

PROCEEDINGS OF SPIE

# ***Free-Space Laser Communications XXXIII***

**Hamid Hemmati**  
**Don M. Boroson**  
*Editors*

**6–11 March 2021**  
**Online Only, California, United States**

*Sponsored and Published by*  
SPIE

**Volume 11678**

Proceedings of SPIE 0277-786X, V. 11678

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

Free-Space Laser Communications XXXIII, edited by Hamid Hemmati,  
Don M. Boroson, Proc. of SPIE Vol. 11678, 1167801 · © 2021 SPIE  
CCC code: 0277-786X/21/\$21 · doi: 10.1117/12.2596748

Proc. of SPIE Vol. 11678 1167801-1

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](http://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 XXXIII*, edited by Hamid Hemmati, Don M. Boroson, Proc. of SPIE 11678, Seven-digit Article CID Number (DD/MM/YYYY); (DOI URL).

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510641914

ISBN: 9781510641921 (electronic)

Published by

**SPIE**

P.O. Box 10, Bellingham, Washington 98227-0010 USA

Telephone +1 360 676 3290 (Pacific Time)

[SPIE.org](http://SPIE.org)

Copyright © 2021 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](http://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](http://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

---

## LASERCOM SYSTEMS: LABORATORY

---

- 11678 04 **Cognitive multi-user free space optical communication testbed** [11678-1]
- 11678 05 **Design of a multi-element FSO transceiver array for mobile communication links** [11678-2]
- 11678 06 **A flexible low-cost optical communications ground terminal at NASA Goddard Space Flight Center** [11678-3]

---

## LASERCOM SYSTEMS: FLIGHT

---

- 11678 08 **Laser communication data storage using angle multiplexing and spatial division multiplexing** [11678-5]
- 11678 09 **In orbit demonstration plans for an optical satellite link between a CubeSat and a ground terminal at TNO** [11678-6]
- 11678 0A **Multi-mission capable optical inter satellite link (Invited Paper)** [11678-7]
- 11678 0B **Small satellite optical communications (Invited Paper)** [11678-37]

---

## LASERCOM FLIGHT DEMONSTRATIONS AND OPERATIONS

---

- 11678 0C **Status of Tesat Lasercomms activities** [11678-8]
- 11678 0D **Experimental results on in-orbit technology demonstration of SOLISS (Invited Paper)** [11678-9]

---

## POINTING, ACQUISITION, AND TRACKING TECHNOLOGIES

---

- 11678 0E **Fine pointing of laser beams by using laser arrays for applications to CubeSats** [11678-10]
- 11678 0F **The pointing performance of the optical communication terminal, SOLISS in the experimentation of bidirectional laser communication with an optical ground station** [11678-11]
- 11678 0I **Beaconless pointing and tracking for bidirectional optical links using MEMS mirror nutation** [11678-14]

---

#### LASER TRANSMITTER AND RECEIVER TECHNOLOGIES

---

- 11678 OJ **A high dynamic-range photon-counting receiver for deep space optical communication** [11678-15]
- 11678 OK **50W, 1.5 $\mu$ m, 8 WDM (25nm) channels PPM downlink Tx for deep space lasercom** [11678-16]
- 11678 OL **Miniaturized modules for space-based optical communication** [11678-17]
- 11678 OM **Comparing high order pulse position modulation to burst differential phase shift keying in intersatellite optical communications links** [11678-18]
- 11678 ON **Parallel optical amplification and multi-aperture transmission with digital coherent reception for wavelength division multiplexed high capacity FSO and its real-time evaluation** [11678-19]
- 11678 OO **Implementation of a high photon efficiency optical receiver using a semiconductor optical amplifier** [11678-20]

---

#### OPTICS TECHNOLOGIES

---

- 11678 OP **Wavefront correction of laser beam distorted by fan heater turbulence using an adaptive optical system with a frequency of 2000 Hz** [11678-21]
- 11678 OS **Telescope metrology and active alignment for RF-optical hybrid receiver** [11678-24]
- 11678 OT **Link analysis for a liquid lens beam steering system, the miniature optical steered antenna for intersatellite communication: MOSAIC** [11678-25]
- 11678 OU **Sensorless adaptive optics for optical communications** [11678-26]
- 11678 OV **Study of lens performance on fog mitigation in low-cost FSO communication link** [11678-27]

---

#### QUANTUM COMMUNICATIONS

---

- 11678 OX **Drone-based quantum key distribution (QKD)** [11678-29]

---

#### ANALYSIS

---

- 11678 OY **Five advantages of managed optical communications array (MOCA) technology over other Lasercomm approaches (Invited Paper)** [11678-30]
- 11678 OZ **M diversity for reliable laser satellite communication** [11678-31]

- 11678 10 **Site diversity considerations for high capacity optical networks in low Earth orbit** [11678-32]
- 11678 11 **Evaluation of the forward error correction format for LEO-ground optical communication using Reed-Solomon product code** [11678-33]
- 11678 13 **Numerical simulation of Gaussian beam propagation through Kolmogorov phase screen** [11678-35]
- 11678 14 **Characterization of multi-level digital waveforms for low-Earth-orbit free space optical communication** [11678-36]

