

PROCEEDINGS OF SPIE

Free-Space Laser Communications XXXVI

**Hamid Hemmati
Bryan S. Robinson**
Editors

**30–31 January 2024
San Francisco, California, United States**

Sponsored and Published by
SPIE

Volume 12877

Proceedings of SPIE 0277-786X, V. 12877

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Free-Space Laser Communications XXXVI, edited by Hamid Hemmati,
Bryan S. Robinson, Proc. of SPIE Vol. 12877, 1287701
© 2024 SPIE · 0277-786X · doi: 10.1117/12.3029989

Proc. of SPIE Vol. 12877 1287701-1

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 SPIDigitalLibrary.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 XXXVI*, edited by Hamid Hemmati, Bryan S. Robinson, Proc. of SPIE 12877, Seven-digit Article CID Number (DD/MM/YYYY); (DOI URL).

ISSN: 0277-786X
ISSN: 1996-756X (electronic)

ISBN: 9781510670143
ISBN: 9781510670150 (electronic)

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time)
SPIE.org
Copyright © 2024 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.

SPIE. DIGITAL LIBRARY
SPIDigitalLibrary.org

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

vii *Conference Committee*

SESSION 1 FLIGHT TRANSCEIVER TECHNOLOGIES

- 12877 04 **Status on laser communication activities at Tesat-Spacecom** [12877-3]
- 12877 05 **NASA's laser communications relay demonstration (LCRD) experiment program: characterization and initial operations** [12877-4]
- 12877 06 **Deep space optical communications technology demonstration** [12877-6]
- 12877 07 **Deep space optical communications (DSOC) technology demonstration pre-launch validation and performance tests with the laser test evaluation station (LTES)** [12877-5]

SESSION 2 GROUND DEMONSTRATIONS I

- 12877 08 **Frequency comb-to-comb synchronization between a 1.3-km free-space link via an optical frequency transfer** [12877-7]
- 12877 09 **Project CHORUS: a hybrid optical/RF antenna system overview and field testing** [12877-8]

SESSION 3 GROUND DEMONSTRATIONS II

- 12877 0B **Ground-to-space optical communications experiment with LCRD using open-loop pointing** [12877-10]
- 12877 0C **The SDA tranche 1 optical interoperability testbed** [12877-11]
- 12877 0D **Measurement of extinction ratio for burst waveform transmitters using a coherent receiver and hybrid time and frequency domain analysis** [12877-12]
- 12877 0E **Coherent optical feeder links for very high throughput satellite systems** [12877-13]

SESSION 4 TRANSMITTER TECHNOLOGIES

- 12877 0G **Photonic integrated circuits for high-throughput optical communications and ranging satellite links** [12877-15]

- 12877 OH **Prototype model of a 100W optical fiber amplifier for 10-channel WDM satellite communication in the 1 μ m wavelength range** [12877-16]
- 12877 OI **High power wavelength division multiplexing (HP-WDM) for high-speed space optical communication** [12877-17]
- 12877 OJ **Physical layer forward error correction for free-space optical links** [12877-18]
- 12877 OK **Erasur e correcting codes for high-throughput optical ground-to-satellite links** [12877-19]
- 12877 OL **FWM-PEV statistics measurements in 8 channel 50W high-power WDM PPM Tx with and without TDM-based FWM mitigation** [12877-20]

SESSION 5 BEAM CONTROL

- 12877 OM **Piezoelectric MEMS fast steering mirror with high reliability for free-space laser communication** [12877-21]
- 12877 OO **Implementing and testing generalized pointing, acquisition, and tracking for a space-based adaptive communications node (Space-BACN)** [12877-23]

SESSION 6 RECEIVER TECHNOLOGIES I

- 12877 OQ **Fiber bundle-based beam tracking demonstrated across 30 km terrestrial FSO communications link** [12877-25]
- 12877 OR **Hybrid FSO/RF communications system demonstrated across degraded 30 km link with integrated commercial radio** [12877-26]
- 12877 OS **Superconducting nanowire single-photon detectors for laser communication** [12877-27]
- 12877 OT **Multiple optical receive system for optical GEO feeder-links** [12877-28]
- 12877 OV **Highly sensitive, high dynamic range OLN A for single digit photons per bit in space applications** [12877-30]

SESSION 7 RECEIVER TECHNOLOGIES II

- 12877 OW **Spatial diversity control law for demultiplexer and active photonic integrated circuits for atmospheric effect mitigation** [12877-31]
- 12877 OY **Testing of a photon-counting optical ground receiver with emulated space-to-ground link effects** [12877-33]

- 12877 0Z **Performance of a real-time photon counting optical receiver in the presence of emulated channel fading** [12877-34]
- 12877 11 **Experimental demonstration of coherent receiver with photonic lantern and digital signal processing** [12877-36]

SESSION 8 SYSTEMS ENGINEERING

- 12877 12 **Connecting the warfighter with lasers in space: the space development agency and the optical communications terminal standard (Invited Paper)** [12877-37]
- 12877 13 **Preliminary design of key optical components onboard laser communication terminal of GEO data relay satellite for cislunar optical communication system** [12877-38]
- 12877 14 **Improving lasercom terminals by reducing optical nonlinearities via hollow-core optical fibers** [12877-39]
- 12877 15 **Empirical model for lasercom size, weight, and power (SWaP)** [12877-40]

SESSION 9 PROPAGATION TECHNOLOGIES

- 12877 16 **The Lasercom atmospheric monitoring and prediction system** [12877-41]
- 12877 17 **Measuring the vertical profile of atmospheric turbulence with the laser communication relay demonstration downlink at Table Mountain Facility** [12877-42]
- 12877 18 **Pre-distortion adaptive optics: experimental results from bi-directional tracking links between DLR's optical ground station and Alphasat's TDP-1 terminal (Best Student Presentation Award)** [12877-43]
- 12877 19 **Design and optimization of a self-referencing interferometer for effective wavefront sensing in adaptive optics systems** [12877-44]
- 12877 1A **Capacity limits of linear avalanche photodiodes for low-complexity lasercom** [12877-45]

SESSION 10 GROUND STATION TECHNOLOGIES

- 12877 1B **Large-aperture ground terminal for high data rate free-space laser communications** [12877-46]
- 12877 1C **Deep space communication with the ANU optical communications ground station** [12877-47]

SESSION 11 OTHER TOPICS AND POST-DEADLINE

12877 1F **Revolutionizing spacecraft communication: optical wireless technology for reduced weight and cost** [12877-50]

12877 1G **Optical ranging for space-to-ground links** [12877-51]

POSTER SESSION

12877 1I **Analyzing beam profile, intensity fluctuations, and beam wander with varying weather conditions on a free-space 1550 nm optical communication link** [12877-53]

12877 1J **Near-IR and Mid-IR wave propagation through patchy fog** [12877-54]

12877 1L **Generation and statistics of time series of received power for ground-to-space laser links** [12877-56]

12877 1M **Field-programmable gate array implementation of a single photon-counting receive modem** [12877-58]

12877 1N **Impact of fog in optical chaos transmission** [12877-59]

12877 1O **Relative distance measurements using inter-satellite optical communication links** [12877-60]

12877 1P **Dual-purpose SDA-compliant optical ground station and laser ranging system concept for satellite applications** [12877-61]

12877 1Q **A free space optical link model for C-band data and power transmission (Sustainability Best Paper Award in LASE)** [12877-62]

12877 1R **Long range propagation of optical vortex beams in atmospheric turbulence** [12877-63]

12877 1S **GEOStar: demonstration of laser guide star adaptive optics for free space optical communications** [12877-64]

12877 1T **Optical camera communications for indoor positioning: high accuracy, low cost, and low power consumption** [12877-65]

12877 1W **Optical fluids: modeling the near field and far field optical effects of atmosphere and turbulent flow of an airborne laser communication system** [12877-69]

12877 1X **Optical system structural and thermal jitter analysis using Ansys Zemax OpticStudio** [12877-70]

12877 1Z **Optical feeder links for GEO satellites at Viasat Inc.** [12877-73]

12877 22 **Technology development for a low-mass solar system and interstellar communications system** [12877-76]

Conference Committee

Symposium Chairs

Stefan Kaierle, Laser Zentrum Hannover e.V. (Germany)
John Ballato, Clemson University (United States)

Symposium Co-chairs

Vassilia Zorba, Lawrence Berkeley National Laboratory
(United States)
Kaoru Minoshima, University of Electro-Communications (Japan)

Program Track Chairs

Bo Gu, Bos Photonics (United States)
Constantin L. Häfner, Fraunhofer-Institut für Lasertechnik ILT (Germany)

Conference Chairs

Hamid Hemmati, ViaSat, Inc. (United States)
Bryan S. Robinson, MIT Lincoln Laboratory (United States)

Conference Program Committee

Erik Alerstam, Jet Propulsion Laboratory (United States)
Abhijit Biswas, Jet Propulsion Laboratory (United States)
Don M. Boroson, MIT Lincoln Laboratory (United States)
Kerri L. Cahoy, Massachusetts Institute of Technology (United States)
Donald M. Cornwell Jr., Amazon.com, Inc. (United States)
Baris I. Erkmen, Aalyria Technologies, Inc. (United States)
Harald Hauschildt, European Space Research and Technology
Center (Netherlands)
Frank F. Heine, Tesat-Spacecom GmbH and Company KG
(Germany)
William S. Rabinovich, U.S. Naval Research Laboratory (United States)
Todd S. Rose, The Aerospace Corporation (United States)
Julie Smith, Air Force Research Laboratory (United States)
Sarah A. Tedder, NASA Glenn Research Center (United States)
Linda M. Thomas, U.S. Naval Research Laboratory (United States)
Morio Toyoshima, National Institute of Information and
Communications Technology (Japan)

