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Satellite-to-Satellite Laser Ranging Instrument for Earth Gravity Measurements

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Abstract: A laser ranging instrument is being developed to measure the spatial variations in the Earth's gravity field. It will range in space to a cube corner on a passive co-orbiting sub-satellite with a velocity accuracy of 20 to 50 um/sec by using AlGaAs lasers intensity modulated at 2 GHz.

Need for Gravity Measurements: Spatial variations in a planet's gravity field is an important indicator of its internal structure, which is often otherwise inaccessible. Knowledge of the spatial structure in the Earth's gravity field is also essential for the precise determination of satellite orbit heights. These are critical for space-based ocean altimetry missions, where radar measurements to the ocean surface are being used to investigate the flow of ocean currents. Spatial variations in the gravity field cause both the local sea surface and satellite orbit heights to vary with location. Lack of knowledge of the gravity field's higher order terms now limits in the spatial resolution of the Topex ocean height measurements.

Mission Overview: The Gravity and Magnetics Earth Surveyor (Games) mission has been developed by NASA-GSFC to measure the Earth's gravity and magnetic fields. The mission is planned as a small Earth-probe for a fall 1998 launch. A small rocket will be used to launch a SMEX-type spacecraft into a 325 km sun-synchronous circular polar orbit. The spacecraft carries a vector and scalar magnetometer on several meter long boom. A GPS receiver is used to determine the low degree and order terms of the gravity field.

The high degree and order gravity field terms are determined from the measurements of a satellite-to-satellite laser ranging instrument (LRI). Once in orbit, the spacecraft ejects a small passive subsatellite, which carries a laser retro-reflector. The main spacecraft then maneuvers ahead of the subsatellite and co-orbits with it, while leading it by ~ 150 km. The LRI is pointed toward the subsatellite, and it tracks and continuously measures the intersatellite range.

As the spacecraft pair pass over the spatial variations in the gravity field, they experience along-track accelerations which change their relative velocity. These time displaced velocity changes are sensed by the LRI with a resolution of 20-50 um/sec. When drag causes the intersatellite range to deviate outside the desired 100-200 km interval, the main spacecraft performs an orbit adjustment to re-establish the desired co-orbiting conditions.

Instrument Description: The LRI is laser diode-based ranging system, which is fix-mounted to the spacecraft. The present LRI configuration is shown in Figure 1 and its block diagram is shown in Figure 2. The LRI measures the range with 3 different intensity modulated signals, which determine the absolute range to the subsatellite. The fine and medium range signals are 2 GHz and 31.25 MHz sinusoids which are intensity modulated onto the 815 nm ranging laser diode. The relative ranges are measured by resolving the phase angles of the reflected ranging tones. The 2 GHz tone is used to measure the most accurate relative range to the subsatellite. The 31.25 MHz medium ranging tone is measured to better than the 75 mm ranging period of the fine tone once per second. The coarse ranging signal is a 31.25 MBit/sec pseudo-noise (PN) code, which is intensity modulated onto the tracking laser diode at 845 nm. It is used to resolve the absolute range to the subsatellite to within a bit-time. The combined ranging signals are used for the gravity determination as well as to guide the orbit correction maneuvers and maintain the 100 to 200 km distance to the subsatellite.

The subsatellite is passive and carries a 9 cm diameter hollow cube corner. After deployment, the spacecraft body points the LRI to the subsatellite. The spacecraft keeps the ranging beam centered on the subsatellite by using the LRI measured angular position to the control the spacecraft pointing.

Instrument Design: The LRI consists of the transceiver, door, electronics and the subsatellite corner reflector. The details of the LRI design are summarized in Table 1. The transceiver is attached to the spacecraft via an interface plate, which provides the common optical bench for the Laser Diode (LD) transmitters and receiver telescope. The transmitter consists of 3 ranging and 5 tracking LDs. The ranging LDs are used for both medium and fine ranging and the tracking LDs are used for both tracking and coarse ranging. The beams from all lasers are co-aligned and fixed with respect to the receiver's optical axis.

The LRI collects the reflected signal from the subsatellite with a 20 cm diameter receiver telescope. The aft optics split the received optical signal to the ranging and tracking detectors. A protective door is open during normal ranging operation, but is closed for launch and thruster firings. The door is used to prevent contamination from the spacecraft thrusters. The door also carries passive optical reflectors, which serve as a test target when the door is closed. The reflectors return attenuated LD beams to the receiver, which permits verification tests of the LRI without the subsatellite.

Acquisition: The tracking LDs transmit a 10 mrad wide beam at 845 nm along the spacecraft's negative velocity vector. Three tracking laser diodes are used at one time, leaving two as spares. To acquire the subsatellite, the spacecraft systematically scans its attitude in pitch and yaw. This scans the fixed-mounted LRI beam. When the subsatellite is illuminated, the reflected power is collected by the telescope, and the tracking signal is split in the aft-optics assembly. Approximately 50% of the power is focused onto the CCD array while the remainder is focused onto the coarse ranging PMT. The CCD readout is processed by the on-board computer, which generates pitch and yaw error signals proportional to the offset of the tracking spot from the array's center. These angular errors are input to the spacecraft control system, which corrects the spacecraft pointing to center the signal on the CCD array.

Tracking: Once acquisition occurs, the tracking algorithm continuously update the angular error signals to the spacecraft. The spacecraft keeps the LRI pointed at the subsatellite to better than 100 urad by adjusting its pitch and yaw angles in response to the error signals.

The coarse ranging signal from the PMT is converted to a photon counting bit stream and is integrated by the receiver histogram electronics for ~ 1 sec. The histogram is correlated with a stored replica of the transmitted code to obtain the most likely range bin (the pseudo range). The multiple code length range ambiguity is resolved by alternating the PN code length between 127 and 511 bits and applying the Chinese Remainder Theorem on the pseudoranges.

Ranging: Ranging occurs simultaneously with tracking. The ranging LDs transmit an intensity modulated beam at 815 nm with a 1 mrad beamwidth. A single ranging LD operates at any time, leaving two as spares. Approximately 80% of the LD's intensity is modulated by the 2 GHz tone, 10% is used by the 31.25 MHz tone and the residual 10% is not modulated.

The LRI laser signals reflected by the subsatellite are collected by the telescope and directed to the ranging PMT. The PMT's electrical output is split into the fine and medium receiver electronics. Both ranging signals are independently down converted to the 7.6 KHz intermediate frequency (IF) by multiplying them with phase-locked local oscillator (LO) signals. Each LO is offset from its ranging tone by 7.6 KHz. The fine and medium IF signals are independently digitized at 30.4 kHz rate. The computer computes the in-phase and quadrature (I&Q) components from the samples at ~ 260 Hz.

The instrument computer collects the received signal components to transmit to the ground. The ground station computes the magnitude and phase angles for both ranging tones from the I&Q samples. The fine ranging phase angle is used to determine the subsatellite velocity. The medium ranging phase angle is used to measure the cycle number of the fine ranging tone to within a bit of the coarse ranging signal. The coarse ranging measurements are used to reference the medium ranging tone to absolute range.

The gravity measurement errors, which are referenced between the main spacecraft and subsatellite CG's, are summarized in Table 2. These are slightly larger than the instrument errors, since they also include the geometrical effects of the positions of the LRI and cube corner. Details on the mission and instrument design, the fine ranging breadboard measurements, and expected instrument performance will be discussed in the talk.

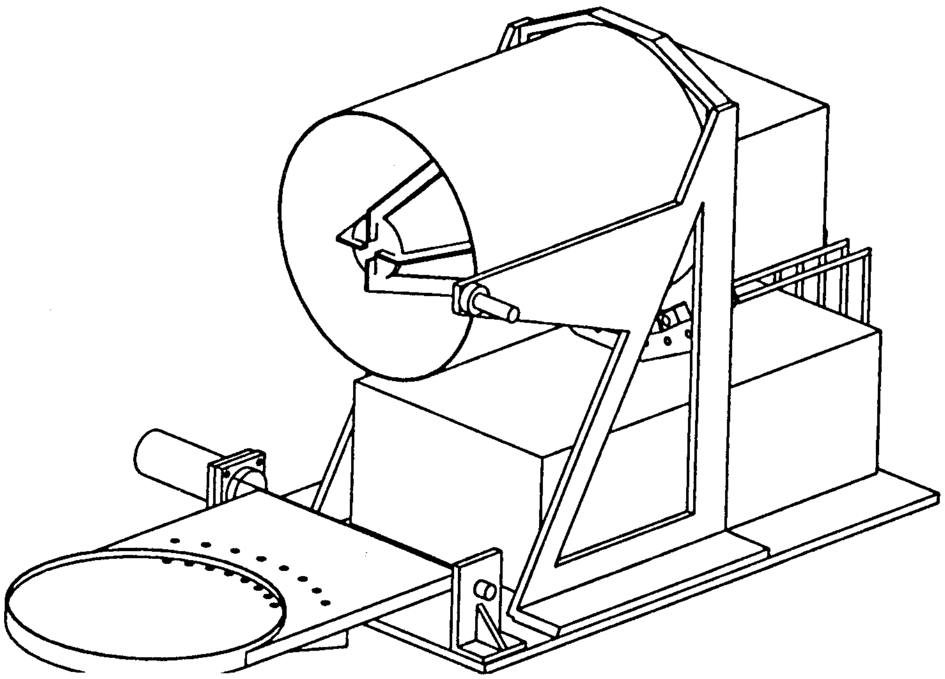
Table 1 - Summary of LRI Transceiver Design

Pointing:	Body pointed by spacecraft to ~ 100 urad
Laser Transmitters:	Single mode AlGaAs Laser Diodes:
Ranging:	60 mW average power, single mode, 1 mrad beam width 815 nm, 2 GHz mod., 3 each - 1 on at a time
Tracking:	90 mW average power, single mode, 10 mrad beam width 845 nm, 31.25 Mbit/sec PN code, 5 each - 3 on at a time
Telescope:	20 cm diameter Be
Ranging Detectors:	PMT with GaAs photocathode, 20% QE (810- 845 nm)
Tracking Detector:	256 x 256 CCD, ~ 10 Hz frame rate
Fine Range Receiver:	2 GHz & 31.25 MHz ranging tones
IF frequency:	7.6 KHz
Sampling rate	30.4 KHz
Phase components:	Compute I&Q, 260 times/sec
Fine Ranging Measurement Precision:	
200 km:	≈ 45 μm/sec (1.5 x signal shot noise)
100 km:	≈ 10 μm/sec (1.5x signal shot noise).
Drift rates:	≤ 2 μm/sec

Table 2 - GAMES-LRI Error Summary in Gravity Measurements

Error Source	Subsatellite Range (km)		
	200	**100**	**Comments**
LRI random ranging error (μm/sec)	45	10	From link analysis
LRI measurement drift rate (μm/sec)	2	2	LRI requirement
LRI-spacecraft CG offset (residual)	2	2	
Subsatellite (μm/sec)	12	12	Dom. error at 100 km
Cube vertex-CG offset: (2 μm/sec) Drag induced accel.: (10 μm/sec)			
Margin - other ranging errors	10	10	Mounting errors, etc.
RSS Gravity Ranging Errors (μm/sec)	48	18	RSS: Root Sum Square

GAMES LRI 2



GAMES Laser Ranging Instrument 2

System Block Diagram V.2