

Satellite Quantum Communication via the Alphasat Laser Communication Terminal

Quantum signals from 36 thousand kilometers above Earth

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Abstract—By harnessing quantum effects, we nowadays can use encryption that is in principle proven to withstand any conceivable attack. These fascinating quantum features have been implemented in metropolitan quantum networks around the world. In order to interconnect such networks over long distances, optical satellite communication is the method of choice. Standard telecommunication components allow one to efficiently implement quantum communication by measuring field quadratures (continuous variables). This opens the possibility to adapt our Laser Communication Terminals (LCTs) to quantum key distribution (QKD). First satellite measurement campaigns are currently validating our approach.

Keywords—satellite quantum communication; satellite-ground laser communication; free-space optical communication; quantum key distribution; quantum cryptography

I. INTRODUCTION

The backbone of today's data communication is provided by optical fiber systems based on coherent communication [1]. Using the homodyne principle, known from radio communication, the signal is mixed with a local oscillator in order to filter out the background and detect small signals. In places where no optical fiber is installed, free space optical communication offers convenient alternative solutions. This applies especially to space optical communication, allowing for devices lighter and smaller than radio frequency links.

Tesat-Spacecom and the German Aerospace Center (DLR) have developed and successfully verified Laser Communication Terminals (LCTs) for space optical communication. LCTs of the first generation are flying on the spacecraft TerraSAR-X and NFIRE in low Earth orbit (LEO)



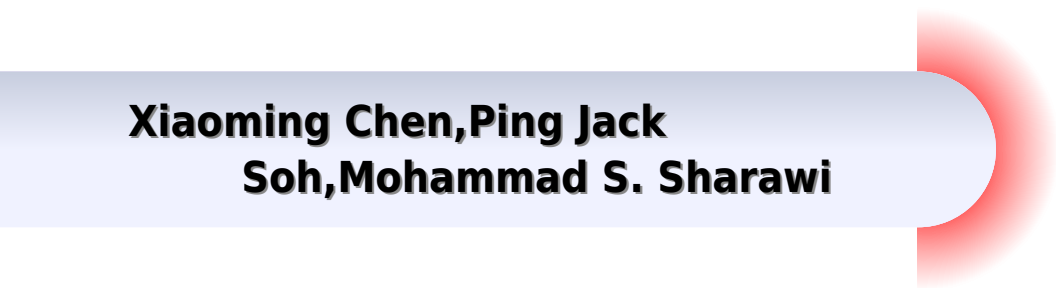
Figure 1: Alphasat I-XL is flying in geostationary Earth orbit (GEO) since 2013. The satellite carries a Laser Communication Terminal (LCT) for optical communication with satellites in low Earth orbit (LEO) and with ground stations. The LCT encodes information in a binary phase-shift keying (BPSK) alphabet using the two coherent quantum states $|\alpha\rangle$ and $|- \alpha\rangle$. Picture: ESA.

since 2007. Coherent optical communication between these LCTs has been verified in 2008 [2] and LEO-to-ground communication in 2009 [3]. The second generation of LCTs is flying on Alphasat in geostationary Earth orbit (GEO) since 2013 (see Fig. 1) and on Sentinel-1a and -2a since 2014 and 2015, respectively. GEO-LEO optical coherent communication has been verified in 2014 [4] and GEO-to-ground communication is currently being verified [5].

The Max Planck Institute for the Science of Light (MPL) in collaboration with the University of Erlangen-Nuremberg has implemented coherent (continuous-variable) quantum communication systems since 2000 [6]. In 2008, MPL has verified the feasibility of continuous-variable quantum

Satellite Quantum Communication Via The Alphasat Laser

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Satellite Quantum Communication Via The Alphasat Laser:

MIMO Antenna Systems for 5G and Beyond Xiaoming Chen, Ping Jack Soh, Mohammad S. Sharawi, 2024-09-05 Discover current design practices and performance metrics in this comprehensive guide to the latest methods of developing MIMO antenna systems Multiple input multiple output MIMO antenna systems use multiple sets of antennas to increase the capacity of a radio link or to send and receive multiple simultaneous data signals over the same radio channel It s become an increasingly integral part of wireless and mobile data networks from the earliest generations of wireless internet to cutting edge 5G systems The coming 6G networks will also rely on 6G antenna systems making it all the more critical for the next generation of engineers and antenna designers to have a firm grasp of this foundational technology MIMO Antenna Systems for 5G and Beyond offers a timely introduction to these systems and their design principles Incorporating the latest designs and a comprehensive overview of current system configurations it provides complete design procedures and performance metrics for MIMO systems The result is a one stop shop for all MIMO applications and wireless standards MIMO Antenna Systems for 5G and Beyond readers will also find The first book ever to cover MIMO design practices specific to 5G wireless communications and beyond Detailed discussion of MIMO configurations including passive reconfigurable beamforming and more Detailed illustrations and design files MIMO Antenna Systems for 5G and Beyond is ideal for practicing engineers as well as researchers in wireless and radio engineering sectors

Near-Earth Laser Communications, Second Edition

Hamid Hemmati, 2020-09-20 This reference provides an overview of near Earth laser communication theory developments including component and subsystem technologies fundamental limitations and approaches to reach those limits It covers basic concepts and state of the art technologies emphasizing device technology implementation techniques and system trades The authors discuss hardware technologies and their applications and also explore ongoing research activities and those planned for the near future This new edition includes major to minor revisions with technology updates on nearly all chapters

Optical Fiber Telecommunications VII Alan Willner, 2019-10-18 With optical fiber telecommunications firmly entrenched in the global information infrastructure a key question for the future is how deeply will optical communications penetrate and complement other forms of communication e g wireless access on premises networks interconnects and satellites Optical Fiber Telecommunications the seventh edition of the classic series that has chronicled the progress in the research and development of lightwave communications since 1979 examines present and future opportunities by presenting the latest advances on key topics such as Fiber and 5G wireless access networks Inter and intra data center communications Free space and quantum communication links Another key issue is the use of advanced photonics manufacturing and electronic signal processing to lower the cost of services and increase the system performance To address this the book covers Foundry and software capabilities for widespread user access to photonic integrated circuits Nano and microphotonic components Advanced and nonconventional data modulation formats The traditional emphasis of achieving higher data rates

and longer transmission distances are also addressed through chapters on space division multiplexing undersea cable systems and efficient reconfigurable networking This book is intended as an ideal reference suitable for university and industry researchers graduate students optical systems implementers network operators managers and investors Quotes This book series which owes much of its distinguished history to the late Drs Kaminow and Li describes hot and growing applied topics which include long distance and wideband systems data centers 5G wireless networks foundry production of photonic integrated circuits quantum communications and AI deep learning These subjects will be highly beneficial for industrial R D engineers university teachers and students and funding agents in the business sector Prof Kenichi Iga President Retired Tokyo Institute of Technology With the passing of two luminaries Ivan Kaminow and Tingye Li I feared the loss of one of the premier reference books in the field Happily this new version comes to chronicle the current state of the art and is written by the next generation of leaders This is a must have reference book for anyone working in or trying to understand the field of optical fiber communications technology Dr Donald B Keck Vice President Corning Inc Retired This book is the seventh edition in the definitive series that was previously marshaled by the extraordinary Ivan Kaminow and Tingye Li both sadly no longer with us The series has charted the remarkable progress made in the field and over a billion kilometers of optical fiber currently snake across the globe carrying ever increasing Internet traffic Anyone wondering about how we will cope with this incredible growth must read this book Prof Sir David Payne Director Optoelectronics Research Centre University of Southampton

Springer Handbook of Optical Networks Biswanath Mukherjee, Ioannis Tomkos, Massimo Tornatore, Peter Winzer, Yongli Zhao, 2020-10-15 This handbook is an authoritative comprehensive reference on optical networks the backbone of today's communication and information society The book reviews the many underlying technologies that enable the global optical communications infrastructure but also explains current research trends targeted towards continued capacity scaling and enhanced networking flexibility in support of an unabated traffic growth fueled by ever emerging new applications The book is divided into four parts Optical Subsystems for Transmission and Switching Core Networks Datacenter and Super Computer Networking and Optical Access and Wireless Networks Each chapter is written by world renown experts that represent academia industry and international government and regulatory agencies Every chapter provides a complete picture of its field from entry level information to a snapshot of the respective state of the art technologies to emerging research trends providing something useful for the novice who wants to get familiar with the field to the expert who wants to get a concise view of future trends

[Optical Wireless Communications for Broadband Global Internet Connectivity](#) Arun K. Majumdar, 2018-10-19 Optical Wireless Communications for Broadband Global Internet Connectivity Fundamental and Potential Applications provides a comprehensive overview for readers who require information about the fundamental science behind optical wireless communications as well as up to date advanced knowledge of the state of the art technologies available today The book is a useful resource for scientists researchers

engineers and students interested in understanding optical wireless communication systems for global channels Readers will find beneficial knowledge on how related technologies of optical wireless communications can be integrated into achieving worldwide Internet connectivity Presents an in depth coverage of information on optical wireless communication in a single source Combines the fundamentals with the most recent advanced technology of achieving global Internet access and connectivity Provides derivations of the mathematical equations Includes between chapter sections where information and learning from one chapter is connected to other chapters

Bulletin Agence Spatiale Européenne European Space Agency,2007

Handbook of Optoelectronics John P. Dakin,Robert G. W. Brown,2017-10-05 Handbook of Optoelectronics offers a self contained reference from the basic science and light sources to devices and modern applications across the entire spectrum of disciplines utilizing optoelectronic technologies This second edition gives a complete update of the original work with a focus on systems and applications Volume I covers the details of optoelectronic devices and techniques including semiconductor lasers optical detectors and receivers optical fiber devices modulators amplifiers integrated optics LEDs and engineered optical materials with brand new chapters on silicon photonics nanophotonics and graphene optoelectronics Volume II addresses the underlying system technologies enabling state of the art communications imaging displays sensing data processing energy conversion and actuation Volume III is brand new to this edition focusing on applications in infrastructure transport security surveillance environmental monitoring military industrial oil and gas energy generation and distribution medicine and free space No other resource in the field comes close to its breadth and depth with contributions from leading industrial and academic institutions around the world Whether used as a reference research tool or broad based introduction to the field the Handbook offers everything you need to get started John P Dakin PhD is professor emeritus at the Optoelectronics Research Centre University of Southampton UK Robert G W Brown PhD is chief executive officer of the American Institute of Physics and an adjunct full professor in the Beckman Laser Institute and Medical Clinic at the University of California Irvine

Greek Space Law Anthi Koskina,Manolis Plionis,2025-02-25 This book provides an overview of the Greek legislation applying to space activity under the responsibility of the Greek State as in line with international space law Greece is not an established space faring country however it is showing particular dynamism making the most of its participation in international and EU space endeavors Indeed along with outstanding achievements in space science Greece took legislative action both at the international and national levels proposals at the UNCOPUOS Greek space law signing of the Artemis Accords Hence the time has come to refer to and present aspects of the Greek space legislation After an introductory section the book provides information first on the national laws providing for the Greek participation in international space systems and in EU activities which could be regarded as being the initial steps of Greece in the context of space Thereafter the rules applying to Greek space activity per se are presented focusing on the authorities competent to decide on space matters then on the substantial law rules allowing for and clarifying the application

of international space law to domestic space operations This book presents an overall view and analysis of the Greek space legislation adding valuable information to the existing bibliography Included as an appendix is a scholarly translation of the 2017 Greek space law *Laser Communication with Constellation Satellites, UAVs, HAPs and Balloons* Arun K.

Majumdar,2022-06-24 This book presents posits a solution to the current limitations in global connectivity by introducing a global laser optical communication system using constellation satellites UAVs HAPs and Balloons The author outlines how this will help to satisfy the tremendous increasing demand for data exchange and information between end users worldwide including in remote locations The book provides both fundamentals and the advanced technology development in establishing worldwide communication and global connectivity using I All Optical technology and ii Laser Optical Communication Constellation Satellites of different types sizes and at different orbits UAVs HAPs High Altitude Platforms and Balloons The book discusses step by step methods to develop a satellite backbone in order to interconnect a number of ground nodes clustered within a few SD WAN software defined networking in a wide area network WAN around the world in order to provide a fully meshed communication network This book pertains to anyone in optical communications telecommunications and system engineers as well as technical managers in the aerospace industry and the graduate students and researchers in academia and research laboratory Proposed a solution to the limitations in global connectivity through a global laser optical communication system using constellation satellites UAVs HAPs and Balloons Provides both fundamentals and the advanced technology development in establishing global communication connectivity using optical technology and communication constellation satellites Includes in depth coverage of the basics of laser optical communication constellation satellites

Near-Earth Laser Communications Hamid Hemmati,2018-10-03 Invented more than a hundred years ago by Alexander Graham Bell the technology of free space optical communications or lasercom has finally reached the level of maturity required to meet a growing demand for operational multi giga bit per second data rate systems communicating to and from aircrafts and satellites Putting the emphasis on near earth links including air LEO MEO and GEO orbits Near Earth Laser Communications presents a summary of important free space laser communication subsystem challenges and discusses potential ways to overcome them This comprehensive reference provides up to date information on component and subsystem technologies fundamental limitations and approaches to reach those limits It covers basic concepts and state of the art technologies emphasizing device technology implementation techniques and system trades The authors discuss hardware technologies and their applications and also explore ongoing research activities and those planned for the near future The analytical aspects of laser communication have been covered to a great extent in several books However a detailed approach to system design and development including trades on subsystem choices and implications of the hardware selection for satellite and aircraft telecommunications is missing Highlighting key design variations and critical differences between them this book distills decades worth of experience into a practical resource on hardware technologies **Satellite**

Signals SREEKUMAR V T,2025-02-20 Embark on an enlightening journey through the cosmic realms of Satellite Signals Navigating the World of Satellite Communication This comprehensive book is a testament to the intricate web of technology innovation and connectivity that envelops our world and extends into the far reaches of the cosmos Explore the rich tapestry of satellite communication from its historical roots to the cutting edge technologies that propel it into the future Delve into the complexities of satellite orbits signal propagation and the diverse frequency bands that form the backbone of our interconnected global communication network The chapters unfold like a cosmic odyssey guiding readers through the nuances of orbital mechanics the challenges of interference mitigation and the fascinating world of satellite payloads Gain insights into the design and deployment of antenna systems modulation techniques and the critical elements that ensure efficient signal transmission in the vast expanse of space The book goes beyond the technical aspects offering a deep dive into the critical infrastructure of Earth stations and the meticulous link budget analysis that optimizes satellite communication performance Readers will discover the instrumental role of satellites in our everyday lives from telecommunications and broadcasting to weather monitoring and military operations Venture into the future of satellite communication with dedicated chapters on emerging technologies including quantum communication artificial intelligence and laser communication in space Uncover the transformative potential of interconnected satellite constellations software defined satellite networks and the secure communication methods that fortify against evolving threats Satellite communication extends its reach into space exploration providing the backbone for real time communication with spacecraft exploring distant planets The book explores the role of satellites in lunar and planetary exploration deep space communication and the exciting prospect of an interplanetary internet The narrative unfolds with a vision of a connected cosmos where global connectivity initiatives bridge the digital divide and space based Internet of Things IoT devices contribute to Earth observation smart agriculture and maritime tracking Authored by experts in the field Satellite Signals Navigating the World of Satellite Communication is not just a book it s a guide to understanding the intricate dance of signals that traverse the celestial pathways Whether you re a seasoned professional in the satellite industry a student eager to explore the depths of space communication or an enthusiast fascinated by the wonders of technology this book offers a captivating journey into the heart of satellite signals Prepare to be captivated by the revelations challenges and possibilities that define the ever evolving landscape of satellite communication Satellite Signals is your passport to navigating the cosmos of possibilities in the realm where innovation connectivity and the wonders of space converge Laser Satellite Communications Morris Katzman,1987 *Laser Satellite Communication* William H. Mott IV,Robert Sheldon,2000-01-30 This introduction to the next generation of human telecommunications enterprise examines the development of laser satellite communications and describes its advantages over previous technologies It looks at the development of the technology and the industry through wired and wireless media and presents the vision promise and challenges of free space lasers The book

balances its focused consideration of the telecommunications industry and markets with practical thoughts on creating a business involved in the introduction of commercial laser satellite communications systems. Scholars, investors, venture capitalists, policy makers, and corporate leaders will find this to be a comprehensive and eye-opening bridge between the existing telecommunications industry and the opportunities of the next generation. The opening chapters introduce the concepts of Migration, Specialization, and Interconnectivity as solutions inherent in third-generation laser satellite communications. The high capacity of the optical spectrum invites migration of applications beyond the narrow RF spectra to the high frequencies of free space laser beams. Migration stimulates specialization of voice and duplex at the lower optimal RF spectra. The third-generation laser wired space focuses around global satellite interconnectivity between fiber optics and RF. The final chapters introduce a model business concept to pioneer the third generation. Several approaches to capitalization, organization, technology development, and business strategies provide an exciting stimulus for pragmatic approaches to commercial concepts.

Laser Space Communications David G. Aviv, 2006. This groundbreaking resource is the first book to offer you a thorough practical treatment of laser space communications. The book focuses on the feasibility of laser space communication links between satellites, satellites and airborne platforms, and satellites and ground-based stations to achieve worldwide connectivity. You get expert guidance on weather avoidance approaches and adaptive antenna subsystems that help mitigate the effects of turbulence. The book presents simplified yet highly accurate engineering expressions of complex mathematics of turbulence that provide you with numerical values in the links signal power budget. Moreover, you find an entire chapter devoted to noise photons and their effect on the bit error rate. This comprehensive volume covers a wide range of critical topics you need to understand for your work in the field: from a discussion on laser vs RF communications in space, basic design features of a laser transceiver, and configuration of inter-satellite communication links to selection of ground station locations, 5th Generation Internet (5G) and signal modulation schemes. The book is supported with over 70 illustrations and more than 100 equations.

Satellite Network Leo Musk, AI, 2024-10-26. *Satellite Network* provides a comprehensive exploration of Starlink's revolutionary satellite constellation project, examining how this ambitious venture aims to transform global internet connectivity through a network of thousands of low Earth orbit satellites. The book skillfully breaks down the three core components of the system: the satellite constellation architecture, ground station infrastructure, and end-user technology, presenting complex technical concepts in an accessible manner. The narrative begins with a historical foundation of satellite communications from the 1960s, before diving into Starlink's innovative approach, particularly its use of LEO deployment and inter-satellite laser communications. Through detailed technical specifications and real-world performance data from beta testing programs, readers gain insights into how this massive network operates, including crucial aspects like collision avoidance systems and signal latency management. The book's analysis is supported by extensive research from aerospace engineers, telecommunications experts, and regulatory

documentation What sets this work apart is its interdisciplinary approach connecting aerospace engineering with telecommunications technology while addressing critical challenges like space debris management and astronomical observation interference The book progresses logically through technical architecture ground infrastructure requirements and broader implications for global connectivity making it an invaluable resource for both industry professionals and educated general readers interested in the future of space based communications Its evidence based analysis of practical applications from disaster response to maritime connectivity provides a solid foundation for understanding this transformative technology

Satellite-Based Quantum Communications, 2010 Single photon quantum communications QC offers the attractive feature of future proof forward security rooted in the laws of quantum physics Ground based quantum key distribution QKD experiments in optical fiber have attained transmission ranges in excess of 200km but for larger distances we proposed a methodology for satellite based QC Over the past decade we have devised solutions to the technical challenges to satellite to ground QC and we now have a clear concept for how space based QC could be performed and potentially utilized within a trusted QKD network architecture Functioning as a trusted QKD node a QC satellite QC sat could deliver secret keys to the key stores of ground based trusted QKD network nodes to each of which multiple users are connected by optical fiber or free space QC A QC sat could thereby extend quantum secured connectivity to geographically disjoint domains separated by continental or inter continental distances In this paper we describe our system concept that makes QC feasible with low earth orbit LEO QC sats 200 km 2 000 km altitude orbits and the results of link modeling of expected performance Using the architecture that we have developed LEO satellite to ground QKD will be feasible with secret bit yields of several hundred 256 bit AES keys per contact With multiple ground sites separated by 100km mitigation of cloudiness over any single ground site would be possible potentially allowing multiple contact opportunities each day The essential next step is an experimental QC sat A number of LEO platforms would be suitable ranging from a dedicated three axis stabilized small satellite to a secondary experiment on an imaging satellite to the ISS With one or more QC sats low latency quantum secured communications could then be provided to ground based users on a global scale Air to ground QC would also be possible

Laser Satellite Communication William H. Mott, 2000 *Quantum Communication: The Physical Layer Of Future Optical Networks* Mahdi Hosseini, 2023-06-15 This book is the second volume in the series New Era Electronics a compilation of lecture notes defining the important concepts tied to the electronics transition happening in the 21st century Quantum communication is introduced in this volume through the coverage of relevant basic concepts of quantum mechanics and the introduction of quantum elements of a quantum optical communication system Also included is a quantum description of electromagnetic fields and its interaction with atoms to generate store measure and control quantum optical information encoded onto optical fields By taking a conceptual and less mathematical approach to quantum optics and quantum information this book becomes accessible to broader audiences and engineers working actively in the technical field

The reader is only required to have a basic understanding of undergraduate linear algebra

*Quantum Communication for Satellite-to-ground Networks with Partially Entangled States**Project Supported by the National Natural Science Foundation of China (Grant Nos. 61072067 and 61372076), the 111 Project (Grant No. B08038), the Fund from the State Key Laboratory of Integrated Services Networks (Grant No. ISN 1001004), and the Fundamental Research Funds for the Central Universities (Grant Nos. K5051301059 and K5051201021).

2015 Abstract To realize practical wide area quantum communication a satellite to ground network with partially entangled states is developed in this paper For efficiency and security reasons the existing method of quantum communication in distributed wireless quantum networks with partially entangled states cannot be applied directly to the proposed quantum network Based on this point an efficient and secure quantum communication scheme with partially entangled states is presented In our scheme the source node performs teleportation only after an end to end entangled state has been established by entanglement swapping with partially entangled states Thus the security of quantum communication is guaranteed The destination node recovers the transmitted quantum bit with the help of an auxiliary quantum bit and specially defined unitary matrices Detailed calculations and simulation analyses show that the probability of successfully transferring a quantum bit in the presented scheme is high In addition the auxiliary quantum bit provides a heralded mechanism for successful communication Based on the critical components that are presented in this article an efficient secure and practical wide area quantum communication can be achieved

A Laser Communication Experiment Utilizing the ACT Satellite and an Airborne Laser Transceiver National Aeronautics and Space Administration, 2018-10-23 The launch of a laser communication transmitter package into geosynchronous Earth orbit onboard the Advanced Communications Technology Satellite ACTS will present an excellent opportunity for the experimental reception of laser communication signals transmitted from a space orbit The ACTS laser package includes both a heterodyne transmitter Lincoln Labs design and a direct detection transmitter Goddard Space Flight Center design with both sharing some common optical components NASA Lewis Research Center's Space Electronics Division is planning to perform a space communication experiment utilizing the GSFC direct detection laser transceiver The laser receiver will be installed within an aircraft provided with a glass port for the reception of the signal This paper describes the experiment and the approach to performing such an experiment Described are the constraints placed on the NASA Lewis experiment by the performance parameters of the laser transmitter and by the ACTS spacecraft operations The conceptual design of the receiving terminal is given also included is the anticipated capability of the detector Provencher Charles E Jr and Spence Rodney L Glenn Research Center RTOP 650 60 23

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Satellite Quantum Communication Via The Alphasat Laser Introduction

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