Adding store and forward features to quantum key distribution space network for secure global and space communications with cubesats

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Background

- For sure, the future “Quantum Internet“, will be based in Quantum Key Distribution (QKD) technique which establishes highly secure keys between two distant points using single photons to transmit each qubit of the quantum key

- Terrestrial QKD networks using fibers optic cables or free-space atmospheric transmission are in operation today, however, truly global distances are still very difficult to achieve for networks based on fiber links and quantum repeaters.

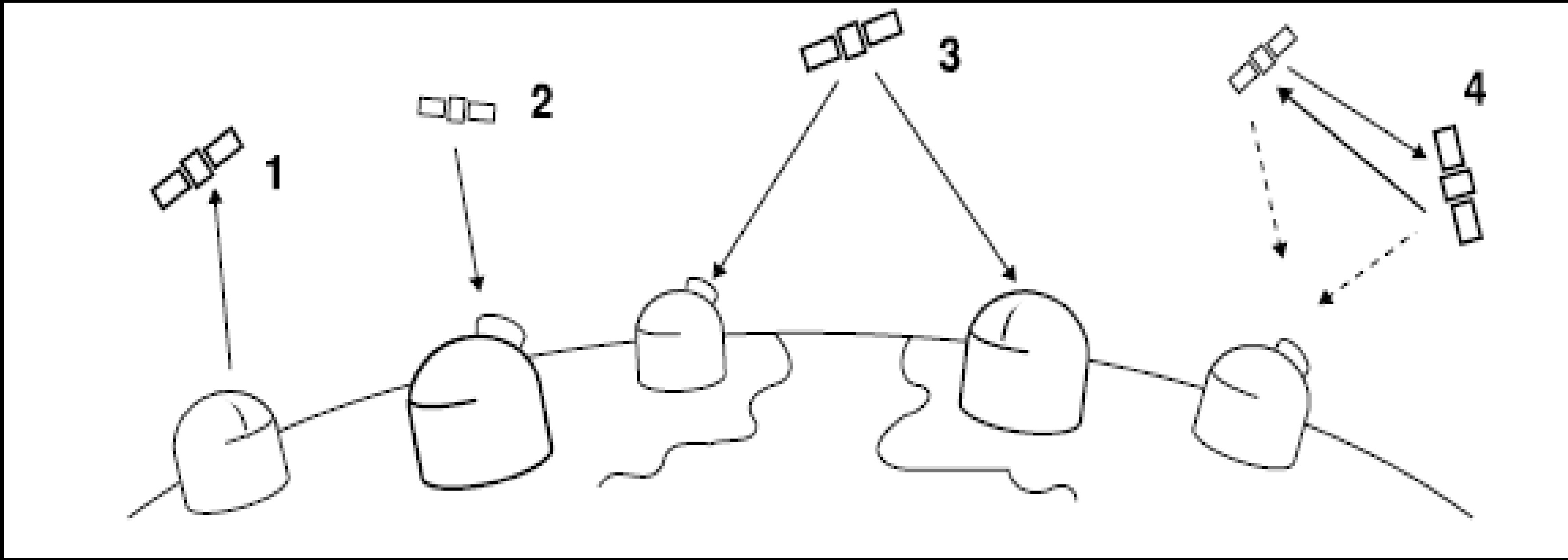
- Satellites in Earth orbit represent the only feasible way using currently technology to provide global distance QKD services. The advantage of quantum communication via satellites is that transmission loss is dominated by diffraction rather than absorption

- By now the most optimistic scenario for terrestrial QKD Network including Quantum Repeaters are distances about 1000 km .

- While very recent results show that a quantum receiver based on satellite links are able to reach 10,000 km

- A new technology has appear in the horizon which introduces the possibility of Quantum Mobile Nodes. This technology uses Quantum Non-Demolition Detectors and a new generation of Forward error corrected Quantum memories

Actual scenarios for QKD in space

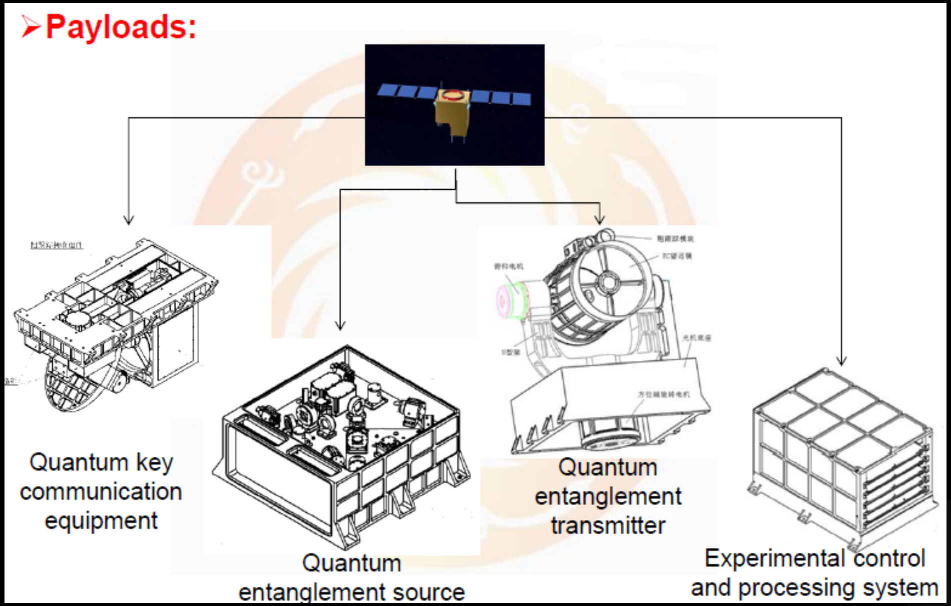


Actual satellite-based QKD implementations goes for:

- 1. Ground-to-space, where the photon source is on the ground and the satellite only carries detectors.
- 2. Space-to-ground, where the satellite carries a source and detectors.
- 3. A platform that can beam down to two ground stations simultaneously.
- 4. Inter-satellite QKD which will be our building block in the future of a larger implementation for secure global and space communications with cubesats.

- Note that all actual scenarios proposed for QKD in Space are line of sight scenarios.
- For Our Proof of concept Mission we will use a mix of scenarios number 1 and Number 2 adding to the satellite store and forward capabilities through quantum memories, and generating a completely new scenario whit no need of line of sight between the 2 Ground Stations and the satellite and only with line of sight between the satellite and each one of them.
- This new scenarios would permit us intercontinental distances for QKD communications.

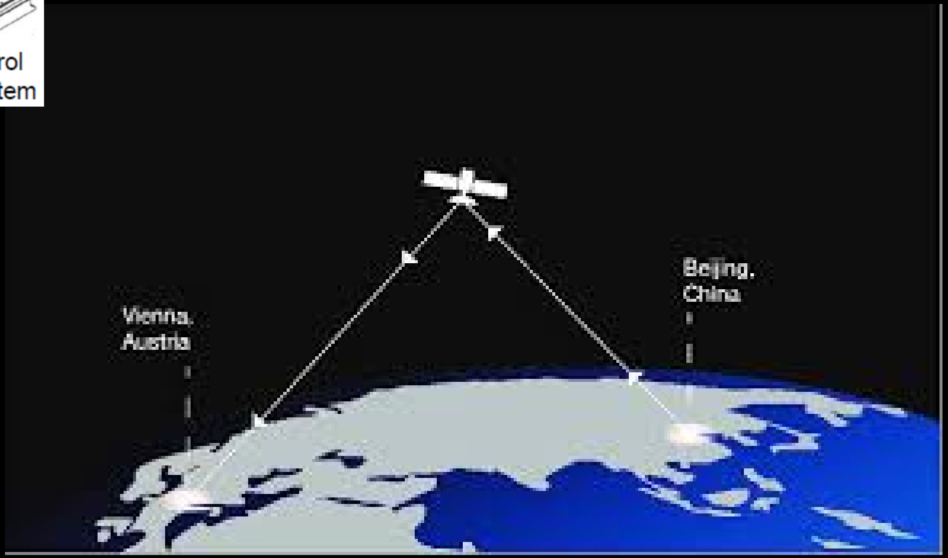
Ongoing Missions: QUESS



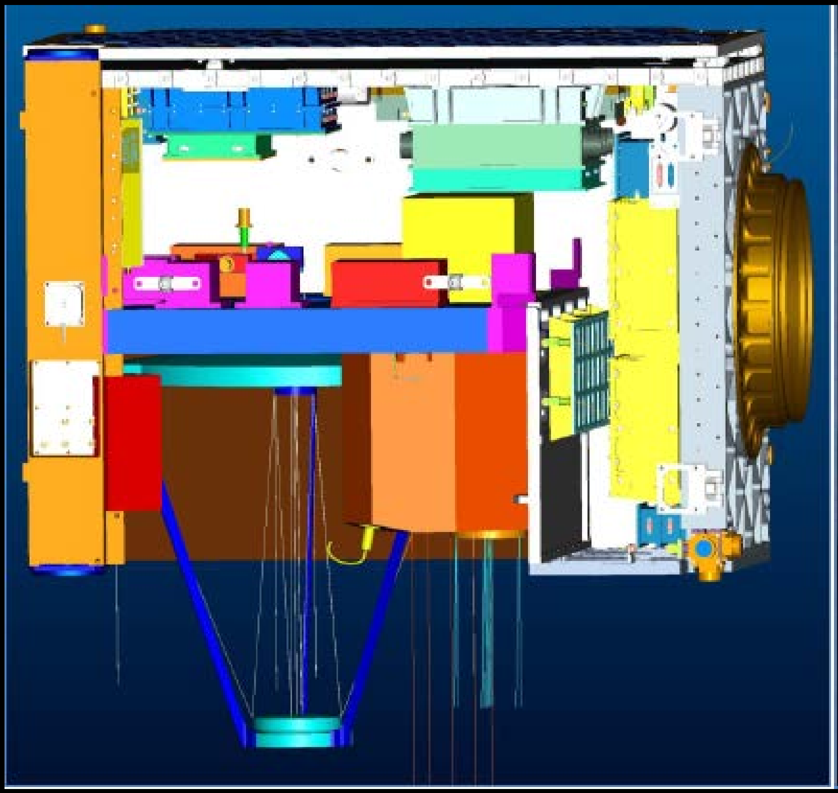
QUESS mission uses a space-based photon source platform that can beam photons down to two ground stations simultaneously on earth to create a QKD channel between the two points, and then perform a bell state measurement (BSM) between them

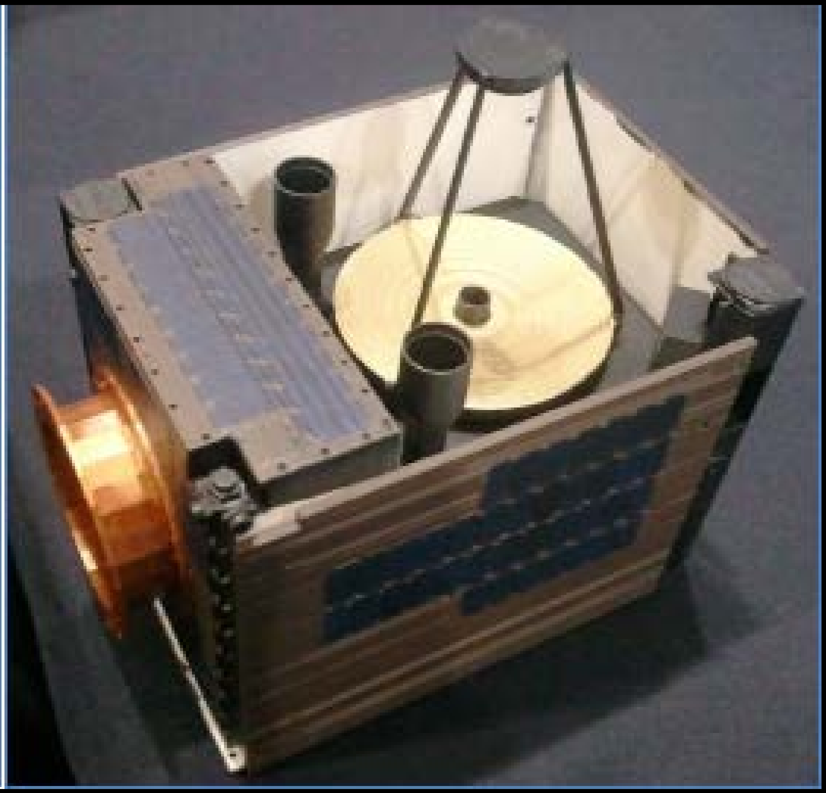
Following this approach QUESS mission has achieved the creation of an "intercontinental" QKD channel of 1200 Km between Beijing and Vienna.

QUESS is clearly non a Nanosatellite mission



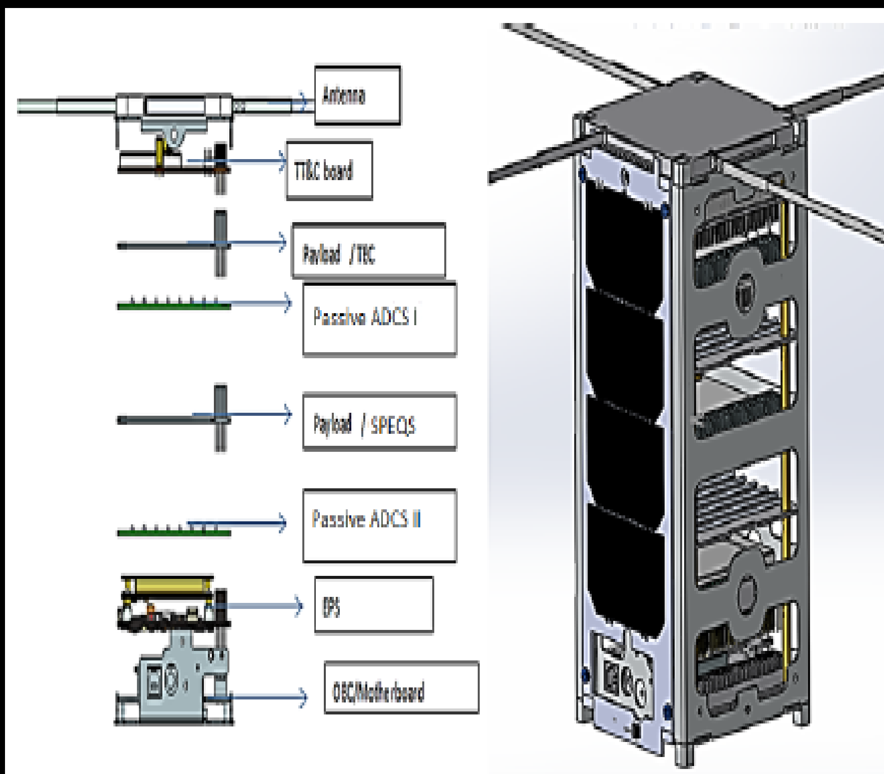
Ongoing Missions: QEYSSat





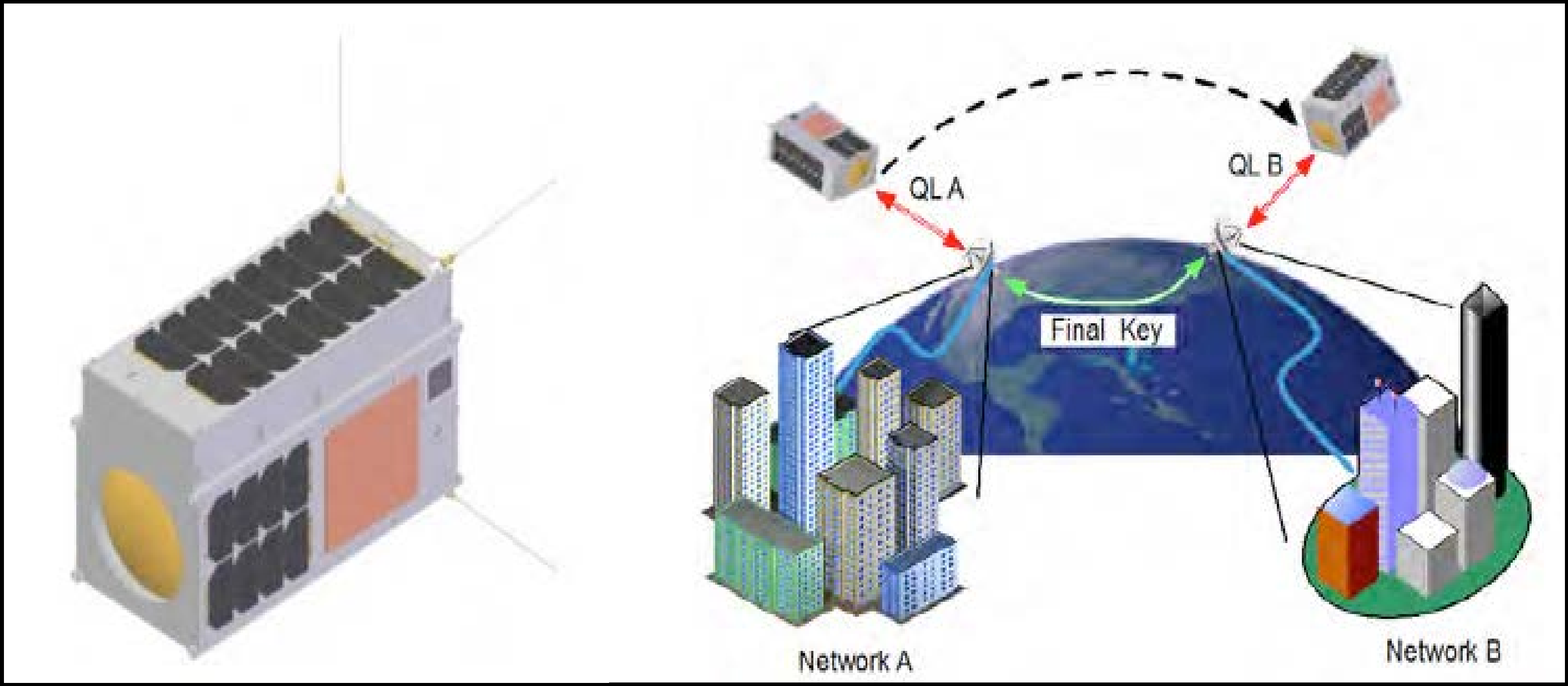
- QEYSSat is a **Mini Satellite** mission demonstration for Global Quantum Key Distribution (QKD)
- The mission is been running by the Canadian Space Agency as major contractor, COM DEV as mission lead, and ICQ as Principal Investigator

Ongoing Missions: SPEQS



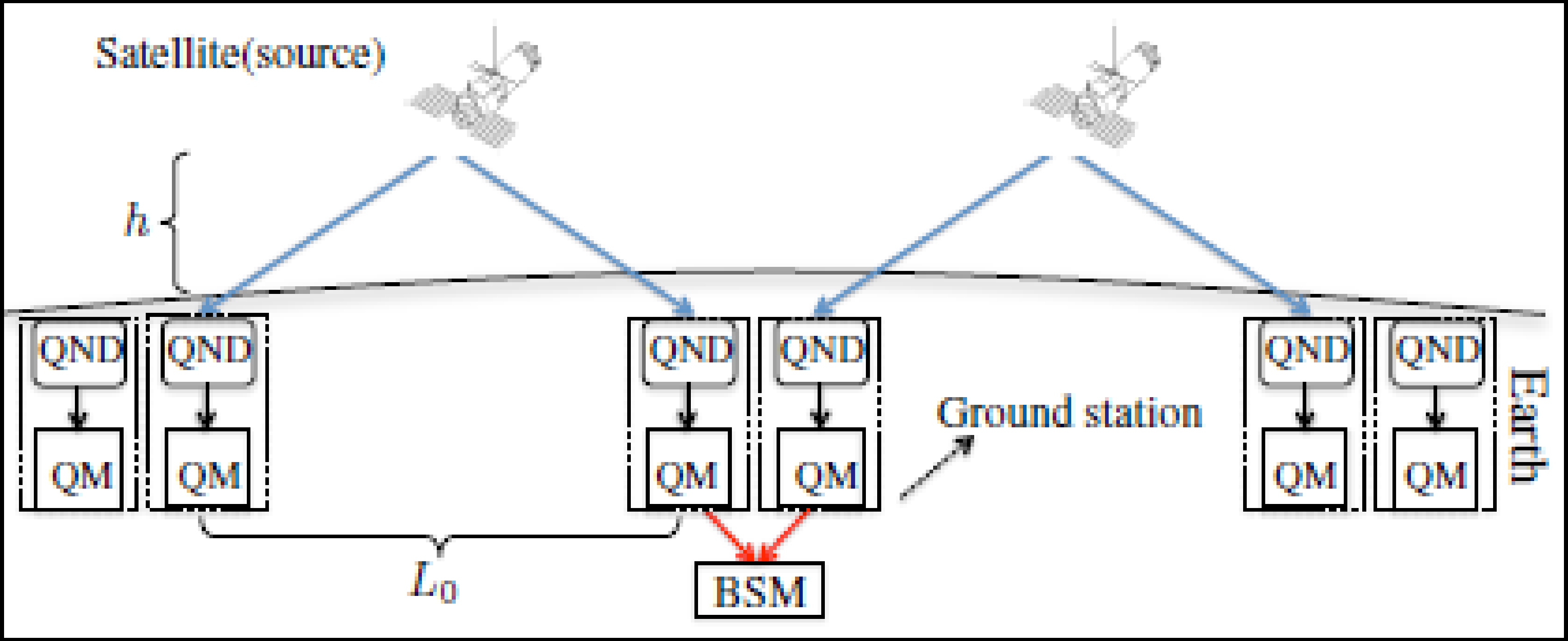
- SPEQS is a nanosatellite (2U) mission for QKD space based network.
- It is a platform that can beam down to two ground stations simultaneously.
- This mission is still in the TRL process
- The first stage is only to deploy small and rugged photon pair sources on a CubeSats, and to verify the operation of the supporting electronics
- No optical link is needed in this mission.
- SPEQS was launched on 16/12/2015

Ongoing Missions: NanoQEY



- NanoQEY is the nanosatellite version of the QEYSSat Mission
- As in our Mission NanoQEY propose quantum communication only between Satellite and Ground Station but NanoQEY do not consider Quantum Memory in the Satellite, it will use bolean operations and classical channels to distribute QKD.

Canadian-Australian Global QKD Satellite Network Architecture proposal.



Proposed quantum repeater architecture with satellite links. Each elementary link (of length L0) consists of an entangled photon pair source on a low-earth orbit satellite (at height h), and two ground stations consisting of quantum non-demolition (QND) measurement devices and quantum memories (QM). The successful transmission of entangled photons to each ground station is heralded by the QND devices, which detect the presence of a photon nondestructively and without revealing its quantum state. The entanglement is then stored in the memories until information about successful entanglement creation in two neighboring links is received. Then the entanglement can be extended by entanglement swapping based on a Bell state measurement (BSM). Calculations shows that 8 such links are sufficient for spanning 20000 Km.

The QAS-EXA "QSNet Space Program"

- Review of the state of the art low Earth orbit satellite quantum communication gives us the big picture necessary to develop the proposal of our QSNet Space Program.
- This proposal will be aligned with the major policy of our institutions:
  - Democratization of space technologies.
  - Develop of high efficient technology at a very low price to make it reachable for developing countries.
- We will clearly choose the nanosatellite technology to implement our mission, reduce budged and fulfill our philosophy, in this line we find two major feasibility obstacles even with the best optical mission proposal (Quantum Repeaters + Satellite Links):
  - first the only mission that have successfully deploy a practical source of entangled photons in space until now is the Chinese QUESS, and it is clearly not a nanosatellite mission, the second mission that proposes an entangled photon source on space, the SPEQS mission, is a nanosatellite mission, not withstanding is still in the process of achieve the necessary technological readiness level (TRL).
  - Second: even with a cheap and affordable nanosatellite quantum source, we still have a budged obstacle due to the operational costs, because in the most optimistic scenario we will need at least 8 ground stations and operations center on the Earth to operate a global QKD Network. This make this project only feasible for major telecom and satellite operator worldwide, leaving behind the emerging actors and developing countries in this field.
- Even more, the use of telescopes as ground stations of approximate 1,5-2m diameter and a system of optical fine pointing in the satellite, lead us to nanosatellites with dimensions like 40x26x20 cm3, at least, and this is not the scope of our work.
- We propose a major technological shift to approach the problem; this is the change of the frequency for the Quantum Chanel from optical domain to Radio Frequency Domain, specifically Microwaves in the X Band. This major technological approach permit us to solve not only the miniaturization of our spacecraft but also the miniaturization of the ground station, with the lower price that all that implies.
- Additional to all of this, our system will add store and forward facilities to the satellites using Quantum Non Demolition Detectors (QND) and Radio Frequency Quantum Memories (RFQM), and a *sneakernet approach* for quantum networks
- This will create Mobile Nodes in the space to transport entangled RF Photons from one place on Earth to a totally different location even in non-line of sight scenarios as we will see.

QSNet Space Program Milestone

YEAR	MILISTONE	LOCATION
2017	Payload Technology Maturation	QAS Laboratories
2017	Ground Station Technology Maturation	QAS Laboratories
2018-2021	Proof of Concept Mission	Low Earth Orbit
2022-2026	QSNet Deploy	Low Earth Orbit

QSat Mission Statement

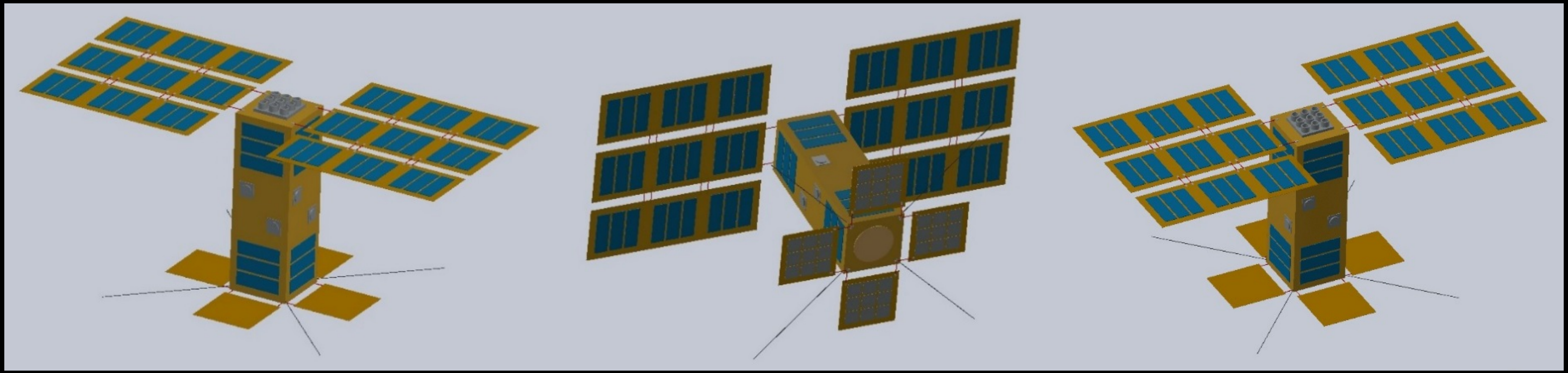
The QSAT (Quantum Satellite) is a Proof of Concept nanosatellite mission developed by Quantum Aerospace Research Institute (QAS) and the Ecuadorian Civilian Space Agency (EXA), which would demonstrate quantum entanglement between intercontinental distances by using a Mobile Quantum Repeater in Space.

The quantum channel will be established with micro wave technology. The QSAT mission will also count with a QKD protocol which includes timing analysis, basis reconciliation, error corrections and privacy amplification, this QKD protocol will use classical channels for transmission, and would enable QKD transmission between the two ground stations.

QSat Mission Objectives

- Transmit an entangled RF photon from Ground Station 1 to QSat Satellite.
- Store the transmited RF photon from Gound Station 1 in the QSat Quantum Memory
- Transmit the entangled RF photon from QSAT Quantum Memory to Ground Station 2.
- Perform a Bell State Measurement between RF photons stored in Ground station 1 and Ground Station 2.
- Distribute QKD Keys between Ground Station 1 and Ground Station 2.
- Perform scientific experiments of quantum teleportation between Ground Station 1 and Ground Station 2.

QSat Mission Architecture



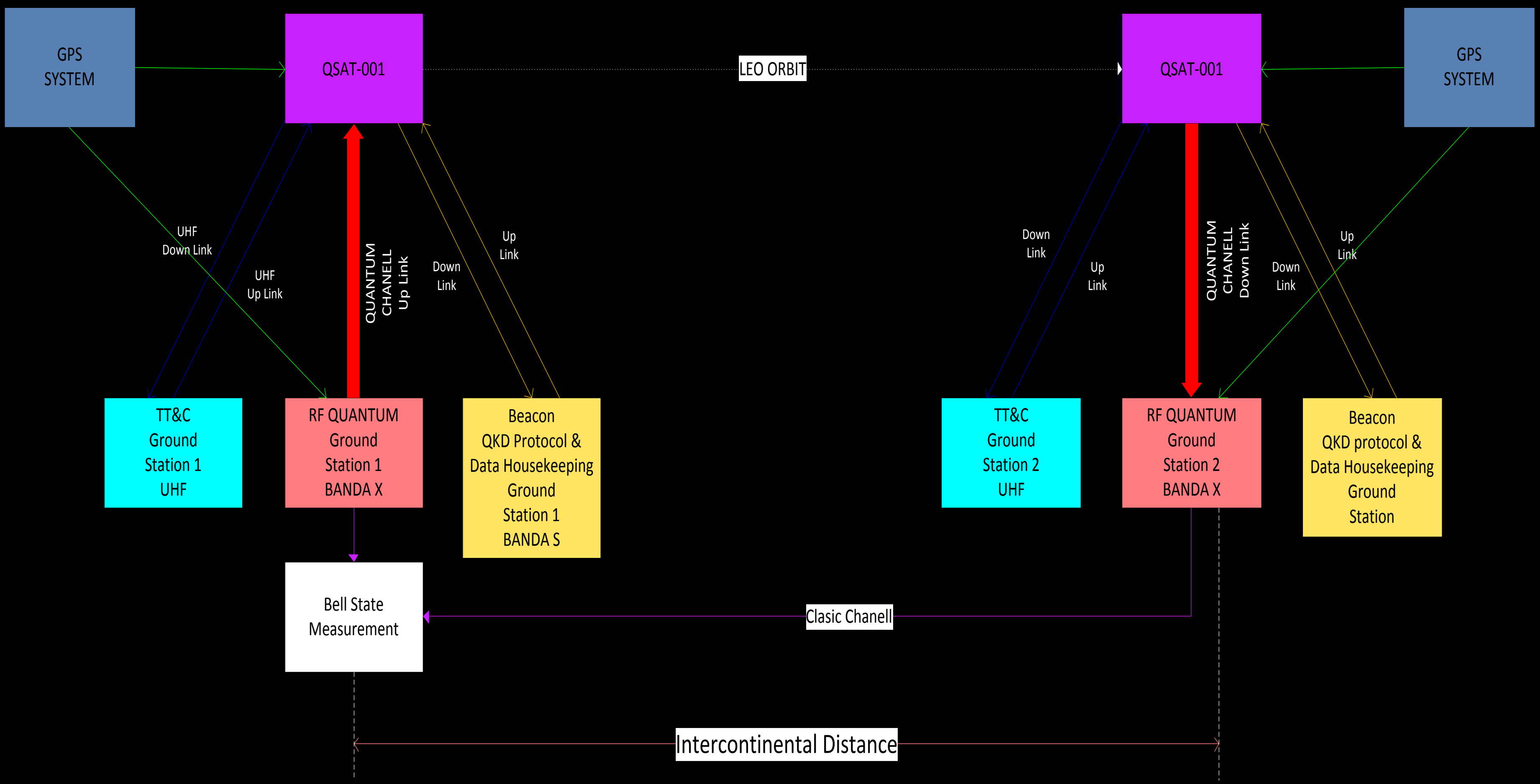
The conceptual design of the space craft was achieved using the PEGASUS Class technology of the Ecuadorian Civilian Space Agency (EXA), that include on board computer and radios, GPS receiver system, IMU system, high capacity batteries, etc. with this technology the QSAT would be developed in a standard 3 cube sat U package of 10x10x30 cm3.

The compound deployable solar array (DSA/3A) with six 3U solar panels will generate a peak power generation of 100.8 Watts, and the high capacity battery banks have a total nominal capacity of 427.2 Watts, having ample power to perform in eclipse.

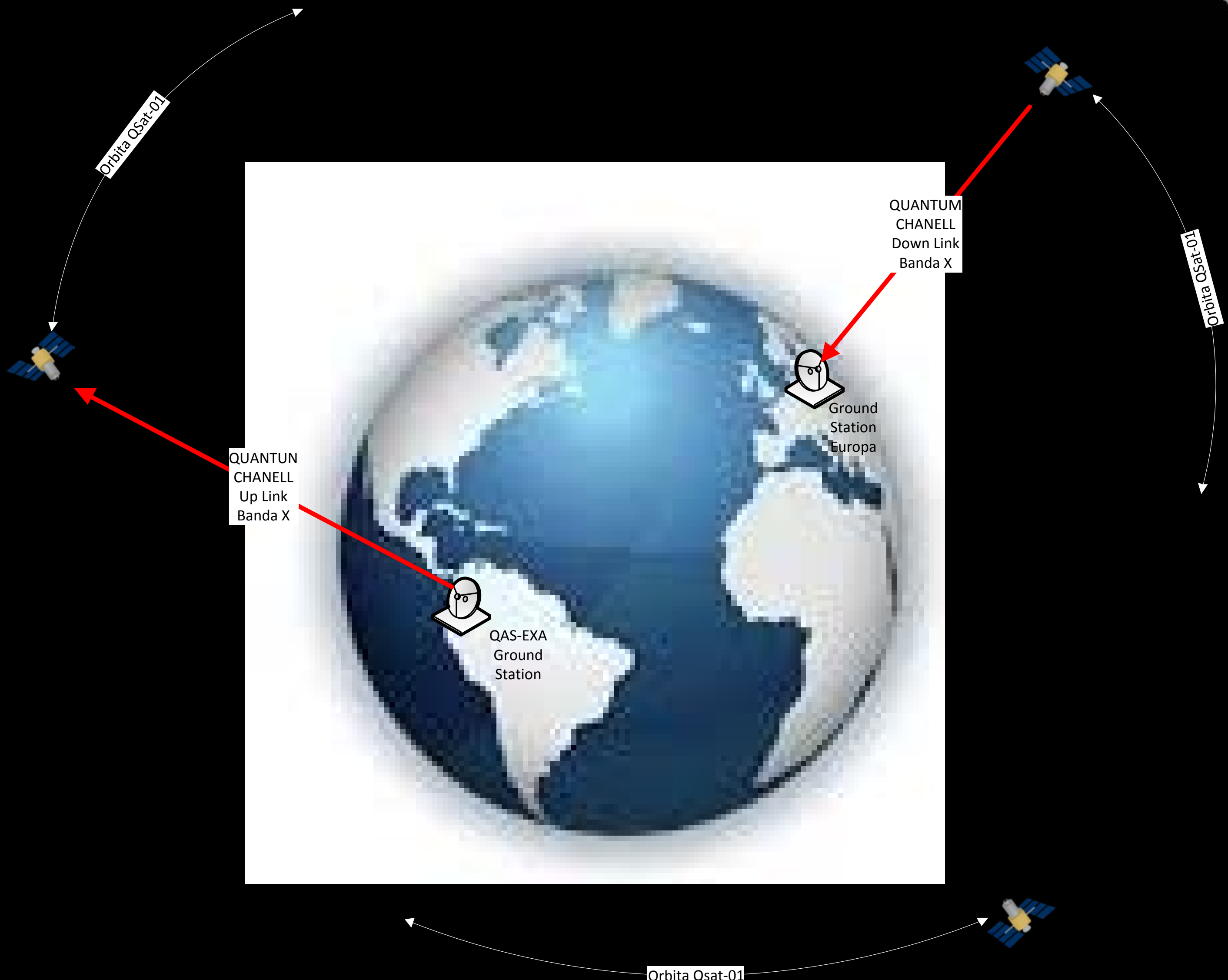
The spacecraft will have a four patch, X-Band antenna array in which would be allocated the 3 links necessary for the correct operation of the mission including the quantum link, the antenna array will be operated using artificial muscle technology from the EXA, specifically the MDH/R2 model so that it can be pointed inward in order to concentrate the transmission beam over a very small footprint and therefore boosting the gain in many orders of magnitude for the ground station 1 and 2.

The QSAT would be launched into a 400 Km – 600 Km orbit and a 98 degree inclination mean LTAN (Local Time of ascending node) of noon +/- 11h00 to 12h00 The mission would employ the HERMES-A ground station in Guayaquil working as Ground Station 1 and a Ground Station in Holland working as Ground Station 2.

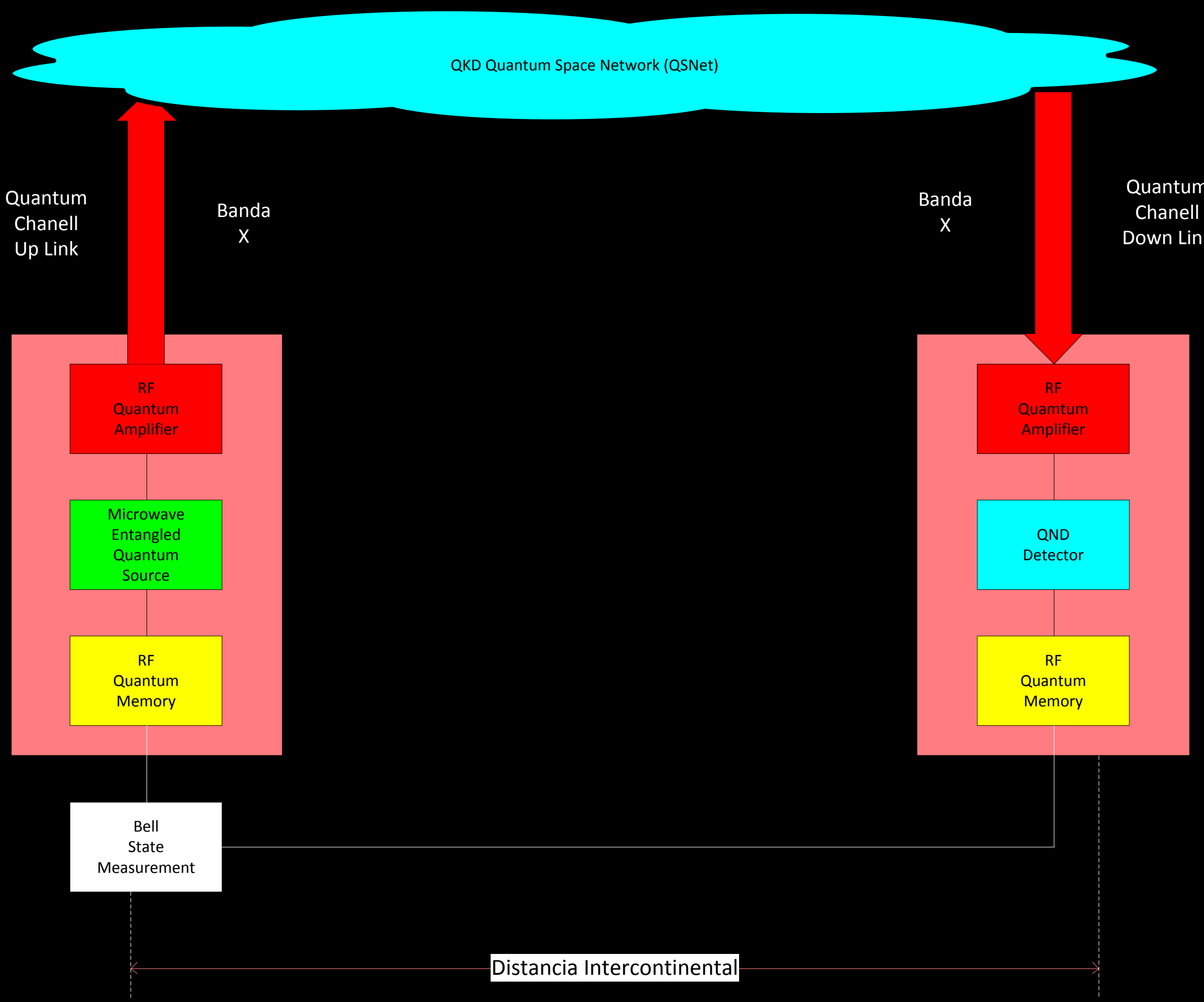
QSat System Overview



QSat Concept of operations



QSat Ground Segment



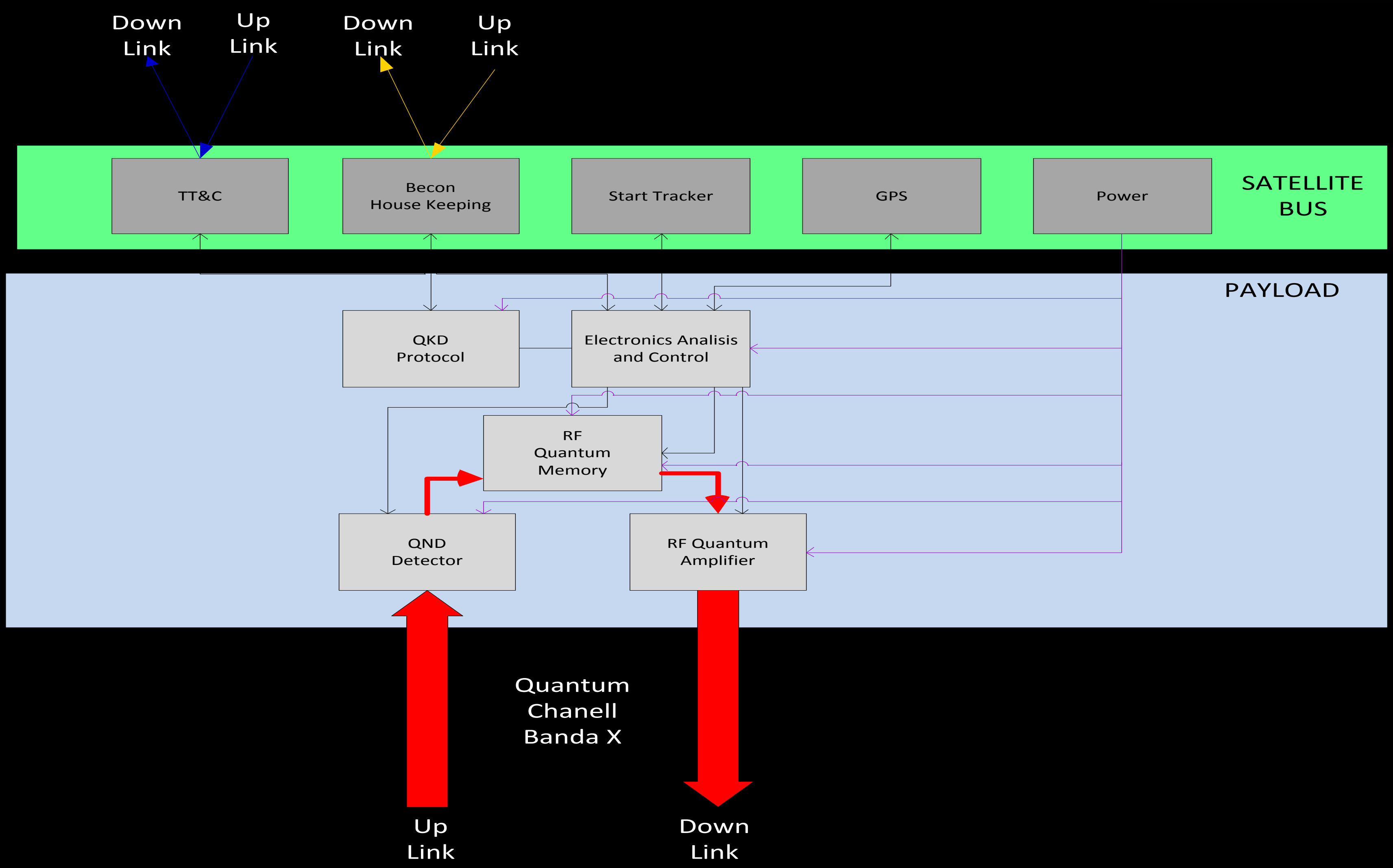
QSat Ground Segment
Groun Station 1

- El arreglo de sensores MINOTAURO tiene 12 mts de alto por 4 mts de ancho, y contiene 7 sensores radiométricos y 2 sensores ópticos.

- La ganancia maxima de MINOTAURO es de 130dB, es el arreglo mas sensible de la región, ha sido probado en comunicaciones con naves espaciales que orbitan a 22.0000km, detectando señales tan débiles como 0.02 W

- MINITAURO fue construido completamente en el país, con materiales disponibles y técnica desarrolladas en Ecuador por la división de ingeniería de EXA.

QSat Quantum Payload Design



Qsat Mission Schedule

	YEAR 1				YEAR 2				YEAR 3				YEAR 4			
TASK	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
Mission Funding	■	■														
Preliminary Design			■	■												
Detailed Design and Miniaturization					■	■	■									
Manufacture, Assembly, Test								■	■	■	■					
Launch												■				
On Orbit Operations													■	■	■	■

Qsat Mission Conclussions

- The feasibility study performed by QAS and EXA show that a nanosatellite mission to demonstrate quantum entanglement over intercontinental distances is feasible and practical with a maturation process of current technology. QSAT will employ proven space technology from EXA to implement the space craft and an innovative compact QKD Payload designed by QAS that would be compatible with the mass, volume, power and performance constrains of low cost nanosatellite platform.

- If it is constructed under the high efficiency approach of EXA, after one year of technology maturation, the proposed QSAT mission would be developed in 2.75 years, from kick-off to launch of the spacecraft, followed by one year on orbit mission.

- When the mission achieve all the scientific objectives, first it would be a new world record for quantum entanglement, second it would demonstrate de feasibility of a Global QKD Space Network based on this technology, adding to this that with the RF technology used in the project we will open the possibility that any parson could afford a low-price ground station to securely communicate point to point with any other place in the world, with all that this means.