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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