ICSO 2016

International Conference on Space Optics

Biarritz, France

18–21 October 2016

Edited by Bruno Cugny, Nikos Karafolas and Zoran Sodnik

***Quantum measurements of signals from the Alphasat TDP1
laser communication terminal***

D. Elser

K. Günthner

I. Khan

B. Stiller

et al.

International Conference on Space Optics — ICSO 2016, edited by Bruno Cugny, Nikos Karafolas,
Zoran Sodnik, Proc. of SPIE Vol. 10562, 105623O · © 2016 ESA and CNES
CCC code: 0277-786X/17/\$18 · doi: 10.1117/12.2296184

Proc. of SPIE Vol. 10562 105623O-1

QUANTUM MEASUREMENTS OF SIGNALS FROM THE ALPHASAT TDP1 LASER COMMUNICATION TERMINAL

D. Elser^{1,2,*}, K. Günthner^{1,2}, I. Khan^{1,2}, B. Stiller^{1,2,§}, Ö. Bayraktar^{1,2}, C. R. Müller^{1,2}, K. Saucke³, D. Tröndle³,
F. Heine³, S. Seel³, P. Greulich³, H. Zech³, B. Gütlisch⁴, I. Richter⁴, S. Philipp-May⁴, Ch. Marquardt^{1,2},
and G. Leuchs^{1,2}.

¹Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1/ Bldg. 24, 91058 Erlangen, Germany

²Institute of Optics, Information and Photonics, Friedrich-Alexander University Erlangen-Nürnberg (FAU),
Staudtstr. 7/B2, 91058 Erlangen, Germany.

³Tesat-Spacecom GmbH & Co. KG, Gerberstr. 49, 71522 Backnang, Germany.

⁴German Aerospace Center (DLR), Space Administration, Königswinterer Str. 522-524, 53227 Bonn, Germany.

*Dominique.Elser@mpl.mpg.de

I. INTRODUCTION

Quantum optics [1] can be harnessed to implement cryptographic protocols that are verifiably immune against any conceivable attack [2]. Even quantum computers, that will break most current public keys [3, 4], cannot harm quantum encryption. Based on these intriguing quantum features, metropolitan quantum networks have been implemented around the world [5-15]. However, the long-haul link between metropolitan networks is currently missing [16]. Existing fiber infrastructure is not suitable for this purpose since classical telecom repeaters cannot relay quantum states [2]. Therefore, optical satellite-to-ground communication [17-22] lends itself to bridge intercontinental distances for quantum communication [23-40].

Fig. 1. Free space continuous variable quantum link between the new building of the Max Planck Institute for the Science of Light (sender) and the computer science tower of the Friedrich-Alexander University Erlangen (receiver). (Picture of Erlangen: Google)

§ Now at the University of Sydney, School of Physics, NSW 2006, Australia.

A. Laser Communication Terminal for Quantum Key Distribution

A space borne Laser Communication Terminal (LCT) is capable to relay quantum key distribution (QKD) between a large number of hubs on ground. In contrast to other satellite-to-ground communication scenarios, QKD does not require real-time availability. Keys can be produced at any convenient time in advance and stored until used.

B. Continuous Variable Quantum Communication

Standard telecommunication components allow for an efficient implementation of quantum communication using continuous variables (CV) of light [41-45]. MPL Erlangen implements free space CV quantum communication (see Fig. 1) based on binary phase-shift keying of coherent states and homodyne detection of the optical field quadratures [46-50]. This operating principle is equal to the one of the TESAT/DLR LCTs [51-53]. Therefore, we have a unique shortcut to implement space borne quantum communication at lower cost than other ambitious programs around the world.

Fig. 2. Space-to-ground link setup: A Laser Communication Terminal (LCT) is embarked as Technology Demonstration Payload (TDP) on Alphasat in geostationary Earth orbit (GEO). The LCT links to the Transportable Adaptive Optical Ground Station (TAOGS), currently located at the Teide Observatory on Tenerife, Spain. By using homodyne detection for quantum signal acquisition, daylight operation is possible without any constraints. (Picture of Alphasat: ESA)

III. QKD FEASIBILITY VERIFICATION

We have tested the feasibility of this proposal by quantum-limited measurements of signals from the Alphasat TDP1 LCT in geostationary Earth orbit (GEO). The Transportable Adaptive Optical Ground Station (TAOGS) [54, 21], currently located at the Teide observatory on Tenerife, is capable of establishing bi-directional communication links with the Alphasat TDP1 LCT (see Fig. 2). We utilize the downlink by extending the TAOGS with equipment for quantum-limited measurements. Our measurement results [55] show that coherence is well preserved after propagation over more than 38 000 km and through Earth's atmosphere. By using a low-noise phase-locking mechanism based on homodyne detection, phase-encoded quantum communication protocols become feasible.

III. CONCLUSION

Our results underpin the feasibility of satellite quantum communication using existing hardware. In order to optimize the system for quantum communication, our next step is the adaptation of the sender and receiver for applied QKD. Furthermore, on the fundamental research side, the large gravitational potential difference between GEO and ground allows to investigate gravitational effects on quantum states [56-60].

Acknowledgements

The Laser Communication Terminal (LCT) and the Transportable Adaptive Optical Ground Station (TAOGS) are supported by the German Aerospace Center (DLR) Space Administration, with funds from the Federal Ministry for Economic Affairs and Energy according to a decision of the German Federal Parliament. We thank our colleagues at the FAU computer science building for hosting our receiver setup and Zoran Sodnik for hosting the TAOGS next to the ESA Optical Ground Station (OGS) on Tenerife.

REFERENCES

- [1] C. Gerry and P. Knight, *Introductory Quantum Optics*, Cambridge University Press, 2005.
- [2] V. Scarani et al., "The security of practical quantum key distribution," *Rev. Mod. Phys.* **81**, 1301 (2009).
- [3] "Quantum safe cryptography and security; an introduction, benefits, enablers and challenges." European Telecommunications Standards Institute (2014). ISBN 979-10-92620-03-0.
- [4] M. Mosca, "Cybersecurity in an era with quantum computers: will we be ready?," *Cryptology ePrint Archive*, Report 2015/1075 (2015).
- [5] A. Poppe et al., "Practical quantum key distribution with polarization entangled photons," *Opt. Express* **12**, 3865 (2004).
- [6] C. Elliott et al., "Current status of the DARPA quantum network," *Proc. SPIE* **5815**, 138 (2005).
- [7] P. Marks, "Quantum cryptography to protect Swiss election," *New Scientist Daily News*, 15 October 2007.
- [8] W. Chen et al., "Field experiment on a 'star type' metropolitan quantum key distribution network," *IEEE Photon. Technol. Lett.* **21**(9), 575 (2009).
- [9] M. Peev et al., "The SECOQC quantum key distribution network in Vienna," *New J. Phys.* **11**, 075001 (2009).
- [10] A. Mirza and F. Petruccione, "Realizing long-term quantum cryptography," *J. Opt. Soc. Am. B* **27**, A185 (2010).
- [11] M. Sasaki et al., "Field test of quantum key distribution in the Tokyo QKD Network," *Opt. Express* **19**, 10387 (2011).
- [12] R.J. Hughes et al., "Network-centric quantum communications with application to critical infrastructure protection," *Proc. QCrypt 2013*, Waterloo, Canada (2013).
- [13] M. LaMonica, "Long-distance quantum cryptography – A hybrid system could secure transmissions over hundreds of kilometres," *IEEE Spectrum*, 23 Jul 2013.
- [14] N. Walenta et al., "A certifiable trusted node QKD network," *Proc. QCrypt 2014*, Tokyo, Japan (2014).
- [15] M. Fujiwara et al., "Unbreakable distributed storage with quantum key distribution network and password-authenticated secret sharing," *Sci. Rep.* **6**, 28988 (2016).
- [16] T. Jennewein and B. Higgins "The quantum space race," *Phys. World* **26**, 52 (2013).
- [17] Y. Arimoto et al., "Preliminary result on laser communication experiment using (ETS-VI)," *Proc. SPIE* **2381**, 151 (1995).
- [18] R. Fields et al., "5.625 Gbps bidirectional laser communications measurements between the NFIRE satellite and an optical ground station," *Proc. IEEE International Conference on Space Optical Systems and Applications (ICSOS) 2011*, p. 44, Santa Monica, CA, U.S.A., May 11–13 (2011).

- [19] D.M. Boroson et al., "Overview and results of the lunar laser communication demonstration," Proc. SPIE **8971**, 89710S (2014).
- [20] A. Biswas et al., "Optical Payload for Lasercomm Science (OPALS) link validation during operations from the ISS," Proc. SPIE **9354**, 93540F (2015).
- [21] M. Toyoshima et al., "Current status of research and development on space laser communications technologies and future plans in NICT," Proc. IEEE International Conference on Space Optical Systems and Applications (ICSOS) 2015, New Orleans, LA, U.S.A., October 27–28 (2015).
- [22] K. Saucke et al., "The Tesat transportable adaptive optical ground station," Proc. SPIE **9739**, 973906 (2016).
- [23] J.G. Rarity, P.R. Tapster, P.M. Gorman, and P. Knight, "Ground to satellite secure key exchange using quantum cryptography," New J. Phys. **4**, 82 (2002).
- [24] P. Villoresi et al., "Experimental verification of the feasibility of a quantum channel between space and Earth," New J. Phys. **10**, 033038 (2008).
- [25] R. Ursin et al., "Space-QUEST: Experiments with quantum entanglement in space," Europhysics News **40**, 26 (2009).
- [26] D. Elser et al., "Network architectures for space-optical quantum cryptography services – Introduction of quantum communications in satellite communication networks," Proc. International Conference on Space Optical Systems and Applications (ICSOS) 2012, Post-1, Ajaccio, Corsica, France, October 9–12 (2012).
- [27] T. Jennewein and B. Higgins, "The quantum space race," Phys. World **26**, 52 (2013).
- [28] T. Scheidl, E. Wille, and R. Ursin, "Quantum optics experiments using the International Space Station: a proposal" New J. Phys. **15**, 043008 (2013).
- [29] J. Yin et al., "Experimental quasi-single-photon transmission from satellite to earth," Opt. Express **21**, 20032 (2013).
- [30] L. Bacsardi, "On the way to quantum-based satellite communication," IEEE Commun. Mag. **51**, 50 (2013).
- [31] J.W. Pan, "Quantum science satellite," Chinese Journal of Space Science **34**, 547 (2014).
- [32] D. Elser et al., "Satellite Quantum Communication via the Alphasat Laser Communication Terminal – Quantum signals from 36 thousand kilometers above Earth," Proc. IEEE International Conference on Space Optical Systems and Applications (ICSOS) 2015, New Orleans, LA, U.S.A., October 27–28 (2015).
- [33] J.-P. Bourgoin et al., "Experimental quantum key distribution with simulated ground-to-satellite photon losses and processing limitations," Phys. Rev. A **92**, 052339 (2015).
- [34] M. Leifgen et al., "Practical implementation and evaluation of a quantum-key-distribution scheme based on the time-frequency uncertainty," Phys. Rev. A **92**, 042311 (2015).
- [35] T. Graham et al., "Superdense teleportation and quantum key distribution for space applications," Proc. IEEE International Conference on Space Optical Systems and Applications (ICSOS) 2015, New Orleans, LA, U.S.A., October 27–28 (2015).
- [36] N. Hosseini-dehaj and R. Malaney, "Gaussian entanglement distribution via satellite," Phys. Rev. A **91**, 022304 (2015).
- [37] M.T. Gruneisen et al., "Adaptive spatial filtering of daytime sky noise in a satellite quantum key distribution downlink receiver," Opt. Eng. **55**, 026104 (2016).
- [38] Z. Tang et al., "Generation and analysis of correlated pairs of photons aboard a nanosatellite," Phys. Rev. Applied **5**, 054022 (2016).
- [39] D. Dequal et al., "Experimental single-photon exchange along a space link of 7000 km," Phys. Rev. A **93**, 010301 (2016).
- [40] A. Carrasco-Casado et al., "LEO-to-ground polarization measurements aiming for space QKD using small optical transponder (SOTA)," Opt. Express **24**, 12254 (2016).
- [41] T.C. Ralph, "Continuous variable quantum cryptography," Phys. Rev. A **61**, 010303 (1999).
- [42] F. Grosshans and P. Grangier, "Continuous variable quantum cryptography using coherent states," Phys. Rev. Lett. **88**, 057902 (2002).
- [43] Ch. Silberhorn, T.C. Ralph, N. Lütkenhaus, and G. Leuchs, "Continuous variable quantum cryptography: Beating the 3 dB loss limit," Phys. Rev. Lett. **89**, 167901 (2002).
- [44] C. Weedbrook et al., "Quantum cryptography without switching," Phys. Rev. Lett. **93**, 170504 (2004).
- [45] P. Jouguet, S. Kunz-Jacques, A. Leverrier, P. Grangier, and E. Diamanti, "Experimental demonstration of long-distance continuous-variable quantum key distribution," Nat. Photon. **7**, 378 (2013).
- [46] S. Lorenz, N. Korolkova, and G. Leuchs, "Continuous-variable quantum key distribution using polarization encoding and post selection," Appl. Phys. B **79**, 273 (2004).
- [47] S. Lorenz et al., "Witnessing effective entanglement in a continuous variable prepare-and-measure setup and application to a quantum key distribution scheme using postselection," Phys. Rev. A **74**, 042326 (2006).

- [48] D. Elser et al., "Feasibility of free space quantum key distribution with coherent polarization states," *New J. Phys.* **11**, 045014 (2009).
- [49] B. Heim, C. Peuntinger, et al., "Atmospheric continuous-variable quantum communication," *New J. Phys.* **16**, 113018 (2014).
- [50] C. Peuntinger et al., "Distribution of squeezed states through an atmospheric channel," *Phys. Rev. Lett.* **113**, 060502 (2014).
- [51] B. Smutny et al., "5.6 Gbps optical intersatellite communication link," *Proc. SPIE* **7199**, 719906 (2009).
- [52] F. Heine et al., "LCT for the European data relay system: in orbit commissioning of the Alphasat and Sentinel 1A LCTs," *Proc. SPIE* **9354**, 93540G (2015).
- [53] H. Zech et al., "LCT for EDRS: LEO to GEO optical communications at 1.8 Gbps between Alphasat and Sentinel 1a," *Proc. SPIE* **9647**, 96470J (2015).
- [54] E. Fischer et al., "Development, integration and test of a transportable adaptive optical ground station," *Proc. IEEE International Conference on Space Optical Systems and Applications (ICSOS) 2015*, New Orleans, LA, U.S.A., October 27–28 (2015).
- [55] K. Günthner, I. Khan, et al., "Quantum-limited measurements of optical signals from a geostationary satellite," *arXiv:1608.03511 [quant-ph]*, 11 August 2016.
- [56] R. Plaga, "A fundamental threat to quantum cryptography: gravitational attacks," *Eur. Phys. J.* **38**, 409 (2006).
- [57] D. Rideout et al., "Fundamental quantum optics experiments conceivable with satellites – reaching relativistic distances and velocities," *Class. Quantum Grav.* **29**, 224011 (2012).
- [58] T.C. Ralph and J. Pienaar, "Entanglement decoherence in a gravitational well according to the event formalism," *New J. Phys.* **16**, 085008 (2014).
- [59] D.E. Bruschi, T.C. Ralph, I. Fuentes, T. Jennewein, and M. Razavi, "Spacetime effects on satellite-based quantum Communications," *Phys. Rev. D* **90**, 045041 (2014).
- [60] G. Vallone et al., "Interference at the single photon level along satellite-ground channels," *Phys. Rev. Lett.* **116**, 253601 (2016).