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Center of Excellence
Jet Propulsion Laboratory
California Institute of Technology

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Deep Space Optical Communications

Edited by
Hamid Hemmati
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Foreword

The Deep Space Communications and Navigation Systems Center of Excellence (DESCANSO) was established in 1998 by the National Aeronautics and Space Administration (NASA) at the California Institute of Technology's Jet Propulsion Laboratory (JPL). DESCANSO is chartered to harness and promote excellence and innovation to meet the communications and navigation needs of future deep-space exploration.

DESCANSO's vision is to achieve continuous communications and precise navigation—any time, anywhere. In support of that vision, DESCANSO aims to seek out and advocate new concepts, systems, and technologies; foster key technical talents; and sponsor seminars, workshops, and symposia to facilitate interaction and idea exchange.

The Deep Space Communications and Navigation Series, authored by scientists and engineers with many years of experience in their respective fields, lays a foundation for innovation by communicating state-of-the-art knowledge in key technologies. The series also captures fundamental principles and practices developed during decades of deep-space exploration at JPL. In addition, it celebrates successes and imparts lessons learned. Finally, the series will serve to guide a new generation of scientists and engineers.

Joseph H. Yuen
DESCANSO Leader
Preface

The ever-increasing demand for data from planetary probe spacecraft is pushing the frequency of telecommunications from radio frequency (RF) bands to the optical and near-infrared regime. Such a transition offers the potential to increase data rates by one to two orders of magnitude over conventional RF links. Early NASA spacecraft telecom systems relied on the S-band frequency. Nearly twenty years later, X-band frequencies were implemented. Over twenty years later, the Ka-band systems are beginning to be implemented in deep space. For the optical band, we are now in the technology maturation and demonstration phase. It is expected that after a number of successful and convincing technology validation demonstrations, the optical band will also move into the implementation phase.

This reference text is intended to summarize and document the optical work performed at the Jet Propulsion Laboratory (JPL) since inception of the Free-Space Optical Communication Group in late 1970s. This text provides an overview of nearly a quarter of century of research and development, performed by JPL’s Optical Communication Group, its associated researchers, and other optical-communications researchers throughout the world. The focus of the research effort has been deep space telecommunications. In recent years, the near-Earth communication technologies have been addressed also. The flight transceiver, the ground receiver, and uplink transmitter technologies were addressed.

During the past 25 years, the focus of the component and subsystem technology efforts had to be adjusted frequently to keep pace with the rapid developments in laser, detector, detector array, and fiber-optic technologies. Therefore, a significant portion of the group’s effort was concentrated on addressing this challenge. This book is intended to bring a novice in the field up to date, and be informative to those interested in learning about the status of
optical communications technology. As a reference book it should help the people in the field to build upon the prior knowledge and become aware of the important design variations and critical differences between them. Also, this book is intended to provide information on the state-of-the-art in component and subsystem technologies, fundamental limitations, and approaches to reach and fully exploit new technologies.

The text is organized into seven chapters in which Chapter 1 provides an overview of deep-space optical communications technology and a historical perspective of deep-space optical communications technology developments by JPL. Chapter 2 discusses the link and the system design drivers. Parameters that influence the design of an optical communications systems and the link control table that takes into all relevant link parameters are discussed here. The atmospheric channel is discussed in Chapter 3. Cloud statistics, atmospheric transmission, background light and sky radiance, laser beam propagation through the turbulent atmosphere and atmospheric issues driving the selection of a ground receiver site are discussed in this chapter. Chapter 4 deals with modulation and coding, including the statistical models for the detected optical fields, modulation formats, rate limits imposed by constraints of modulation, performance of uncoded optical modulation schemes, optical channel capacity, channel codes for optical modulations, and performance of optical modulations. Chapter 5 deals with the subsystems that constitute the flight terminal. Subchapter 5.1 is on acquisition, tracking and pointing. The most challenging aspect of deep-space Optical Communication technology has been and remains as the tracking and pointing function. This subchapter deals with precise beam pointing throughout the Solar System, options, design drivers and requirements, and examples of system implementation. Subchapter 5.2 deals with the laser transmitter. Flight laser transmitters continue to be a major risk item due to current less-than desired lifetime. Requirements, wavelength effects, candidate sources, modulators, laser efficiency, timing jitter, and thermal management are discussed in this subchapter. The opto-mechanical subassembly including a description of general requirements, the optical channels, design approaches, transmit/receive isolation, stray light control, structure materials, and optical design examples are described in Subchapter 5.3. Flight qualification of lasers and detectors, including environmental requirements, flight qualification approaches and procedures are described in Subchapter 5.4. Chapter 6 discusses the Earth-based terminal architecture. Single-station downlink reception and uplink transmission are discussed in Section 6.1.1. Options and approaches, site diversity, receiver stations located above clouds (e.g., balloons, airplanes, or spacecraft) uplink beacon, safe laser beam propagation, and atmospheric effect mitigation are among the topics discussed in this section. Section 6.1.2 discusses arraying of telescope receivers, including trades, implementation schemes, and performance analysis. Subchapter 6.2 discusses photodetectors, including both single element (6.2.1) and array of photodetectors (6.2.2).
Requirements and challenges, a description of photon-counting detectors, implementation options and performance are discussed here. Subchapter 6.3 discusses receiver electronics, including demodulator architectures, synchronization and post-detection filtering, demodulator variations, and system models and architectures. Chapter 7 discusses future prospects and applications, including certain technology developments to date, navigational tracking, and light science.

Hamid Hemmati,
Pasadena, California
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Contributors

All contributors are with the Jet Propulsion Laboratory, California Institute of Technology (Caltech), Pasadena, California, USA.

Abhijit Biswas received his PhD from Southern Illinois University (Carbondale, Illinois) in molecular science in 1986. He has participated in optical communications technology development at JPL since 1992. Most recently Dr. Biswas served as the ground network systems engineer for the Mars Laser Communication Demonstration Project.

Chien-Chung Chen received his PhD from University of Illinois at Urbana-Champaign in 1987, where his dissertation was on free space optical communications. He joined JPL in 1987, and he has worked on both optical communications and deep space radio frequency (RF) systems development. He has extensive experience in both the development and operations of the deep space communications links. Dr. Chen is the principal investigator for the JPL Mars Laser Communications Demonstration Project.

Samuel J. Dolinar received his PhD in electrical engineering from the Massachusetts Institute of Technology (Cambridge, Massachusetts) in 1976, where his master's and doctoral theses were on optical communications. He worked at MIT Lincoln Laboratory, before joining JPL in 1980. Dr. Dolinar has focused his research on channel coding and source coding for the deep-space channel, especially turbo codes and low-density parity-check (LDPC) codes during the past decade. He teaches data compression at Caltech.

William H. Farr attended Caltech from 1976 through 1980, and has traversed a variety of fields including chemistry, neurobiology, electrical
engineering, and computer science, resulting in publications in seven fields. Prior to joining JPL in 2001, he worked for several engineering and high tech firms, including the Nucleonics Development Corporation, where he was head of the research and development department developing radioisotope and optical instrumentation for industrial monitoring applications, and had two patents. Mr. Farr is now the manager of JPL's Optical Communications Technology Program of the Interplanetary Network Directorate.

Andrew A. Gray received his PhD in electrical engineering in 2000, and his master of business administration (MBA) in 2004, both from the University of Southern California (Los Angeles). Prior to joining JPL in 1998, he worked at the NASA Goddard Space Flight Center for three years. He is a group supervisor in the Communications Architecture and Research Section. The primary focus of the group is development of first-to-the-world prototypes for communications and radar systems. He holds three patents. Dr. Gray is also an affiliate faculty member at the University of Washington (Seattle, Washington).

Jon Hamkins received his BS from Caltech in 1990, and PhD from the University of Illinois at Urbana-Champaign in 1996, both in electrical engineering. Dr. Hamkins has been at JPL since 1996, where he is the supervisor of the Information Processing Group, which performs research in optical communications, information theory, channel coding, data compression, and synchronization.

Hamid Hemmati received his MS in physics from the University of Southern California, and his PhD in physics from Colorado State University (Fort Collins, Colorado) in 1981. Prior to joining JPL in 1986, he worked at the NASA Goddard Space Flight Center and at the National Institute of Science and Technology (NIST, Boulder, Colorado) as a researcher. He is now the supervisor of the JPL Optical Communications Group, which is developing laser-communications technologies and systems for deep space and satellite communications. Dr. Hemmati holds seven patents. He has taught optical communications courses at the University of California at Los Angeles (UCLA) Extension.

Chi-Wung Lau received his BS in physics from the University of California at Berkeley in 1996 and his MS in electrical engineering from the University of Southern California in 2001. He has been with JPL since 1996 involved with such projects as Deep Impact, the optical array receiver, and the telecom forecaster predictor tool. Mr. Lau is currently working on applying quantum theory to communications.
Shinhak Lee received his PhD from the University of Washington in electrical engineering in 1997, and he has been with JPL since then. He has made contributions to the acquisition, tracking, and pointing technology. Dr. Lee is a member of technical staff of the Optical Communications Group in the Communications Research Section.

James R. Lesh received his PhD from the University of California at Los Angeles in electrical engineering in 1976, and he has been with JPL since 1971. He has held numerous technical and managerial positions, including head of the Optical Communications Program, and currently he is the chief technologist and manager of the Technology Program of the Interplanetary Network Directorate. He holds three patents, and he has taught classes in communications theory, information theory, channel coding, and signal processing at Caltech. Dr. Lesh is a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and of the International Society for Optical Engineering (SPIE).

Bruce E. Moision received his PhD from the University of California at San Diego in electrical engineering in 1999, and has been with JPL since 2000. He has worked primarily on the design and implementation of error correction codes and modulation schemes for optical communications links. Dr. Moision is a member of the Information Processing Group of the Communications Research Section.

Gerardo G. Ortiz received his PhD from the University of New Mexico in opto-electronic engineering in 1997, and he has been with JPL since 1987. He has made contributions to the development of high electron mobility transistor (HEMT) ultra low noise amplifiers for deep space radio frequency communications, multiple wavelength vertical cavity surface-emitting laser arrays for backbone networks, and acquisition, tracking, and pointing (ATP) technologies for free-space optical communications. Dr. Ortiz is a senior member of the staff in the Optical Communications Group.

Sabino Piazzolla received his PhD in electrical engineering from the University of Southern California in 1997. He has been at JPL since 2004, focusing on optical communications. Dr. Piazzolla is also a part-time faculty member at the University of California at Los Angeles, and at the University of Southern California.

William T. Roberts received his PhD in optical sciences from the University of Arizona in 2001. He has been with JPL since 2001. Dr. Roberts has focused his effort on development of deep-space communication lasers, flight qualification of communication terminal parts, and the conversion of
large astronomical telescopes to perform as deep-space optical communication receivers.

Meera Srinivasan received her BS from Caltech in 1990, and her PhD from the University of Illinois at Urbana-Champaign in 1996, in electrical engineering. Dr. Srinivasan has been with JPL since 1996. Her research interests lie in the areas of optical communications, wireless and spread-spectrum communications systems, array signal processing, and detection and estimation theory.

Victor A. Vilnrotter received his PhD from the University of Southern California in electrical engineering in 1978, specializing in optical communications. Dr. Vilnrotter has been at JPL since 1979, and has conducted research in the application of optical and quantum communications to the deep space optical channel, electronic compensation for deep-space RF antennas via focal-plane signal processing, optical focal-plane detector arrays to mitigate atmospheric turbulence effects, and development and demonstration of fundamental optical array receiver concepts.

Keith E. Wilson received his PhD from the University of Southern California in 1980. Before joining JPL in 1988, he worked in laser research at Hughes Research Laboratories, Allied Corporation, and Litton Guidance and Control. He was a faculty member in physics at California State Polytechnic University at Pomona. Dr. Wilson has managed JPL's successful optical communications demonstrations with spacecraft. He is a principal engineer in the Communications Architectures and Research Section at JPL.

Malcolm W. Wright received his PhD in physics from the University of New Mexico (Albuquerque, New Mexico) in 1992, and was with the Air Force Research Laboratory researching high power lasers before coming to JPL in 1998. Dr. Wright's current work has focused on developing high power fiber lasers for downlink and uplink, space qualification of semiconductor and fiber based lasers and communication performance of various free space optical link demonstrations in the lab and the field.