The Lunar Orbiter Laser Altimter and the Laser Ranging System on the Lunar Reconnaissance Orbiter

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Abstract: The design of Lunar Orbiter Laser Altimeter on the Lunar Reconnaissance Orbiter is presented. The one-way laser ranging system that provides precision tracking of the spacecraft position from Earth is also described.

OCIS codes: (280.3400) laser range finder, (280.3640) lidar

The Lunar Orbiter Laser Altimeter (LOLA) is one of the six payload instruments on NASA's Lunar Reconnaissance Orbiter (LRO) to be launched in October 2008. The primary objective of LOLA investigation is to measure the lunar surface elevation and to produce a geodetic topographic map of the moon for lunar science studies and future explorations. LOLA will measure the laser pulse time of flight from LRO to the surface of the moon from a nominal 50 km orbit altitude. The LOLA instrument design is similar to those of the Mars Orbiter Laser Altimeter (MOLA) and the Mercury Laser Altimeter (MLA), but with five laser beams and five receiver channels. The laser transmitter consists of a single stage diode-pumped Q-switched Nd:YAG laser at 1064-nm wavelength, 2.7-mJ pulse energy, 6-ns pulse width, 28-Hz pulse rate, and 100 μrad beam divergence angle. A diffractive optics element (DOE) is used to equally split the laser beam into five slightly off pointed beams. The DOE is made of fused silica with an etched-in diffraction pattern and is specially designed such that the five laser spots form a cross pattern at 0.5-mrad spacing. The reflected signal is collected by a 14-cm diameter telescope and a 5-optical-fiber array at the focal plane of the telescope, each aligned to one of the five laser spots on the Lunar surface and delivers the signal to one of the five avalanche photodiode (APD). The transmitted laser pulse and the five received laser pulses were timestamped with respect to the spacecraft mission elapsed time (MET) using a set of time-to-digital converters (TDC) at <0.5 ns precision. LOLA also measures the transmitted and the received pulse energy by integrating the pulse waveforms, which provides a measure of the lunar surface reflectance to the laser pulses. The on board science algorithm running on an embedded microprocessor autonomously adjust the receiver detection threshold levels, the detector gain, and to keep the range window centered about the Lunar surface echoes. The key instrument parameters are listed in Table 1.

LRO also carries a laser ranging (LR) system to detect and timestamp the laser pulses transmitted from Earth. With precision timing on Earth and a stable clock oscillator on the spacecraft, a one-way laser ranging can be accomplished, which provides a relative range measurement between the Earth station and LRO every half orbit when the spacecraft is in the front side of the moon. The LR measurements will be combined with the S-band radio frequency tracking (RF) data and LOLA topographic data to determine the LRO orbit position and to detect small orbit variation caused by the uneven lunar gravity field distribution.

The LR system consists of a flight system and ground system. The flight system includes a 30-mm diameter telescope mounted on the LRO high gain antenna, an optical fiber bundle, and the timing electronics. The telescope is co-aligned with the RF beam and has a relatively wide field of view to encompass almost the entire Earth so that laser ranging can be performed while LRO is conducting its routine data transmission and RF tracking. The optical fiber bundle consists of seven multimode optic fibers that couple the laser signal from the telescope on the high-gain antenna, through the gimbals and down the boom, to the spacecraft deck. LR does not have its own timing electronics but share one of the five LOLA receiver channels for laser pulse timestamping. The spacecraft carries an ultra stable oven controlled quartz oscillator and distributes the timing signal to LOLA and other payload instruments. The ground system consists of a satellite laser ranging (SLR) station at 532 nm laser wavelength, a precision event timer, and a laser trigger timing control synchronized to the LRO MET. The LR measurement is expected to have a 10 cm precision when averaged over a second and less than 2 m drift over the course of an hour or one half LRO orbit. The system parameter of the LR system is given in Table 2.

Table 1. LOLA instrument parameters

Laser	
Pulse energy	2.7±0.3 mJ
Wavelength	1064 nm
Pulse width, and rate	6 ns FWHM, 28 Hz
Beam splitting	5-way, >13% total per beam
Beam divergence, each beam	100 μrad
Beam separation	500 μrad
Receiver Optics	
Receiver aperture diameter	0.14 m
Field of view	400 μrad
Optics transmission	>70%
Optical bandwidth	0.8 nm
Photodetector/Preamplifier	
Detector active area	0.7 mm diameter
Detector quantum efficiency	40%
Noise equivalent power (NEP)	0.05 $pW/Hz^{1/2}$
Impulse response pulse width	6 ns
Timing Electronics	
Timing resolution	<0.5 ns
Clock frequency uncertainty	<1e-7 (short term)
Total Instrument:	
Mass, Power	12.6 kg, 34 W
Volume, Main housing	45x51x36 cm^3
Electronics unit	28x17x12 cm^3
Date rate	28 kbits/s

Table 2. LRO LR system parameters

Ground station	
Laser pulse energy	>30 mJ
Wavelength	532 nm
Pulse width and rate	<10 ns FWHM, 28 Hz, synchronized to MET
Beam divergence	55 μrad
Timing accuracy	0.1 ns shot to shot, <1e-12/hour drift rate, <100 ns to UTC at any time
LRO LR Receiver Optics	
Receiver aperture diameter	1.9 cm clear aperture, 3.0 cm outer diameter
Field of view	30 mrad
Optical fiber bundle	400 μrad core diameter, 7 each, 0.22 NA, step index 40% transmission, including fill factor and connector losses
Optical bandwidth	0.3 nm

LOLA will be the first multibeam laser altermeter in space. The LRO LR system will be the first spacecraft laser ranging system beyond near Earth orbits. The combined LOLA and LR measurements will provide a precise geodetic topographic map of the moon and a much improved lunar gravity field model for lunar science investigations and future missions.