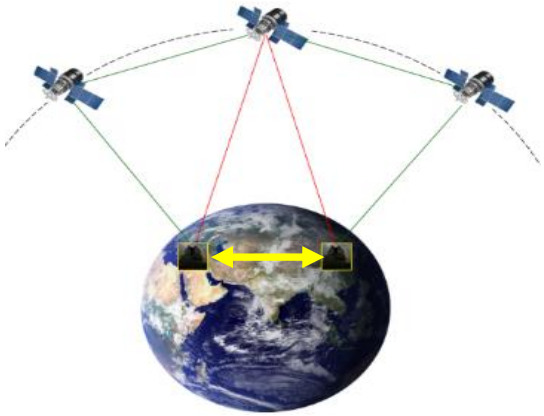
"Building a Quantum Network"

Quantum Technologies in Satellite Communication



The single biggest problem in communication is the illusion that it has taken place !

--- George Bernard Shaw (GBS)

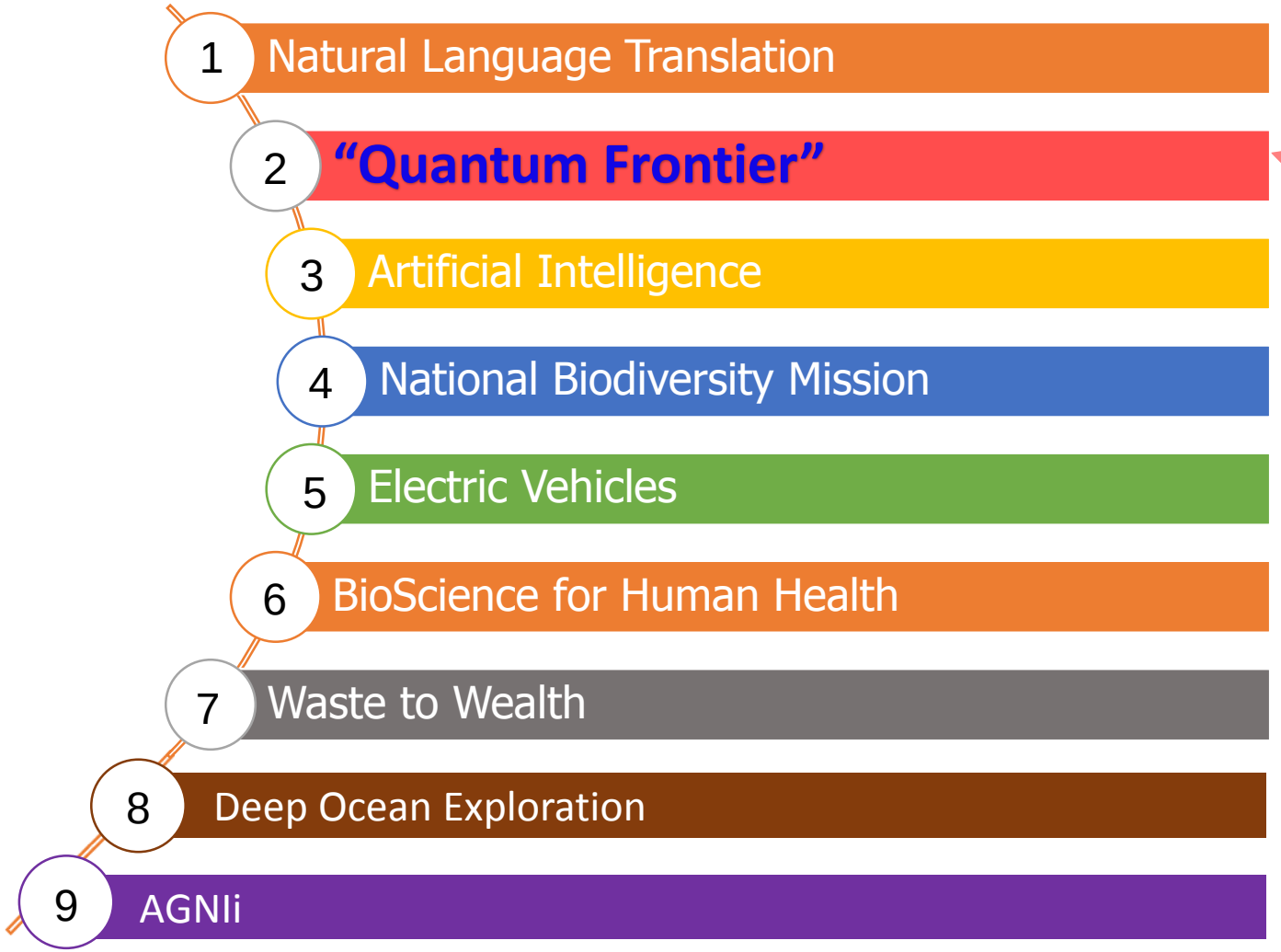
By
Nilesh M Desai
Director

Space Applications Centre (ISRO)
Ahmedabad

March 27, 2023

Prime Minister's Science, Technology And Innovation Advisory Council (PM-STIAC)

Key National Missions: "Enabling future preparedness in emerging domains of science and technology"



Building excellence in the quantum frontier through this mission is essential for national security and development of quantum computers, **quantum communication**, new materials, **quantum sensors**, and **quantum cryptography**.

The Nobel Prize in Physics 2022

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2022 to

Alain Aspect

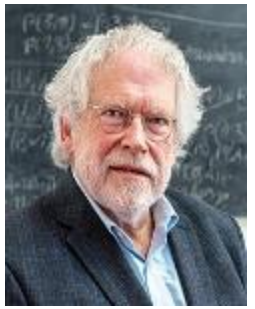
Université Paris-Saclay and
École Polytechnique, Palaiseau, France

John F. Clauser

J.F. Clauser & Assoc.,
Walnut Creek, CA, USA

Anton Zeilinger

University of Vienna, Austria

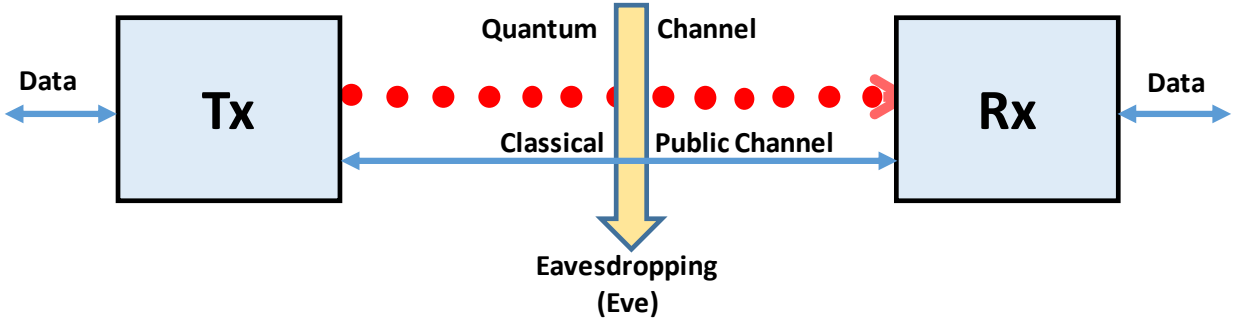


- **They experimented with entangled photons, establishing the violation of Bell inequalities and pioneered quantum information science.**

- **At the heart of their research was quantum physics, a field of science that aims to study matter and energy at the most fundamental level. Each of the three winners conducted groundbreaking experiments using entangled quantum states, where two particles behave like a single unit even when they are separated.**

The world is now moving towards quantum communication, which is being held as the safest way of communicating that works on principles of hard encryption.

Quantum communication



Quantum Channel	Classical public channel
Secure key generation & distribution	Encrypted Communication

Salient Features :

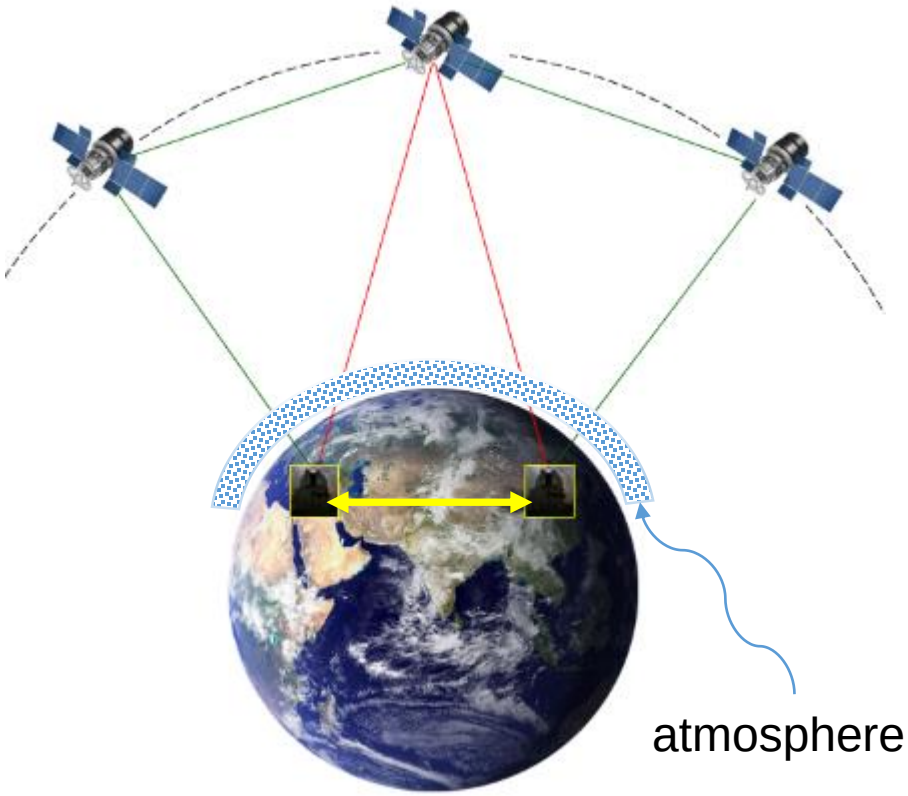
- **Security of cryptographic protocols is based on the laws of quantum physics, and not on the unproven assumptions of computational complexity theory.**
- **Quantum cryptography or Quantum Key Distribution (QKD) provides a level of communication security that cannot be obtained by classical cryptographic means.**
- **Urgency for secure Quantum communication is due to threat perception from quantum computing that is drawing huge investments from industry as well as governments.**

Applications :

- ❑ **Satellite based Quantum Key Distribution (QKD) over larger distances**
- ❑ **Banking/ Finance Industry: Protecting sensitive client information**
- ❑ **Credit card industry: Protecting customer credit card information**
- ❑ **Government and defence industry**
- ❑ **Protecting high value/sensitive data in remote data centres**
- ❑ **NavIC based RS-Key distribution**

Why Satellite based Quantum Communication (SBQC) ?

- The quantum communication relies on individual photons to carry quantum information.
- But even the best optical fibers/ terrestrial free space can carry these photons only upto few hundreds of kilometers before light absorption makes the process impossible.
- The Quantum satellites can be set up for intra & intercontinental quantum cryptography services for secure data communication and distances of the order of thousands of kilometer are possible.
- China & Japan have successfully demonstrated Quantum Communication experiments from satellite to ground.



Worldwide Developments Related to Satellite based quantum communication (SBQC)

2005 - 2010

- ✓ *Free space entangled photon distribution over 13km* ***(China)***
- ✓ *Free space QKD over 144km using decoy state BB84 & E91 protocol* ***(Spain)***
- ✓ *BB84 QKD achieved over 148.7 km of optical fiber*
- ✓ *Measuring polarization characteristics through LEO-to-ground atmospheric transmission paths* ***(OICETS-Japan)***

2011 - 2015

- ✓ *Free space entangled photon distribution over 100km & Gnd-Sat QKD verification using hot air balloon* ***(China)***
- ✓ *BB84 between moving airplane and OGS* ***(DLR-Germany)***
- ✓ *LEO-Gnd polarization measurements* ***(SOTA- Japan)***
- ✓ *Validating entangled photon source in space -1U Cubesat* ***(SPEQS-1 - Singapore)***
- ✓ *GEO-Gnd CV-QKD experiment* ***(AlphaSat XL - ESA)***

2016 – 2020

- ✓ *Decoy state BB84 QKD & Entangled photn distribution over 1200km using Micius satellite* ***(QUESS-China)***
- ✓ *Sat-Gnd quantum-limited communication & polarization measurement using a 50-kg-class microsatellite* ***(SOTA- Japan)***
- ✓ *Miniaturized polarization entangled photon pair source on board testing - 3U CubeSat (**SpooQy-1-Singapore**)*

2021 - 2025

- ▪ *Receiver onboard satellite to measure uplink quantum signals* ***(QEYSSAT-Canada)***
- ▪ *Long distance QKD using CubeSat uplink* ***(NanoQEY-Canada)***
- ▪ *BB84 QKD and Sat-Gnd entangled photon distribution using 6U satellite* ***(CQuCoM-UK, Austria, Singapore, Italy)***

- ▪ *Space-to-ground QKD experiment from the ISS* ***(SpaceQUEST-ESA)***
- ▪ *Network of 6U CubeSats for communication with ground stations across UK* ***(QUARC-UK)***
- ▪ *WCP source downlink QKD and compact QRNG - 3U CubeSat* ***(QUBE-Germany)***
- ▪ *Uplink polarisation based Quantum comm. on 12U & 3U CubeSat* ***(NanoBob & Q3sat - Austria)***

- ▪ *Downlink QKD demonstration using 6U cubesat* ***(ROKS – UK)***
- ▪ *Sending an integrated entangled photon source (810nm+1550nm) to ISS (**SEAQUE - NASA**)*
- ▪ *Deploy a satellite QKD test bed using 12U cubesat* ***(SPEQTRE - Singapore)***
- ▪ ***Spaceworthy entanglement and WCP source based QKD validation onboard (QuantESS and QuTDS - India)***
- ▪ ***OQC payload development and establishment of satellite to ground Quantum comm. link (India)***

Demonstrated milestones

Proposed missions

Successful Demo missions/programs related to QKD

Micius

Year	2016
Organization	Chinese Academy of Sciences, University of Vienna, Austrian Academy of sciences
Objective	**Decoy state BB84, Entanglement distribution, Optical communication link**
Orbit/Link details	LEO (600km) -> Gnd
Parameters	BB84 QKD (weak coherent source based) @ 850nm : keyrate ~ 1.1 kbps to 10kbps, BBM92 QKD (entangled source based) @ 810nm : < 1 bps keyrate

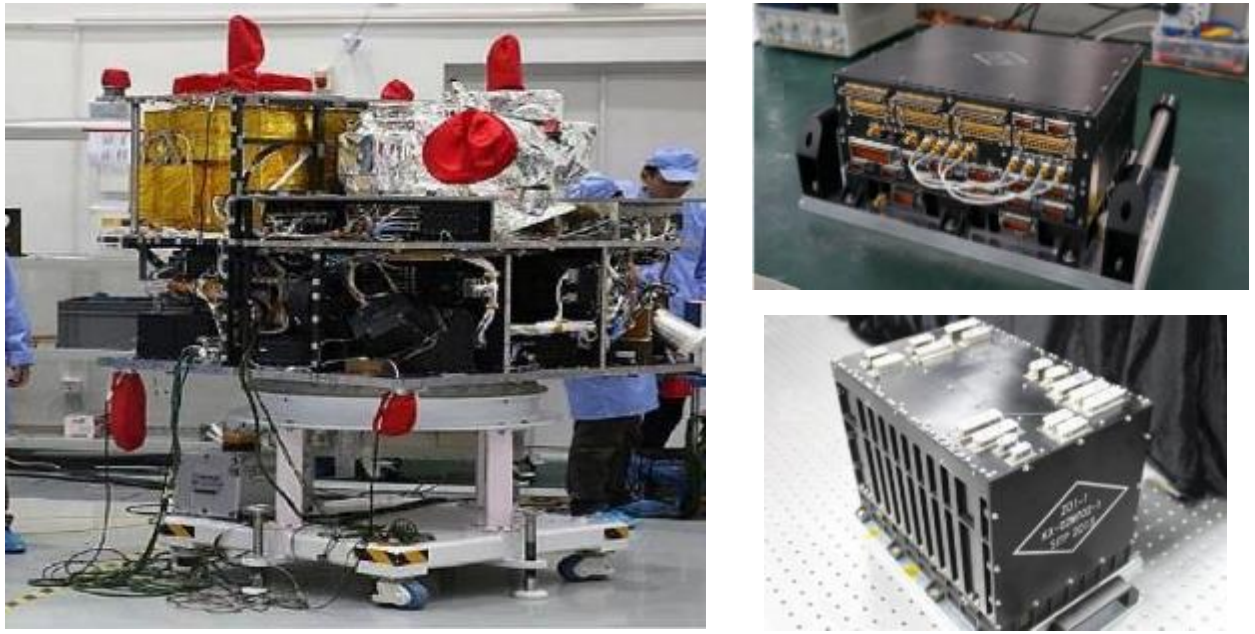


Fig. The Micius satellite and the payloads

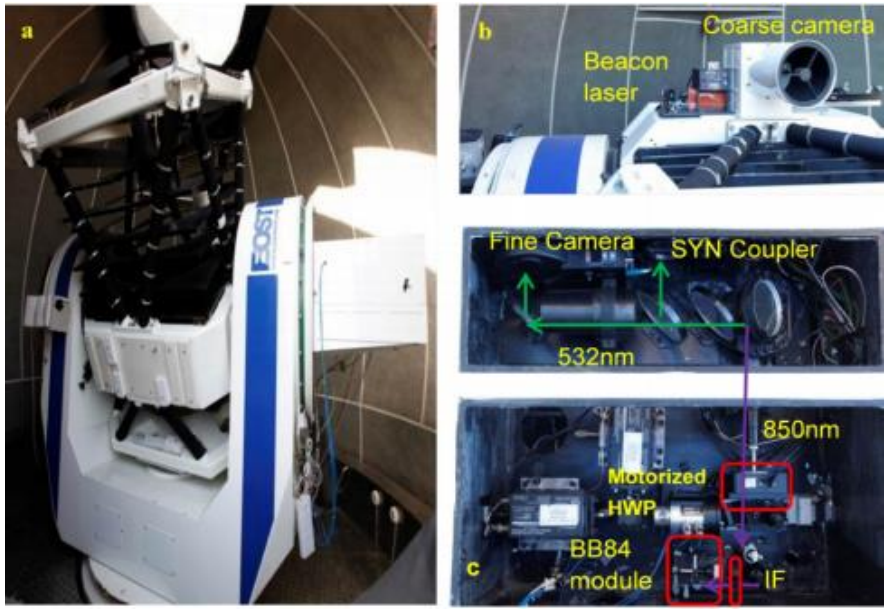
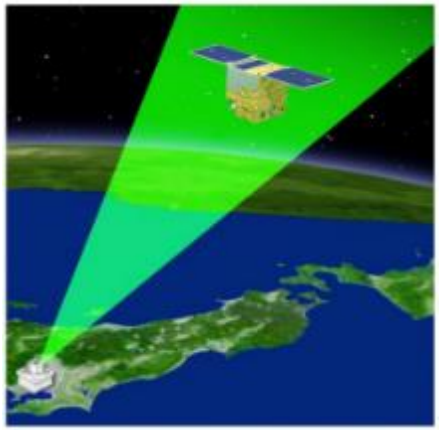


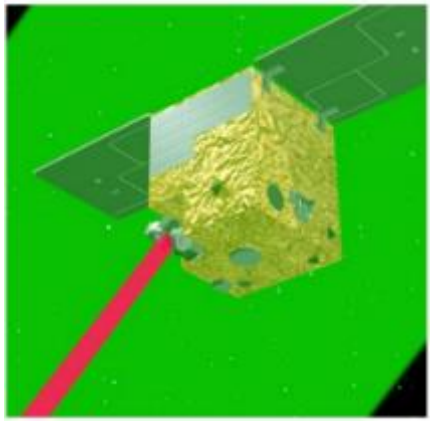
Fig. Optical ground station (OGS) at Xinglong

Recent successful missions/programs related to QKD

SOCRATES

Year	2017 (Japan) (Satellite-to-ground **quantum-limited** communication using a microsatellite)
Organization	NICT, Japan
Objective	LEO-to-ground polarization measurement through small optical transponder (SOTA terminal), B92 **Quantum key distribution**
Orbit/Link	LEO -> Gnd
Parameters	800 nm - 10 MHz on board pulse rate

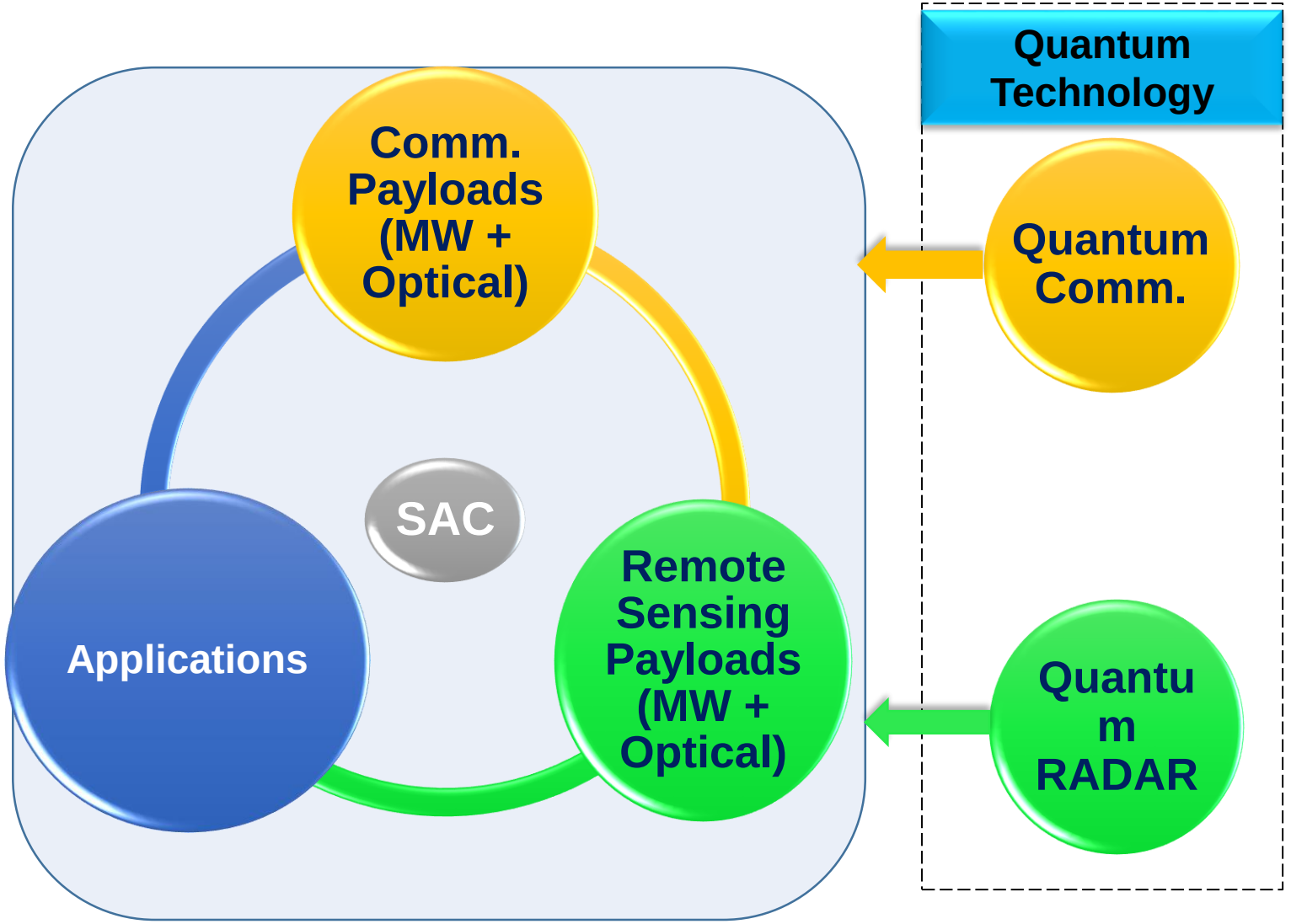




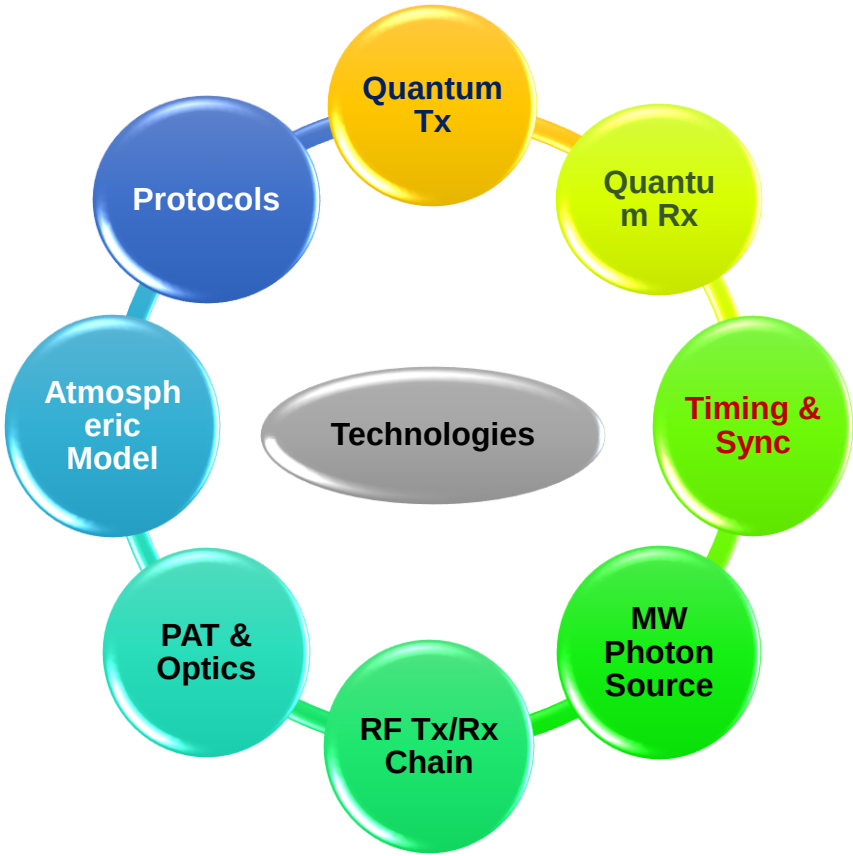
SpooQY-1

Year	2019 (Singapore)
Organization	The CQT (Center for Quantum Technologies) at NUS (National University of Singapore)
Objective	Demonstrated the operation of a compact, low-power, lightweight, and robust source of **entangled photon pairs** into low Earth orbit. **(Loop-back mode)**
Orbit/Link	LEO (onboard)

Quantum Technologies @ SAC



Needed Technologies

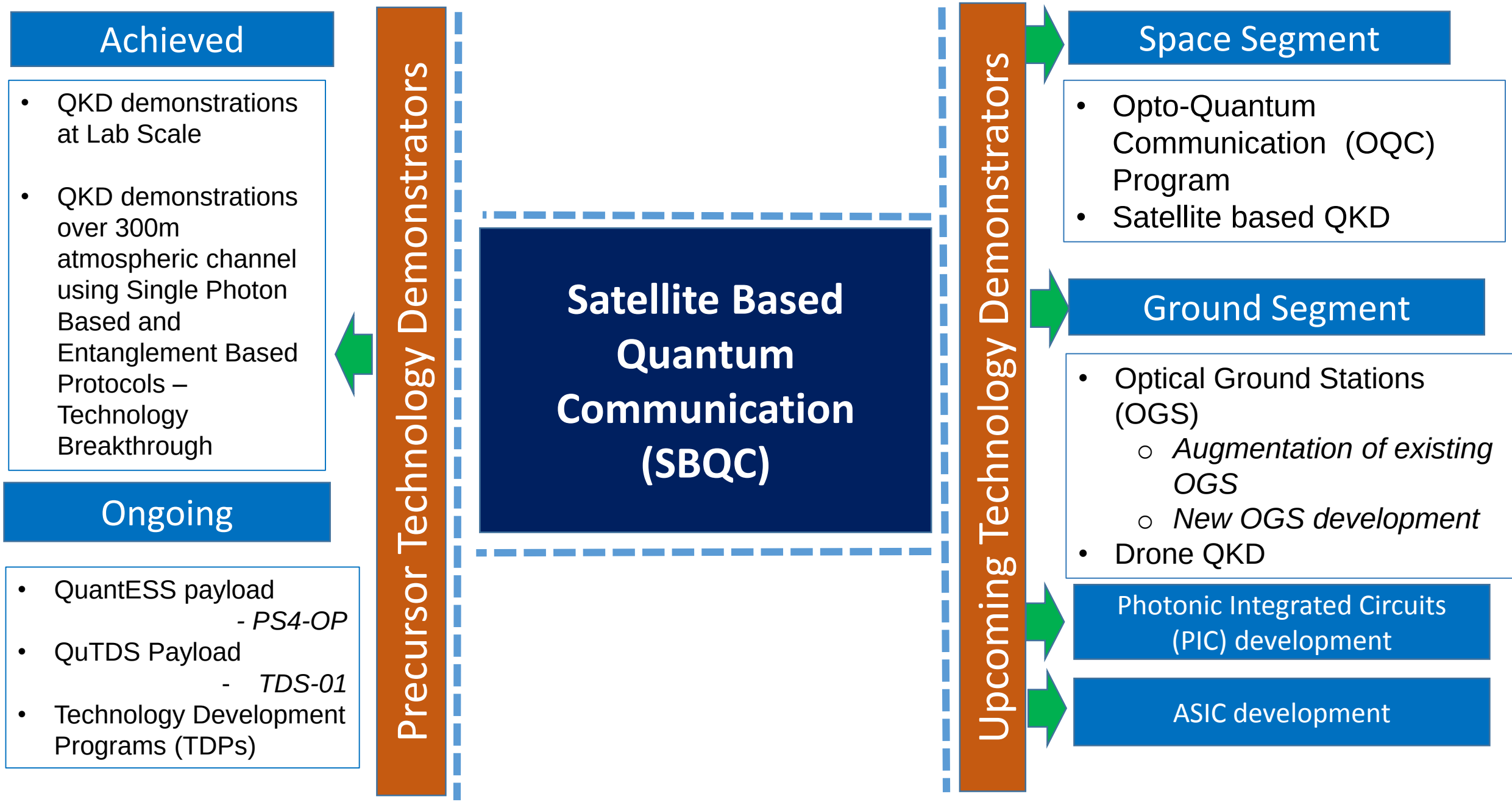


Baseline Technologies for SBQC

Quantum Tx	• Weak Coherent Pulse (WCP) Source • Single photon source • Entangled Photon Source
Quantum Rx	• Single Photon Counting Module (SPCM) • Single Photon Avalanche diode (SPAD) • Polarization compensation
Time tagging & Synchronization	• NavIC Based Clock Synchronization • Time To Digital Converter (TDC) & Coincidence Counter
QKD Protocols	• BB84 / Decoy BB84 • BBM92
Telescope with PAT system	• Pointing, Acquisition & Tracking (PAT) mechanism • Optics and Gimbal design & development
Atmospheric Channel Modelling	• Free Space atmospheric Channel Studies & Experiments
Microwave Quantum Source	• Josephson Junction Fabrication • Development of Entangled Photon Source

System-level Technologies for SBQC

Single Photon based QKD System	• End-to-End BB84 QKD System has been demonstrated over 300m Free Space Channel • Validated: WCP source, BB84 IP, Qu Rx, NavIC-Sync System technologies
Entangled Photon based QKD System	• End-to-End BBM92 QKD System has been demonstrated over 300m Free Space Channel • Validated: EPS source, Qu Rx, NavIC-Sync System, TDC, BBM92 IP
QKD over moving platform	• Demonstration of QKD Link on moving platform like drone • Validate: PAT system, polarization compensation for moving scenarios
QuantESS Payload	• Transformation of BB EPS to Space worthy EPS and qualification for Space • Validation in Space (loopback mode): EPS, Qu Rx, Ruggedized SPCM, HOM
TDS Payload	• Realization of WCP source and qualification for Space use • Validation in Space (loopback mode) : WCP source, Qu Rx, Ruggedized SPCM, QRNG, cryptography
Optical Ground Station (OGS)	• Augmentation of existing 700mm OGS facility at SAC Ahmedabad • Establishment of new OGS facilities at Mt. Abu & Hanley.
Opto-Quantum Communication (OQC) Payload	• Technology development and demonstration of SBQC • Technology development & demonstration of SBOC • Quantum secured communication between two ground stations


Achieved
QKD demonstrations at Lab Scale
QKD demonstrations over 300m atmospheric channel using Single Photon Based and Entanglement Based Protocols – Technology Breakthrough
Ongoing
QuantESS payload - PS4-OP
QuTDS Payload - TDS-01
Technology Development Programs (TDPs)
Precursor Technology Demonstrators
Satellite Based Quantum Communication (SBQC)
Upcoming Technology Demonstrators
Space Segment
Opto-Quantum Communication (OQC) Program
Satellite based QKD
Ground Segment
Optical Ground Stations (OGS)
Augmentation of existing OGS
New OGS development
Drone QKD
Photonic Integrated Circuits (PIC) development
ASIC development

Inter-building Free Space Single-Photon based Quantum key distribution (QKD) inside SAC campus ：March, 2021

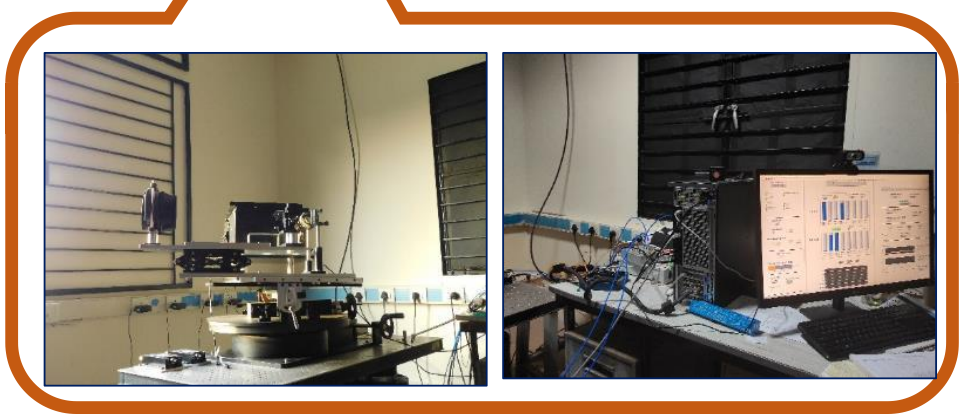
End-to-end Free Space quantum comm. link experiment b/w 2 buildings (During March-2021)

Buildg-38 (Quantum Tx)

Free space quantum communication Link (~300m)

(~300 Metres Apart)

Buildg-22 (Quantum Rx)



End-to-end Free Space quantum comm. link establishment between 2 buildings (contd..)

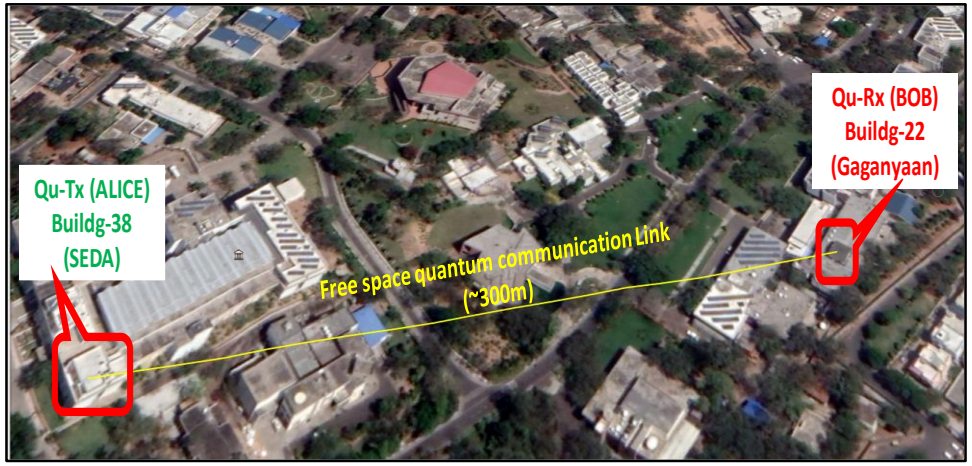


Fig. Aerial view of two buildings inside SAC campus

Fig. Coarse alignment using visible beacon laser

Salient Features:

- **INDIA's first probabilistic single photon based inter-building free space quantum communication link establishment over a distance of ~300m of atmospheric channel**
- **INDIA's first 2-way quantum secured client-to-client live video conferencing demonstration**
- **NavIC enabled synchronization mechanism implemented**
- **Presence of Eavesdropper(eve) emulated in the software and validated during experiment**
- **Polarization encoded single photon transmission and reception**
- **BB84 protocol based quantum key distribution (QKD) protocol**
- **Secure key rate ~300 Kbps, QBER <3%, mean photon no./pulse 'μ' ~0.15**
- **Indigenously designed & developed weak coherent pulse source @785 nm wavelength.**
- **Reported/published in India's leading news papers and websites**

News on Social media and other websites incl. ISRO Website

ISRO

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Indian Space Research Organisation

Bangalore isro.gov.in Joined December 2013

31 Following 4.2M Followers

Tweets Tweets & replies Media Likes

ISRO @isro · 14h

For the first time in the country, ISRO has successfully demonstrated free-space Quantum Communication over a distance of 300 m.

For details visit: isro.gov.in/update/22-mar-...

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Quantum Communication Over 300 Metres

The Quantum Key Distribution technology underpins Quantum Communication technology that ensures unconditional data security by virtue of the principles of quantum mechanics, ISRO explained.

All India | Press Trust of India | Updated: March 23, 2021 1:21 am IST

The free-space QKD was demonstrated at Space Applications Centre (SAC), Ahmedabad, between two line-of-sight buildings within the campus.

The experiment was performed at night, in order to ensure that there is no interference of the direct sunlight.

View in Hindi: R भारत

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Last Updated: 23rd March, 2021 12:46 IST

ISRO Successfully Demonstrates India's First Free-space Quantum Key Distribution Over 300m

Indian Space Research Organisation (ISRO) on Monday successfully demonstrated free-space Quantum Communication over a distance of 300 m for the first time.

Written By Srishti Goel

ISRO develops key technologies to accomplish the demonstration

Live videoconferencing using quantum-key-encrypted signals was part of the demonstration. This is a significant step forward in the use of quantum technology to provide unconditionally data communication, read the statement. It added, "The free-space QKD was at Space Applications Centre (SAC), Ahmedabad, between two line of sight in the campus. The experiment was performed at night, in order to ensure that erference of the direct sunlight."

ગુજરાત સમાચાર

રો અમદાવાદ સ્થિત સંસ્થા સ્પેસ એપ્લિકેશન સેન્ટરની સફળતા

ન થઈ શકે એવા ક્વૉન્ટમ કમ્યુનિકેશનનો સફળ પ્રયોગ

જાગરण

Play

कम्युनिकेशन पर इसरो की बड़ी कामयाबी

स्पेस क्वांटम कम्यूनिकेशन का सफल पर

असंभव होगी हैकिंग

इसरो ने इसे एक महत्वपूर्ण उपलब्धि बताया है। क्वांटम तकनीक की विशेषता

जरिए भेजे गए संदेशों को कोई हैक नहीं कर सकता जिसे क्वांटम

प्रौद्योगिकी भी कहा जाता है। इस बेहद महत्वपूर्ण तकनीक का प्रदर्शन अहमदाबाद स्थित स्पेस

एप्लीकेशन सेंटर में किया गया। परीक्षण रात में किया गया जिससे कि सूर्य का प्रकाश सीधे

डेटा प्रभावित न कर सके।

ईसરોએ ફ્રી સ્પેસ ક્વોન્ટમ કમ્યુનિકેશનનું સફળતાપૂર્વક પરીક્ષણ કર્યું

આજ તક

ट्रेंडिंग

ISRO ने पहली बार प्रकाश के कणों पर भेजा संदेश, हैक करना असंभव

TIMESNOWNEWS.COM

ISRO successfully demonstrates free-space quantum communication over 300 m, plans to extend it to satellites

The Indian Space Research Organisation (ISRO) has successfully demonstrated free-space quantum communication over a distance of 300 metres.

Bengaluru: In the first step towards developing quantum satellite technology, the Indian Space Research Organisation (ISRO) late last week successfully demonstrated free-space quantum communication over a distance of 300 metres.

The demonstration for the free space Quantum Key Distribution took place at Space Applications Centre (SAC) in Ahmedabad, between two line-of-sight buildings within the campus. The experiment

Inter-building Free Space Entanglement based Quantum key distribution (QKD) inside SAC campus : Nov.-2021

Salient Features/ Achievements of Entanglement Based QKD

- **INDIA's first Entanglement based, fully automated with real time processing & NavIC Synchronized inter-building free space quantum communication link establishment over a distance of ~300m atmospheric channel**
- **Applications Demonstrated :**
  - ✓ ***Quantum secured text and image encryption and decryption***
  - ✓ ***2-way quantum assisted client-to-client live video & audio calling demonstration***
- **Technical Performance Achieved :**
  - ✓ ***Secure key rate ~2.0 Kbps, QBER <10%, Visibility > 80%, Bell's parameter > 2.2***
  - ✓ ***Repeatable & Stable quantum link performance observed over atmospheric channel during several nights***
- **Technologies Developed:**
  - ✓ ***Robust, High brightness entangled photon source (EPS)***
  - ✓ ***BBM92 protocol IP implemented for quantum key distribution (QKD) involving data acquisition, timing and clock synchronization, key sifting, QBER computation, post processing viz. error correction & privacy amplification etc.***
  - ✓ ***NavIC enabled synchronization mechanism implemented***
  - ✓ ***Polarization compensation technique implemented***
  - ✓ ***Application software for Text, image, audio and video applications developed***

Major Breakthrough Step: End-to-end Free Space quantum communication link experiment between 2 buildings (~300 Metres Apart) during Nov-Dec, 2021

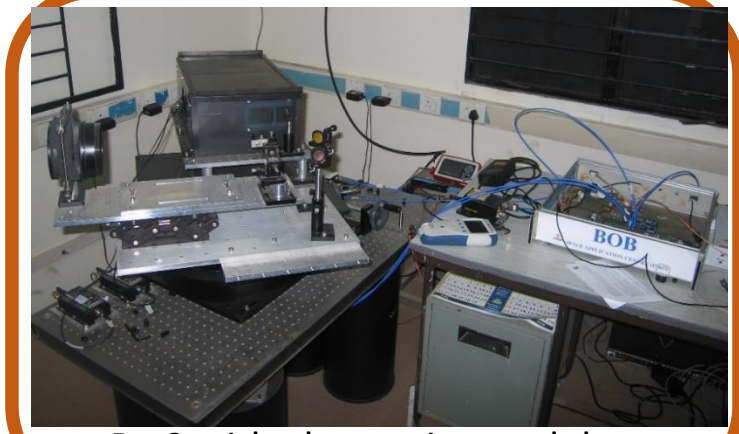
Buildg-38 (EPS and Quantum Rx-1)

Free space quantum communication Link (~300m)

Buildg-22 (Quantum Rx -2)

Entangled photon source (developed by PRL)

Rx-1 with electronics module



Rx-2 with electronics module

Measured performance results for inter-building Free Space Quantum Comm. link

- Weak coherent pulse based probabilistic single photon source (BB84 QKD Protocol)
- Entangled photon pair source (BBM92 QKD Protocol)

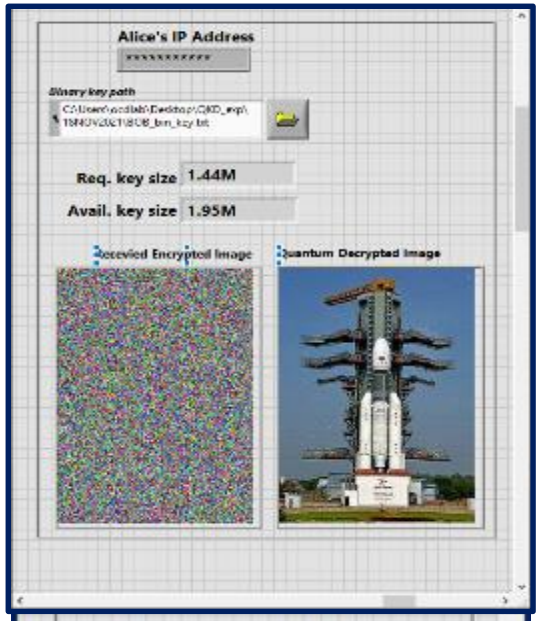
TABLE. BB84 QKD System
(Demonstrated in March-2021)

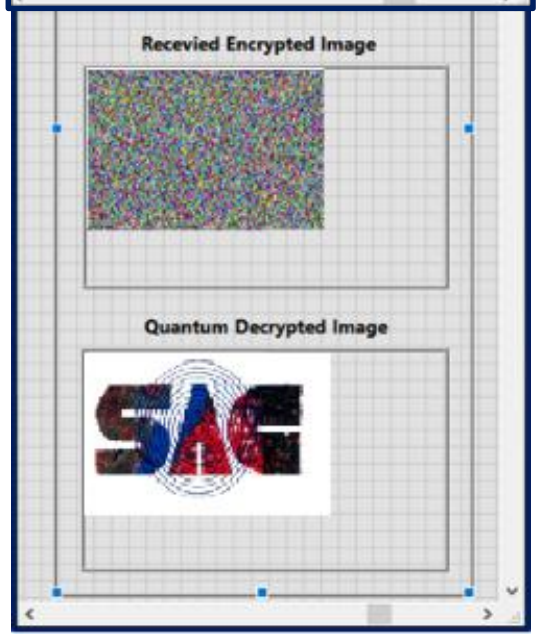
Sr.	Parameters	Measured Results
1.	Source	Weak coherent pulse (probabilistic single photon)
2.	Wavelength	~785 nm
3.	QBER	< 3 %
4.	Sifted Key Rate	390 - 450 Kbps
5.	Secure Key Rate	260 - 300 Kbps @ 20 MHz

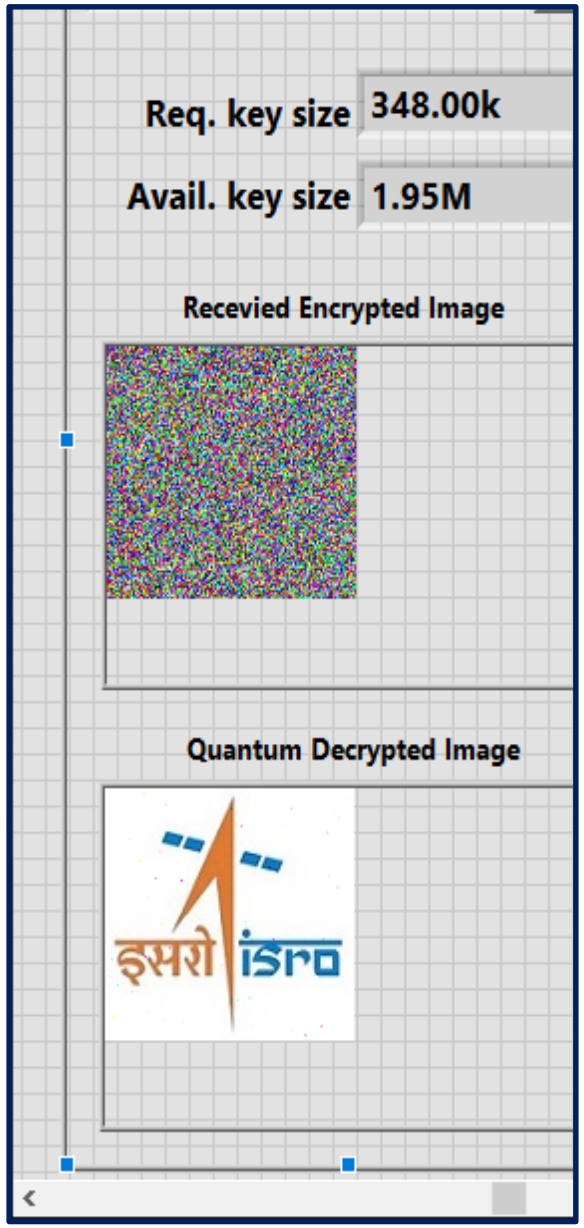
TABLE. BBM92 QKD System
(Demonstrated in November-2021)

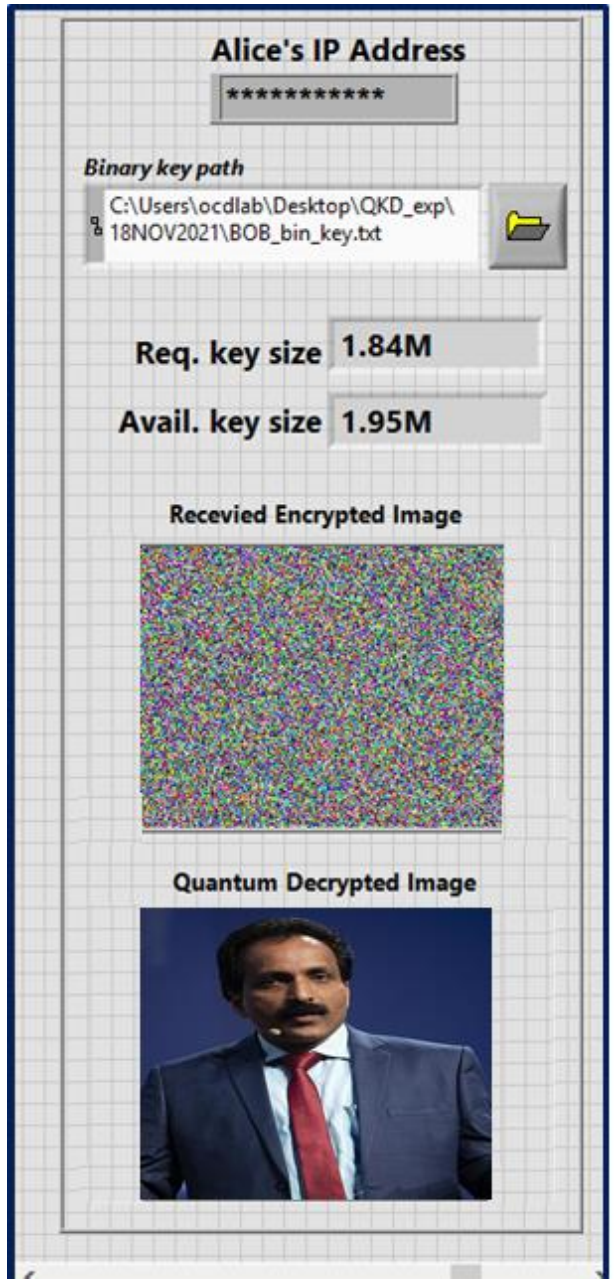
Sr.	Parameters	Measured Results
1.	Source	Entangled photon Pair source
2.	source wavelength	~810 nm
3.	QBER @ 78% Visibility	< 10 %
4.	Sifted Key Rate	4.5 - 5 Kbps
5.	Secure Key Rate	1.3 -1.8 Kbps

Quantum key encrypted Image data transmission and reception

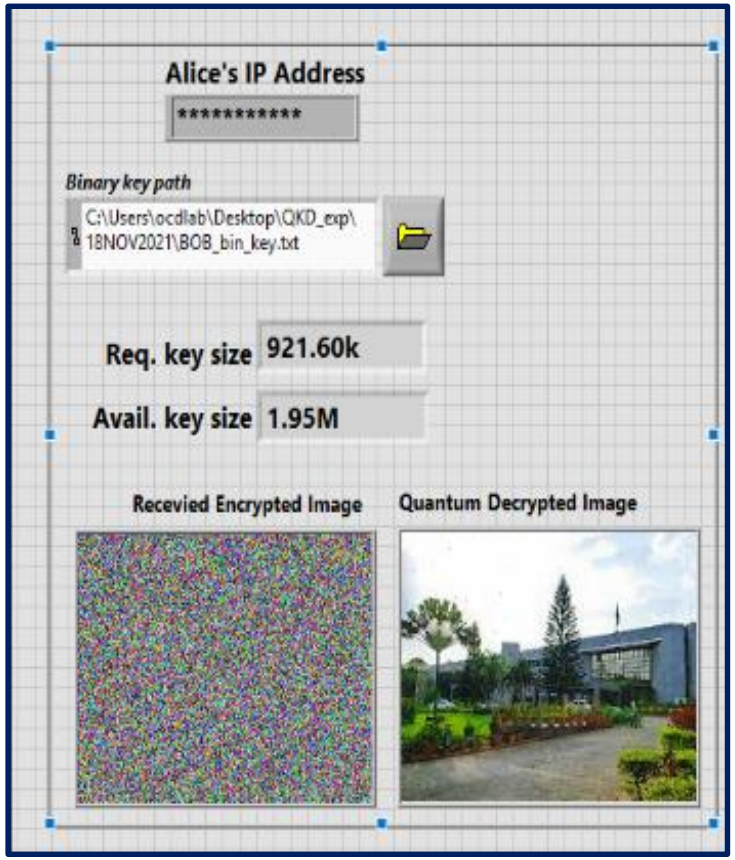








- One time pad (OTP) based encryption



Satellite Based Quantum Communication : Prototype Demo using COTS Technology

QuantESS Payload (Quantum Entanglement studies in Space) onboard POEM-2 on PSLV-C55

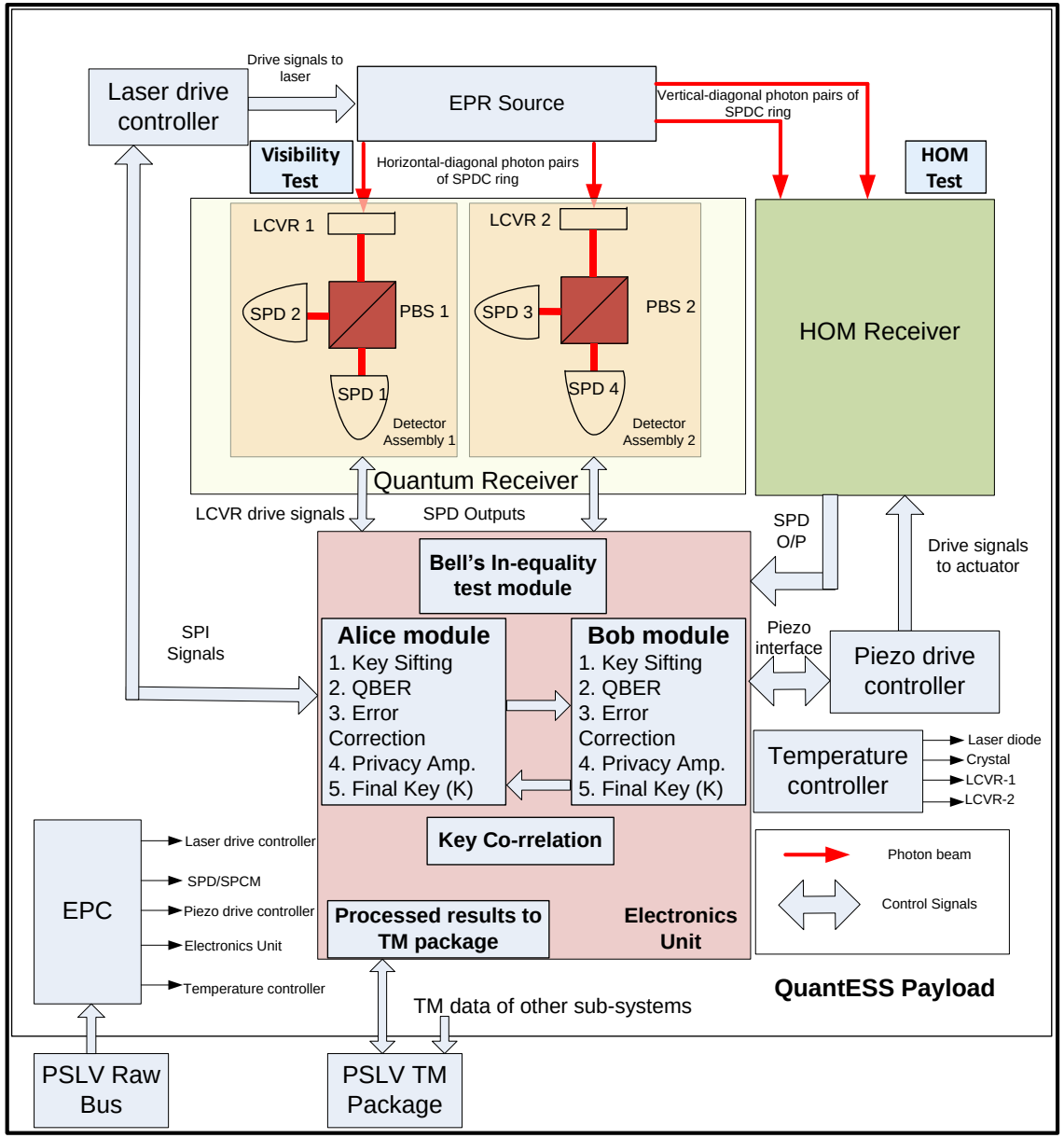
Objectives:

Technology:

1. Development of space worthy entangled photon source and prove its reliability and robustness in space by performing Bell's inequality, Visibility & Hong-Ou-Mandel (HOM) Bench tests.
   - Entanglement Study: visibility test and Bell's inequality violation test
   - HOM interference Experiment: photon indistinguishability test
2. Demonstration of entangled photon source application in space by generating quantum keys using end-to-end entanglement based QKD protocol implementation with limited hardware.
3. Study of impact of space environment on performance of single photon detectors for long mission durations
4. Proving / Evaluating many associated technologies (like a quantum receiver, time tagger, Single-photon detector, LCVR, etc.).

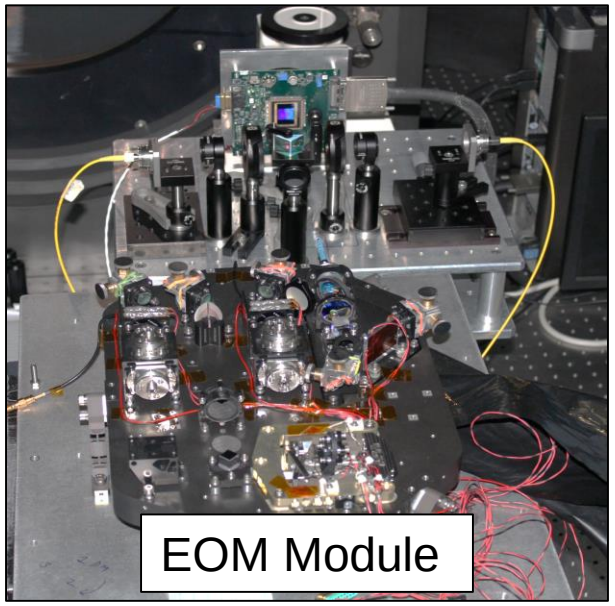
Scientific:

1. Demonstration of HOM experiment under space conditions. This will be the first of its kind experiment and the starting point of a future HOM experiment between two satellites to measure the photon delay due to the space-time curvature.
2. The HOM experiment will also enable us to study the single-photon quality of the entangled photon source required for secure quantum communication.



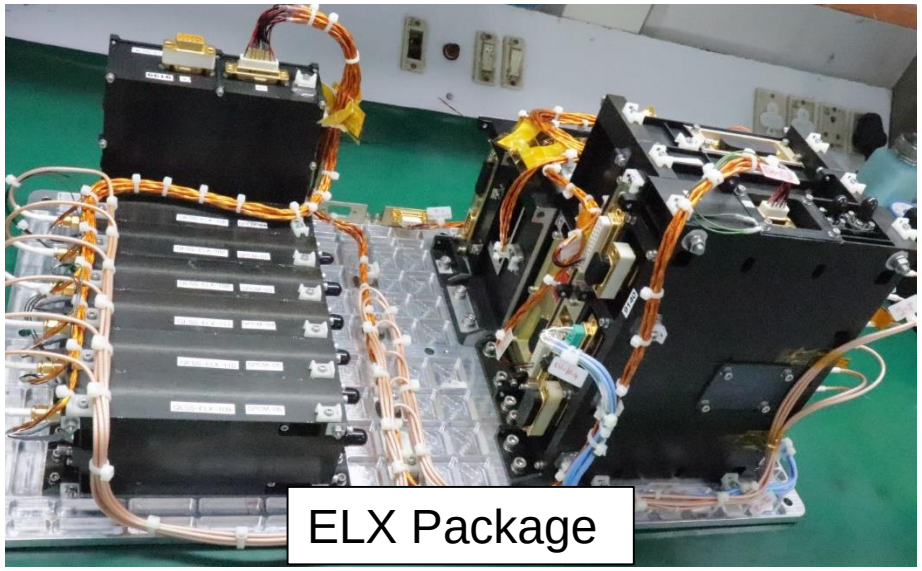
Payload Block Diagram

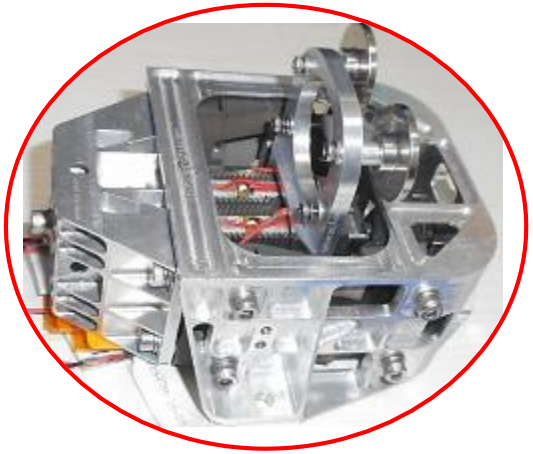
QuantESS Payload onboard POEM-2 on PSLV-C55 (Contd..)


EOM Module

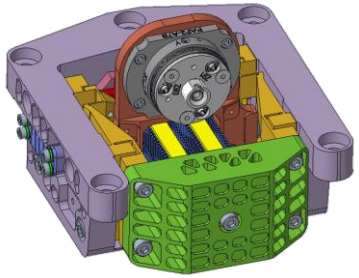
Payload Mass	14.7 Kg
EOMM Mass (Al)	4.5 Kg
EOMM	370x300x150mm
ELX dimensions	500x260x225mm
ELX Mass	9 Kg
Harness Mass	1.2 Kg

Payload Power	134W
PDE_LD	20W
SPCM_EU	58W
Temp. CS	56W

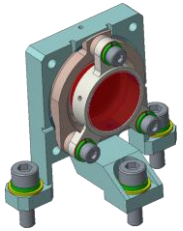

ELX Package


Piezo drive mechanism

Mechanical Amplified Linear Actuator



Gonio Optical Mount




HOM Test using DVM Hardware

Space Segment: QuTDS Payload (Quantum Technology Demonstration in Space)

(Proposed for TDS-01 satellite)

	Objectives
1.	Quantum Random Number Generation (QRNG)
2.	Quantum Cryptography
3.	Optical beacon link from satellite to ground
4.	Quantum key distribution (QKD)

Outcome

- QKD set-up based quantum random bit sequence generation and downlink
- Triggering of pulse laser modules by generated QRNG sequence

Quantum key encrypted data downlink

- Optical beacon link evaluation
- Validation of synchronization methodology for upcoming Satellite based quantum communication.
- Polarisation characterisation with moving satellite platform

Weak coherent source based BB84 protocol

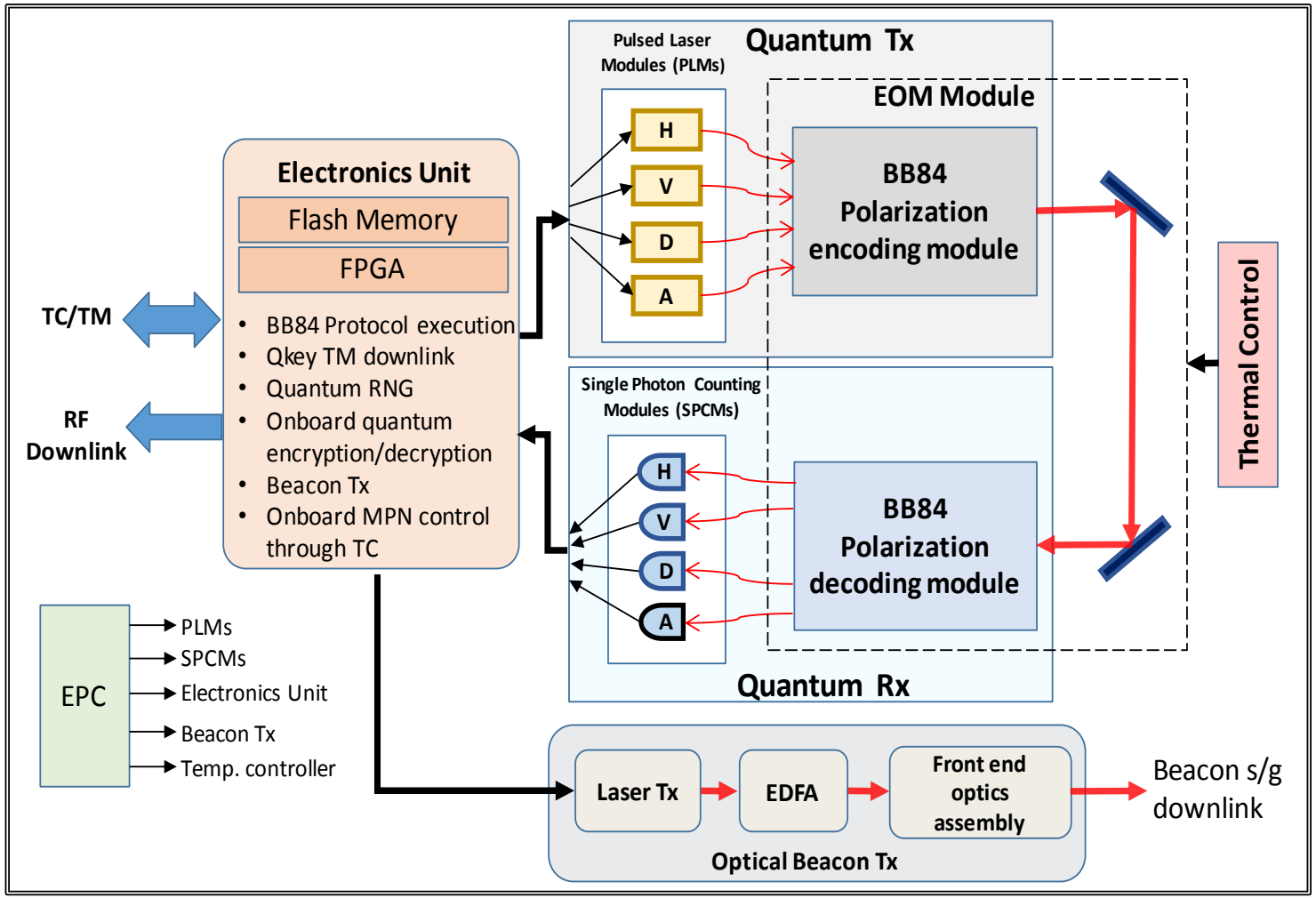
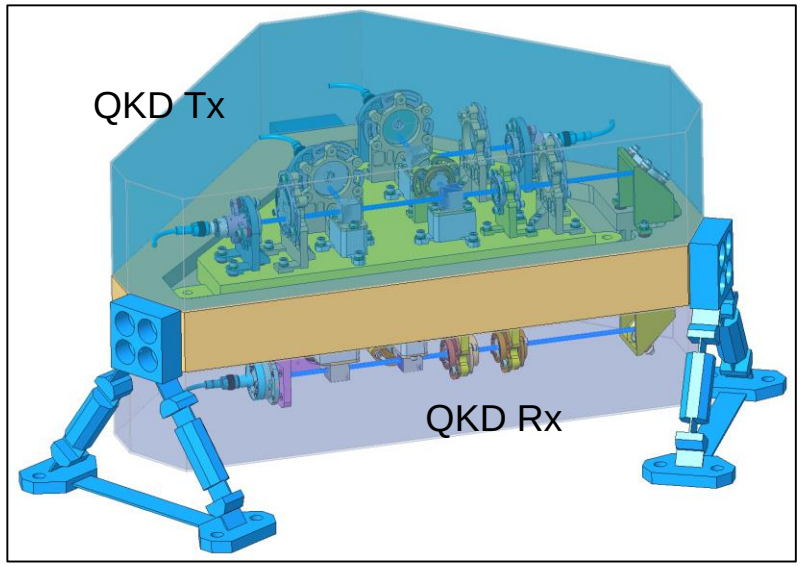
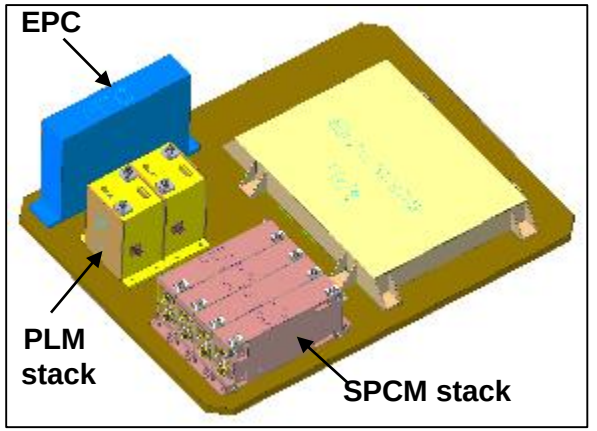


Fig QuTDS Payload Block diagram

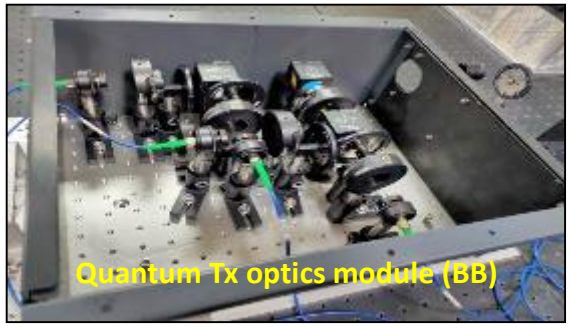
Space Segment: QuTDS Payload (Contd..)

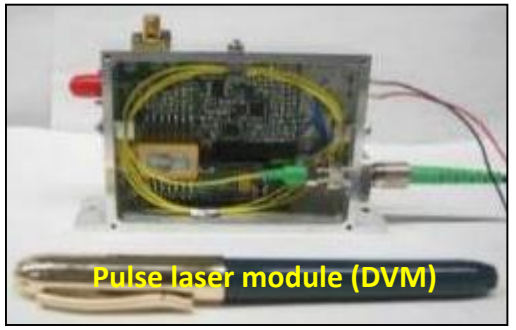


QuTDS Electronics packages



QuTDS EOMM





Developed BB model

Technology Developments @ SAC / ISRO

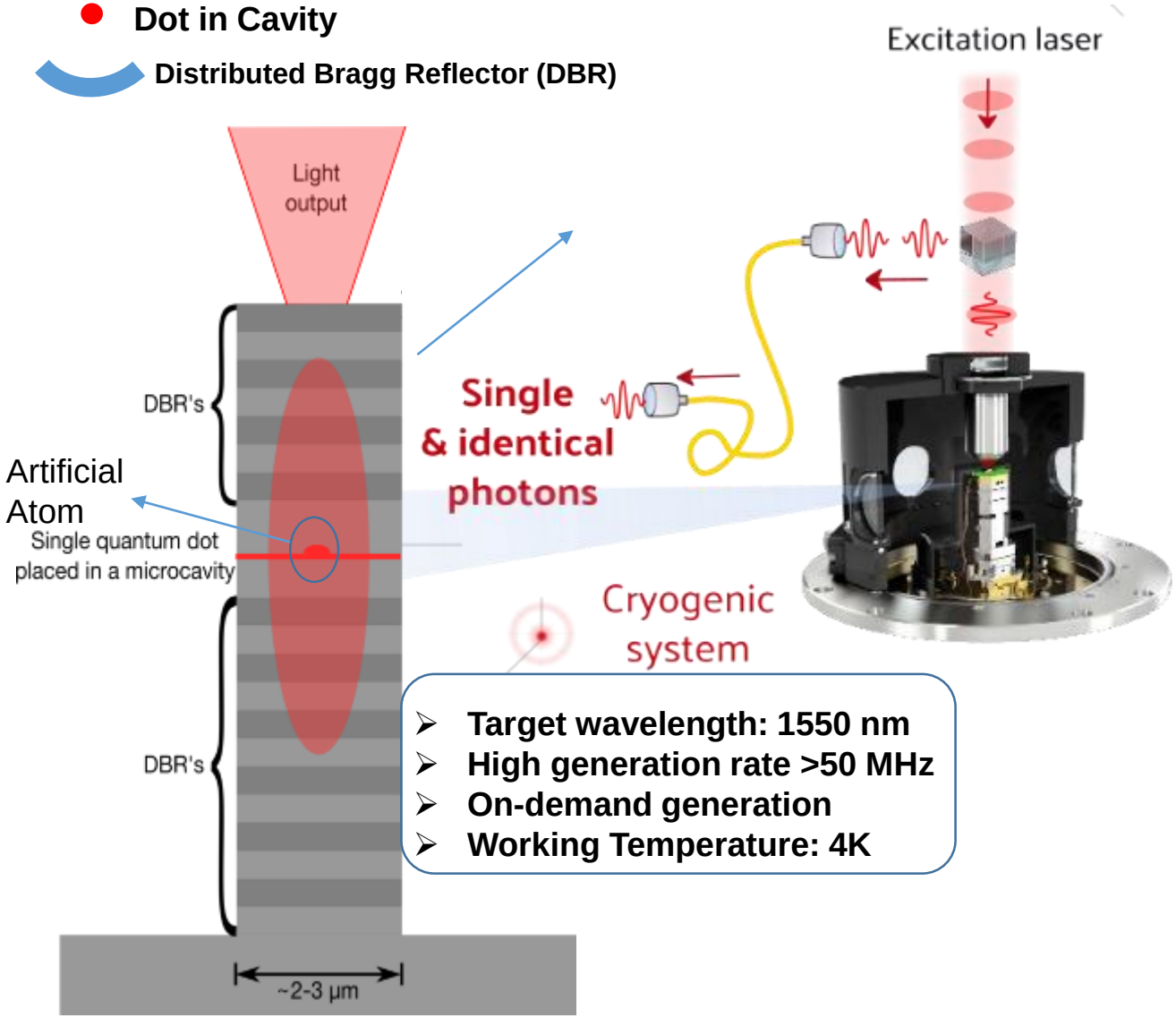
Quantum-Dot Single/Entangled Photon Source and Single Photon Avalanche Detector SPAD development

Quantum Dot + Optical Cavity Electrical Tunable

Distributed Bragg Reflector (DBR)

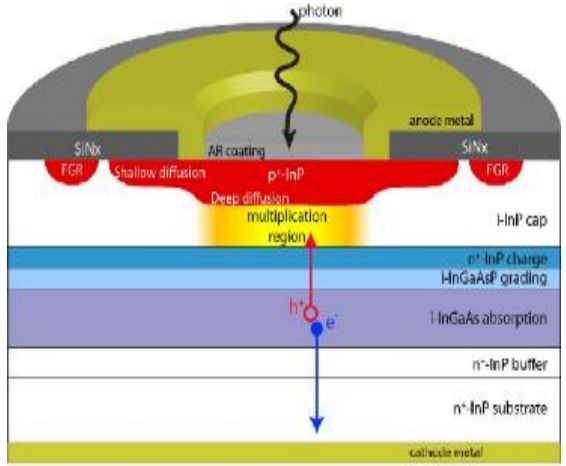
Dot in Cavity

Distributed Bragg Reflector (DBR)



- Target wavelength: 1550 nm
- High generation rate >50 MHz
- On-demand generation
- Working Temperature: 4K

Avalanche Diode- Geiger Mode Operation

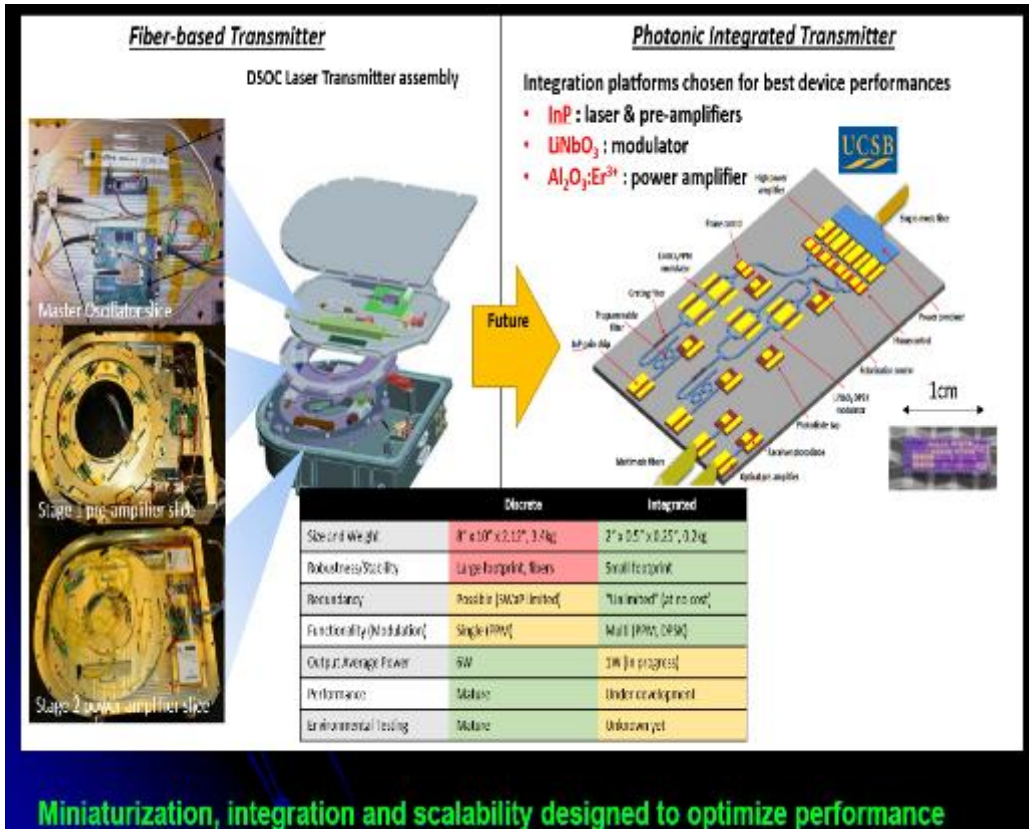


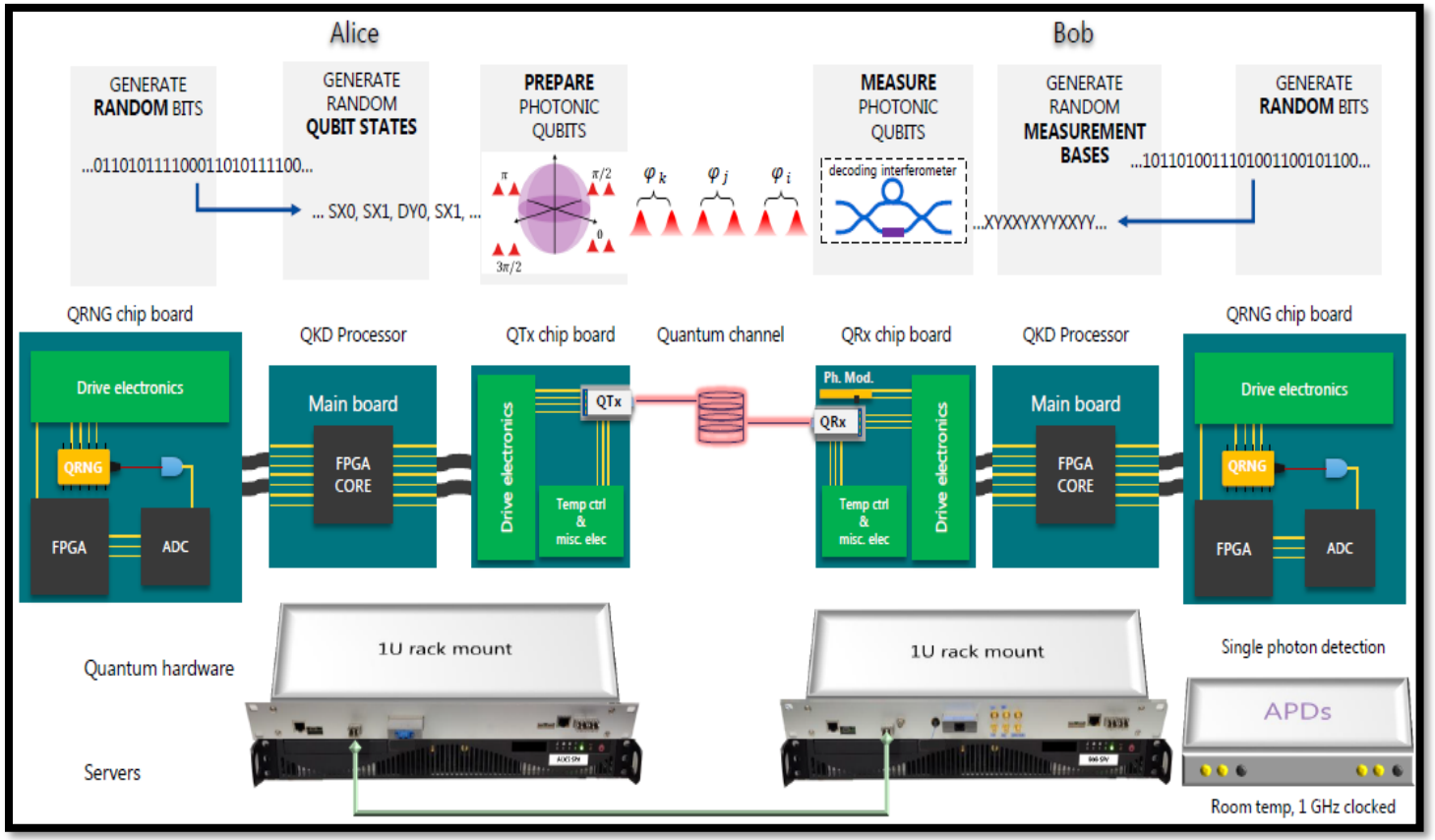
Stack based on $In_{0.47}Ga_{0.53}As$ absorption region

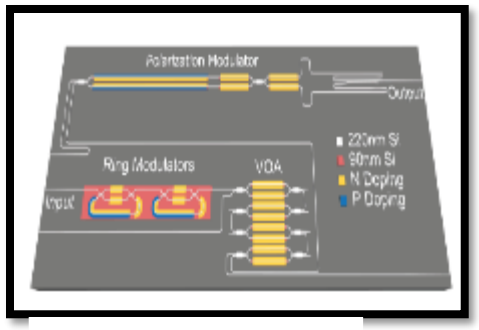
(Ref: 978-1-4577-0733-9/12 IEEE)

- Target wavelength: 1550 nm
- Overall Photon Detection Efficiency: >25%
- Dark Count Rate < 1 KHz
- Jitter Time : <200 ps
- Dead Time: 100 ns

Photonic Integrated Circuit Development





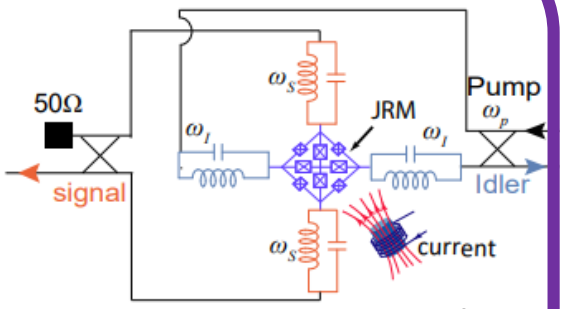


QKD Tx chip

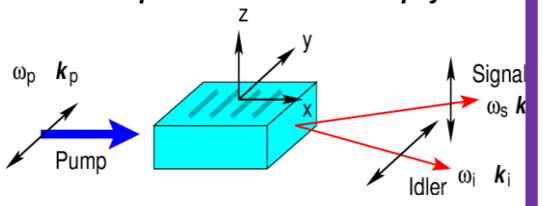
- PIC- Single Chip Integration of multiple optical components
- PIC QKD transmitter chip

Summary of Technologies Involved – SBQC and Quantum Radar

Transmitter

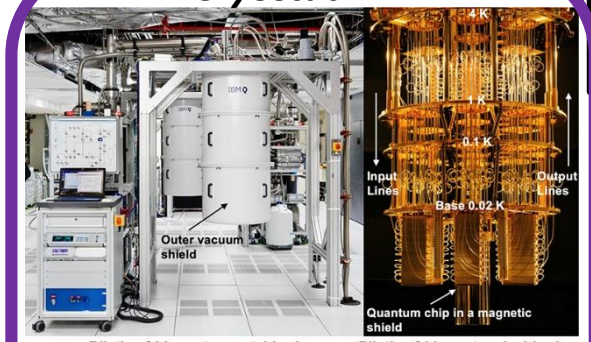


Josephson Parametric Amplifier



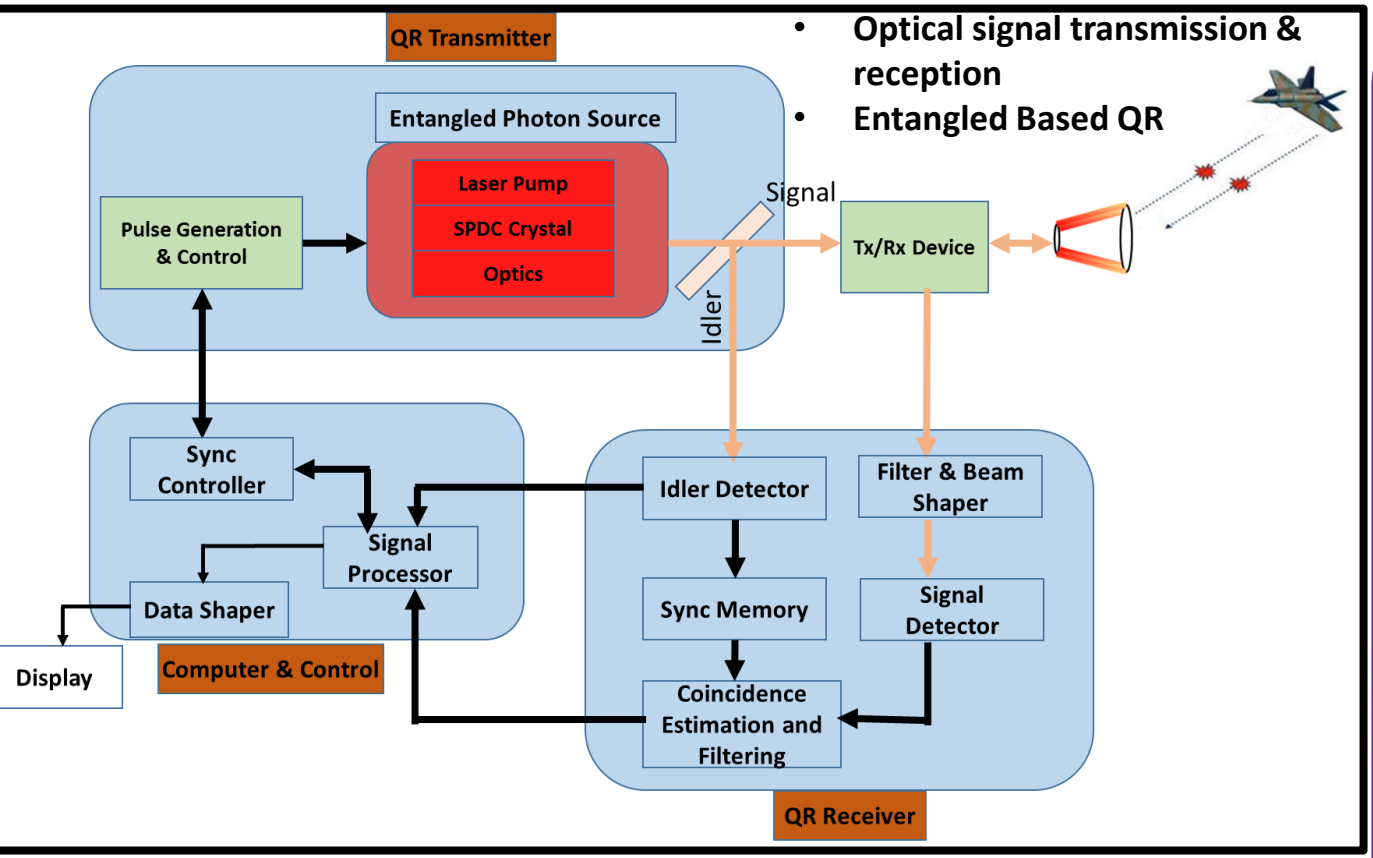
Spontaneous Parametric Down Conversion

Cryostat

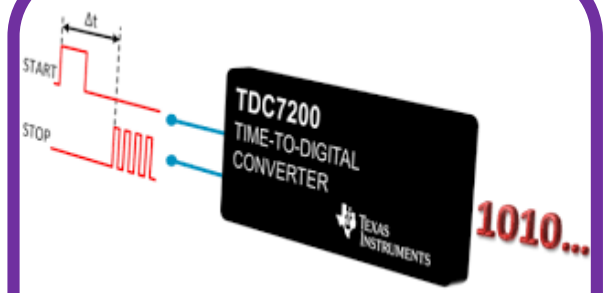


Dilution fridge setup: outside view Dilution fridge setup: inside view

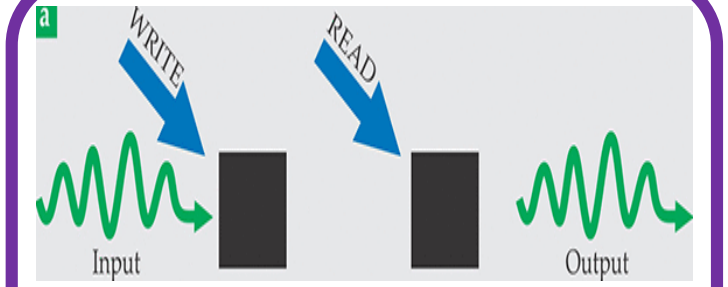
Ref: 'Rising Above the noise: Quantum Limited Amplifiers empowers the readout of IBM Quantum Systems', IBM Research Blog



- Optical signal transmission & reception
- Entangled Based QR

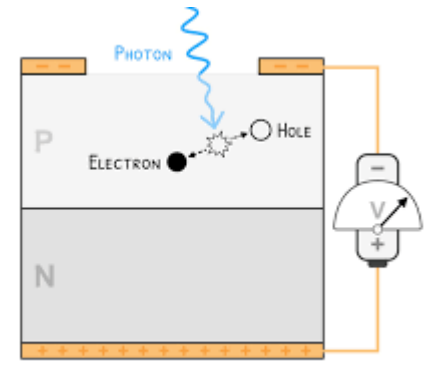


Time to Digital Converter

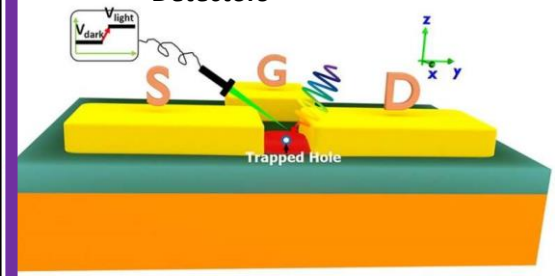


Quantum Memory

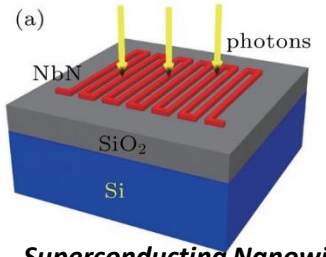
Receiver



Single Photon Avalanche Detectors

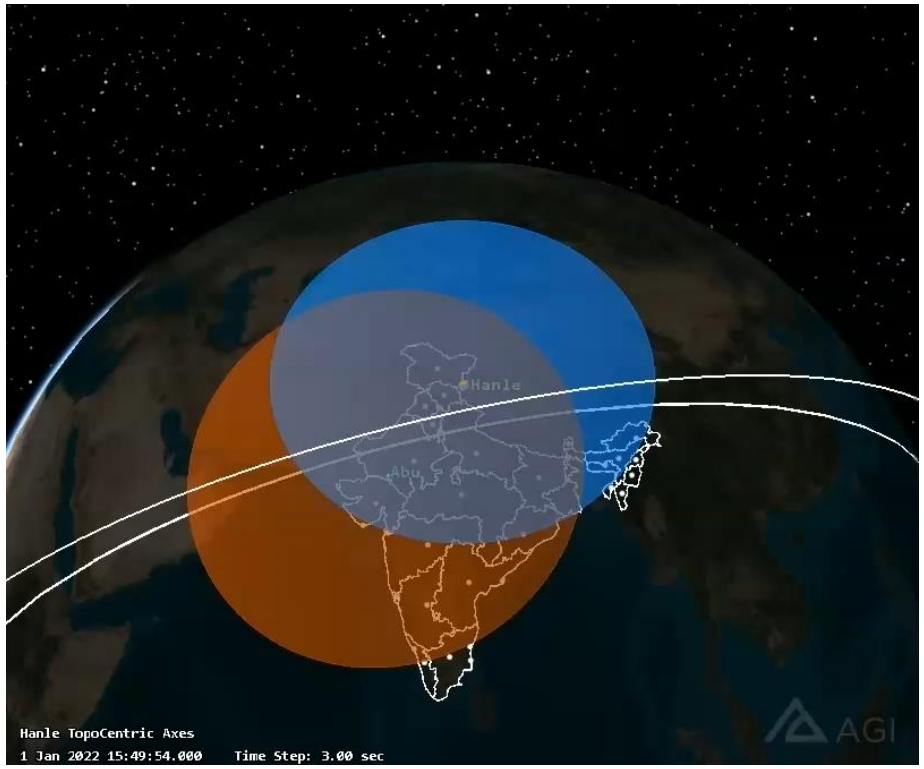


Quantum Dot Based Detectors



Superconducting Nanowire Single Photon Detector

ISRO’s Satellite based Quantum Communication (SBQC) Programme Roadmap



2018	2019	2020	2021	2022 - 23	2023-25	2025-26
R & D Started	QC lab established	Lab demo of QKD sys.	• Inter-building QKD with WCP • with EPS	• Moving platform (Drone) based QKD • QKD Payload in loopback mode	Optical Gnd St. (OGS) OQC program	Integrated satellite to GND QKD network

Opto-Quantum Communication (OQC) Program

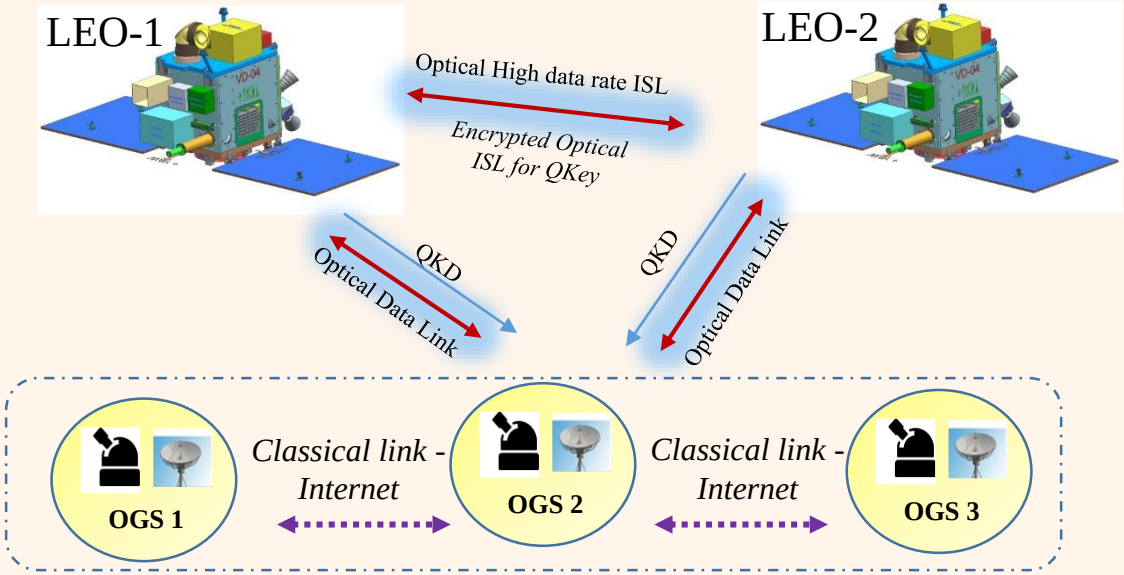
PART-1

Deliverables:

- OQC Terminal on LEO satellite 1 and LEO satellite 2
- Optical Ground stations – 3 nos

Demonstration:

- Satellite based Optical and Quantum Communication between LEO spacecraft and Optical Ground Stations
- High Data Rate Optical Inter satellite link(LEO-LEO)
- Encrypted Optical ISL for QKD (LEO-LEO)



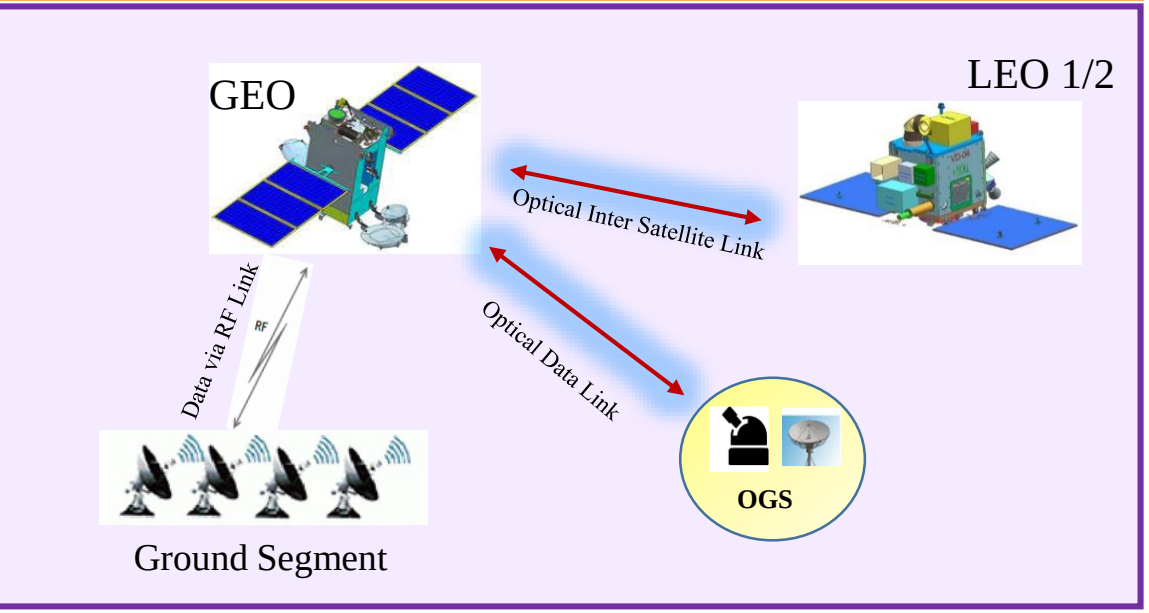
PART-2

Deliverables:

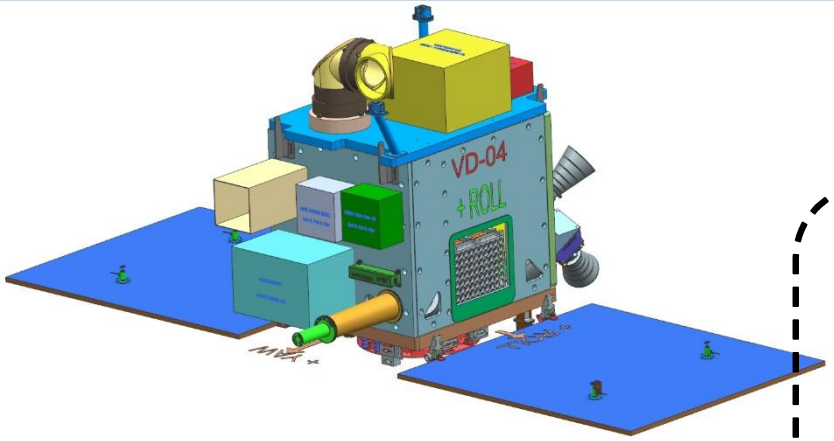
- OC Terminal on a GEO satellite

Demonstration:

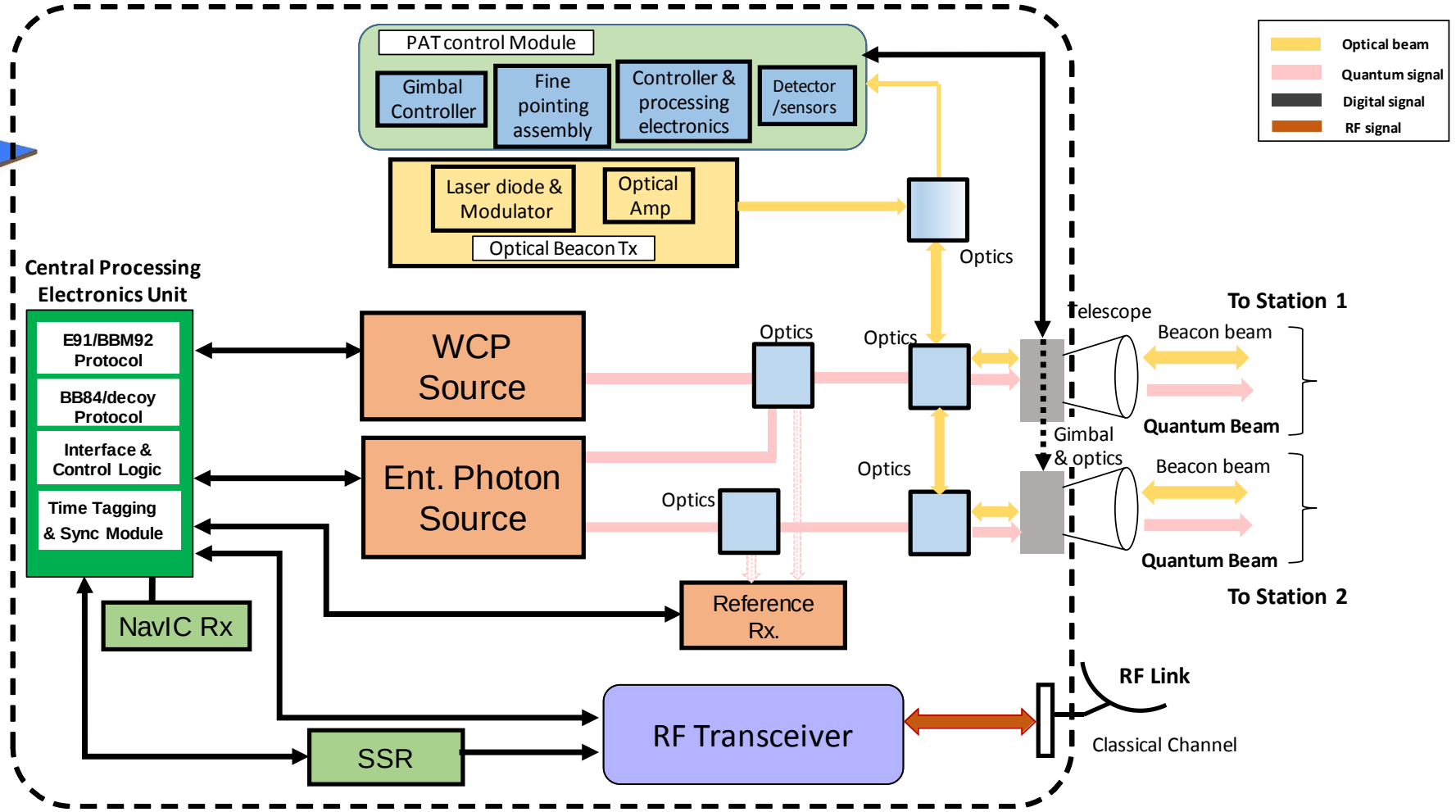
- High Data Rate Optical Inter satellite link(LEO-GEO)
- High Data Rate Optical link(GEO-OGS)
- Satellite Based Optical Data Relay via GEO platform



Opto-Quantum Communication (OQC) Block Schematic

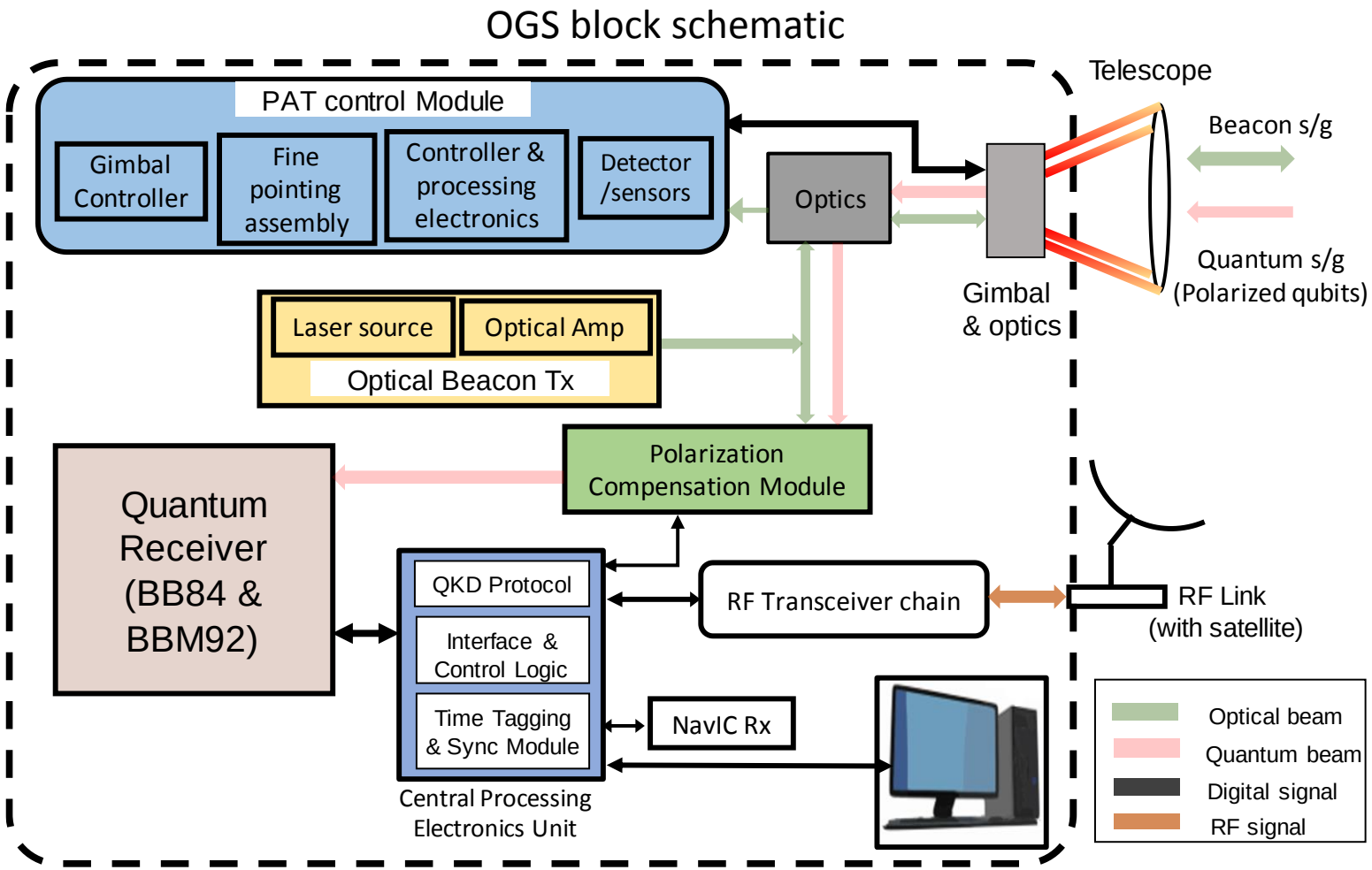


OQC Satellite



Payload Block Schematic

Optical Ground Station (OGS) Block Diagram



OGS site at SAC

SPROC site at Ponmudi

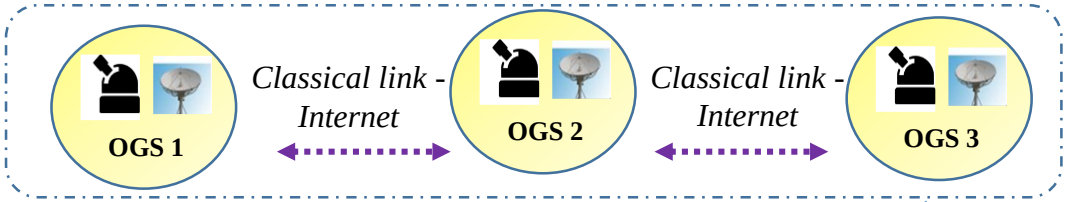
SPROC site at Mt. Abu

Potential OGSs

- Mt. Abu
- Ponmudi
- OGS, SAC, Ahmedabad
- Hanle, Ladakh

Optical Ground Stations (OGS)

- Establishment of new OGS facility at Mt Abu and Hanle locations.
- Augmentation of existing OGS facility at SAC.
- Establishment of new RF ground stations co-located with OGS facility to support classical QKD channels

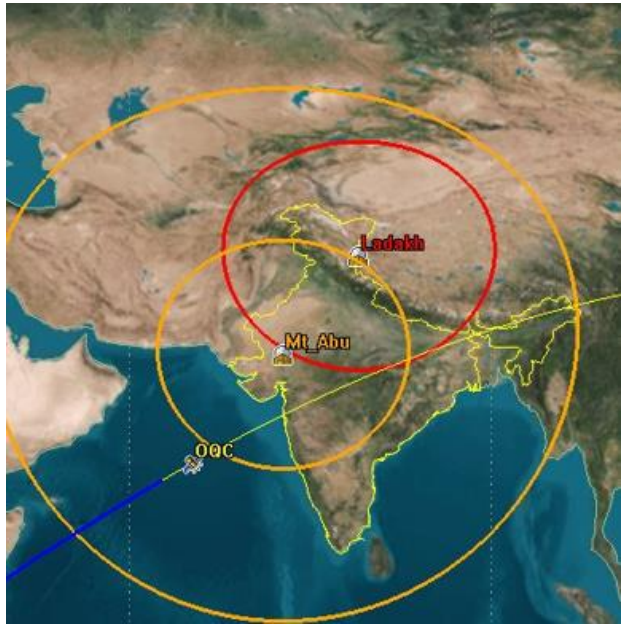


New OGS facility with portable 1m telescope at **Mt Abu & Hanle-Ladakh** along with RF ground station for QKD

Existing SAC,Ahmedabad 700mm Telescope OGS + Augmentation for QKD

1m Portable Telescope (Facility to be established)

Mt.Abu & Hanle location



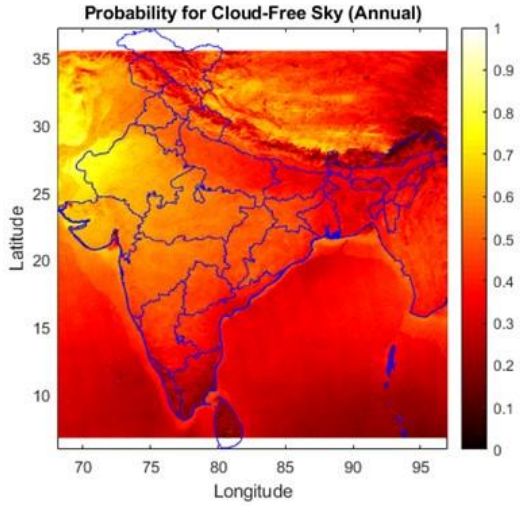
Atmospheric Studied for OGS locations

- Five year (2017-2020) MODIS cloud product is used to estimate monthly & annual maps of probability for station visibility (cloud free) for entire Indian landmass.
- Probability of occurrence (Annual) of cloud-free state at Ponmudi is 21%, while at other 3 OGS, it is >50%.

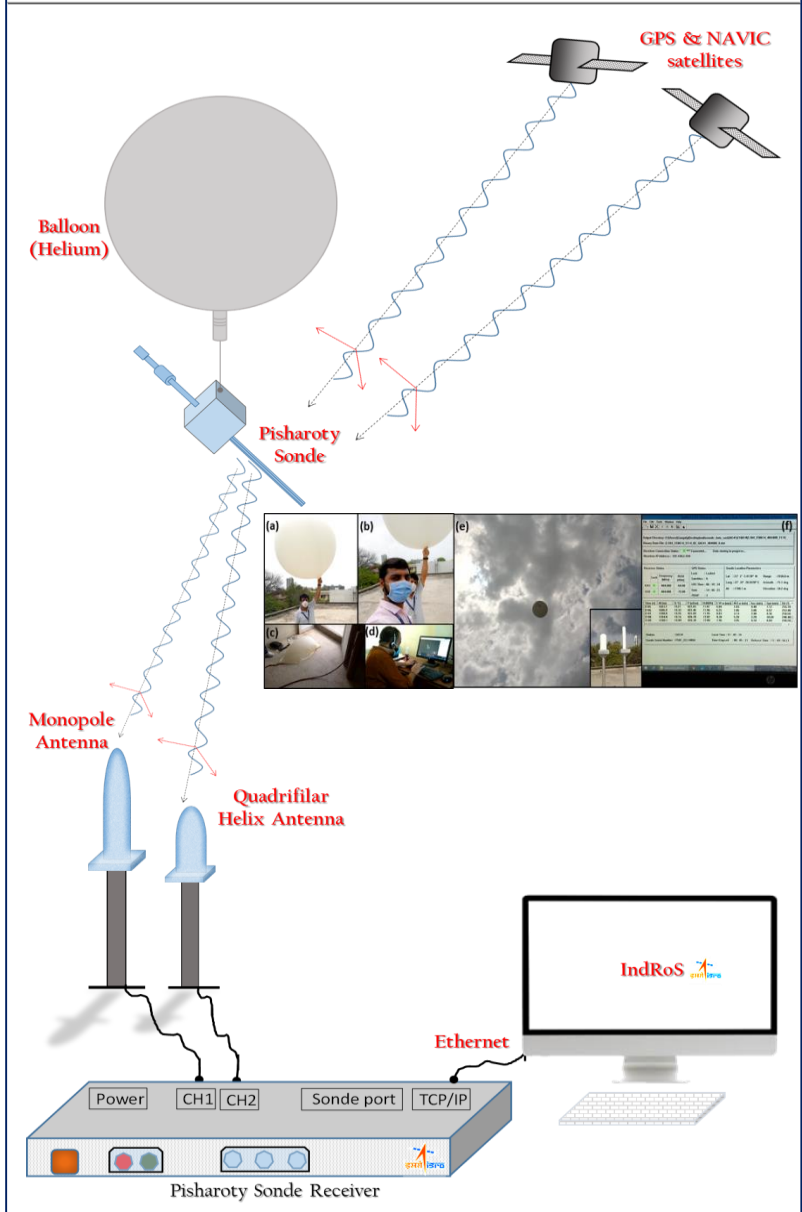
Table-1. Map for the probability for station to be visible (cloud-free) for conducting SBQC.

OGS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Ahmedabad	0.67	0.81	0.88	0.95	0.97	0.34	0.14	0.05	0.22	0.72	0.78	0.61	0.57
Mount Abu	0.83	0.86	0.85	0.8	0.94	0.48	0.2	0.06	0.32	0.73	0.82	0.76	0.62
Ponmudi	0.62	0.71	0.38	0.21	0.07	0.02	0.02	0.01	0.05	0.07	0.19	0.34	0.21
Hanle	0.50	0.47	0.60	0.56	0.51	0.68	0.51	0.51	0.71	0.84	0.65	0.72	0.62

Priority (Cloud free state)
Hanle = Mount Abu (62%)
Hanle = Mount Abu (62%)
Ahmedabad (57%)
Ponmudi (21%)



SAC/ISRO BALLOON FACILITY
DR. PISHAROTY SONDE SYSTEM



Satellite QKD Schemes

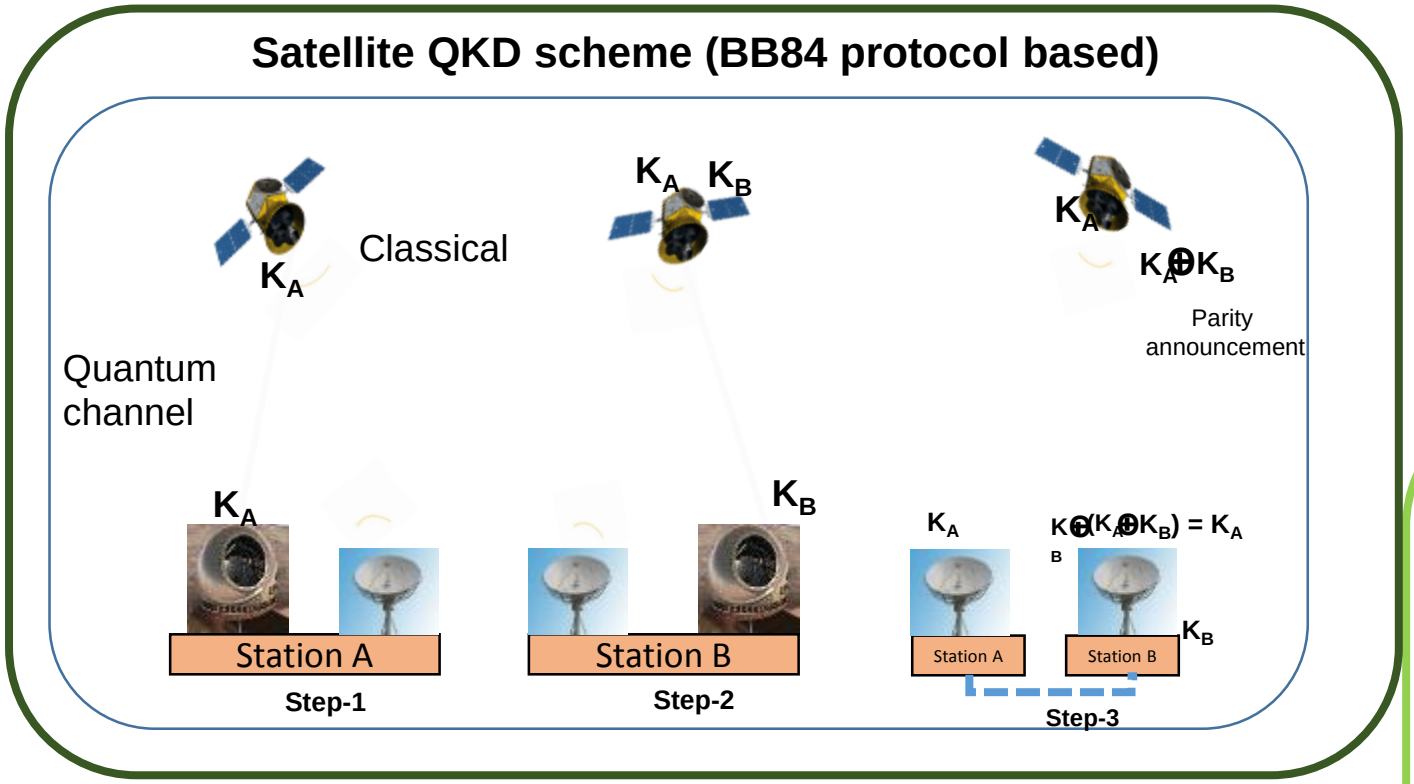


Fig. Single photon based Scheme

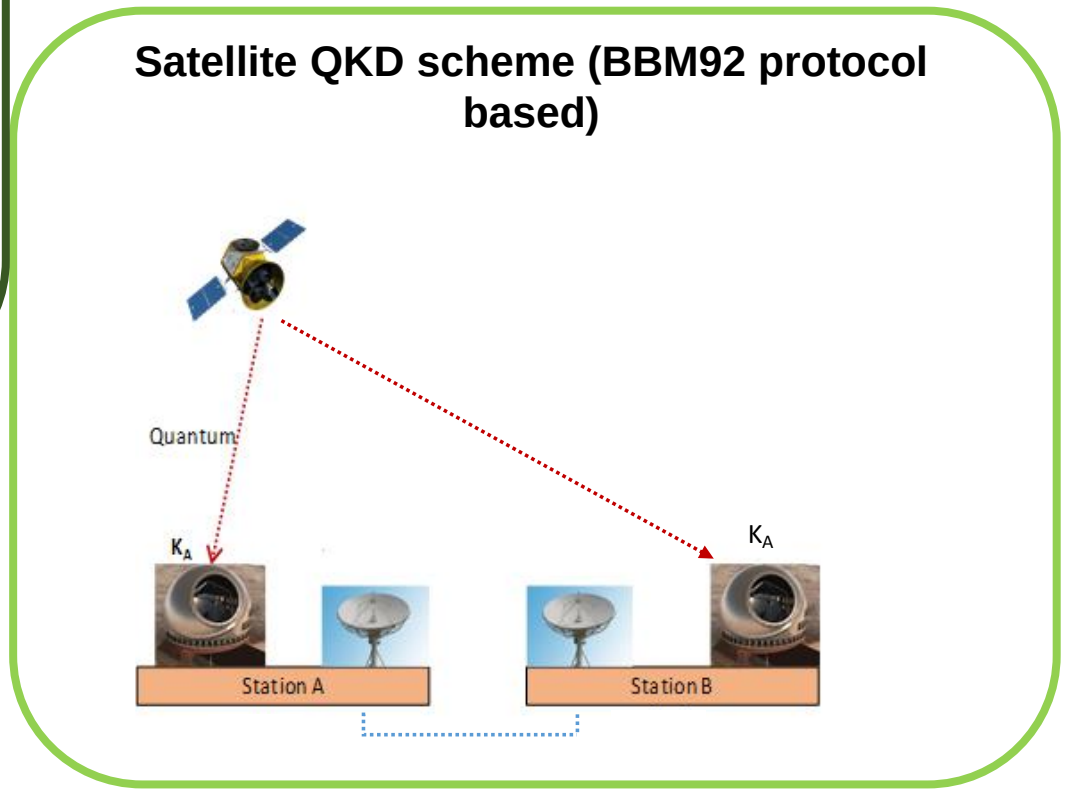
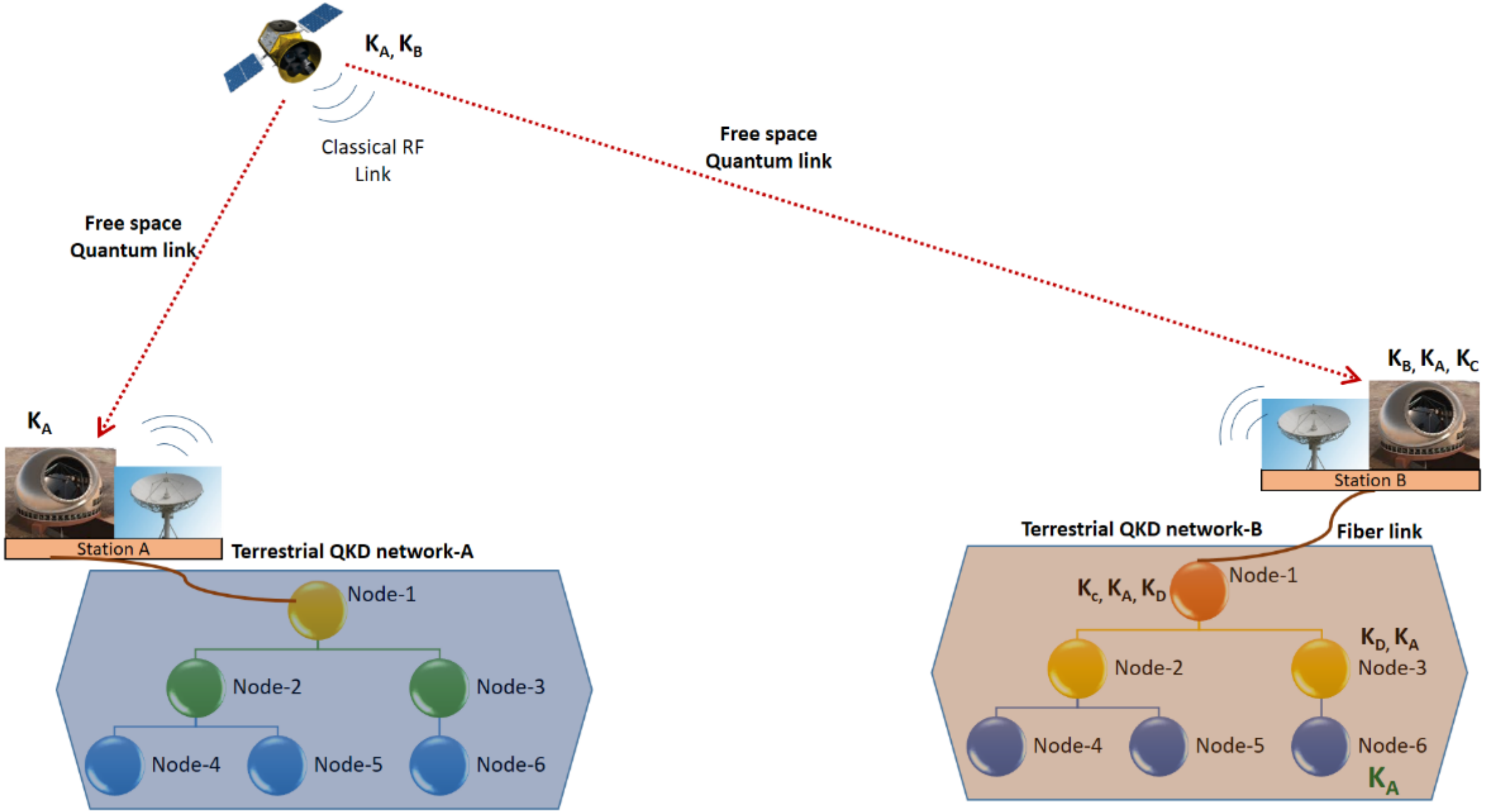


Fig. Entangled photon pair based Scheme

Integrated Satellite and terrestrial QKD Network



THANK YOU

Insanity is doing the same thing, over and over again, but expecting different results.

- Rita Mae Brown

Questions ?

The future depends on what we do in the present.

- Mahatma Gandhi