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Galassia System and Mission

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ABSTRACT

Galassia is a 2U Cubesat, which is currently developed by undergraduate students at the National University of Singapore (NUS). Galassia is the first NUS Cubesat, and is planned to be launched on the Polar Satellite Launch Vehicle (PSLV) developed by the Indian Space Research Organization (ISRO) between September - December 2015. The Cubesat will be launched into a near equatorial orbit with an altitude of 550 km and an inclination of 15°. There are many educational and scientific objectives in this project. The educational objectives are for students to gain hands-on experience with real hardware and software integrations, to design and verify Cubesat system mechanisms, to test some in-house developed devices, and to work and integrate the two scientific experiments into the Cubesat.

INTRODUCTION

Since 1999 when the Cubesat specifications were developed by California Polytechnic State University and Stanford University, the research and developments of satellites have entered a new phase- Cubesat [1]. A 1U Cubesat is defined to have a volume of 10x10x10 cm^3. By using commercial off-the-shelf (COTS) components for its electronics, the cost and development duration of a satellite for space applications have been significantly reduced. Because of many advantages of developing a Cubesat, many Cubesat programmes have been conducted in universities in terms of both education and research purposes. University Cubesats have been developed to educate students about space technologies [2]-[11], to test some satellite subsystems [2]-[11], to test imagery payloads for observation of the Earth [6]-[8], and to conduct some scientific experiments [9]-[11].

This paper introduces the first Cubesat, Galassia, that is developed in the National University of Singapore (NUS). As a university programme, the main objective is for students to understand space technologies and to gain practical experiences while building, integrating and testing 2U Cubesat bus and payloads. Galassia carries two scientific payloads. The first payload aims to measure the Total Electron Count (TEC) in the ionosphere above Singapore, and the second payload aims to acquire quantum correlation data in space for the concept verification of quantum-based communication using Small Photon-Entangling Systems (SPES). The life duration of Galassia is expected to be half a year.

OBITAL INFORMATION

Galassia will be launched by a Polar Satellite Launch Vehicle (PSLV) to a near equatorial orbit with an altitude of 550km and an inclination of 15°. The ground track of orbits is shown in Figure 1. Since the latitude of Singapore is around 1.35°, Galassia will fly over Singapore on average six times per day.

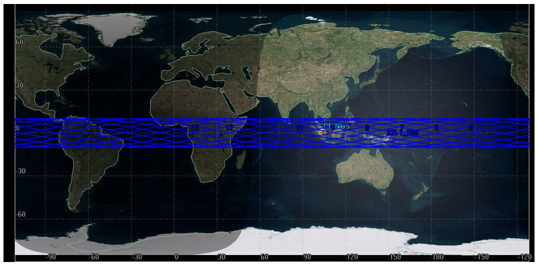


Figure 1: Ground track of Galassia

MISSIONS

Total Electron Count (TEC) Payload

The first primary payload measures the Total Electron Count (TEC) in the Ionosphere above Singapore. The TEC is defined as

$$I = \int_0^R N ds \tag{1}$$

where N is the electron density and R is the vertical path between the satellite and the ground station. TEC is a measure used to characterize the conductivity of the ionosphere, which consists of ionized layers in the upper atmosphere. The free electrons in the ionosphere affect the propagation of radio waves. Several candidate methodologies that could be used to measure the TEC include pseudorange, carrier phase, and three frequencies method. After studying and researching on different methods and taking into account the constraints of our Cubesat, the three frequencies method is chosen for implementation in Galassia. The payload is based on the transmission of three continuous waves (CWs) with center frequencies of f_0-f_m, f_0, and f_0+f_m. The measurement principle is based on the different delays for the signals with three frequencies. At the ground station, the signals with three frequencies need to be separated. The terms with center frequencies of f_0-f_m, and f_0+f_m are mixed with the f_0 signal, respectively. The resulting two signals after mixing both have a center frequency of f_m. The phase difference between these two signals, $\Delta\Phi$, can be used to calculate N as

$$N = 5.97 \times 10^5 \frac{f_0{}^3}{f_m{}^2} \Delta\Phi \tag{2}$$

The maximum value of N ever measured is lower than 1000 x 10^6 electrons/m^2. We use 145MHz as the carrier frequency, f_0. The modulation frequency (f_m) can be chosen to be relatively small. We set f_m to be 0.8MHz. As a result, a simple Amplitude Modulation (AM) transmitter can be designed for this purpose and integrated with the Cubesat bus. The block diagram of the TEC receiving part at the ground station is proposed as shown in Figure 2. The TEC payload only works when Galassia is just above Singapore to obtain vertical TEC data. There is no data storage required for this payload.

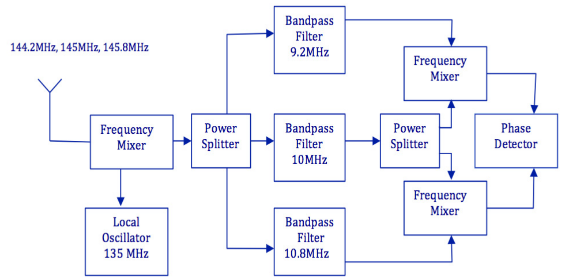


Figure 2: Block diagram of the TEC receiver

Small Photon-Entangling Quantum System (SPEQS) Payload

The second primary payload is the Small Photon-Entangling Quantum System (SPEQS) payload, which is developed by the Center for Quantum Technologies (CQT) in NUS. Polarization-entangled photon pairs are widely used in Quantum Communication. A compact and efficient system for generating and detecting photon pairs is conducted. The SPEQS experiment utilizes a process called Spontaneous Parametric Down Conversion (SPDC) to generate entangled photon pairs which can be used to establish a quantum communication link between two sites. The generation and detection of photon pairs are performed within the package to check the quality of the entanglement and this is the first step to verify if such communication protocol is feasible in space. This package achieves high entanglement fidelity and enables a quantum light source to be deployed on mobile field communication systems where resources are scarce.

The SPEQS payload conducts the science experiment for a maximum duration of 30 minutes. The SPEQS is designed to operate in three modes which are housekeeping, experiment and data transfer. Table 1 illustrates the power budget.

Table 1: Power budget of SPEQS

Mode	Maximum Power (Watts)	Duration (Mins)
Housekeeping	2.5	10
Experiment	2	10
Data Transfer	0.5	10

Figure 3 illustrates the concept of operation to be adapted by the Galassia On-Board Computer (OBC). The connection between SPEQS and OBC is through an Universal Asynchronous Receiver/Transmitter (UART) bus. The SPEQS data should be stored until they are downloaded to the ground station. A failure of the OBC to transfer data completely to the ground station in a single pass shall not affect the next scheduled SPEQS experiment.

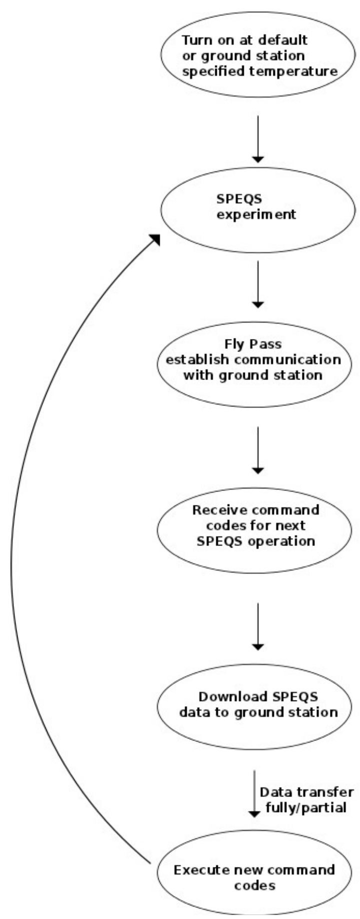


Figure 3: Operation of SPEQS

SYSTEMS

Galassia follows a 2U Cubesat design to fit PSLV requirements. The dimension of Galassia is 100mm x 100mm x 200 mm. The total mass is less than 2 kg. Besides TEC and SPEQS payloads, the Cubesat bus includes 6 basic hardware subsystems. They are the structure, Passive Attitude Determination and Control System (ADCS), On-Board-Computer (OBC), Electrical Power System (EPS), Telemetry, Track and Command (TT&C), and antenna system. Figure 4 shows a general overall look of Galassia.

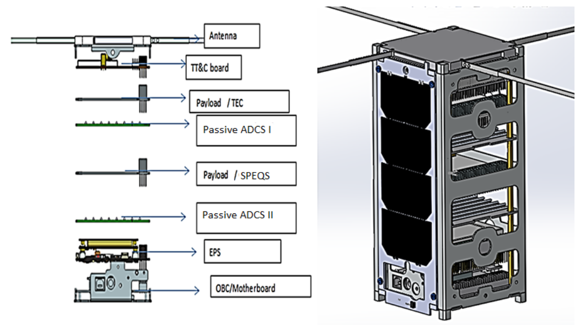


Figure 4: Galassia outlook

Structure

The main purpose of the structure is to provide mechanical support for Galassia during launch and operation phases. The 2U structure is designed and fabricated using aluminum alloy 5052, as shown in Figure 5. The dimension follows the Cubesat standard and the overall weight is 212g.

Figure 5: Galassia's structure

ADCS

The function requirements of the ADCS is to stabilize Galassia after detaching from the rocket during the de-tumbling phase, and to maintain a reasonable stable attitude for Galassia throughout its lifespan. There is no pointing requirement from both TEC and SPEQS payloads. A simple Passive Magnetic Attitude Control System (PMAC) is implemented in this situation. The PMAC consists of 8 permanent magnets (z axis) and 4 pairs of hysteresis rods (x and y axes). The permanent magnets are used to align the body axis parallel to the magnet dipole axis with the Earth magnetic field vectors. The magnets with a diameter of 1 cm and a height of 4 cm are chosen to be rare Earth magnet grade N42. Hysteresis rods are used to reduce the kinetic energy of the satellite, and to damp the angular velocity of the oscillations during tracking, but only in the plane perpendicular to the magnet axis. The material of hysteresis rods is HyMu 80 alloy. The diameter and the height of rods are 1 and 95 mm, respectively. The more pairs of hysteresis rods there are, the faster the satellite will become stable after de-tumbling. Due to the space and weight constraints, after calculations and simulations, 4 pairs of rods are finally determined to be implemented in our design. Figure 6 shows the simulation results of body rate responses under the random initial body rate of 10 degree/s.

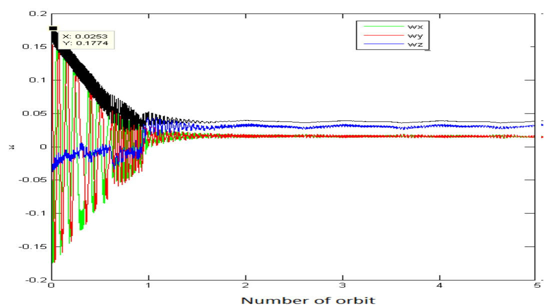


Figure 6: Simulations of Galassia's body rate

We can see that with this PMAC, Galassia is supposed to be stable with a body rate less than 0.05 rad/s in all 3 axes after 2 orbits. The fabricated PMAC is shown in Figure 7. Only one pair of rods can be realized in one side of a PCB board. Therefore, two PCB boards are required to implement all 4 pairs.

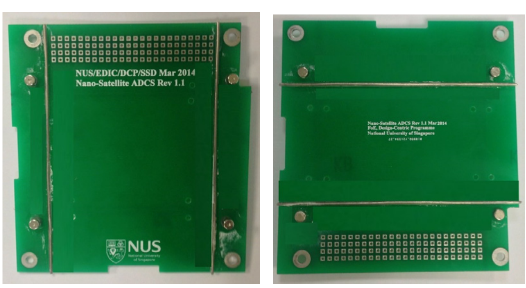


Figure 7: Fabricated PMAC board

OBC and On-Board-Data-Handling (OBDH)

The tasks performed by OBC and OBDH are to deploy the antennas, to monitor the satellite operation by doing periodic housekeeping, to respond to the battery low status, to turn on/off payloads, to save SPEQS data, and to respond and execute commands from the ground station. The commercial product, 16bit dsPIC33, is used as the OBC for Galassia. The OBDH subsystem consists of the OBC, Salvo Real Time Operating System for scheduling the tasks, and an optional flash card for secondary data storage. Salvo is chosen because of its small size, optimized codes and flight heritages.

As described in Table 2, there are four modes involved in Galassia's operations. The transitions between modes are defined in Figure 8.

Table 2: Galassia's Operating Modes

Number	Mode	Description
1	Initialization / Recovery	Entered first time / after resets
2	Power Saving	No Payload operation
3	Normal No Communication	Normal mode when not communicating to Ground Station
4	Normal Communication	Normal mode when communicating to Ground Station

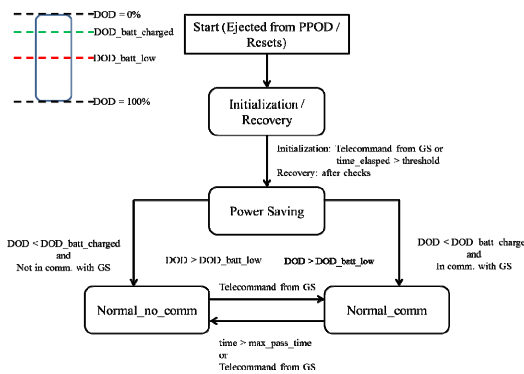


Figure 8: Mode transitions

To ensure successful data communication between the OBC and other subsystems, the data interfaces between them are through Inter-Integrated Circuit (I2C) buses except SPEQS, as I2C protocol can provide a graceful handling of error occurrence during I2C communication. The AX.25 protocol and space package protocol are implemented together to define the data format between the Galassia and the ground station. The simple data format is shown in Figure 9.

AX. 25 Headers	Space Package	AX. 25 Trailers

Figure 9: Simplified data format

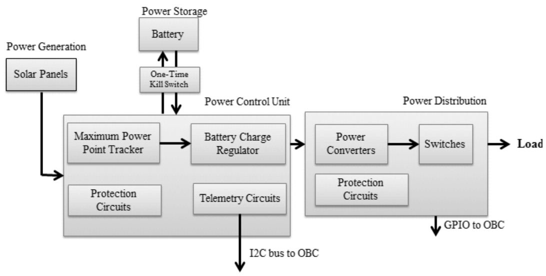


Figure 10: EPS block diagram

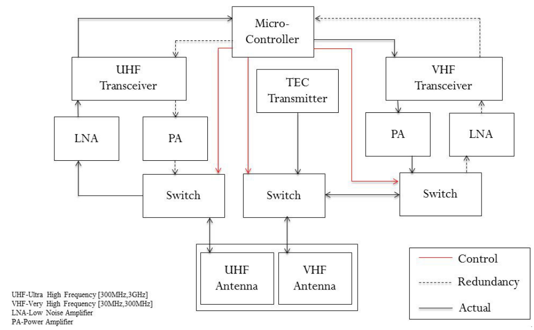
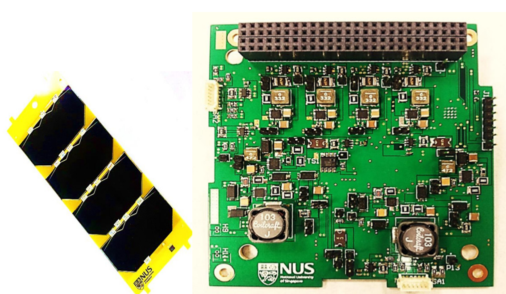


Figure 12: TT&C block diagram

EPS

The functions of the EPS are to generate and store power for Galassia's operation, to distribute power to respective loads, and to provide over-current and under-voltage protections of electrical components. The EPS includes a 20Whr integrated rechargeable Lithium Polymer battery, four sides of GaAs solar panels, and a power control and distribution unit. Figure 10 shows the block diagram of EPS. The fabricated engineering model of solar panels and EPS board are displayed in Figure 11. Many tests are conducted to measure and successfully verify the functions of solar panels, battery charging, and power control and distributions. The next step is to work on the qualification and flight model of EPS board.



(a) **(b)**

Figure 11: Engineering models. (a) Solar panel, and (b) EPS

TT&C

The functions of TT&C are to transmit data received from the OBC to the ground station, to receive data from the ground station and forward it to the OBC, and to broadcast beaconing signals. In this system, the transceiver is designed using ADF7021 and PIC18F47J53 based on software defined radio principles. The uplink is in UHF and the downlink is in VHF. The data rate and modulation scheme for both uplink and downlink are 9600bps and Frequency Shift Key (FSK), respectively. Figure 12 illustrates the block diagram of the TT&C subsystem.

After verifications of the transmitting and receiving data using ADF7021 and PIC18F47J53, the engineering model of TT&C is designed and fabricated as shown in Figure 13.

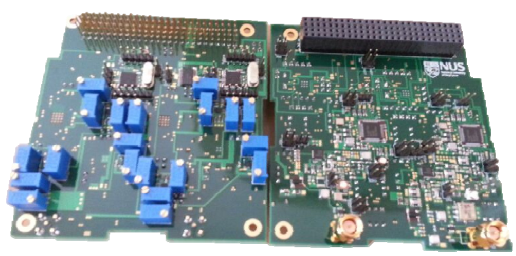


Figure 13: Engineering model of TT&C

SCHEDULE

The launch window has been confirmed to be September-December 2015. The project started in August 2013. Therefore, we are running a very tight schedule. Table 3 lists the schedule and status of Galassia.

Table 3: Galassia's Schedule and Status

Important Milestones	Planned Date	Status
Project Kickoff	16 Aug 2013	Completed

Preliminary Design Review (PDR)	20 Sep 2013	Completed
Critical Design Review (CDR)	8 May 2014	Completed
Flight Readiness Review (FRR)	23 Mar 2015	
Shipment to Launch Site (Sriharikota)	After 30 Mar 2015	
Launch Window	Sep to Dec 2015	
Scientific Experiments	Dec 2015 to May 2016	

CONCLUSION

Galassia is NUS's first Cubesat and is developed by undergraduate students. Galassia follows the standard 2U Cubesat specifications with OBC, passive ADCS, EPS, TT&C and antenna subsystems. The two scientific payloads are TEC and SPEQS. Except OBC and antenna, all the other subsystems and flight software are designed and developed in NUS. Currently, the engineering models of EPS and TT&C are fabricated and verified. The passive ADCS boards are assembled. The next phase of development will be system integration and tests.

Acknowledgments

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