CUBESATS FOR QUANTUM COMMUNICATION: CHALLENGES AND OPPORTUNITIES IN QUANTUM ENTANGLEMENT AND CUBESAT DESIGN AND DEVELOPMENT

Nikkisha S, Utkarsh S Srivastava, Patel Dixita Devendrabhai, Kuntesh Rawal
[1]Aerospace Department,
AEROIN SPACE TECH PVT LTD, CHENNAI,TAMIL NADU

Abstract - This explores the utilization of CubeSats for amount communication trials in space, fastening on crucial aspects including amount trap and CubeSat design. CubeSats are arising as a cost-effective and accessible platform for advancing amount technology. The study delves into the challenges and openings in planting CubeSats for amount communication and aims to give perceptivity into the specialized, practical, and scientific aspects of similar operations.

Index Terms – CubeSat, Entanglement, Quantum Communication, Bloch Sphere

I.INTRODUCTION (HEADING 1)

We considered several possible designs and individual factors. Each time, the CubeSat's effectiveness was estimated and design choices were made to minimize the size, weight, and power consumption of the outfit(exchange). Iterative procedures were followed to produce a satellite technology that wouldbeprofitableforQ.Com. Our CubeSat charge is called Q3Sat(pronounced Q- CubeSat). former long-distance prosecutions have approached thelimitsofterrestrialQ.com in terms of distance, exercising optical fibre(1) and free space overland lines(2). former studies like(3 – 4) showthatspace-groundedQ.Com is theoretically realizable(indeed with small satellites). As a result,twosuccessfulQ.Com satellites were created, and further quantum trials were carried out in route(5). various aspects of the generality have been demonstrated by earth- rested trials analogous as the vehicle of quantum connections over 144 km(6), QKD from an airplane to base(7), ground to air(8), catching bits patches from retroreflectors in route(9 – 10), and other moving platforms(11 – 12). multitudinous associations around the world are working toward space- rested communication using quantum technology demonstrations(13 – 14), though ultimate of them have yet to be created productively. The 600 kg Quantum examinations at Space Scale(QUESS) Satellite was recently launched by the China National Space Agency on August 17, 2016, at 1740 UTC(15 – 16). A geostationary communication satellite, on the other hand, generally has a mass 1000 times lower. Because the cost of advancement, launch, and operations of nanosatellites scales with mass, they offer access to space at vastly reduced price that is affordable for small businesses along with academic groups(17). Also, we report on experimental studies performed on a shaft- ranging orbital on the individual photons exchange between a low earth encircling(LEO) transmitter and a ground- rested receiver. For geodynamical examinations(e.g., crustal dynamics, polar stir, time- varying geopotential monitoring), these systems have been developed by carrying the time demanded to travel back and forth(range) of an optical tempo from an Earth point and the retroreflectors on the satellites demanded 18). This fashion is known as satellite internet shaft ranging, or SLR. We took advantage of the fact that their progressions can be directly predicted in real time by the International Laser Ranging Service(ILRS)(19) network because of largely accurate modelling rested on their former passes. In these situations, effective quantum error correction styles are applied to meliorate QKD- rested satellite communication performance(20 – 21). analogous programming is more applicable for quantum information carriers analogous as shaft light. The magnitude as well as phase of the shaft light can be considered as being pertaining to the field's quadrature variables, which represent the quantum state. In CV technology, information is generally decrypted onto the quadrature variables of the optical field. As a result, CV countries can be produced and detected using readily available, state- of- the- art optical outfit(22 – 23). The degree of trap produced by the quantum communication ruses under consideration, as well as the quantum vital rates of the EB CV- QKD schemes in these schemes, have been the subject of recent analysis in(24 – 25). Since the rigorousness of these unvarying quantum altering is finite, realizing romantic channel requires banning the qubits from their surroundings. This sequestration is not perfect because in real- world prosecutions we would like to unite with the qubits(26). One of the Italian researchers reported on the experimental deployment of the single- photon lieu between a satellite and a base of operations. To descry transmitted photons, they have erected trial that replicates a single photon source on a satellite, which they plan to observe through the eyepiece at the Italian Space Agency's Matera Laser Ranging overlook. The low- Earth route(LEO) satellite Ajisai, who's apex height is 1485 km, was employed by them(27). There are special difficulties in designing CubeSats for quantum disquisition. Innovative results are demanded due to their compact size, mass restrictions, and power limitations. The most recent technology developments, CubeSat design challenges, and how these meliorate the viability of quantum communication operations are covered in this part. New avenues for quantum trap disquisition are getting available thanks to CubeSats. An essential idea in quantum medicines, trap is demanded for both quantum vital distribution(QKD) and quantum communication. We club the significance of space- rested trap trials for secure quantum communication made possible by CubeSat. The space terrain presents obstacles for optical polarization, which is vital for quantum communication. Air conditions and interference are two of these difficulties. We examine the unique challenges and ways in which CubeSat operations affect optical polarization for secure communication.

II.LITERATURE SURVEY

Renema(et.al 2018), This paper presents a design for a 3U CubeSat to demonstrate quantum vital distribution(QKD) between an optical ground station and a CubeSat in route. The paper discusses the challenges of administering QKD in a CubeSat terrain, analogous as the limited space, power, and pointing and tracking capabilities. The authors propose a design that uses a new optical system to achieve the demanded pointing and shadowing delicacy.(28)

Vallone(et.al 2018), This paper presents a charge generality for a CubeSat to demonstrate quantum communication trials in an uplink configuration. The authors propose to place the entangled photon source on the ground, which would simplify the CubeSat design and reduce its power consumption. The authors also club the challenges of administering quantum communication in a CubeSat terrain and propose results to address these challenges.(29)

Sidhu(et.al 2021), This paper provides a comprehensive overview of the advances in space quantum dispatches. The author discusses the implicit operations of space quantum dispatches, analogous as QKD, quantum teleportation, and quantum trap distribution. The author also reviews the challenges of administering quantum communication in space and proposes results to address these challenges.(30)

Vallone(et.al 2015), This paper describes the practical performance and trial of satellite- rested quantum dispatches, marking a significant step toward global quantum networks.(31)

Yin(et.al 2012), This paper describes the Quantum teleportation and the distribution of entangled quantum countries over significant distances are mooted, pressing the teleportation of quantum information.(32)

Liao(et.al 2018), The paper presents the establishment of a satellite- bear quantum vital distribution(QKD) network for secure communication. QKD uses parcels of single photons to ensure unconditional security in vital exchange. The Micius satellite acts as a trusted relay, enabling secure vital distribution between China and Europe. Real- world operations include reworded image transfer and transnational video conference(33)

Vallone(et.al 2015), Demonstration of quantum communication(QC) with polarization garbling between satellites and ground. Achievement of a low quantum bit error rate(QBER) suitable for various quantum information protocols. Offer for a practical satellite quantum vital distribution(QKD) system using retroreflectors. Discussion of the feasibility and eventuality of global quantum communication networks via satellite links.(34)

Bascardi(et.al 2013), This paper gives prolusion to the eventuality of quantum- rested satellite communication. Emphasis on the significance of Quantum Key Distribution(QKD) for secure communication. Discussion of challenges in administering quantum communication over long distances via satellites. Outlook on the development of a complex network for global space- member-rested quantum communication.(35)

Gisin(et.al 2002), This paper provides a comprehensive overview of the field of quantum satellite communication. The authors club the basics of quantum communication, analogous as quantum vital distribution and quantum teleportation. They also review the challenges of administering quantum communication in space and propose results to address these challenges.(36)

Renema(et.al 2022), This paper provides a comprehensive overview of the use of optical polarization control for CubeSat quantum communication. The authors club the various challenges of administering optical polarization control on CubeSats, and they review the various CubeSat operations that have been proposed or launched to demonstrate optical polarization control for quantum communication.(37)

Vishal Sharma(et.al, 2018), In this paper we employ an effective birdman- rested quantum error correction fashion to palliate the goods of the noisy quantum channel in quantum- rested satellite networks. Findings from the simulation show that the birdman-rested quantum error correction scheme in terms of quantum vital distribution, satellite networks perform better than quantum error correction system of classical cascade in relation to quantum proliferation effectiveness, making quantum- rested implicit satellite connectivity.(38).

Nedasadat Hosseinidehaj(et.al, 2018), Said the most recent advances in wisdom applicable to low- Earth route satellite- rested CV quantum communication have been mooted. It appears that CV quantum communication across large ether distances is now entirely doable rested on recent experimental results on numerous DV- rested quantum protocols for commerce gathered from the Micius satellite. Homodyne(or heterodyne) and off- the- shelf limelights can simplify the installation of CV systems, but DV sources and detectors are precious and delicate to use.(39)

Arun G(et.al, 2014) Present the quantum medicines has come to play a major part in computers and communication. It opens a vast area for disquisition and development and provides a secure, effective way to communicate and reckon data. This sedulity provides access to a wide range of knowledge disciplines, including memory product, algorithm development, router development, networking, space communication, and other sectors. The disciplines of computing and communication will witness a transition from classical to quantum rivals in the future.(40)

Lazlo Bacsardi(et.al, 2013), In this composition, we give a summary of the current state of quantum- rested satellite dispatches. We will learn how to use satellite communication to transfer entangled quantum bits. More accurate device manufacturing will enable satellite quantum vital dissipation. It's possible that satellite QKD technology will relieve fiber QKD technology. The proliferation of quantum- rested technology.(41)

III.QUANTUM COMMUNICATION

The ignominious EPR contradiction was brought about by Einstein, Podolsky, and Rosen in 1935 with the intention of establishing (only theoretically) that the realist station is the only bone that can be sustained. I'll go over David Bohm's simplified understanding of the EPR disarray or EPRB, as it's known. suppose about how the neutral pi meson decays to produce a flyspeck known as an electron and a flyspeck known as positron. Both the electron and the positron take off in contrary directions, assuming that the pion was still at rest but if the electron is configured to have spin up, the positron has to have whirl down, and vice versa. Allow the electron and positron to go far down — ten times, in a real trial, or ten times the speed of light — and measure the electron's spin as well. Say you get spin up. directly you know that someone 20meters (or 20 light times) down will get spin down, if that person examines the positron. Your dimension of the electron collapsed the swell function, and presently " produced " the spin of the positron 20 measures(or 20 light times) down. Einstein, Podolsky, and Rosen considered analogous "spooky action- at-a-distance" (Einstein's enjoyable term) preposterous. Your dimension of the electron collapsed the swell function, and presently "produced" the spin of the positron 20 measures (or 20 light times) down. Einstein, Podolsky, and Rosen considered analogous "spooky action- at-a-distance" preposterous.

3.1 The Bell Theorem

Insofar as it goes, quantum mechanics is right, according to Einstein, Podolsky, and Rosen; they just assert that it's an amiss explanation of physical reality. A system's state can't be properly characterized by the swell function alone; an fresh volume,, is demanded. Since we don't know how to quantify or measure it at this time, we relate to it as the" sheltered variable." Any localised buried particularity philosophy is at odds with quantum medicines, as demonstrated by J.S.Bell. Here we can see into the figure which represent the mixed state bloch sphere which have multiple caste and different

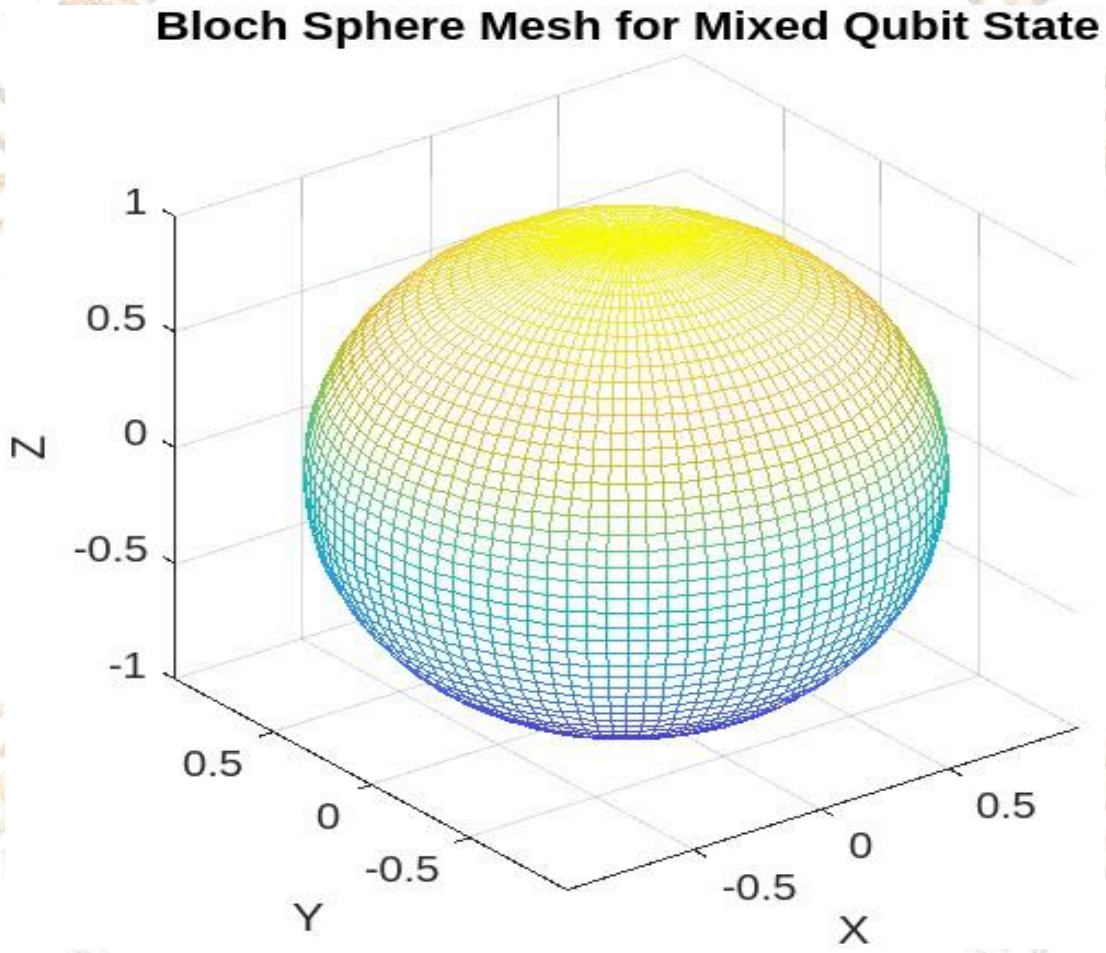

Fig.1 Bloch sphere for mixed state by using the MATLAB

3.2 Simplified and Detailed Schemes for Digital Revolution

It's common practice in the study of digital systems to reduce dispatches to a single symbol in order to simplify them, but in actuality, a series of symbols and their temporal elaboration should be taken into account. The question is How important generality do we lose when allowing about the transmission of a single sign? If {An} is a stationary sequence of independent symbols, the channel is endless and memoryless, and there is no interference between the symbols (i.e., no intersymbol interference), also the proposition developed for a single symbol may be extended to a series {An}ofsymbols.

3.3 Entanglement:

When two patches are released from the same source and under the trap state, they've nearly associated characteristics that don't alter as they separate. also, when the other's condition is measured, the state of one of them snappily changes with a" spooky action at a distance," fully defying conventional sense. Information in amount drugs is the natural sphere where amount mechanics finds use. The presuppositions of Quantum Mechanics, which have held true for the once 100 times, are the source of the essential generalities.

Following a significant revamping, these generalities prevision veritably inventive uses similar as amount cryptography, amount coding, amount computing, and amount dispatches. The four major hypothesizes will be employed in the expression of amount mechanics

hypothetical 1 provides a general way to describe any physical system on the field of complex figures as a Hilbert space.

hypothetical 2 without pertaining to other systems, mimics the independent, time- grounded development of unrestricted physical system.

The **3rd hypothetical** addresses the quantum of data that can be attained (by an amount dimension) from an amount system at any one moment.

hypothetical 4 combines numerous Hilbert spaces into a single Hilbert space to define the commerce between physical systems.

Small, affordable satellites known as" CubeSats" are being employed to probe the viability of space- grounded amount communication. They've polarization- entangled, largely- miniaturized photonic brace sources that may produce transnational network for the dispersion of amount keys grounded in space. The photon brace directors can be installed on further sophisticated satellites with optic connections, allowing for the safe delivery of important encryption keys between any two locales on Earth.

The creation of small caught photon- brace the sources for atomic satellites is anticipated to have a major impact on global amount networks in the future. CubeSat- style satellites may

be used to snappily qualify technology in route and need minimum coffers to design and launch.

lowers the quantum of trusted factors as compared to other systems, and offers security traceable to introductory correlations between photons. analogous toother popular QKD styles, its swath limit is anticipated to Future amount networks will use liaison with optic amount communication satellites as well as fiber- grounded results for impacts of events amount crucial distribution(QKD), which is a well- established technology.

To add up, the viability of space- grounded amount communication is being delved through the application of CubeSats. They've sources of photon dyads that are able of creating a worldwide amount crucial distribution network grounded on space. unborn global amount networks are anticipated to be significantly impacted by the development of small entangled photon- brace sources for CubeSats. When compared to other systems, trap- grounded QKD has smaller trusted factors and offers sequestration hackable to vital correlations between photons. It's a established technology.

3.4 QUBITS

We go over the crucial distinctions between a qubit and a bit. Anyhow of how it's physically enforced, a bit is always allowed of as either a 0 or a 1. Take a light switch, for case, where the on position is represented by the number 1 and the off position by the number 0. Qubits are unnaturally extremely different from ordinary bits, despite significant parallels between them. A qubit can have two implicit values, 0 and 1, just like a bit. Qubits can be zero, one, or a superposition of both, in discrepancy to bits, which can only be one or the other. Are qubits set up in nature? The first concrete trial, known as the Stern – Gerlach trial, was designed by Stern in 1921 and executed by Gerlach in 1922. It included tableware tittles projected magnetically. These days, a number of studies use less complicated ways to convert a system into a qubit state. These tactics include the two distinct photon polarizations, nuclear spin alignment, and the two orbital countries of electrons within tittles.

4.7Simulation Results and Analysis

The conducted simulation was designed to probe the principles of amount communication and assess the impact of error rates on the transmission and event of amount bits(qubits). The crucial parameters and issues of the simulation are bandied as follows

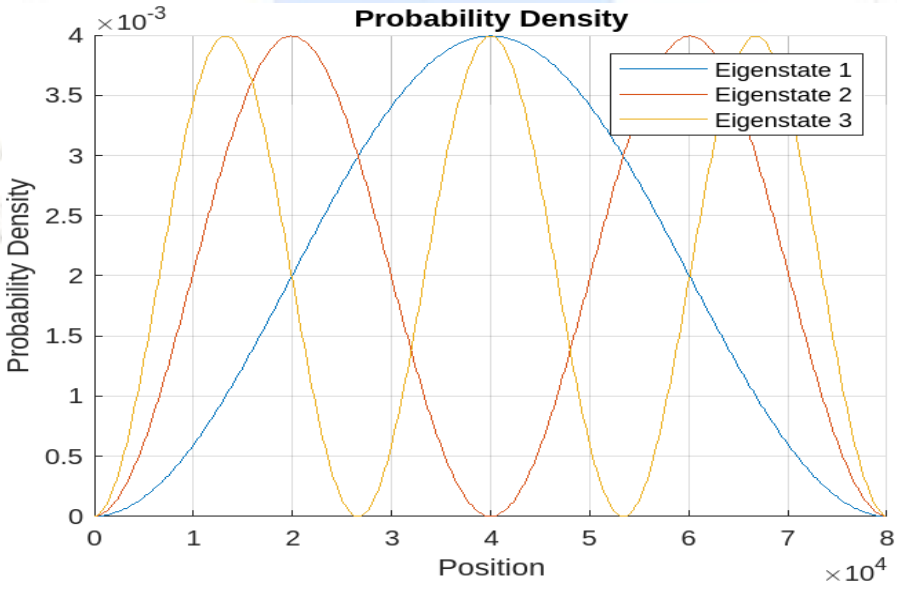

Fig.2 **Probability Density of Quantum Bits at different Eigen States**

3.8Schrödinger Wave Equation Analysis:

The Schrödinger surge equation, a abecedarian equation in amount mechanics, was employed to dissect the geste of amount patches within a one- dimensional space. The simulation considered a spatial grid with specified confines(length'L' and number of spatial points'num_points') and employed the reduced Planck's constant(' hbar') and flyspeck mass(' m') as physical constants. The implicit energy function(' V') was assumed to be zero for simplicity, but it can be modified to study different scripts. The simulation successfully answered the Schrödinger equation, yielding eigenfunctions and eigenvalues that describe the amount countries within the defined spatial sphere. The issues include probability viscosity plots for named eigenstates, offering perceptivity into the spatial distribution of amount patches.

3.9Qubit Transmission and event with crimes

To assess the robustness of amount communication, qubit transmission was dissembled with an introduced error rate('error rate'). The simulated qubits were subject to bit wise crimes during transmission, and the entered qubits were anatomized. Quantum Bit Error Rate(QBER)

3.10Quantum Bit Error Rate (QBER)

It was calculated to quantify the delicacy and trust ability of the amount communication process. QBER is a vital standard that provides perceptivity into the dedication of amount transmission and event. The attained QBER value was expressed as a chance and is reflective of the error rate in the transmission of amount information.

3.11Probability viscosity and Eigenstates

The probability viscosity plots for the first'num_states_to_plot' eigenstates were presented, illustrating the spatial probability distribution for each eigenstate. These plots are critical for understanding the localization of amount patches within the given spatial sphere. The intertwined probability chance for each eigenstate was reckoned, furnishing perceptivity into the donation of individual eigenstates to the total probability. The simulation underscores the complications and challenges of amount communication. It not only reveals the geste of amount patches in a controlled terrain but also addresses practical issues related to qubit transmission and event. The advised QBER serves as a standard for assessing the trust ability of amount communication systems. These results serve as a foundational reference for the broader disquisition of amount communication and the development of robust amount technologies. The simulation lays the root for farther examinations into amount error correction, secure communication, and amount crucial distribution. The law handed for the simulation is necessary in the study of amount communication, and it can be acclimated for different scripts and trials. It serves as a precious tool for experimenters and scientists in the field of amount technology.

4. **Design and Development of the 2U CubeSat for Quantum Communication Satellite:**

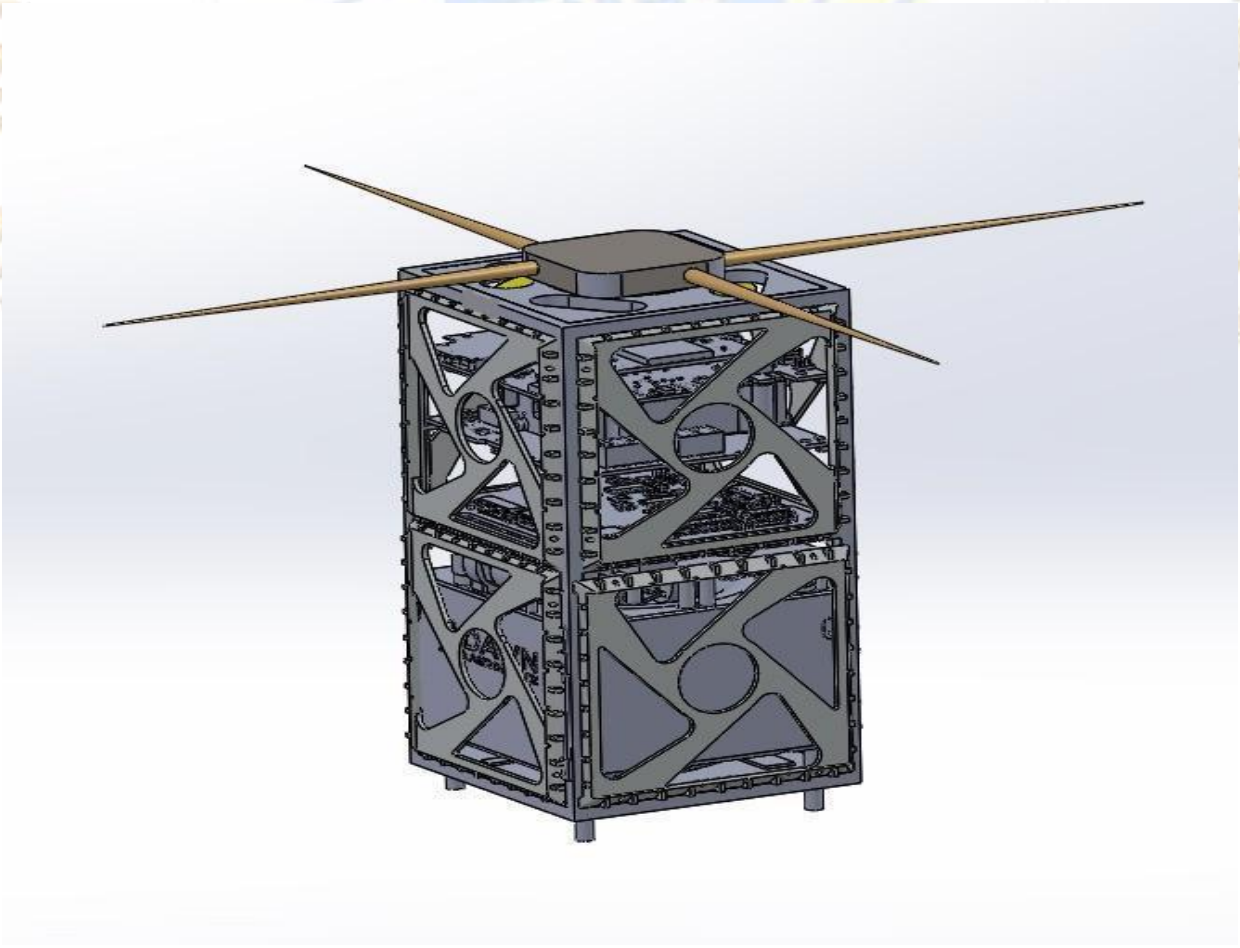

Fig.3 2U CUBESAT DESIGN – ISOMETRIC VIEW

The 2U CubeSat developed for the Quantum Communication Satellite represents an innovative emulsion of colorful crucial factors and technologies, performing in a compact and effective satellite design acclimatized for amount communication operations. This section elaborates on the integrated design and development aspects .

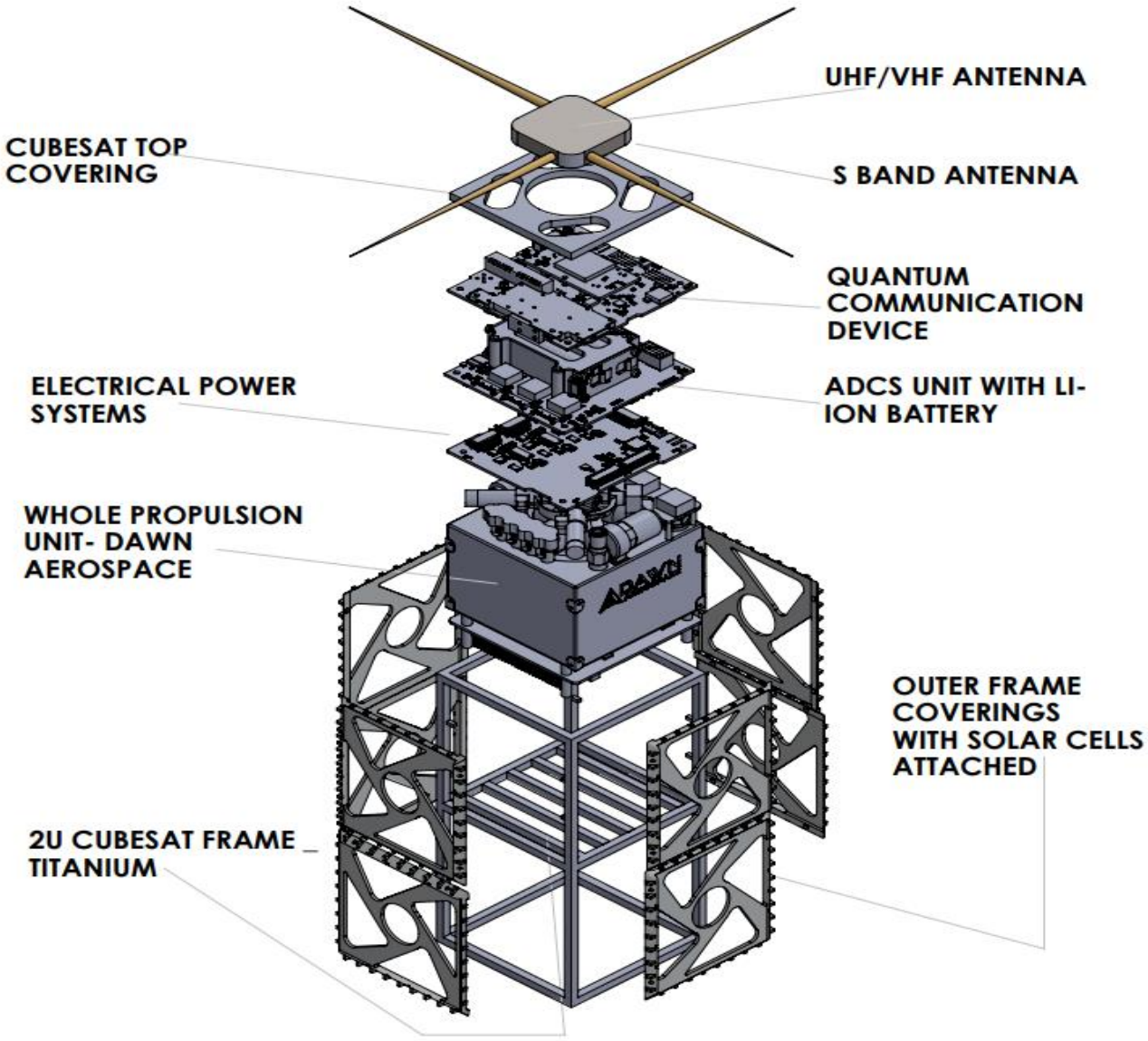

Fig.5 2U CUBESAT EXPLODED VIEW WITH COMPONENT DETAILS

4.1 Quantum Communication Device Integration

Central to the CubeSat's design is the objectification of a slice- edge Quantum Communication Device. This device is seamlessly integrated into the CubeSat's structure, icing its precise alignment and minimum hindrance with other subsystems. The integration process involves custom casing to give environmental protection and radiation shielding for the sensitive amount factors. .

Communication Systems The CubeSat features both UHF/ VHF and S Band antennas, enabling protean communication capabilities. The antennas are strategically deposited to optimize data transfer rates and insure robust communication links with ground stations. The CubeSat's onboard computer and communication system are strictly designed to handle amount data and encryption processes. .

station Control and Power Management To maintain the CubeSat's stability and power force, an station resolve and the cantrollsystem (ADCS) is seamlessly integrated. The ADCS unit, paired with a Li- ion battery, provides precise control over the CubeSat's exposure and power operation. It's programmed to insure that the amount communication device, antennas, and solar panels remain duly acquainted.

The Electrical Power System(EPS) unit is pivotal for the CubeSat's power operation. It efficiently distributes power from the solar cells to the colorful factors while also storing redundant energy in the Li- ion battery. This design ensures continued operation, indeed during orbital phases without direct sun exposure. .

Propulsion for Orbital Control A devoted propulsion unit is incorporated to enable Earth- bounding manoeuvres. This unit, precisely integrated into the CubeSat's structure, allows precise route adaptations and manoeuvres as demanded to insure the satellite's alignment with ground stations for amount communication tasks. .

Structural Design and Solar Cells The CubeSat's structural frame is erected from titanium, offering a featherlight yet robust construction. This 2U frame provides protection and support for all internal factors. The external face is equipped with solar cells strategically placed to crop solar energy while also acting as defensive coverings for the satellite's internal systems.

In summary, the 2U CubeSat design for the Quantum Communication Satellite represents a scrupulous mix of amount technology and traditional space satellite factors. The integration of amount communication, precise station control, advanced communication systems, effective power operation, and propulsion ensures the CubeSat's readiness for ground breaking operations in the field of secure amount communication. This design leverages the CubeSat platform's inflexibility and compact form factor to advance amount communication technology in space while maintaining a strong emphasis on performance, trust ability, and effectiveness.

5. FUTURE COMPASS

The unborn compass of CubeSat for amount communication is to establish a network of ringing bumps that can give QKD services to ground stations and other satellites. This would enhance the security and effectiveness of global communication systems, as well as enable new operation similar s amount teleportation and distributed amount computing.

One of the challenges of CubeSat for amount communication is to design and develop a weight that can induce and transmit amount signals from space to base, while prostrating the goods of atmospheric turbulence, noise, and hindrance. Another challenge is to ensure the harmony and interoperability of the CubeSat with being and unborn satellite constellations and ground stations.

The CubeSat Quantum Dispatches Mission (CQuCoM) is a proposed design that aims to demonstrate the feasibility of CubeSat for amount communication. The design would involve lunching a 2U CubeSat that can perform QKD and trap distribution between space and ground, as well as testing colorful aspects of amount communication technology, similar as sources, sensors, protocols, and algorithms.

IV.CONCLUSIONS

In an period marked by the grim pursuit of secure and effective communication systems, CubeSats have surfaced as redoubtable players in the realm of amount technology. This disquisition has exfoliate light on the remarkable eventuality of CubeSats in advancing amount communication, and the multidimensional geography that unfolds when we cross the disciplines of amount trap, CubeSat design, and optic polarization. The foundation of secure amount communication lies in the intricate parcels of amount trap. CubeSats, with their compact confines and innovative technological acclimations, now enable space- grounded trials in amount trap, propelling the boundaries of secure amount communication. These endeavours not only support the indispensability of trap in amount crucial distribution but also herald a new period where amount technologies transcend terrestrial constraints. CubeSat design, despite its challenges, has paved the way for revolutionary advancements in amount communication. The elaboration of miniaturized platforms, using slice- edge technology, accentuates the feasibility of amount communication operations. CubeSat enterprise have effectively aligned themselves with the amount cause, reshaping the boundaries of what's attainable through compact satellite design. In the arena of optic polarization, CubeSats defy the complex complications of space surroundings. Atmospheric interferences and adversities in space polarization demand robust results. CubeSat operations stand as settlers, contributing precious perceptivity and strategies that will fortify secure communication and lay the foundations for amount communication networks that defy terrestrial limitations. Still, amid the breadth of progress, space debris operation emerges as a critical cog in the ministry of CubeSat operations. The accreditation to maintain sustainability is vital, and this exploration underscores the significance of meeting-orbiting directives. By citing the CQuCoM charge as a case study, we regard a future where CubeSats seamlessly operate in harmonious concurrence with their elysian counterparts. This disquisition casts a limelight on the cooperative nature of exploration and the vital part of colleges like the CQuCoM Consortium. They represent the twinkle of invention in amount technology and hold the power to inclusively shape the amount geography. As CubeSats continue to access the sphere of amount communication, cooperative endeavours will incontrovertibly be the linchpin of progress. In the grand homestretch of this disquisition, it becomes apparent that CubeSats aren't just revolutionizing amount communication; they're forging new paradigms, prostrating challenges, and leaving an unforgettable mark in the pursuit of secure and effective amount communication. Our exploration underscores the significance of sustainable practices and cooperative sweats, emphasizing the significance of CubeSats in realizing the bottomless eventuality of amount communication.

In ending, as we chart the line forward, it's the pioneering spirit of CubeSats and the unvarying commitment of the scientific community that shall guide us into the amount future, where secure and effective communication knows no bounds. I hope this conclusion fits your requirements. However, please let me know, If you'd like any variations or have specific points you'd like to include.

V.REFERENCES

[1] . Yin HL, Chen TY, Yu ZW, Liu H, You LX, Zhou YH, et al. Measurement-device-independent quantum key distribution over a 404 km optical fiber. Phys Rev Lett. 2016;117(19):190501.

[2] Ursin R, Tiefenbacher F, Schmitt-Manderbach T, Weier H, Scheidl T, Lindenthal M, et al. Free-space distribution of entanglement and single photons over 144 km. Nat Phys. 2007;3:481–6.

[3] Ursin R, Jennewein T, Kofler J, Perdigues JM, Cacciapuoti L, de Matos CJ, et al. Space-quest, experiments with quantum entanglement in space. Europhys News. 2009;40(3):26–9.

[4] Kerstel E, Gardelein A, Barthelemy M, Team TC, Fink M, Joshi SK, et al. Nanobob: a Cubesatmission concept for quantum communication experiments in an uplink configuration. 2017.arXiv:1711.01886.

[5] Bedington R, Arrazola JM, Ling A. Progress in satellite quantum key distribution. npj Quantum Inf.2017;3(1):30.

[6] Ursin, R., Tiefenbacher, F., Schmitt-Manderbach, T., Weier, H., Scheidl, T., Lindenthal, M.,Blauensteiner, B., Jennewein, T., Perdigues, J., Trojek, P., et al.: Entanglement-based quantum communication over 144 km. Nature physics 3(7), 481–486 (2007)

[7] Nauerth, S., Moll, F., Rau, M., Fuchs, C., Horwath, J., Frick, S., Weinfurter, H.: Air-to-ground quantum communication. Nature Photonics 7(5), 382–386 (2013)

[8] Pugh, C.J., Kaiser, S., Bourgoin, J.-P., Jin, J., Sultana, N., Agne, S., Anisimova, E., Makarov, V., Choi, E., Higgins, B.L., et al.: Airborne demonstration of a quantum key distribution receiver payload. arXiv preprint arXiv:1612.06396 (2016)

[9] Villoresi, P., Jennewein, T., Tamburini, F., Aspelmeyer, M., Bonato, C., Ursin, R., Pernechele, C., Luceri, V., Bianco, G., Zeilinger, A., et al.: Experimental verification of the feasibility of a quantum channel between space and earth. New Journal of Physics 10(3), 033038 (2008)

[10] Vallone, G., Bacco, D., Dequal, D., Gaiarin, S., Luceri, V., Bianco, G., Villoresi, P.: Experimental satellite quantum communications. Physical Review Letters 115(4), 040502 (2015)

[11] Wang, J.-Y., Yang, B., Liao, S.-K., Zhang, L., Shen, Q., Hu, X.-F., Wu, J.-C., Yang, S.-J., Jiang, H., Tang, Y.-L., et al.: Direct and full-scale experimental verifications towards ground-satellite quantum key distribution. Nature Photonics 7(5), 387–393 (2013)

[12] Bourgoin, J.-P., Higgins, B.L., Gigov, N., Holloway, C., Pugh, C.J., Kaiser, S., Cranmer, M., Jennewein, T.: Free-space quantum key distribution to a moving receiver. Optics Express 23(26), 33437–33447 (2015)

[13] Morong, W., Ling, A., Oi, D.K.L.: Quantum optics for space platforms. Optics & Photonics News 23, 42–29 (2012)[14] Elser, D., Gunthner, K., Khan, I., Stiller, B., Marquardt, C., Leuchs, G., Saucke, K., Trondle, D., Heine, F., Seel, S., et al.: Satellite quantum communication via the alphasat laser communication terminal-quantum signals from 36 thousand kilometers above earth. In: 2015 IEEE International Conference on Space Optical Systems and Applications (ICSOS), pp. 1–4 (2015). IEEE

[15] WU, J., SUN, L.: Strategic priority program on space science. Space Science Activities in China 5, 001 (2014)

[16] China launches first-ever quantum communication satellite.

[17] Shao, A., Koltz, E.A., Wertz, J.R.: Performance based cost modeling: Quantifying the cost reduction potential of small observation satellties. In: AIAA Reinventing Space Conference, AIAA-RS-2013-1003, Los Angeles, CA, Oct, pp. 14–17 (2013)

[18] Bender P and Goad C C 1979 Probable LAGEOS contribution to a worldwide geodynamics control network The Use of Artificial Satellites for Geodesy and Geodynamics vol II ed G Veis and E Livieratos (Athens: National Technical University) pp 145–61

[19] Pearlman M R, Degnan J J and Bosworth J M 2002 The international laser ranging service Adv. Space Res. 30 135–43

[20] William K Wootters and Wojciech H Zurek. A single quantum cannot be cloned. Nature, 299(5886):802–803, 1982.

[21] Charles H Bennett. Quantum cryptography: Public key distribution and coin tossing. In Proceedings of IEEE Conference on Computers, Systems and Signal Processing, 1984, 1984

[22] T. C. Ralph “Continuous variable quantum cryptography,” Physical Review A 61, 010303(R) (1999).

[23] F. Grosshans, N. J. Cerf, J. Wenger, R. Tualle-Brouri, and P. Grangier, “Virtual entanglement and reconciliation protocols for quantum cryptography with continuous variables,” Quantum Information and Computation 3, pp. 535-552 (2003).

[24] N. Hosseinidehaj and R. Malaney, “Gaussian entanglement distribution via satellite,” Physical Review A 91, 022304 (2015).

[25] N. Hosseinidehaj and R. Malaney, "CV-QKD with Gaussian and nonGaussian entangled states over satellite-based channels," Proceedings of IEEE Global Communications Conference (GLOBECOM), Washington, DC, USA, pp. 1-7 (2016).

[26] S. Imre and L. Gyongyosi, "Advanced Quantum Communications: An Engineering Approach,"Wiley, 2012.

[27] P. Villoresi et al., "Experimental Verification of the Aeasibility of a Quantum Channel between Space and Earth," New J. Physics, vol. 10, no. 3, 2008, p. 33–38.

[28] J. J. Renema, D. Mogilevtsev, M. A. Van den Brink, M. H. Skrzypczyk, J. Huijben, J. Lugthart, R. J. van Weelden, J. S. Biteau, S. Ecker, W. Gisin, et al., Q3Sat: quantum communications uplink to a 3U CubeSat—feasibility & design, EPJ Quantum Technology 5(1), 1 (2018)

[29] A. Vallone, V. D'Ambrosio, V. Giovannetti, A. Sponselli, S. Pirandola, L. Calderaro, A. Meda, A. Gulinatti, M. De Micheli, A. Fiore, et al., Nanobob: a CubeSat mission concept for quantum communication experiments in an uplink configuration, EPJ Quantum Technology 5(1), 2 (2018)

[30] R. Sidhu, IET Research Hub 1(1) (2021), Advances in space quantum communications – Sidhu - 2021 - IET Research Hub

[31] Vallone, G., Bacco, D., Dequal, D., Gaiarin, S., Luceri, V., Bianco, G., & Villoresi, P. (2015). Experimental Satellite Quantum Communications. *Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Padova, Padova 35131, Italy*, *e-GEOS spa, Matera 75100, Italy*, *Matera Laser Ranging Observatory, Agenzia Spaziale Italiana, Matera 75100, Italy*. Published on July 20, 2015.

[32] Yin, J., Ren, JG., Lu, H. *et al.* Quantum teleportation and entanglement distribution over 100-kilometre free-space channels. *Nature* **488**, 185–188 (2012)

[33] (Liao, Cai, Handsteiner, Liu, Yin, Zhang, Rauch, Fink, Ren, Liu, Li, Shen, Cao, Li, Wang, Huang, Deng, Xi, Ma, Hu, Liu, Koidl, Wang, Steindorfer, Kirchner, Lu, Shu, Ursin, Scheidl, Peng, Wang, and Zeilinger, 2018).

[34] Vallone, G., Bacco, D., Dequal, D., Gaiarin, S., Luceri, V., Bianco, G., & Villoresi, P. (2015). Experimental Satellite Quantum Communications. Physical Review Letters, 115(4), 040502. doi:10.1103/PhysRevLett.115.040502.

[35] Bacsardi, L. (2013). On the Way to Quantum-Based Satellite Communication. IEEE Communications Magazine, 51(8), 50-54.

[36]N. Gisin, G. Ribordy, W. Tittel, H. Zbinden, Quantum Satellite Communication: From Theory to Practice**, Rev. Mod. Phys. 74(1), 145 (2002)

[37] Johannes J. Renema, David Mogilevtsev, and Johannes Lugthart, Optical Polarization Control for CubeSat Quantum Communication**, arXiv preprint arXiv:2208.04002 (2022)

[38] Laszlo Bacsardi ∗, Sandor Imre Department of Telecommunications, Budapest University of Technology and Economics, Magyar tudosok krt. 2., Budapest H-1117, Hungary

[39] Nedasadat Hosseinidehaj[1], Zunaira Babar[2], Robert Malaney[1], Soon Xin Ng[2], Lajos Hanzo[2] [1]School of Electrical Engineering & Telecommunications, The University of New South Wales, Sydney, NSW 2052, Australia. [2]School of Electronics and Computer Science, University of Southampton, Southampton SO17 1BJ, U.K.

[40] Arun G, Vivekanand Mishra, A review on quantum computing and communication, SVNIT, Surat, arungovindankutty@gmail.com

[41] Laszlo Bacsardi, On the Way to Quantum-Based Satellite Communication, IEEE Communications Magazine