ALTER TECHNOLOGY TÜV NORD

DEVELOPMENT OF A QUANTUM OPTICAL TRANSCEIVER FOR SPACE APPLICATIONS

SCOPE

- **SPACE QUANTUM COMMUNICATIONS**
- **QUANTUM KEY DISTRIBUTION (QKD)**
- **QUANTUM KEY DISTRIBUTION (QKD) FOR SPACE APPLICATIONS**
- **QUANTUM PHOTONIC TRANSCEIVER:**

DEVELOPMENT OF A QUANTUM PHOTONIC TRANSCEIVER ELEGANT BREADBOARD FOR SECURE SPACE COMMUNICATIONS

SPACE QUANTUM COMMUNICATIONS

Need of secure transmission between two parties

Confidentiality, integrity, availability and eavesdropper´s detectability is highly important for space communications.

Cryptography

Transmitted information is coded exchanging a randomly generated enciphering key between two parties through a non-secure channel.

Quantum Cryptography

New secure-communication technology used to implement space quantum communication protocols

Quantum key distribution (QKD)

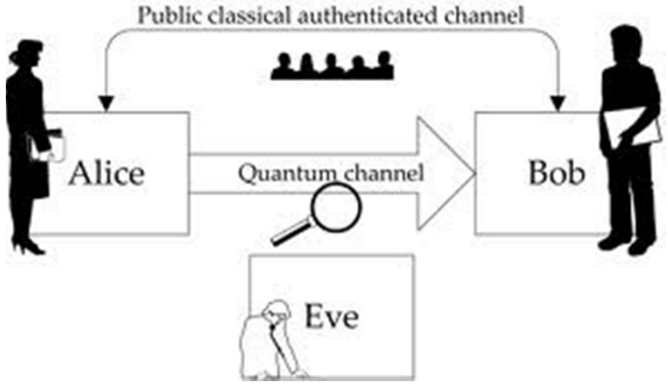
QUANTUM KEY DISTRIBUTION

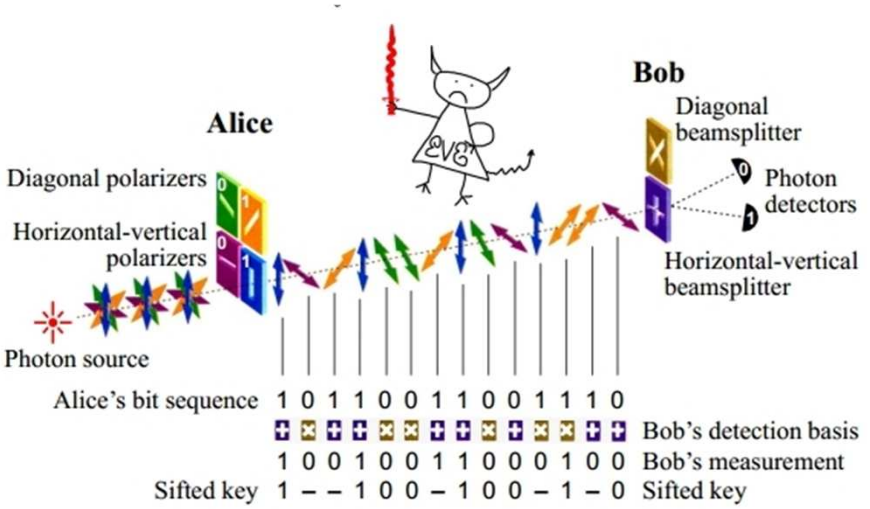
- Based on quantum physics principles: Data encoded in quantum bits (qbits)

- Both parties shares the enciphering secure key through a private quantum channel. It uses the correlation between two (or more) particles (e.g. photons).

- Information is coded at the level of a single photon-per-bit.

- It uses a quantum physical property such as the polarization of a photon. E.g. polarization in vertical and horizontal directions are a coding basis for one bit.



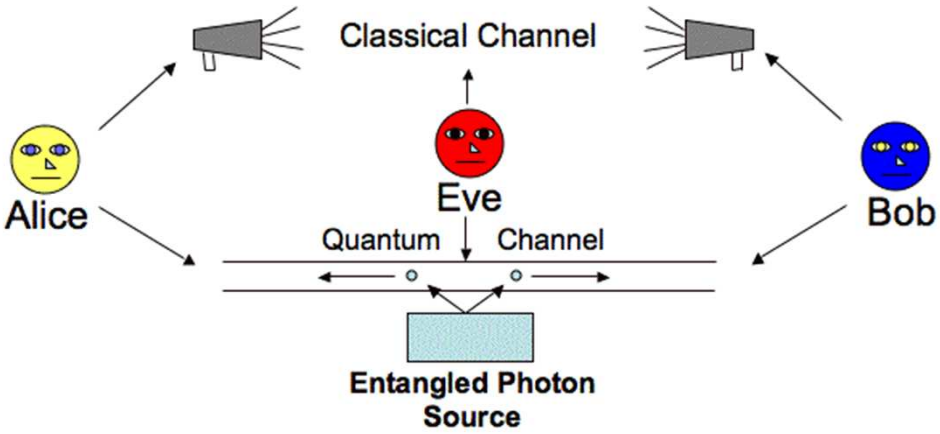


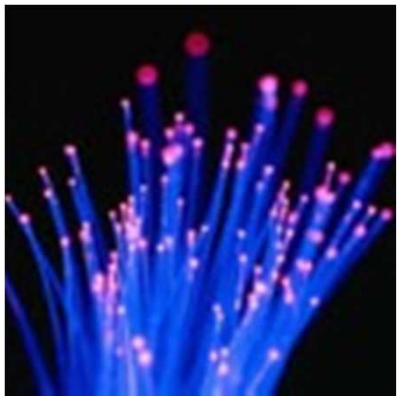
QUANTUM KEY DISTRIBUTION

➢Single photons cannot be cloned or split and, by measuring them you change them from their initial state.

➢ Superposition of states and entanglement lead to innovative methods for QKD more powerful than their classical counterparts

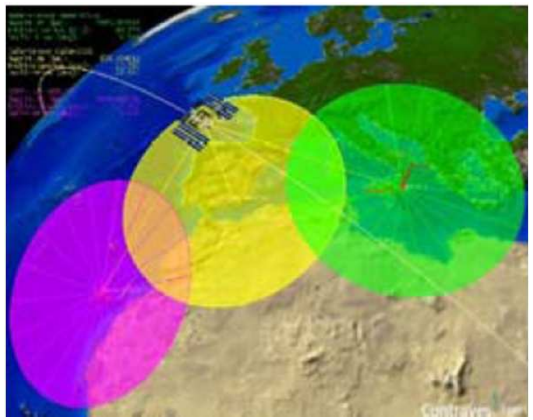
➢Quantum communication system uses single photons to transmit unique random secret keys of ones and zeros.



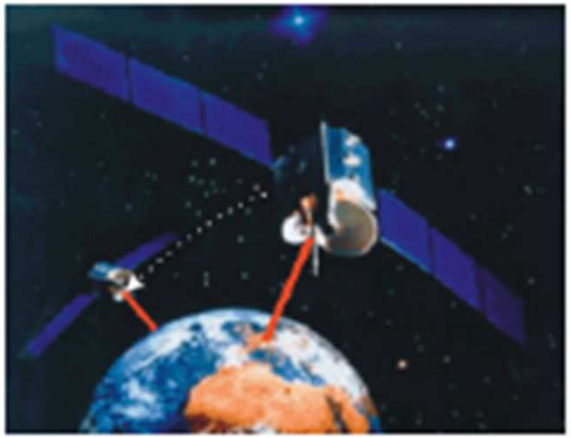


Entangled Photon Source Overview

QKD FOR SPACE COMMUNICATIONS



Free space QKD (e.g. inter-satellite and between Earth and satellite)

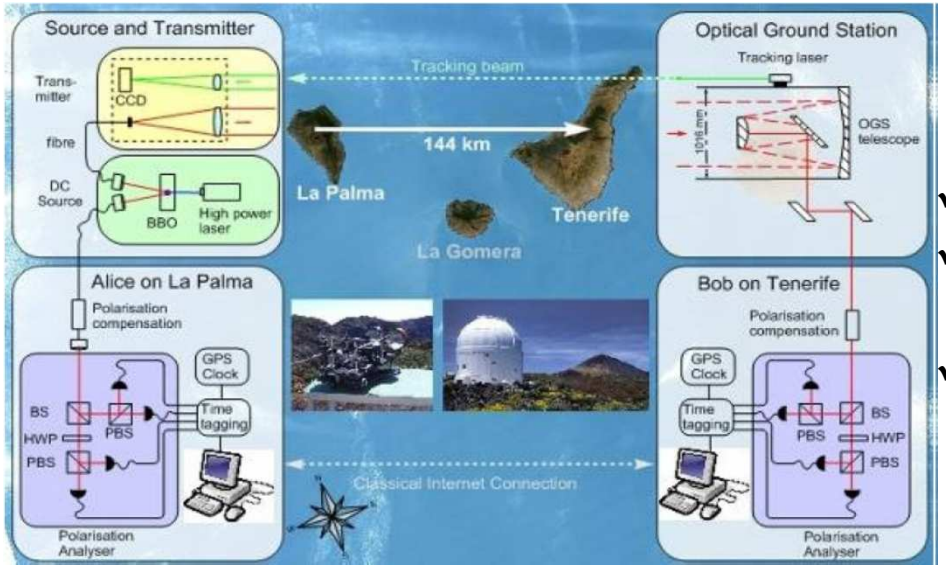


- Absence of absorption effects and birefringence of the optical fibre
- Longer distances: links between terrestrial stations
- Longer distances for space communications: links between satellites and Earth-satellite: Incoherence effects due to atmospheric disturbances are insignificants.
- ESA has supported studies in the field of quantum communications in space applications (e.g. TRP, ARTES and GSP programmes).

QKD FOR SPACE COMMUNICATIONS- Proof of principle
Entangled photon pair

- Quantum optical terminal demonstrator capable of generating entangled photon pairs
- Feasibility of QKD for space communications
- Single photon channel, testing atmospheric effects, entanglement distribution
- Evaluation for future links between Space-Earth and satellites.

Transmitter telescope



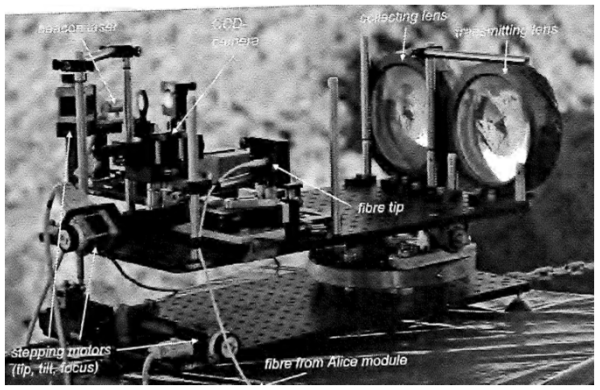
- ✓ Optical free space link
- ✓ Entangled photon pair using SPDC
- ✓ Photon pairs remained entangled over a distance of 144Km

First step towards future satellite-based quantum communication systems

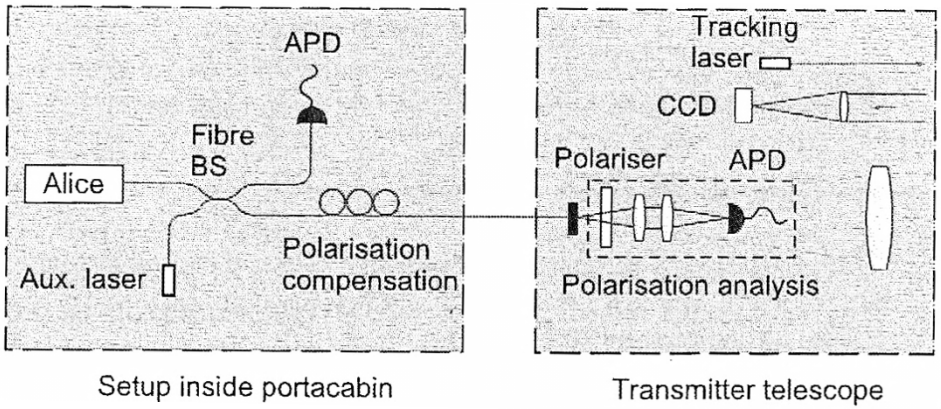
1) Rupert Ursin *et al* "*Free-Space distribution of entanglement and single photons over 144 km* " *Europhysics News* Vol. 40, No. 3, (2009)

QKD FOR SPACE COMMUNICATIONS- Proof of principle
Free space faint pulses

- Quantum optical terminal demonstrator capable of generating single photons pulses from faint laser source.
- Feasibility of QKD for space communications
- Evaluation for future links between Space-Earth and satellites.



Transmitter telescope



Setup inside portacabin | Transmitter telescope

- ✓ Optical free space link at a distance of 144Km
- ✓ Emitting indistiguishable faint pulses with random polarization states and with different intensity levels
- ✓ High secure key rate exchange

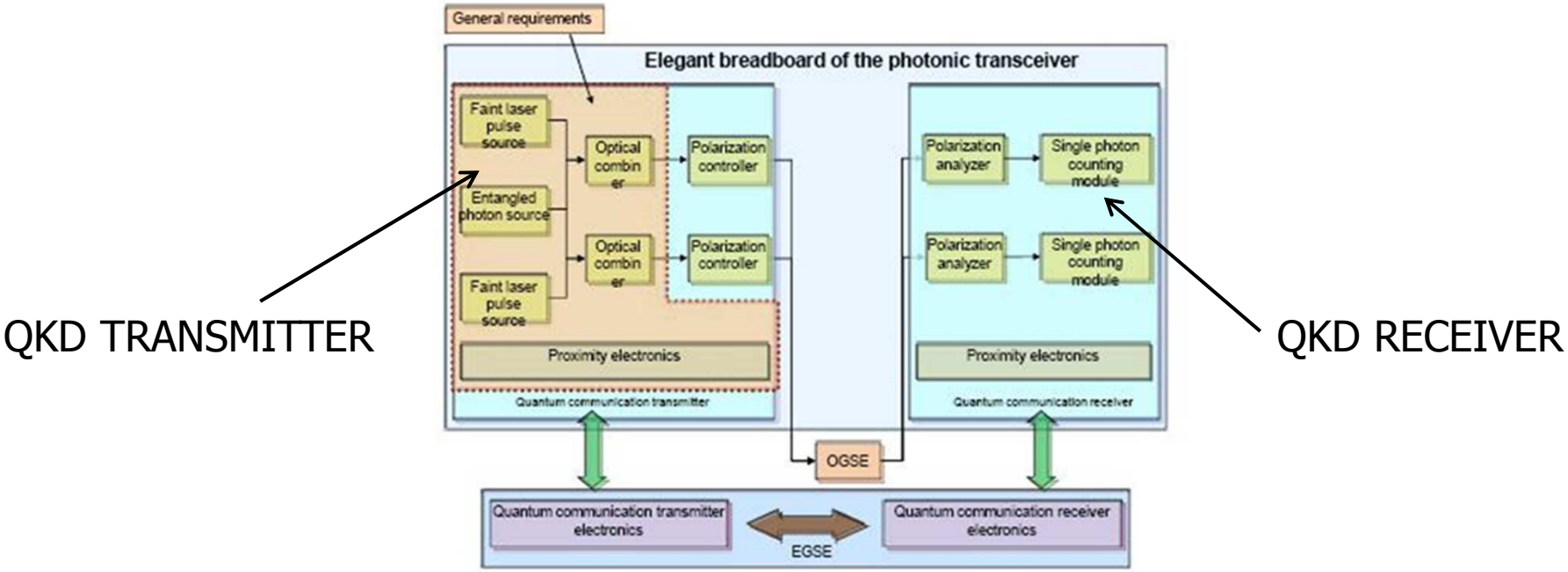
First step towards future global QKD via low-earth-orbit satellites.

2) Tobias Schmitt-Maderbach "*Long distance free.space quantum key distribution " Thesis* (2007)

QUANTUM PHOTONIC TRANSCEIVER (QPT)
CONSORTIUM MEMBERS

ATN is the prime contractor of a consortium for the development of a compact, robust and reliable solution of a QKD transceiver for space applications in the frame of an ARTES programme

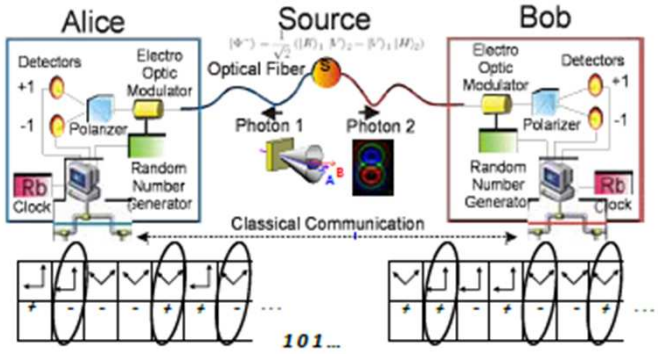
QUANTUM PHOTONIC TRANSCEIVER
Project Overview

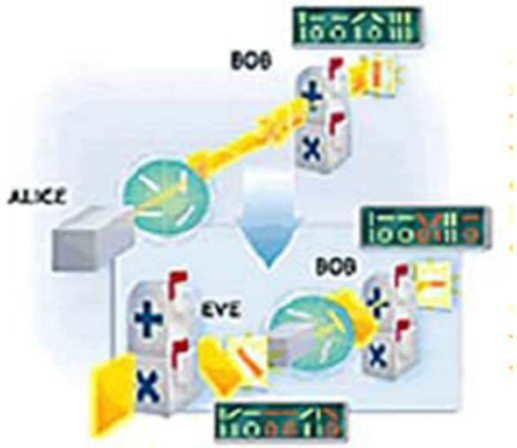


- Subsystem for quantum communication in space to potentially be placed on the ISS.
- Photonic transceiver Elegant Breadboard capable of generating and detecting entangled photons pairs as well as faint laser pulses.
- A space validated Quantum Transceiver performance.

QUANTUM PHOTONIC TRANSCEIVER
General concepts

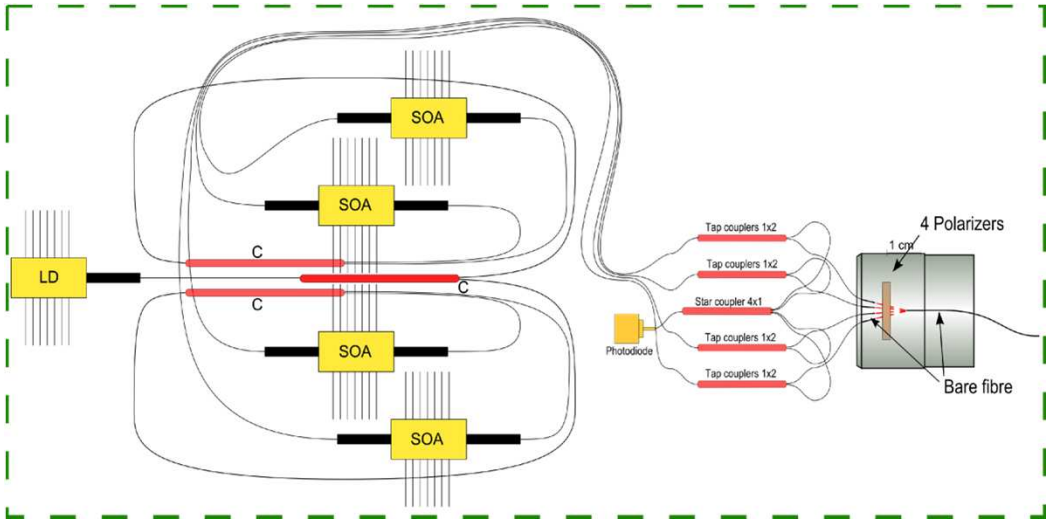
• The entangled photon source (EPS) distributes random but perfectly correlated sequences.
• EPS is used in simultaneous key transmission scheme (Eckert Protocol)
• Each station received one photon of each entangled pair. The received key is compared and *an unconditionally secure* key is computed.

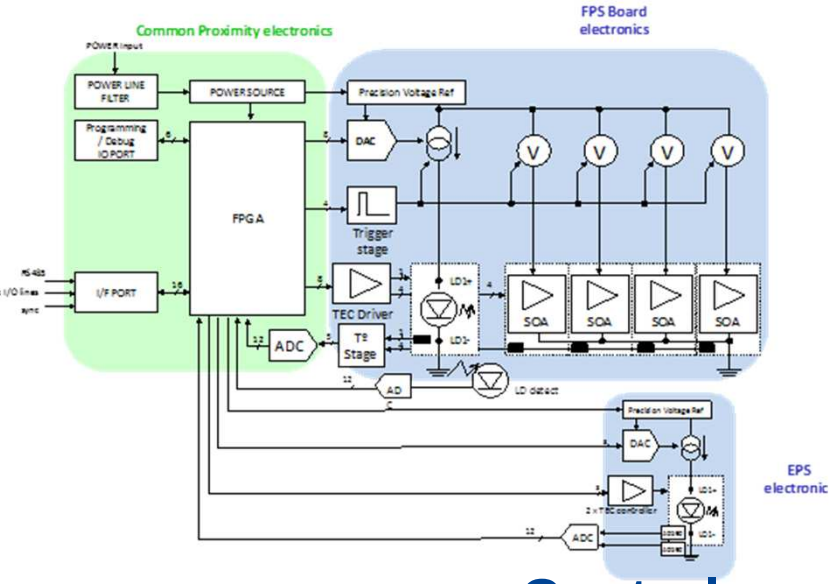




• The faint pulse source (FPS) distributes deterministic sequence.
• FPS is used for consecutive key transmission scheme (BB84+decoy State Protocol)
• Each station received two keys from the terminal
•After transmission one station sends a XOR of both keys to the other station and thus, one unconditionally secure key is computed.

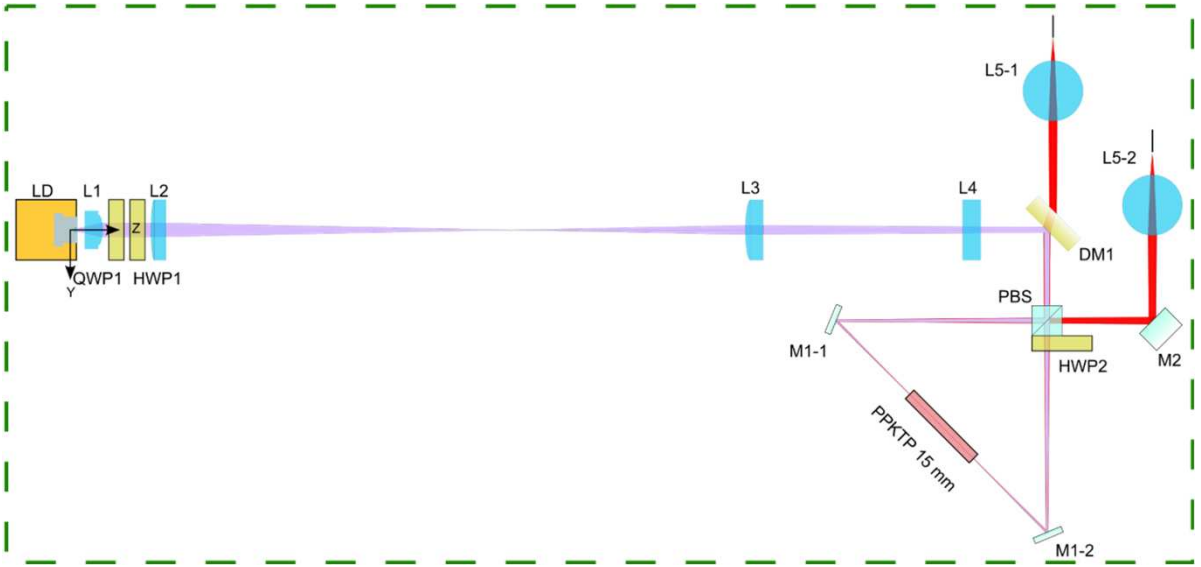
QUANTUM PHOTONIC TRANSCEIVER
Transmitter QPT potential lay out





Control electronics

FPS Layer



EPS Layers

QUANTUM PHOTONIC TRANSCEIVER
Main Requirements

- **General Requirements**
  - Total mass ≤ 4Kg
  - Total Size ≤290x120x100mm^3
  - Total Power Consumption ≤ 15W(peak)
- **Optical Requirements**
  - Optical BW ≤ 3nm
  - Back to back detected coincidence rate > 105
  - Visibility >95% (in 0/90 and +45/-45 basis)
  - QBER<2.5%
  - Detection Probability >40%
  - Weak Pulse Repetition Rate >10MHz
  - Dark Count < 100 counts/sec
  - Time Resolution < 1ns
- **Environmental Constraints**
  - Operational Temperature -35º/60º
  - Storage Temperature -50º/75º
  - Operational Relative Humidity Range 5-85%
  - Storage relative humidity range 5-95%
  - Vacuum Environment <10^{-6} mbar
  - Radiation : Gamma , Displacement damage and Single Event transient.

QUANTUM PHOTONIC TRANSCEIVER
Critical Aspects

- Critical optical and opto-electronics elements must be space validated: They must undergo environmental and mechanical tests to prove its functionality and feasibility in space environment.

- Opto-mechanical design compatibility with space environment must be demonstrated by a suitable combination of analysis and testing.

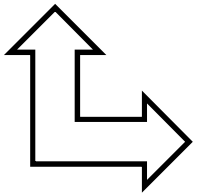
- Functional performance is subjected to precision and stability of the opto-mechanical assembly in space environmental conditions. Stable and robust opto-mechanical integration.

- Thermo-mechanical active control of optical and opto-electronic components.

SPACE QUANTUM COMMUNICATION: ATN I+D TECHNOLOGY ROADMAP

- Quantum Communication in Space is becoming a cutting-edge information technology.
- ATN Optoelectronic Innovation department is open to new challenges and promising technologies in the space sector.
- ATN Optoelectronic and Innovation department offers specific high level engineering capabilities to support and promote photonic technologies for space applications
  - Assessment of optoelectronic related systems to meet specific mission requirement
  - Parametric and environmental testing for parts and systems
  - Broad collaboration with research institutes and universities

- **ATN Innovation strategy** in the space quantum communication field:



- ✓ Leap ahead in space business sector
- ✓ Step forwards the information technology arena » e.g. support and analysis of future implementation and commercialisation of QKD systems for secure encryption systems in space applications.

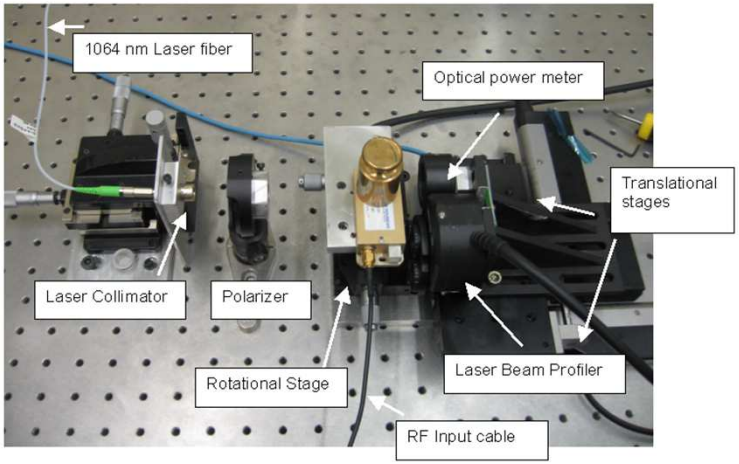
Main I + D activities and capabilities (I)

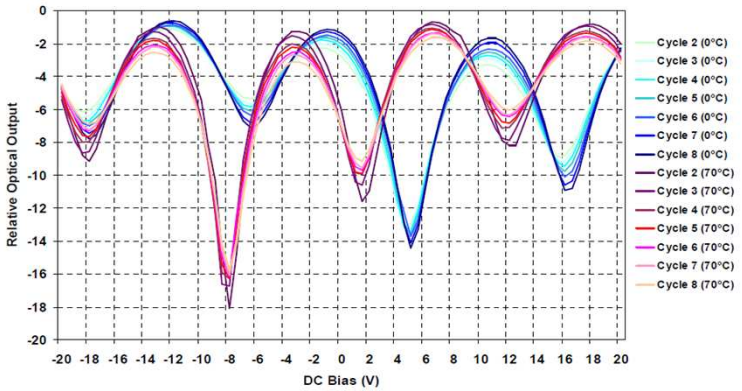
Space evaluation for the complete range of optoelectronics and photonics parts:

- Laser & Leds characterization 250 to 5000 nm.
- Receivers modules (180 to 11000 nm).
- Optical Amplifiers & Optical modulators
- Switches and splitters.
- Optocouplers & Photodiodes
- Multimode and monomode Fibers
- Liquid Crystal Devices

In house capabilities for complete characterization and environmental testing

- Electro-optical parameters.
- Time and spectral response.
- Thermal and Thermal Vacuum
- Endurance Tests
- Mechanical Tests
- Reliability test
- Radiation.
- Constructional analysis.

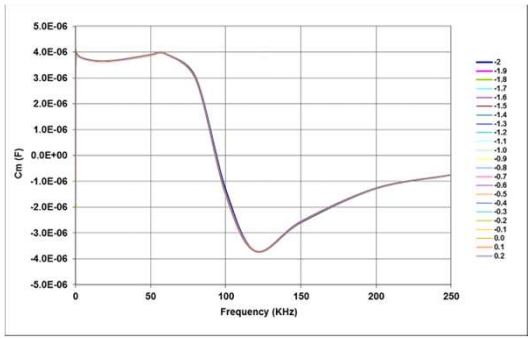


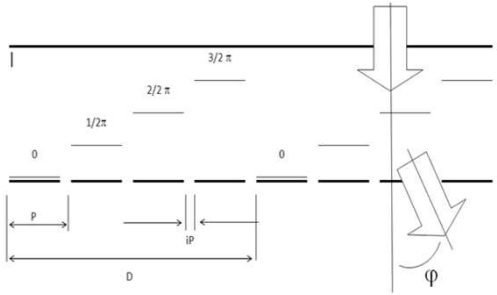


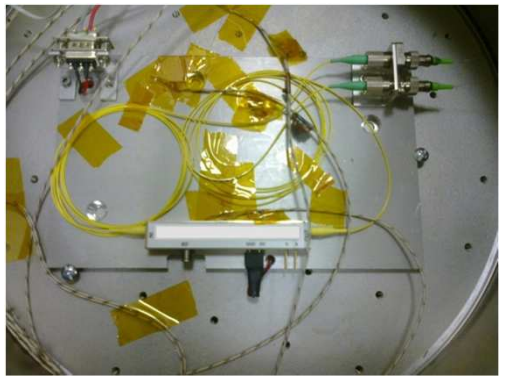
Main I + D activities and capabilities (II)

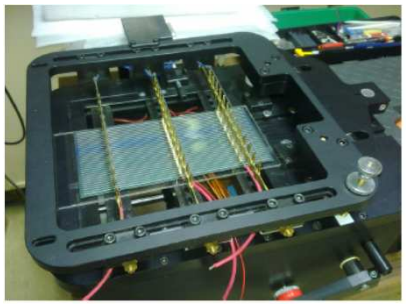
Development & Characterization of Optical and Photonic systems:

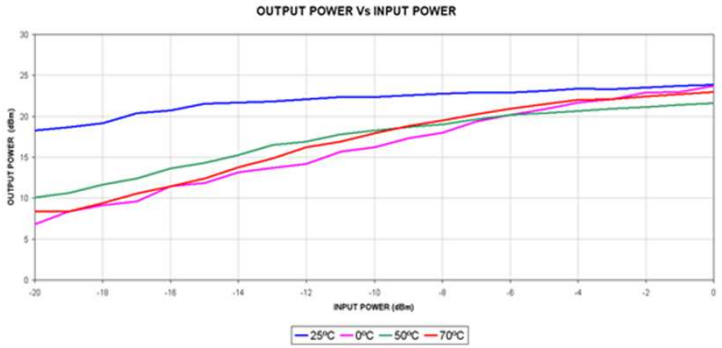
- Optical programmable devices based on liquid crystals.
- Frequency stabilisation modules for LIDAR applications
- Fibre Optic Data Link system validated for space applications

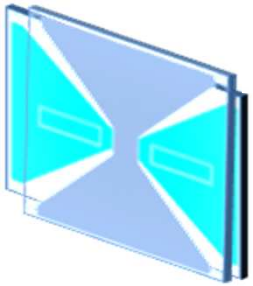


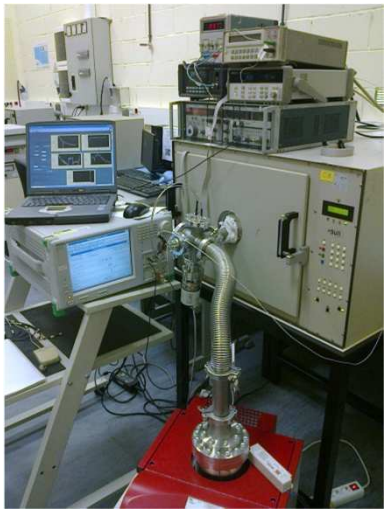












The INNOVATION department is open to new challenges and developments in collaboration with customer requirements

Thank you

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