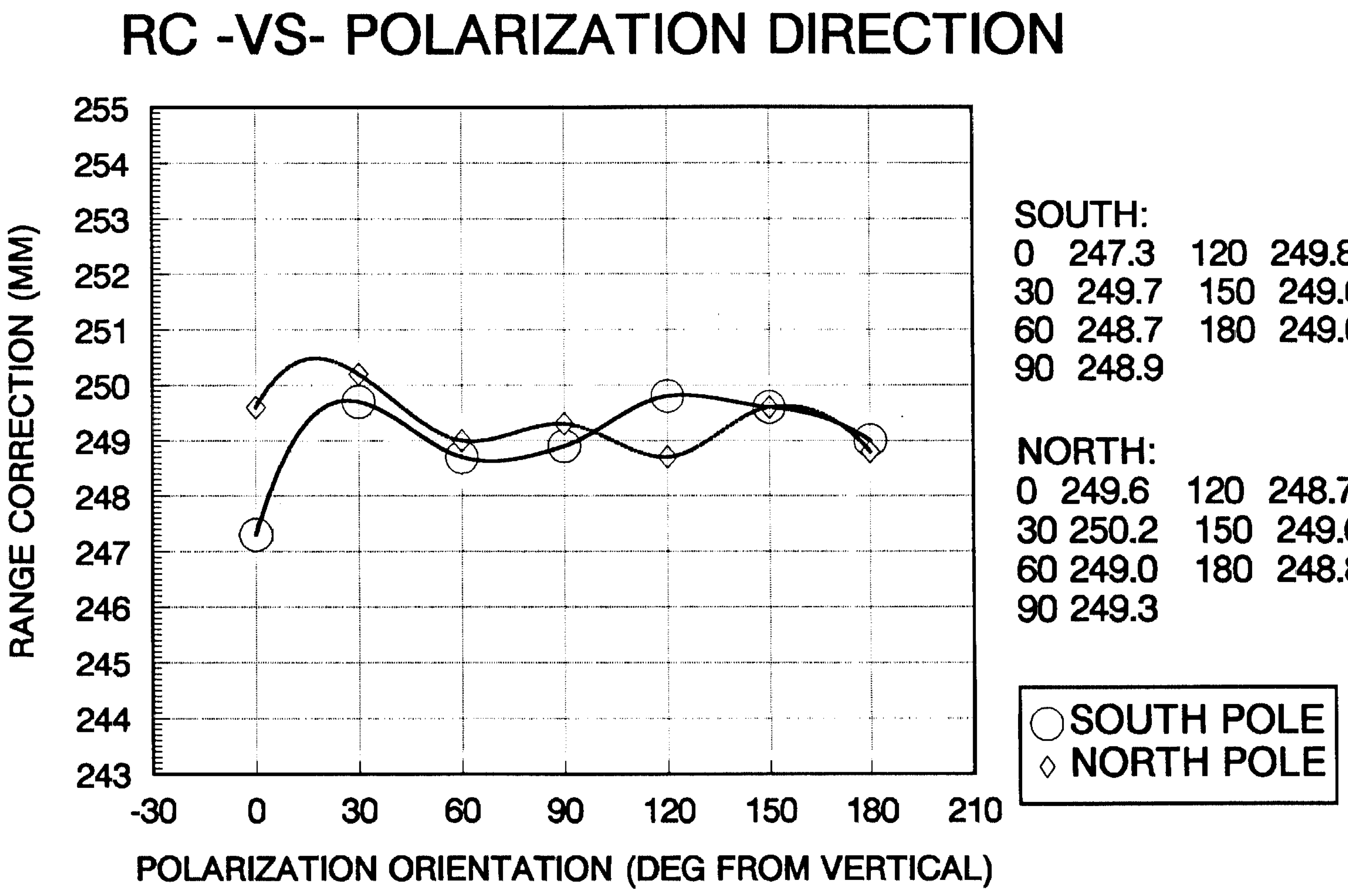
LINEAR POLARIZATION

20	248.5
40	250.0
140	250.8

CIRCULAR POLARIZATION

20	250.4
40	251.8
140	252.8

Plot illustrating the Range Correction difference between circularly polarized and linearly polarized laser beams for various pulsewidths. An offset of ~2mm was consistently observed in each case.



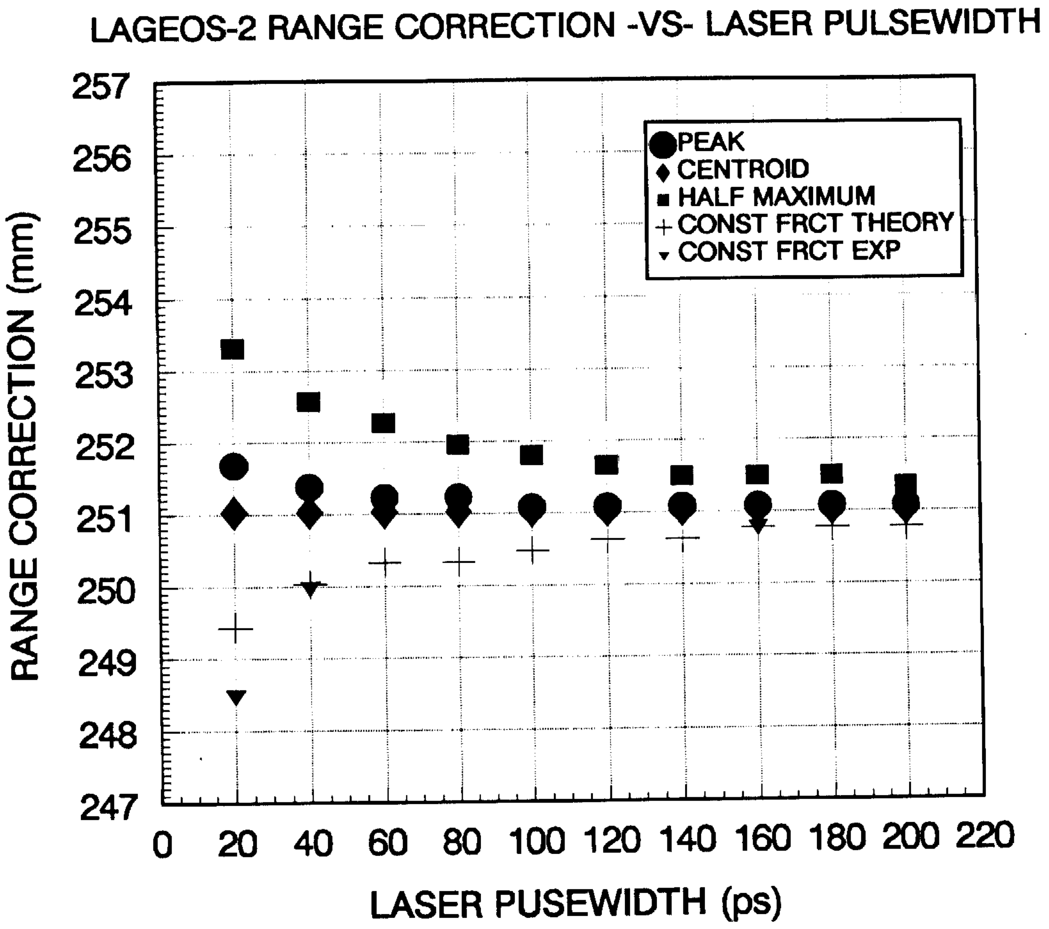
SOUTH:

0	247.3	120	249.8
30	249.7	150	249.6
60	248.7	180	249.0
90	248.9		

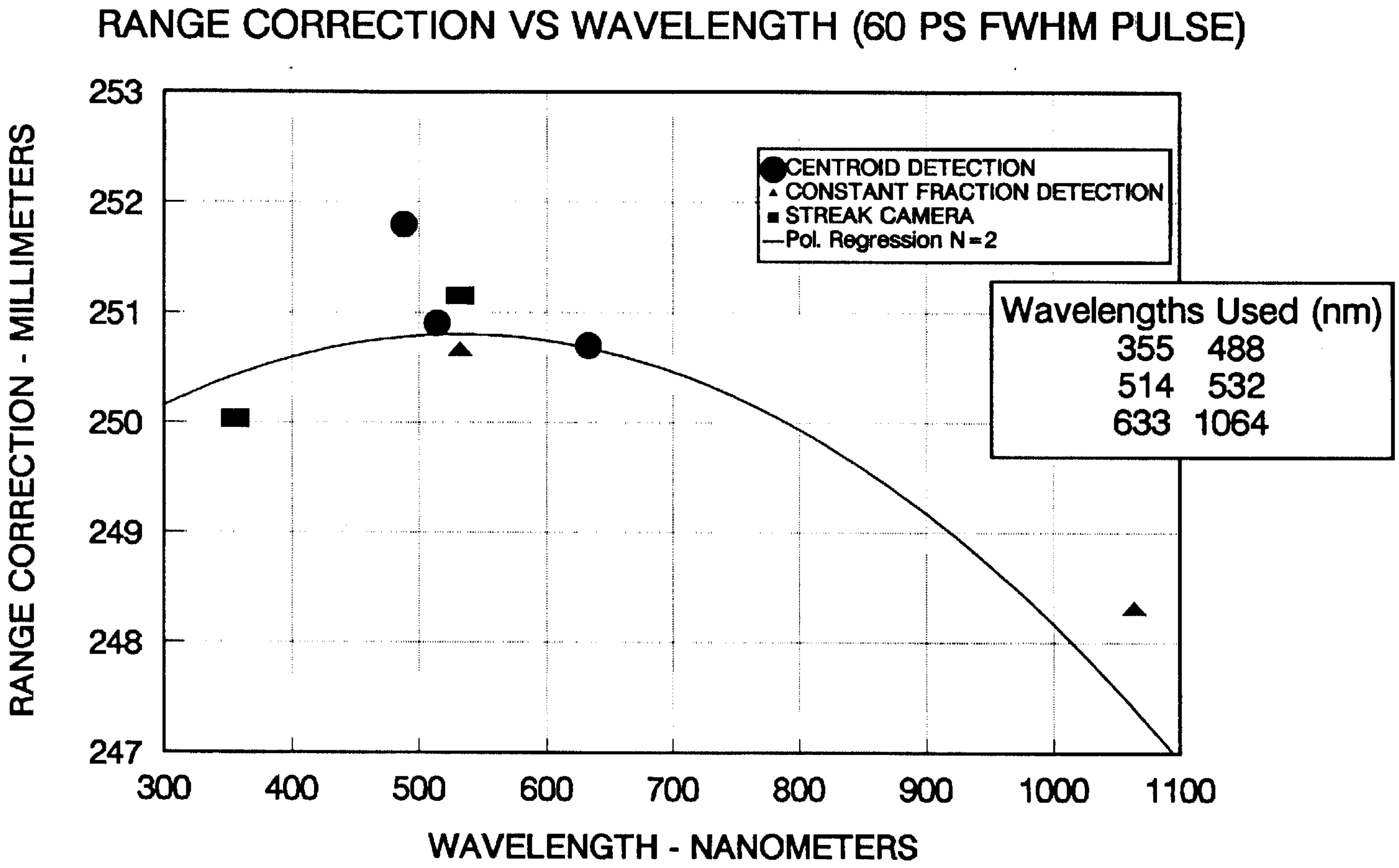
NORTH:

0	249.6	120	248.7
30	250.2	150	249.6
60	249.0	180	248.8
90	249.3		

Plot illustrating the variation of RC as a function of orientation of the E-vector for linearly polarized light. Both polar regions of the satellite showed a similar response.



Plot to highlight the dependence of RC on laser pulsewidth as a function of signal processing technique, with special emphasis on constant fraction (CF),which is widely used in the global network. Theoretical values for peak,centroid and CF were computed by P. Minott/GSFC based on a model of the satellite.



Plot illustrating the dependence of RC on wavelength for various experimental signal processing techniques. The centroid data was computed by P. Minott/GSFC based on a model of the satellite.