## PROCEEDINGS OF SPIE

## Free-Space Laser Communications XXXV

Hamid Hemmati Bryan S. Robinson Editors

30 January – 1 February 2023 San Francisco, California, United States

Sponsored and Published by SPIE

**Volume 12413** 

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIEDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings: Author(s), "Title of Paper," in Free-Space Laser Communications XXXV, edited by Hamid Hemmati, Bryan S. Robinson, Proc. of SPIE 12413, Seven-digit Article CID Number (DD/MM/YYYY); (DOI URL).

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510659315

ISBN: 9781510659322 (electronic)

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA Telephone +1 360 676 3290 (Pacific Time)

SPIE.ora

Copyright © 2023 Society of Photo-Optical Instrumentation Engineers (SPIE).

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of fees. To obtain permission to use and share articles in this volume, visit Copyright Clearance Center at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher.

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

Publication of record for individual papers is online in the SPIE Digital Library.



**Paper Numbering:** A unique citation identifier (CID) number is assigned to each article in the Proceedings of SPIE at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a seven-digit CID article numbering system structured as follows:

- The first five digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

## Contents

ix Conference Committee FLIGHT DEMONSTRATIONS 12413 02 On-orbit demonstration of 200-Gbps laser communication downlink from the TBIRD CubeSat (Invited Paper) [12413-1] 12413 03 Early results from NASA's laser communications relay demonstration (LCRD) experiment program (Invited Paper) [12413-2] 12413 05 On-orbit results of pointing, acquisition, and tracking for the TBIRD CubeSat mission [12413-4] 12413 06 Optical satellite links at DLR [12413-71] MISSION CONCEPTS AND SYSTEM ARCHITECTURES 12413 07 Telesat Lightspeed: enabling mesh network solutions for managed data service flexibility across the globe [12413-5] 12413 08 High-rate 256+ Gbit/s laser communications for enhanced high-resolution imaging using space-based very long baseline interferometry (VLBI) [12413-6] 12413 09 Laser transmission of quantum bits and multi-tera-bits over multi-hop satellite orbital constellations [12413-7] 12413 0A Optical communications operations concept for the Artemis II crewed mission to the Moon [12413-9] FLIGHT TRANSCEIVER TECHNOLOGIES AND STUDIES 12413 0C Status on laser communication activities at Tesat-Spacecom [12413-11] 12413 0E System level TVAC functional testing for the Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T) payload destined for the International Space Station [12413-13] 12413 OF FWM-PEV statistics in 8 channel 50W high power WDM PPM Tx with and without TDM based FWM mitigation [12413-14]

## TRANSMITTER TECHNOLOGIES

12413 0G	Development of a continuous wave single transverse mode polarization-maintaining 10 W Er/Yb-codoped fiber amplifier for space communications [12413-15]
12413 OH	Extremely powerful optical sources (EPOS) for Tbit/s satellite links [12413-16]
12413 01	1.06-micron high power laser propagation in low-altitude atmosphere [12413-17]
12413 OJ	High-capacity optical wireless VCSEL array transmitter with uniform coverage [12413-18]
12413 OK	Coherent beam combine based on a single photodetector without local beam optics [12413-19]
12413 OL	Hemispherical retro-modulation technologies for passive free-space optical communication links [12413-20]
	BEAM-POINTING COMPONENTS
12413 OM	Demonstration of high-speed wireless data transmission using passive silica optical phased array [12413-21]
12413 0N	Conceptual design and analysis of a compact liquid crystal on silicon non-mechanical optical beam steering antenna for lean platforms [12413-22]
12413 00	Fast-steering prism for correction of tip tilt aberrations [12413-23]
	GROUND TRANSCEIVER TECHNOLOGIES I
12413 OP	A real-time optical ground receiver for photon starved environments [12413-26]
12413 0Q	The Deep Space Optical Communications project ground laser transmitter [12413-27]
12413 OR	The Deep Space Optical Communications project ground laser receiver [12413-28]
12413 OS	A transmitter and receiver for lunar communications on the ANU optical ground station [12413-29]
	GROUND TRANSCEIVER TECHNOLOGIES II
12413 OT	Optical-to-Orion (O2O) ground terminal (GT) at Table Mountain Facility (TMF) [12413-30]

12413 OU	Fiber-detector subsystem loss comparison for a ground-based photon-counting optical receiver [12413-31]
12413 OV	Current status of NASA's Low-Cost Optical Terminal (LCOT) at Goddard Space Flight Center [12413-32]
12413 OW	18km bidirectional free-space optical link with multi-aperture antenna and DWDM SFP+ transceivers (VERTIGO project) [12413-33]
12413 OX	NASA's LCOT (low-cost optical terminal) FSOS (free-space optical subsystem): concept, design, build, and test $[12413-34]$
	GROUND TRANSCEIVER TECHNOLOGIES III
12413 11	Ground station for terabyte infrared delivery (TBIRD) [12413-38]
	AO-ASSISTED MITIGATION I
12413 12	Evaluating the performance of a sensorless wavefront correction algorithm for turbulent horizontal point-to-point links [12413-39]
12413 14	Optimisation of the pre-compensation phase for GEO-feeder optical uplinks [12413-42]
	AO-ASSISTED MITIGATION II
12413 15	Large field of view wavefront correction with deformable lenses [12413-45]
12413 16	Performance analysis of adaptive optics compensated uplink and downlink channels [12413-46]
	RECEIVER TECHNOLOGIES
12413 17	Dual-control technique for temperature stabilization and tunability of narrowband fiber Bragg gratings [12413-47]
12413 18	Recovery of single-polarization waveforms with dual-polarization coherent receivers at low SNRs [12413-48]
12413 19	Large-area SNSPD array for RF/optical hybrid 7-segment pathfinder receiver [12413-49]

	ATMOSPHERICS I
12413 1B	Global atmospheric turbulence forecasting for free-space optical communications (Invited Paper) [12413-51]
12413 1C	A small, low-cost, turbulence profiling instrument for free-space optical communication [12413-52]
12413 1D	Wavefront reversal (phase conjugation) using a MEMS spatial phase modulator (SPM) integrated with a metasurface retro-array: a proposal [12413-53]
	ATMOSPHERICS II
12413 1E	The 24hSHIMM: a continuous day and night turbulence monitor for optical communications [12413-54]
12413 1F	Atmospheric optical turbulence analysis in London's financial district [12413-55]
12413 1G	Atmospheric optical turbulence measurements at varying elevation angles [12413-56]
	POSTER SESSION
12413 11	Folded optical design for high fidelity atmospheric emulation with a spatial light modulator [12413-58]
12413 1J	Analysis of diversity gain and outage capacity in multiple beam transmission spatial diversity vertical FSO links $[12413-59]$
12413 1K	Simulation framework for classical and quantum communications over the free-space optical channel [12413-60]
12413 1L	Statistical analysis of fading power vectors for real-time atmospheric channel emulation [12413-61]
12413 1M	Characterization of infrared laser beam through atmospheric optical turbulence in laboratory environment $[12413\text{-}63]$
12413 1N	Research and development of key technologies for cislunar optical communication systems in Japan [12413-64]
12413 10	Entanglement-based QKD over LEO satellite-to-ground time-varying atmospheric channel [12413-65]
12413 1P	Development of spatial coherent optical receiver with a size of 100mm square for inter-satellite
	communication [12413-67]

12413 1R	Lighthouse: an externally mountable high-power beacon for use in optical ground stations [12413-69]
12413 1U	Radiation hardness studies of butterfly single mode DFB lasers at 1064 nm [12413-74]