Light-1: A 3U CubeSat for Detecting and Monitoring Terrestrial Gamma Ray Flashes - System Design and Concept of Operations

Light- 1 team*

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I. SCIENTIFIC BACKGROUND

Thunderstorms produce numerous spontaneous flashes of gamma rays which occur very briefly, with time periods of less than a fraction of a second. These **extremely high energy** particles have a magnitude similar to radiation worth 400 chest X-rays. These particles are discharged during thunderstorms within very close proximity of airplanes, hence, engaging passengers with a **potential threat of extreme radiation exposure.** The confirmed association of **terrestrial gamma ray flashes (TGRF)** with thunderstorm activity makes TGRFs are a beneficial area of study with potential for a CubeSat mission. Light-1 is a CubeSat mission proposed to study terrestrial gamma ray flashes by developing and building two payload detectors using a combination of photomultiplier tubes and scintillating crystals. The payload detectors are designed, developed, and tested by the students.

II. MISSION OBJECTIVES

Light-1 is a mission with the following educational and scientific objectives:

- Science – evaluate the performance of a new miniature TGFD system in the space environment
- Educational – provide students experience with designing, integrating and testing CubeSats
- Educational – provide students experience with designing space grade electronics and electrical systems

III. MISSION CONCEPT

Light-1 operates in three main modes which are the initial, normal, and safe mode, illustrated in Figure 1.

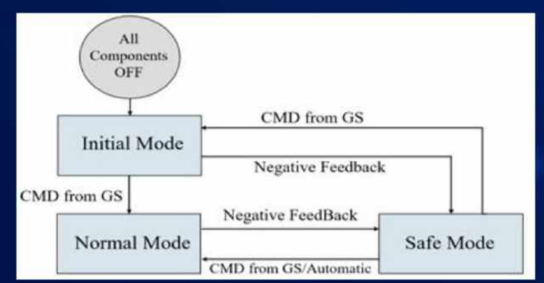

Figure 1: Light-1 modes of operation

Initial mode: The CubeSat stays in the initial mode for the first 45 minutes after ejection from the PPOD, during which all components are switched off. The ADCS will operate in case of de-tumbling only. Upon initial checkout, the antennas and solar panels will be deployed. Subsequently, the CubeSat will begin beacon transmission.

Normal mode: On receiving a command from the ground station, Light-1 will switch to normal mode and begin regular operations such as payload data collection, CubeSat pointing, payload data transmission, and housekeeping data transmission.

Safe mode: In case of an emergency or negative feedback during either modes, Light-1 will enter safe mode. Light-1 will return to normal mode when the problem is resolved or when commanded by the ground station.

IV. MISSION ANALYSIS

Lifetime analysis: In the unpredictable space environment, the drag area and altitude are the only controllable variables amongst solar flux, atmospheric drag, Earth gravity, orbit configuration, that affect the lifetime directly. A life time analysis was conducted using STK, for all possible orientations of the CubeSat. Though Light-1 will have an horizontal orientation, as seen in Table 1, all drag areas simulated based on the CubeSat orientation can satisfy the minimum mission lifetime requirement of 6 months with a drag coefficient of 2.2.

Table 1: Lifetime analysis parameters and results

Orientation	Drag Area (mm^2)	Mission Lifetime ($months$)
Vertical with deployed solar panels	0.09	6.4
Vertical with stowed solar panels	0.03	15.6
Horizontal with stowed solar panels	0.01	26.4

Access time analysis: Light-1 can communicate with three ground stations; Abu Dhabi in United Arab Emirates, Vilnius in Lithuania and Aalborg in Denmark. The access time simulation was conducted using STK for the three ground stations at different elevation angles. The overlap in access time due to the close proximity of Vilnius and Aalborg was taken into consideration. The access time analysis revealed that in the worst case scenario of 10°, Light-1 can achieve significant access durations as shown in Table 2.

Table 2: Access time analysis results

	Access duration (min/day)
Average access time	32
Minimum access time	12
Maximum access time	57

V. PLATFORM SUBSYSTEM DESIGN

The Light-1 bus, like any other CubeSat bus consists of the mechanical, power, command and data handling, attitude determination and control and communication subsystem, hardware of each of which has been described in detail in the following sections. An overall system-level block diagram of Light-1 is shown in Figure 2.

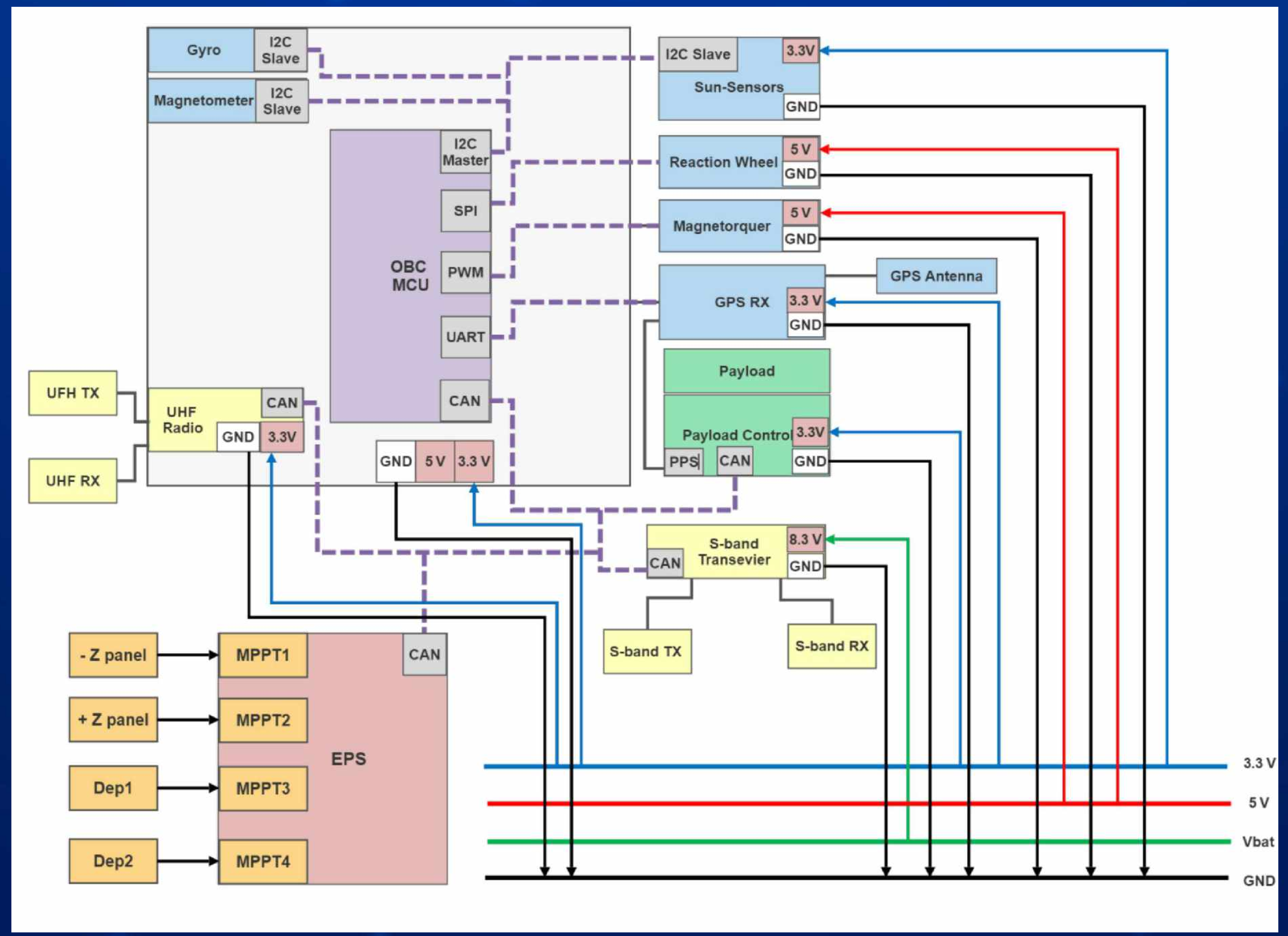

Figure 2: Light-1 system level block diagram

i. MECHANICAL SUBSYSTEM

The Light-1 is a 3U assembly, of which 2U is occupied by the payload while 1U is made up of bus components. A labelled CAD assembly of Light-1 can be seen in Figure 3. The total mass of the 3U CubeSat is 5.2 kg. The labelled components are as listed below:

1. UHF antenna
2. Payload 1: PMT detector
3. Deployable solar panel
4. GPS receiver
5. Electric power system
6. Payload controller
7. Onboard computer
8. Reaction wheels
9. S-band transceiver
10. Magnetorquer board
11. Payload 2: SiPM detector
12. CubeSat frame

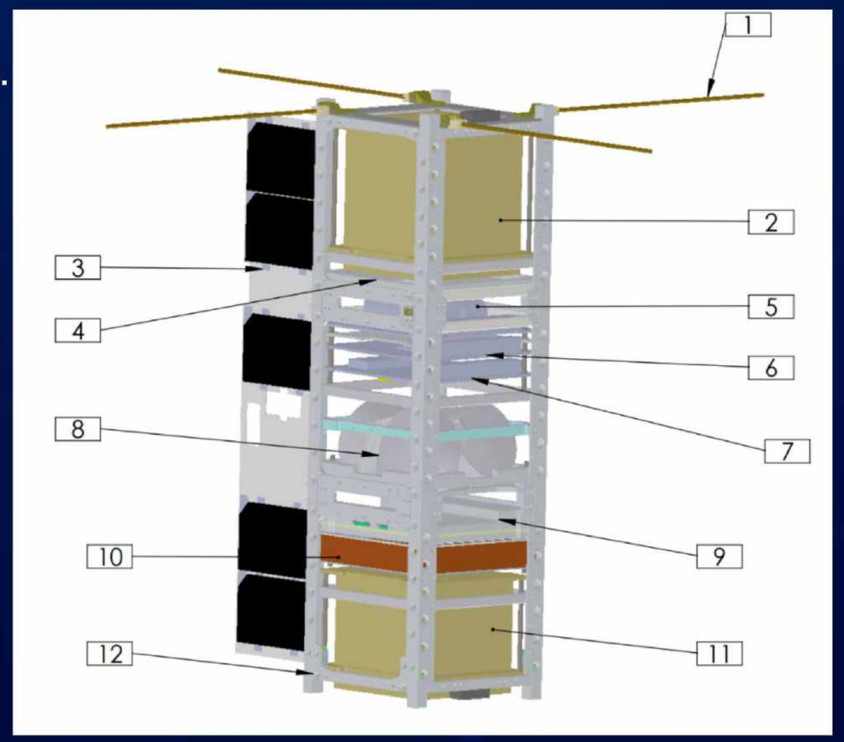

Figure 3: Light- 1 assembly

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ii. POWER SUBSYSTEM

The Light-1 power subsystem consists of three main components: the solar cells, the EPS board and the battery pack, seen in Figure 4. Light-1 generates power from high-efficiency solar cells and converts it into electricity, the excess of which is stored in a rechargeable battery. The voltage of each cell in the Li-ion batteries is **3.6V** with a capacity of **3200 mAh**. The EPS board is responsible for managing and distributing the electrical power. The solar cells in the solar panels have a maximum power of **1.05W** with an efficiency of **29.5%**. Light-1 has nineteen solar cells distributed across four solar panels of which two are deployable.

Figure 4: a) Light-1 EPS board with battery pack b) Light-1 solar panel

iii. COMMAND AND DATA HANDLING SYSTEM

The On-Board Computer (OBC) acts as the brain of the satellite and allows controlling the Operation and data handling of all the subsystems by managing the different subsystem modules. The SatBus3C2 OBC board, seen in Figure 5, has an integrated UHF module and ADCS sensors, magnetometers and gyroscopes with a low power consumption of 0.287W. Its processing unit implements the flight controller software as well as the ADCS algorithm on board. It is an ARM 32-bit with 400 MHz processing speed. Though it supports different data buses like I2C, CAN, UART, and SPI, the CAN bus is mandatory for payload interfacing with the OBC due to its higher transmission speed compared to the I2C bus.

Figure 5: Light-1 OBC board

iv. ATTITUDE DETERMINATION AND CONTROL SUBSYSTEM

The attitude determination and control subsystem (ADCS) stabilises the satellite and holds it in position, fulfilling the mission and payload requirements. The Light-1 control system, seen in Figure 6, consists of:

- four reaction wheels- to stabilize the CubeSat and perform fine attitude pointing.
- three magnetorquers - responsible for high spinning control situations and desaturation of reaction wheels.

Figure 6: Light-1 control system a) reaction wheels b) magnetorquers

The Light-1 determination system consists of:

- three 3-axis gyro sensors – to measure the angular velocity for attitude determination during eclipse [cross axis sensitivity is 1 deg/sec].
- six fine sun sensors- to measure the sun vector for attitude determination and partial sun tracking mode.
- three 3-axis magnetometers – to measure the magnetic field of Earth for attitude determination.

v. COMMUNICATION SUBSYSTEM

The communication subsystem's role is to transmit and receive telemetry, mainly payload data and housekeeping data, between the ground station and the satellite. For the uplink telecommands and downlink of house-keeping data, the subsystem utilizes Ultra High Frequency (UHF) for communication. The UHF Digital Radio has a sensitivity of 118 dBm and uses a frequency between 430-440 MHz and operates at 9600 bps. The UHF transceiver is coupled with a UHF dipole antenna that has a gain of 2 dBi. For downlink of payload data, the subsystem utilizes S-band for communication. The S-band transceiver has a sensitivity of 110 dBm and uses a frequency between 2200 and 2290 MHz. It has a transmission rate of 1.06 -5.12 MB/s. Additionally, the S-band is coupled with a directional antenna, S-band patch antenna which has a gain of 6 dBi.

VI. INTERIM SUMMARY

This student-led project is a collaboration between students of the **Khalifa University of Science and Technology** and **New York University** in Abu Dhabi supported by university students from Bahrain and funded by the UAE Space Agency. It is currently in it's assembly, integration and testing phase.

The Light-1 CubeSat is expected to be ready by the end of 2020, ready for launch by the Japanese Aerospace Exploration Agency (JAXA) in the first quarter of 2021 from the International Space Station (ISS).