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Development of Electrical Power Subsystem of Cube Satellite STEP Cube Lab for Verification of Space-Relevant Technologies

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Abstract

STEP Cube Lab (Cube Laboratory for Space Technology Experimental Project) is a 1U standardized pico-class satellite. Its main mission objective is an on-orbit verification of five fundamental core space technologies. For assuring a successful missions of the STEP Cube Lab with five payloads, electrical power subsystem (EPS) shall sufficiently provide an electrical power to payloads and bus systems of the satellite during an entire mission life. In this study, a design process of EPS system was introduced including power budget analysis considering a mission orbit and various mission modes of the satellite. In conclusion, adequate EPS hardware in compliance with design requirements were selected. The effectiveness and mission capability of EPS architecture design were confirmed through an energy balance analysis (EBA).

Key Words : Pico-class Satellite, Electrical Power Subsystem (EPS), Power Budget, Mission Mode, Energy Balance Analysis (EBA)

1. Introduction

STSL (Space Technology Synthesis Laboratory) at Chosun University in Korea has participated in a cube satellite development project entitled STEP Cube Lab (Cube Laboratory for Space Technology Experimental Project). Its main mission objective is to verify fundamental space technologies researched by domestic universities through mission data obtained from on-orbit operation of cube satellite. The payloads consist of a MEMS solid-propellant thruster, a holding and release (H&R) mechanism triggered by nichrome burn wire heating, a variable emittance radiator, a phase change material, and a concentrating photovoltaic (CPV) system employing Fresnel lens system.

For achieving successful mission of STEP Cube Lab, electrical power subsystem (EPS) shall provide functions of generating, conditioning, distributing, and storing the electrical power to stably operate payloads and bus systems during an entire mission duration of satellite [1-4]. Obland et al. [1] performed the power subsystem design for the cube satellite Montana EaRth Orbiting Pico-Explorer (MEROPE). They estimated the total amount of power consumption and generation from the satellite, as well as the electrical design of the EPS board with Li-ion batteries. Darbali-Zamora et al. [2] performed the electric power supply design for the cube satellite space plasma ionic charge analyzer (SPICA) through the numerical approach. In addition, the design was validated by functional tests using a

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prototype of EPS board. Pajusalu et al. [3] performed design of the EPS for nanosatellite ESTCube-1. They implemented a maximum power point tracking (MPPT) system, a fault-tolerant battery system, a power distribution system, and an AVR microcontroller-based control solution on their EPS design.

In this study, we introduce a series of EPS architecture design procedures and results for the STEP Cube Lab. A power budget of the satellite was estimated based on mission orbit and operation modes of the satellite. As a result, adequate EPS hardware including EPS board, solar panel and battery in compliance with the design requirements were selected. The effectiveness and survivability of the STEP Cube Lab were demonstrated through an energy balance analysis (EBA). The EBA includes a power generation analysis using systems tool kit (STK) software [4] considering on-orbit attitude profile, and a power consumption analysis considering power on-off profiles of the satellite in the worst case mission mode. In the analysis, we also predicted enhancement of power generation performance with the CPV system using Fresnel lens system, based on the power generation analysis results.

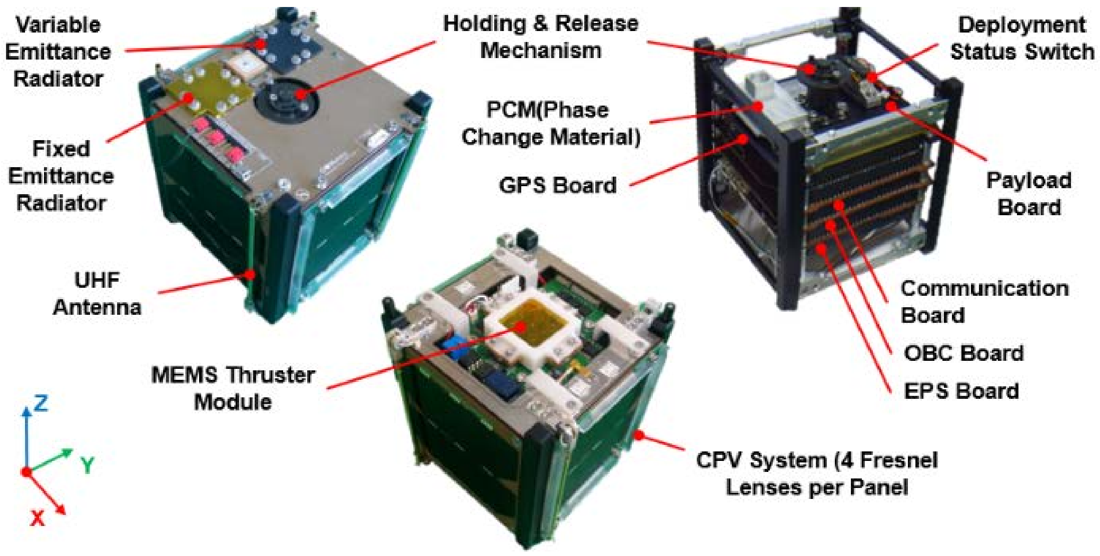

Fig. 1 Configuration of STEP Cube Lab

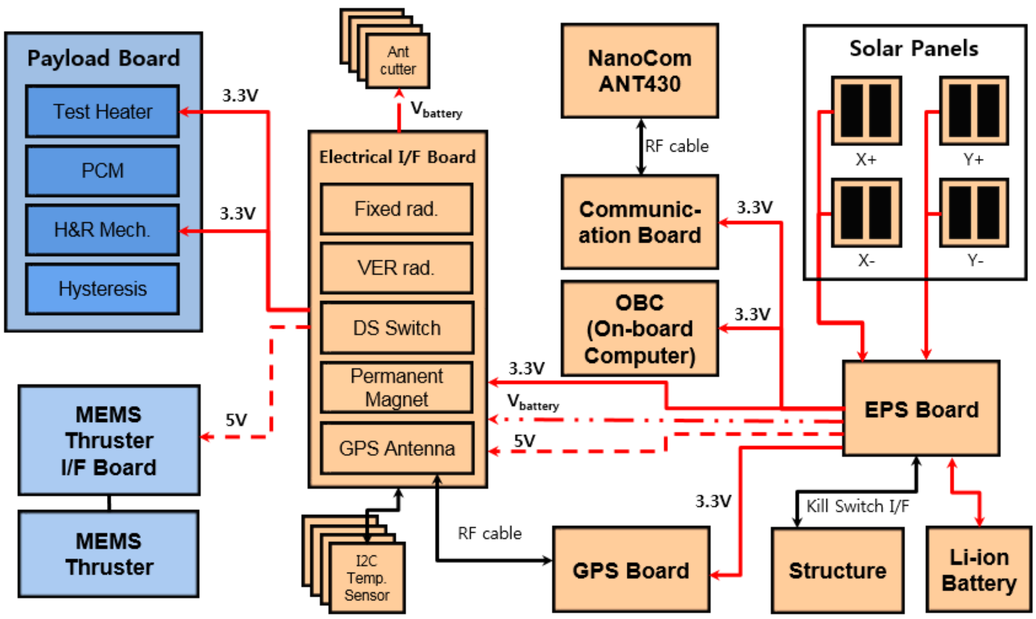

Fig. 2 System-level Electrical Power Block Diagram of STEP Cube Lab

Table 1 Average Power Consumption in Communication Mode

Units	Stand-by (W)	Peak Power (W)	Peak Duty (%)	Ave. Power (W)	Remark
OBC	0.43	0	0	0.430	Always On
EPS	0.125	0	0	0.125	Always On
MEMS Thruster	0	0	0	0	-
H&R Mechanism	0	0	0	0	-
Electrical I/F Board	0	0	0	0	-
Test Heater	0	0	0	0	-
COMM	0.23	5.5	5.17	0.52	Contact Time: 5 min
GPS	0	0	0	0	-
Margin (10%)	-	-	-	0.05	-
Total	**-**	**-**		**1.12**	-

Table 2 Summary of Power Budget Estimation

Time (min)		Parameter	Power (W)	Power (Wh)	Charge / Discharge (Wh)	Remark
Daylight	61.4	Generation	2.07	2.12	-	Effective Area ($60.36 cm^2$ = 1/4 of Total Area of Solar Panels)
		Consumption	-1.12	-1.15	-	Comm. Mode
Available Power for Charging					0.97	-
Actual Power for Charging					0.90	Converter Eff. = 0.93
Eclipse	35.3	Consumption	-1.12	-0.66	-0.66	Comm. Mode
Margin (Remained Power)					0.24	-
Power Budget (Remained Power w.r.t. Total Generated Power)					11.3 %	> 0% → Satisfied

2. System Overview of STEP Cube Lab

The STEP mission will be performed at sun-synchronous orbit with 600km of altitude and an orbital inclination angle is 97.78°. A mission duration of the satellite is 1 year. Figure 1 shows configuration of the STEP Cube Lab including accommodation locations of five payloads for technology verification. The bus systems composed of GPS, communication, on-board computer (OBC), and electrical power boards are located inside the satellite structure. In case of the STEP Cube Lab, the satellite uses a passive attitude stabilization method using a permanent magnet combined with a hysteresis damper [5], because the STEP mission does not require precise attitude control. This attitude control strategy has been an attractive solution for cube satellites with extremely small accommodation space, due to its advantages of simplicity, small mass, and no power consumption. A satellite using permanent magnet installed on the +Z axis of the satellite performs two cycles of rotation per orbit, by aligning with earth's magnetic field. The hysteresis dampers installed on the other two orthogonal axis of the satellite give a damping characteristics, such that the stabilized satellite slowly tumbles with respect to the rotational direction in Z axis of the satellite.

Figure 2 shows a system-level electrical power block diagram of the STEP Cube Lab. Total of four solar panels integrated on the X and Y side of the structure generate the electrical power to operate the satellite. The both panels on the Z direction are used for payload accommodation. The most of 3.3V and 5V power buses are connected to an electrical interface (I/F) board for ease of electrical integration between the payloads and the bus system boards.

This is one of the main features of electrical design of the STEP Cube Lab.

3. Power Budget Estimation

The operation modes of STEP Cube Lab comprise an initial separation mode, a normal mode, a communication mode, an emergency mode, and a payload verification mode for on-orbit tests of each five payloads. The power budget estimation was performed with respect to the communication mode, because this is the worst case mode in the viewpoint of power consumption. In this mode, the MEMS thruster, H&R mechanism, electrical I/F board, test heater and GPS board do not operate in order to minimize an unnecessary power consumption. Table 1 summarizes estimation results of average consumed power in the communication mode, including stand-by and peak power and peak duty of each hardware. Here, a peak duty corresponds to a ratio of peak operation time with respect to the 96.7 minutes of orbital period at 600km altitude.

The total average power consumption of STEP Cube Lab is 1.12 W, including 10% of margin. Based on the results, we estimated the power budget of STEP Cube Lab, as summarized in Table 2. In the estimation, a total generated power was simply estimated under assumption that only one-fourth of entire area of solar panels can view the sun, considering the attitude characteristics of the satellite using permanent magnet stabilization method. The estimation results indicate that the power budget is 11.3%, which satisfies the requirement of above 0%.

Considering the system requirements and power budget estimation results, we selected EPS hardware including EPS board, battery, and solar panel. Figure 3 shows the configuration of 'NanoPower P31u' EPS board from GomSpace company. Table 3 lists the specifications of the EPS board. The EPS board comprises a battery charging regulator (BCR), a power conditioning module (PCM), a power distribution module (PDM) and two integrated Li-ion battery cells with 8.4V of voltage and 2600mAh of capacity. The BCR uses the maximum peak power tracking (MPPT) method using micro controller for charging the batteries. The PCM provides 3.3V and 5V bus voltage. And the PDM distributes these voltage buses into three controllable outputs to supply electrical power for the payloads and the other bus system boards, respectively.

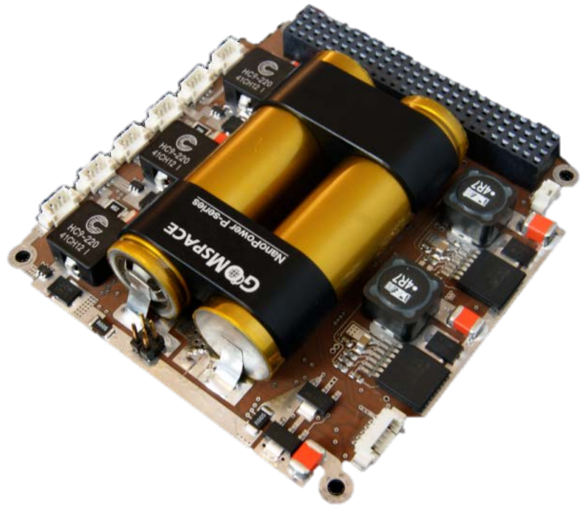

Fig. 3 'NanoPower P31u' EPS Board (GomSpace)

Table 3 Specifications of 'NanoPower P31u' EPS Board

Parameter	Value
Name	NanoPower P31u (GomSpace)
Volume	96 mm × 90 mm × 26 mm
Mass	200g(with 2600mAh Battery)
BCR	MPPT Control Method using Micro-controller
PCM	3.3V, 5V Bus Voltage Controller,
PDM	6 Controllable Output Switches (3.3V: 3EA / 5V: 3EA) with Over-current Shut-down and Latch-up Protection System
Battery	2600mAh Li-ion (Total 2 Cells)

Figure 4 shows the 'P110 solar panel' from the same vendor. Table 4 lists the specifications of the solar panel. The solar panel comprises total of two solar cells integrated on the printed circuit board (PCB). These solar cells are '3G30A' triple-junction gallium arsenide (GaAs) solar cell from AzurSpace Company with 30% of conversion efficiency at a beginning of life (BOL). All of the EPS hardware selected for the STEP mission have actual flight heritage through the several space programs. In addition, these hardware offer relatively higher electrical and mechanical compatibility with respect to the other subsystem boards of STEP Cube Lab, than those of the hardware from the other cube satellite vendors.

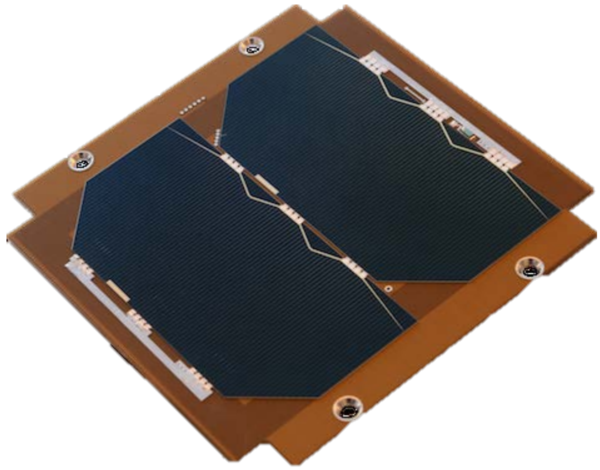

Fig. 4 ‘P110’ Solar Panel (GomSpace)

Table 4 Specifications of ‘P110’ Solar Panel

Parameter	Value
Cell Type	TJ(Triple Junction) GaAs
Solar Cell	3G30A Solar Cell (AzurSpace)
Efficiency	30% (BOL)
Dimension	98.0mm x 82.6mm x 1.1mm (with PCB) 40mm x 80mm (per Single Solar Sell)
Mass	26g (per Single Solar Panel)

4. Energy Balance Analysis

To verify the effectiveness of EPS architecture design of the STEP Cube Lab, the EBA was performed with respect to the communication mode [6]. The simulation to predict power generation from the satellite was performed using the STK. The on-orbit attitude profile of the satellite and the specifications of EPS hardware at end-of-life (EOL) were used as an input data. In the simulation, a local time of ascending node (LTAN) was assumed to be 12:00 PM, which is the worst condition to generate electrical power due to the shortest sunlight period.

In this study, we also predict power generation enhancement with the CPV system, which is one of the main payloads for STEP mission. Figure 5 illustrates an operating principle of the CPV system. The CPV system is a photovoltaic power system that can enhance the power generation performance of solar panel by concentrating and illuminating solar energy using the Fresnel lens system installed on the edge of the solar panel even under the worst condition of incidence angle between the solar panel and sun. The commercial Fresnel lens system made by poly-methyl methacrylate (PMMA) are installed on the +Y and -Y solar panel, as shown in the Fig. 5.

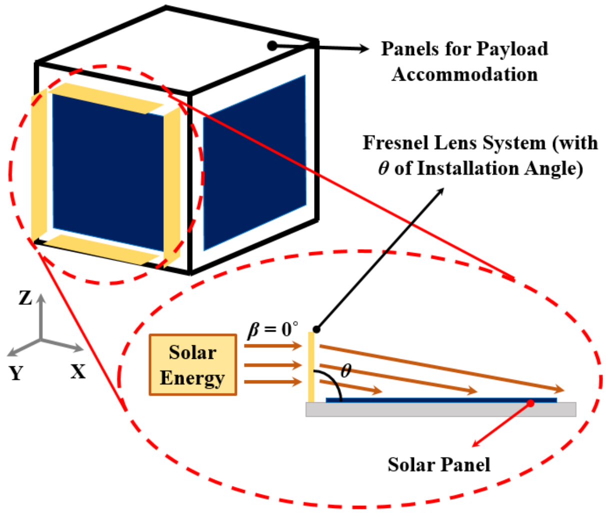

Fig. 5 Schematics of the Satellite with CPV System using Fresnel lens System

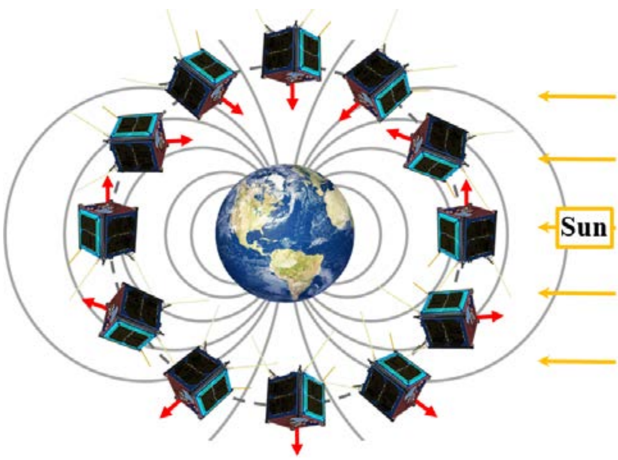

Fig. 6 On-orbit Attitude Profile of STEP Cube Lab with Passive Permanent Magnet Stabilization Method using combined with Hysteresis Damper

Figure 6 illustrates an on-orbit attitude profile of the satellite with passive permanent magnet attitude stabilization method. In the simulation, the tumbling phenomenon of the satellite after stabilization was also considered. Figure 7 shows an on-orbit power generation profile of the satellite with and without CPV system, respectively. The generated power with CPV system, calculated from the power generation profile, is 2.3Wh. This is 8% enhanced power generation compared with that without CPV system of 2.13Wh. The results indicate that the CPV system would be effective for providing enhanced power generation performance of the STEP Cube Lab.

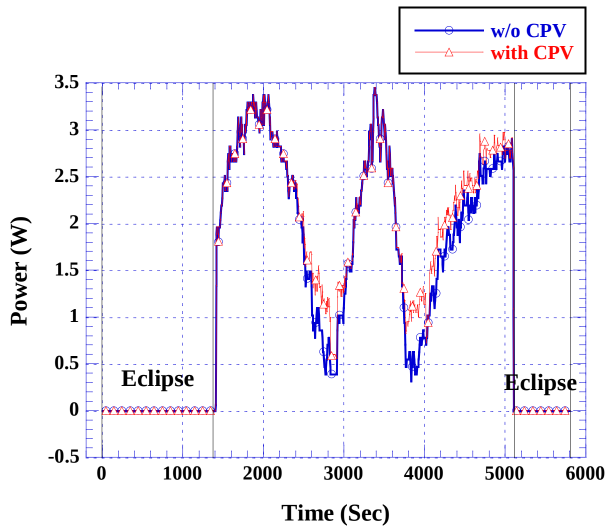

Fig. 7 Power Generation Simulation Results of STEP Cube Lab with and w/o CPV System

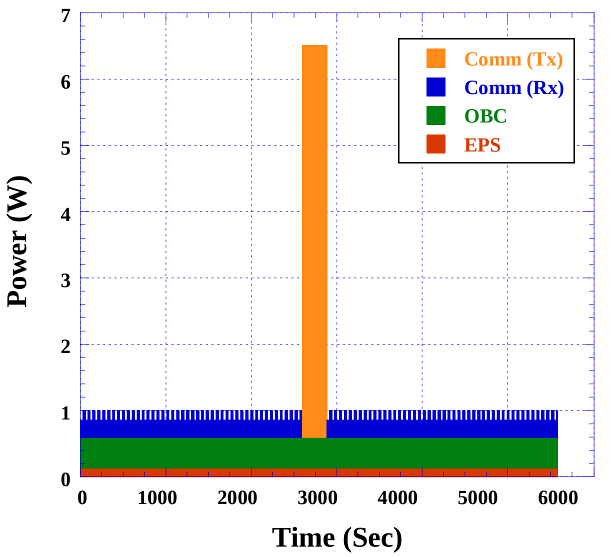

Fig. 8 Power Consumption Profile of STEP Cube Lab in Communication Mode

Figure 8 shows power consumption profile of STEP Cube Lab in the communication mode, which is the worst condition in the EPS of STEP Cube Lab. In this case, we assumed that the satellite performs downlink using Tx mode for 5 minutes, and maintains the Rx mode during the rest of the orbital period. The power consumption and the maximum battery DOD during eclipse period are 0.71Wh and 4.85%, respectively. However, an available power for charging battery after sunlight period is 0.89Wh, which is 0.18Wh higher than the consumed power from the battery during the eclipse period. This indicates that the battery would be fully recharged in the sunlight period of subsequent orbit of satellite. Therefore, we can say that the EPS architecture design performed in this study is effective to stably provide the electrical power during entire mission duration of the STEP Cube Lab.

5. Conclusions

In this study, design of electrical power subsystem architecture of STEP Cube Lab for achieving mission objectives was designed and investigated. The power budget was estimated with respect to the communication mode, which is the worst condition in the viewpoint of power consumption, considering power consumption of each hardware and on-orbit attitude profile of satellite. Based on the estimation results, proper EPS hardware in compliance with the system design requirements were selected. The energy balance analysis results demonstrated that the EPS architecture design is effective for providing sufficient electrical power during an entire mission duration of the STEP Cube Lab.

Acknowledgement

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