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Evro Wee Sit *Editor*

Sensors and Instrumentation, Volume 5

Proceedings of the 33rd IMAC, A Conference and Exposition on Structural Dynamics, 2015

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Preface

Sensors and Instrumentation represents one of ten volumes of technical papers presented at the 33rd IMAC, A Conference and Exposition on Structural Dynamics, 2015, organized by the Society for Experimental Mechanics, and held in Orlando, Florida February 2–5, 2015. The full proceedings also include volumes on Nonlinear Dynamics; Dynamics of Civil Structures; Model Validation and Uncertainty Quantification; Dynamics of Coupled Structures; Special Topics in Structural Dynamics; Structural Health Monitoring and Damage Detection; Experimental Techniques, Rotating Machinery and Acoustics; and Shock and Vibration Aircraft/Aerospace, Energy Harvesting; and Topics in Modal Analysis.

Each collection presents early findings from experimental and computational investigations on an important area within Sensors and Instrumentation. Topics represent papers on calibration, smart sensors, rotational effects, stress sensing and tracking of dynamics. Topics in this volume include:

Experimental Techniques
Smart Sensing
Rotational Effects
Dynamic Calibration

The organizers would like to thank the authors, presenters, session organizers, and session chairs for their participation in this track.

Hermosa Beach, CA, USA
Evro Wee Sit

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Chapter 1
LLCD Experimental Line-of-Sight Jitter Testing

Brandon J. Dilworth

Abstract The LLCD program at MIT Lincoln Laboratory is the first space laser communication system for NASA. The optical communications terminal was carried into lunar orbit by the LADEE spacecraft which launched on September 6, 2013. The primary goal of the LLCD program is to demonstrate optical communication from lunar orbit to the Earth's surface.

Optical communication systems have many advantages over RF systems which include achieving higher data rates using lower size, weight and power (SWaP). Optical communication systems rely on much narrower beams than RF systems to achieve these advantages; the penalty is that the optical beam must have good stability in order to maintain the communication link between the transmitter and receiver. There are a number of factors that play a role in the stability of the optical beam, but the focus of this talk is on the residual LOS jitter resulting from unrejected spacecraft excitation. Experimentation with physical hardware is a common method for validating mathematical models, including residual LOS jitter models. The LLCD program developed a test bench in order to validate the residual LOS jitter model which provides higher confidence in the computational results.

Keywords LOS jitter • Optical communication • Model validation • MIMO sine testing • LLCD

Nomenclature

DOF	Degree of Freedom
FEM	Finite Element Model
ICD	Interface Control Document
IR	Infrared
LADEE	Lunar Atmosphere and Dust Environment Explorer
LLCD	Lunar Laser Communication Demonstration
LOS	Line-of-Sight
MAC	Modal Assurance Criterion
MIMO	Multiple Input Multiple Output
MIRU	Magneto-hydrodynamic Inertial Reference Unit
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
PSD	Power Spectral Density
RF	Radio Frequency
SNR	Signal-to-Noise Ratio

Statement
This work is sponsored by the National Aeronautics and Space Administration under Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the United States Government.

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1.1 Introduction

The LLCD program developed and fielded the first duplex laser communication system for NASA. MIT Lincoln Laboratory designed and built a space terminal for lunar orbit and the primary ground terminal to execute the demonstration. A month after launch, the LLCD system demonstrated a 20 Mbps uplink and a 622 Mbps downlink between the Moon and the Earth. Both links represent data rates much higher than ever achieved previously over that distance. An overview of the system architecture and demonstration results have been previously published [1].

Optical communication systems use much shorter (>10,000×) wavelengths as compared to existing RF communication systems. The shorter wavelengths enable large bandwidth modulation, higher data rates and low diffraction losses as compared to RF systems. The shorter wavelength results in a narrow beamwidth which means that the optical terminals (at both ends of the link) can be much smaller and require less power than their RF counterparts. However, a narrow beamwidth means beam stability becomes a much more significant challenge. For the LLCD space terminal, the resulting requirement was that the beam had to be stabilized better than 4.2 μrad to maintain the communication link.

The space terminal optical module included several features in order to achieve the pointing requirements which are graphically summarized in Fig. 1.1. Initial pointing of the terminal is executed by the spacecraft with accuracy based on the performance of its star trackers. The 2-axis gimbal provides coarse pointing while the MIRU provides the fine pointing and inertial stabilization of the optical head. The telescope is an all-beryllium structure with a 10 cm primary mirror. The approach of the control system and the architecture of the optical paths have been described previously [2].

1.2 Line-of-Sight Jitter

Line-of-sight jitter is simply defined as the time-varying motion of the image on the detector plane [3]. In imaging systems (like cameras), LOS jitter can result in blurred images. In laser communication systems, LOS jitter can result in loss of data rate. In both scenarios, the LOS jitter can be induced either internally from or externally to the system. Typical sources of self-excitation are due to the tracking system mechanism(s). On the LLCD Space Terminal, the dominant sources of self-excitation were due to the Gimbal motion (stepper motors) and the nutation mechanism on the Optical Head. Primary sources of external excitation were due to the reaction wheels on the LADEE spacecraft coupling through the spacecraft structure and acting as base excitation to the Instrument Panel. The external excitation was prescribed early in the program based on

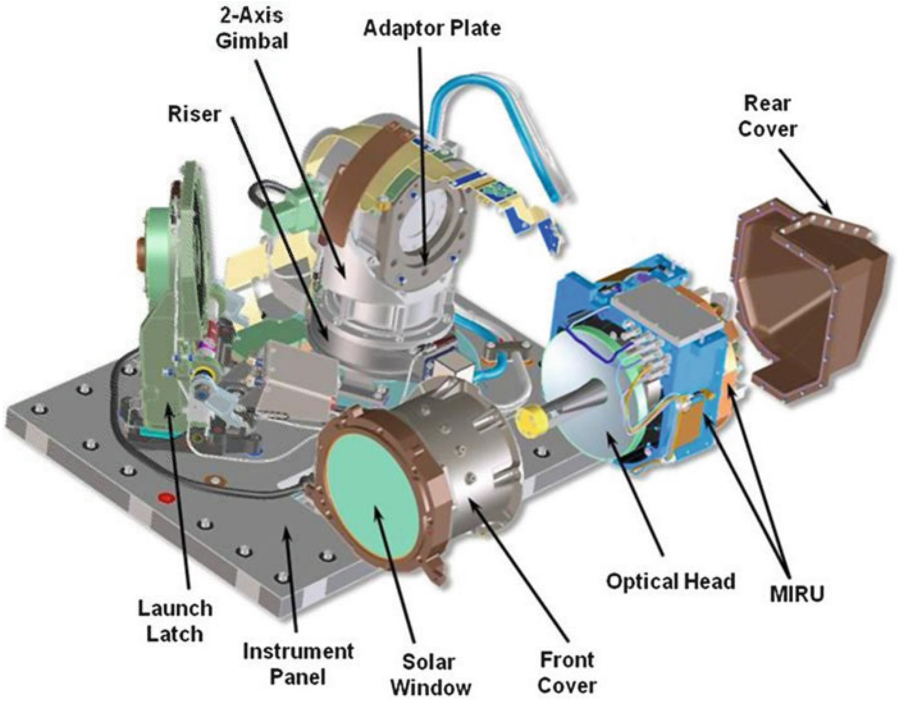

Fig. 1.1 LLCD space terminal optical module