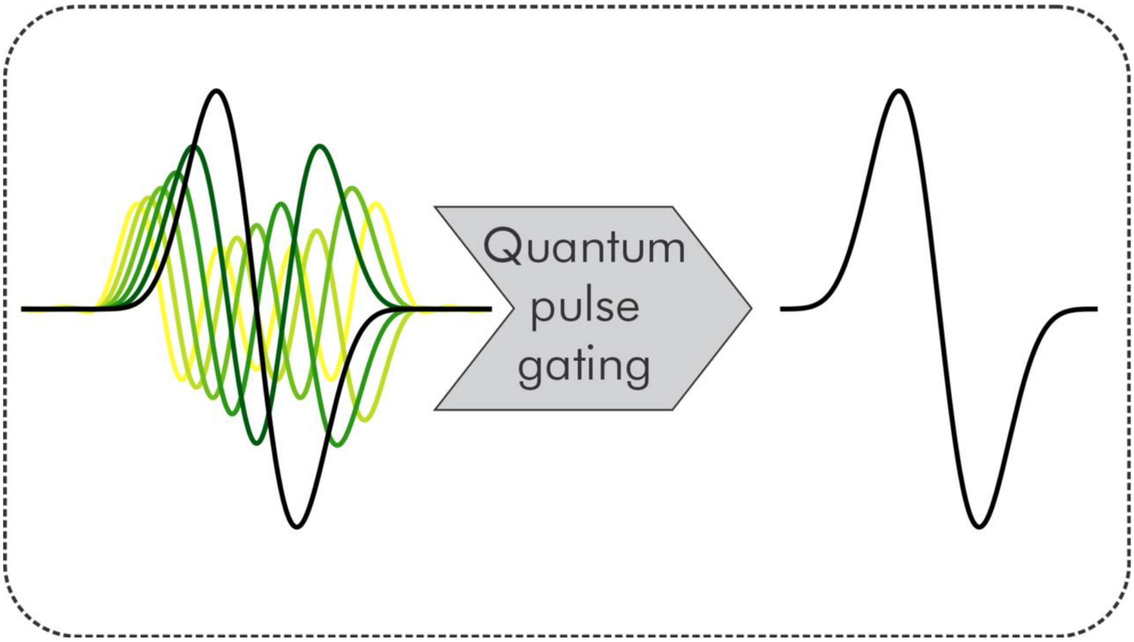

NOISE REJECTION IN OPTICAL COMMUNICATION SYSTEMS USING QUANTUM PULSE GATING

Executive summary

Study

Open Discovery Ideas Channel

Affiliations: Quantum Optical Technologies sp. z o.o. (Prime), Paderborn University (Sub)

Activity summary:

The feasibility and performance of the quantum pulse gate technique for noise rejection in optical communication systems is analysed and found to be promising for free-space optical link enhancement, both in classical and quantum communication. We verify that QPGs could significantly increase data rates available during daytime communication with space missions, as well as vastly extend the range of quantum key distribution links. The idea is ready for a laboratory proof-of-concept demonstrations, for which we propose the best approaches.

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Introduction

This activity analyses the feasibility and performance of the quantum pulse gate (QPG) technique for noise rejection in optical communication systems. The optical frequency band is expected to play an increasingly important role in space communications due to a substantial increase in available data rates with respect to radio transmission, as well as enhanced information security. The main limiting factor for the performance of an optical link is the background noise collected by the receiver, especially when operated at low signal powers, e.g. in the photon-starved regime typical to deep-space communication and quantum key distribution protocols with single photons.

The conventional technique of narrowband spectral filtering of the received signal followed by temporal gating does not allow one to select in a lossless manner the signal mode from the remaining background noise. On the other hand, the recently demonstrated quantum pulse gate technique allows for genuine single-mode filtering, accomplished by carefully engineered sum-frequency generation in a $\chi^{(2)}$ nonlinear optical medium. In the context of communication, the technique may then be used to separate the single information-carrying mode of a received signal beam from the remaining modes containing only unwanted noise. The activity report presents a careful consideration of this prospect, in which we conclude the noise reduction capabilities of the QPG to be promising for free-space optical link enhancement.

Key Findings

During the activity, we first reviewed the current free-space optical communication industry standards with which a hypothetical QPG-enhanced architecture should comply. For power-efficient communication, the spaceborne mission transceiver beams downlink information by generating short pulses and placing them within frames of the PPM format. Next, we examined the theory of the QPG and its state-of-the-art laboratory demonstrations. Importantly, we have identified the main limiting factor to be the inherent noise added by the operation of the QPG. To enhance the link with noise suppression by QPG at the output, the generated pulses need to have carefully chosen characteristic. Additionally, the temporal profile of the PPM transceiver pulses must match the temporal profile of the QPG pump pulses.

Next, we investigated the advantage that can be expected from QPG adoption in classical and quantum communication. In the former case we found that while attaining similar performance to conventional filtering at nighttime, QPGs could significantly increase data rates available during daytime communication with space missions, or actually enable it at all. For the latter case, exemplified by quantum key distribution, we determined that at daytime the range of such links could be vastly extended, while at nighttime it would also be possible, provided that experimental improvement limits further the noise added to the channel by the QPG.

We also proposed system specifications for an experimental proof-of-concept validation of the QPG noise rejection idea, and additionally delineated the current development status of a QPG that operates fully in the telecom band and would warrant the easiest integration into existing infrastructure. The activity was concluded with an assessment of the Technology Readiness Level 3 of QPG-enhanced optical communication, a roadmap for further development of the idea and proposed risk mitigation strategies.

Future Work

We suggest to move forward with the development of the QPG noise suppression idea by constructing a laboratory demonstration that operates a QPG setup with the state-of-the-art waveguides that manufactured by the activity subcontractors from Paderborn University. The prime contractor Quantum Optical Technologies sp. z o.o. possesses a robust implementation of error correction PPM codes, flexible for adaptation to various link conditions, as well as extensive experience in modelling and simulations of information transmissions over free space optical channels, making it an ideal candidate for further implementation of the proposed idea.