Pre-Mission Analysis and Architecture Design of Electrical Power Subsystem for 2U CubeSat

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Abstract: The 2U CubeSat project Phoenix is being developed at NCKU as a part of the QB50 mission in collaboration with Von Karman Institute (VKI). Among all the subsystems, Electrical Power Subsystem (EPS) is a critical one which is responsible for generating, saving, and distributing the power as during the mission lifetime. This paper introduces the pre-mission analysis and overall bench design of EPS. Besides, results of fundamental functional tests are displayed and discussed. Moreover, to improve the efficiency and reliability in the power transformation, the Maximum Power Point Tracking (MPPT) methodology is applied to EPS system and related illumination experiments are also implemented and recorded in the final.

KEYWORDS: Electrical power system, CubeSat, Pre-mission analysis

1. INTRODUCTION

CubeSats have gained more attention these years and been considered as an affordable means to enter the prestigious space technology development field. NCKU, one of the member in QB50 project, combines with the inherited experiences and capabilities to build the 2U CubeSat, Phoenix, which is partially based on COTS components. The project team has gained valuable experience from critical design process, integrating science units and carrying out space mission simulation.

This paper focus on describing the entire bench model design of the EPS containing estimation before mission as well as the board architecture and functional testing which must satisfy the mission requirements. The power generation is completely calculated and analyzed by the approach of Satellite Tool Kit (STK) software, which is used to simulate the scenario for Phoenix in space, and the results will be compared to the power budget to ensure that it meets the mission requirements. Besides, solar arrays assembly procedure and EPS functional testing both in process and results will be displayed to verify its feasibility.

2. ELECTRICAL POWER SYSTEM

2.1 EPS overall architecture

The power system of Phoenix includes a power control and distribution board with six latch-up protected switches. Two on-board Lithium-Ion batteries for a total capacity of 2600mAh are installed and solar panels are equipped with advanced triple junction GaAs solar cells. Moreover, strictly Killer-Separation Switch (KISS) design philosophy is applied on the system in order to enhance the stability. All power system hardware elements are space proven COTS. The EPS overall architecture is shown in figure 1.

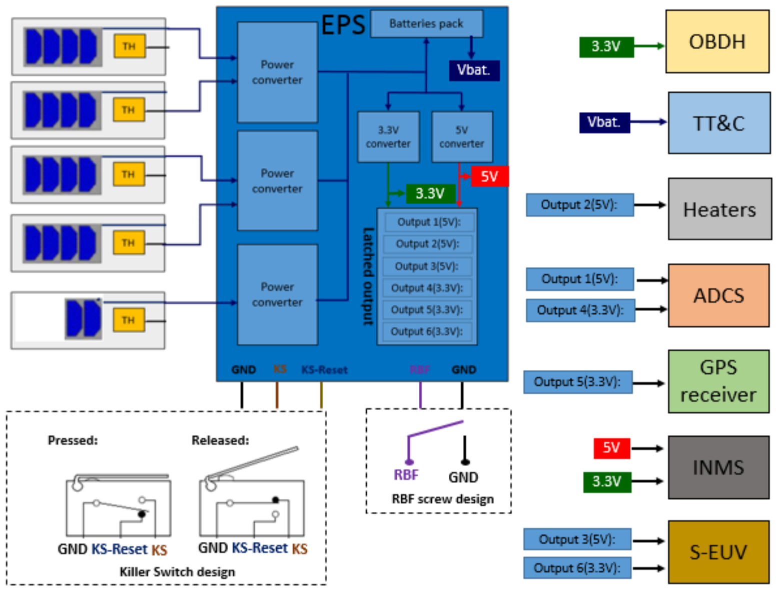

Figure 1: EPS overall architecture

2.2. Hardware

2.2.1 Solar cells

The advanced triple-junction solar cells from EMCORE Corporation which possess the high efficiency as 26.9%, are chosen for Phoenix design [1]. Figure 2 displays its appearance, and table 1 indicates its characteristics. Every surface on Phoenix is body-mounted with solar cells except the +Z one which is arranged for science payload – Ion/Neutral Mass Spectrometer (INMS). Each slice of the high performance solar cell generates the average power around 0.56W in one orbit, which is qualified for the mission.

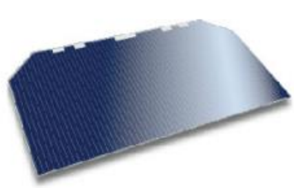

Figure 2 – BTJ solar cell

Type:	Triple junction
Efficiency:	26.9%
Voc:	2.6V
Isc:	0.4A
Vpmax:	2.37V
Ipmax:	0.39A

Table 1: Characteristics of BTJ solar cells

2.2.2 EPS board

According to mission requirement, the GomSpace NanoPower P31u is qualified and chosen for Phoenix as shown in figure 3[2]. It features two Li-ion 2600mAh batteries and advanced functions for system. Its architecture is composed of three photovoltaic power converters, self-locking switch and 3.3V/5V power regulator. The control and sensor unit on EPS board can monitor the status including voltage and current as well as receiving command from OBDH by I2C transmission.

Figure 3: Nanopower P31-u

2.3 Software

Nanopower is capable to communicate with PC through GOSH terminal. This interface is provided by GOMspace which enables users to easily implement testing. In the Gosh terminal, several libraries commands are provided and can be used to either acquired EPS status data or setting configuration. The figure 5 indicates the EPS status diagram which captured from GOSH terminal.

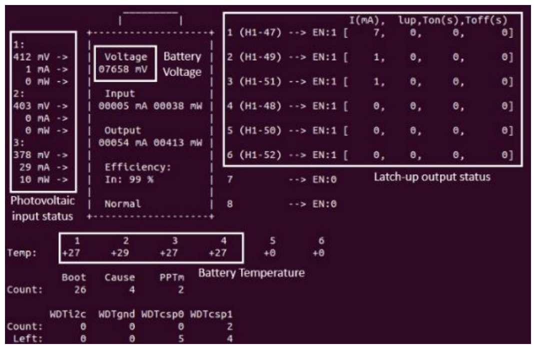

Figure 4: EPS board status shown in GOSH terminal

3. PRE-MISSION ANALYSIS

3.1 Orbital analysis

According to QB50 requirements [3], the orbit profile of QB50 satellite was clearly defined. Following those definitions in, there are some restrictions that must be fulfilled:

- The orbit must be circular
- The initial orbit altitude must be 400 km ±20km
- The inclination should be 98.18±2˚
- The eccentricity should between 0 and 0.04
- The mission should at least 6 months (Simulate from 2/14/2016 – 7/14/2016)
- The local time of descending node (LTAN) is 6am, which equals 235˚ in RAAN

The software **STK** from **Analytical Graphics Inc**. (AGI) allows engineers and scientists to perform complex analysis in space condition. As the orbital parameters shown in Table 2 are setup correspondingly in the initialization process for Phoenix scenario in STK, orbital analysis could be conducted and recorded using the software inbuilt functions [4]. One average orbit period of Phoenix is 92 minutes, comprising 77 minutes of lighting time and 15 minutes of umbra time. The mean duration between Phoenix and NCKU ground station is 7.96 minutes. Figure 5 is the Phoenix illustration in STK scenario.

Type	Phoenix
Altitude	400km
Eccentricity	0.02
Inclination	98.18˚
Argument of Perigee	0
RAAN	235˚
True anomaly	75˚

Table 2: Phoenix orbital parameters

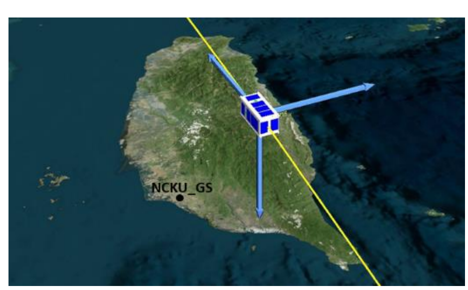

Figure 5: Phoenix in STK scenario

The Lifetime tool in STK provides an estimation predicting the amount of time a satellite can be expected to remain in orbit before atmospheric drag and other perturbations cause it to decay. The atmospheric density model is set to NRLMSISE 2000, and the initial conditions are treated as mean orbital elements. The values of options that effects calculating lifetime are shown in table 3.

Atmosphere Drag Coefficient	2.2
Solar Radiation Pressure Coefficient	1,0
Main drag Area	$0.01m^2$
Mean area Exposed to Sun	$0.02m^2$
Mass	2kg

Table 3 – Values of options in life tool

The result indicates that Phoenix could survive for around 2.5 years before decaying, which is more than 6 months of requirement mission; therefore, it can be conclude that the design of Phoenix is feasible. In figure 6, the height of Apogee and Perigee in Phoenix life time is clearly displayed. Obviously, it would decay to the altitude lower than 200km after 2 year, which fulfill the mission required life time.

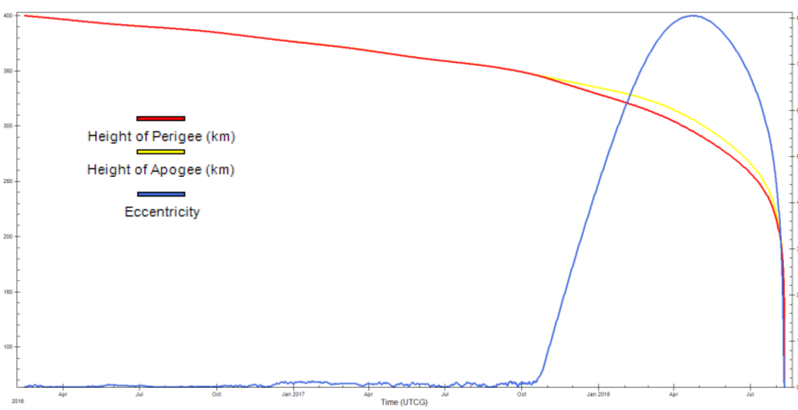

Figure 6 – Lifetime estimation for Phoenix

3.2 Power generation

The solar panel tool provides the method to model the exposure on solar panels array mounted on spacecraft or aircrafts over the mission time. The result of this analysis can be used to determine varying availability of electrical power for operations, which would be performed by the other subsystem and onboard apparatus.

To compute the electrical power captured by the solar panels array at a given point in time, the Solar Panel tool applies the following Power Equation [5]:

$$P = A_{array} \times S \times \theta \times \eta_{cell} \quad (3.2.1)$$

The following table are the parameters value of Phoenix for power equation:

Area of solar cells array	$\mathbf{A}_{array}$	Total for 0.045 m^2
Solar constant	**S**	Using average value around 1361W/m^2
Incident angle of sunlight	$\boldsymbol{\theta}$	It depends on solar panels location & timing.
Efficiency of Solar cells	η_{cell}	Normal case: 26.9 %

Table 4 – Parameters of power equation

The Solar Panel tool computes solar illumination over time by animating the scenario and periodically counting the pixels related to illuminated portions of the solar panels under consideration. There are two main flight scenario should be considered for power generation in Phoenix: one is three-axis stable mode, and the other is stabilizing mode.

3.2.1 Three-axis stable mode:

During three-axis stable flying mode under well attitude control, Phoenix flies aligned its body's X vector without spinning. The average power generation consider all power generated in both lighting time and umbra time in each day according to the simulation from the STK. The graph of results is shown in figure 7, and the average value is 3.23W.

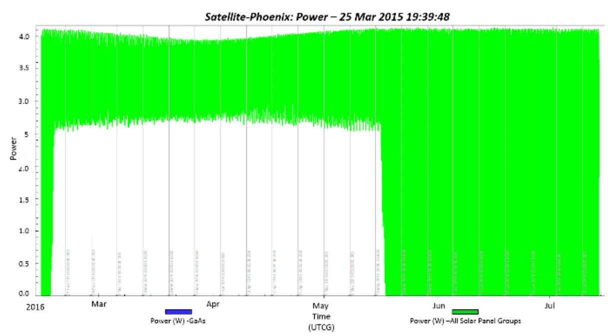

Figure 7 – Phoenix power generation in three-axis stable mode

3.2.2 Stabilization mode:

In first orbits after deployment from P-Pod, it's expected that Phoenix spends couple days stabilizing to reach three-axis stable status. Considering that this case leads a different result of power generation compares with the one under three-axis flying mode. Therefore, a 7200 seconds of scenario of first orbit simulation has been carried on which was based on satellite attitude results referred from Phoenix Attitude determination and control subsystem (ADCS) algorithm [6]. The power generation results is displayed in figure 8, and the average value is 2.47W.

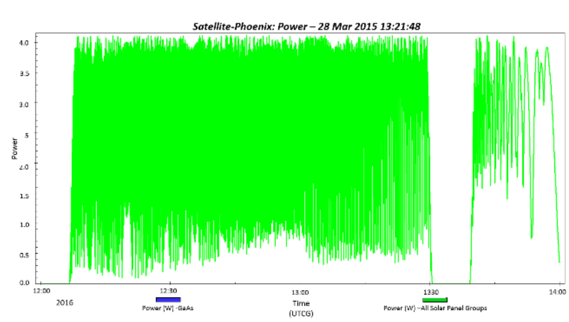

Figure 8: Phoenix Power generation in first orbit's stabilization mode for 5400S

3.3 Power management

Phoenix operates in different mode during the QB50 mission handling various situation. Thus, the different orbital scenarios can be described and have better understanding of the detail power management. Both power budget and power analysis are carried on and explained in detail in following section.

3.3.1 Power budget

Each mode during Phoenix mission activates different components, which leads to diverse power consumption as consequence. The power budget computes the power profile in different mode by multiplying the duty cycle which the component is activated in one orbit, with the average power consumption it consumes. The Table 5 provides the Phoenix power budget in five different modes. The scenario in stabilizing case is also considered. It is clear that the margin always stay positive during the mission which confirms the feasibility of supplying sufficient power.

Subsystem power consumed			Duty cycle in one orbit (%)				
Load	**Power consumption (W)**	**Number of units on**	**Initial mode**	**Stabilization mode**	**Nominal mode**	**Comm. mode**	**Safe mode**
OBDH	0.29	1	100	100	100	100	100
TT&C – TX	1.53	1	0	3	3	10	0
TT&C – RX	0.20	1	100	100	100	100	100
ADCS	0.56	1	100	100	100	100	0
EPS	0.13	1	100	100	100	100	100
EPS-heaters	1.25	1	5	5	5	5	5
GPS	1.14	1	0	30	30	30	0
INMS	0.76	1	0	0	60	66	0
S-EUV	0.81	1	0	0	60	60	0
	Sum loads (W)		1.30	1.69	2.61	2.79	0.74
	Efficiency (%)		91	91	91	91	91
	Power Consumed (W)		1.43	1.85	2.87	3.03	0.82
	Power Generated (W)		3.23	2,51	3.23	3.23	3.23
	Power Margin (%)		55.68	26.17	11.19	5.49	75.46

Table 5: Phoenix power budget

3.3.2 Power analysis

According to power budget, complete power analysis in different scenario are carried out which not only provides with higher accuracy but also an in-depth comprehension to power management in whole mission. The power analysis are presented in graphical format which are easier to understand and illustrate.

Scenario 1: First orbit:
After the deployment from P-POD, Phoenix will have to wait for 30 minutes until all the CubeSats are scattered apart. Afterwards, the flight software will start to initialize each subsystem and enter the stabilization mode to recover angular rate of the satellite from tip-off rate within one and half hour. The figure 9 shows its power analysis.

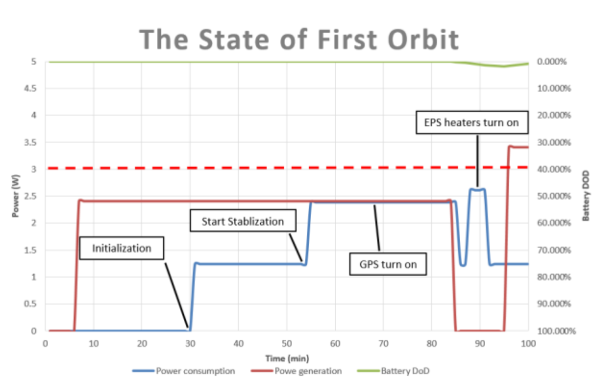

Figure 9: Power analysis in first orbit

Scenario 2: Nominal &Communication

It is expected that Phoenix spend most of mission time in this scenario implementing scientific mission and data transmission with NCKU ground station**.** Phoenix is requested to download the scientific data during passing the ground station, which is also the most power-consumed scenario. Meanwhile, Phoenix will turn off the scientific payloads and focus on communication. Figure 10 shows the power analysis in this scenario.

According to figure 10 that it reveals the battery depth of discharge (DOD) decrease gradually during eclipse, which may lead power failure to the mission. In case of this kind of situation, Safe mode is applied to mode design to prevent any possibilities which is hazardous to Phoenix.

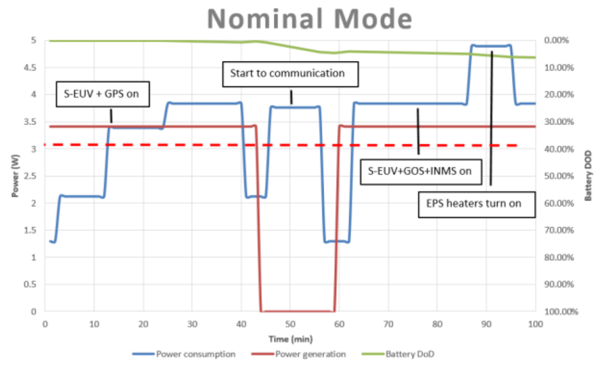

Figure 10: Power analysis in Nominal and Communication scenario

4. FUNCTIONAL TEST

4.1 Battery level tests

The DOD and cycle life time play important role in this section. In order to well-understand the value of DOD, charge and dis-charge cycle test based on constant current rate 1/5C are conducted. The dis-charge test aim to acquire the period for Phoenix to fully dis-charge. The DOD threshold to safe mode is set to 40% currently. According to result shown in figure 11, the V-cut appears at around 6.5V, which also mapped with the critical voltage in EPS board. The Nanopower will shut down all functions once it reaches the voltage, and can only be turned on after gaining power from external device. As a remark, Phoenix should avoid this situation. The charge test aim to acquire the period for Phoenix to fully charge. The Nanopower features over-charged protection function and will stop charging once it reach the voltage as 8.4V. Referred from results shown in figure 12, it takes around 5 hour to fully charge the battery.

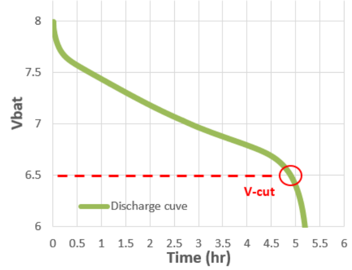

Figure 11: Discharge curve of battery

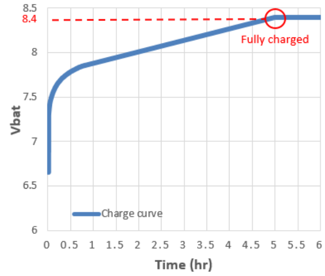

Figure 12: Charge curve of battery

4.2 Power generation tests

Each side panel is covered with four solar cells are applied for conducting a short cycle of Illumination test. This test aim to examine the solar cell's charging capability, and verify the function of photo-voltaic input on Nanopower. The solar panel and testing configuration are shown in figure 13 and figure 14 respectively. MPPT are applied in Nanopower and used for maximizing the power input. Each side panel generates an average power of 2.21W under MPP condition, which satisfies the mission requirement. The testing results are shown in Table 6

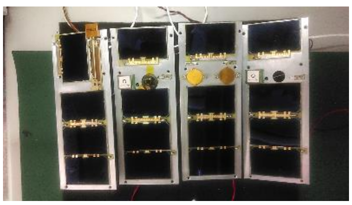

Figure 13: Phoenix's Side panel

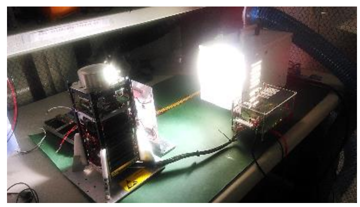

Figure 14: Illumination testing

Panel name	Maximum power voltage	Maximum power
+X	4.18V	2.15W
+Y	3.92V	2.28W
-X	4.23V	2.29W
-Y	4.07V	2.10W

Table 6: Testing results

4.3 Power Distribution tests

The distribution and regulation of power are an essential issue which should be tested and verified cautiously. Accordingly, the EPS are tested to supply power to other subsystem, and both 3.3V converter and 5V converter are under monitoring in the entire process. The results of 5V converter output in average is 4.96 with 0.8% of error, while results of 3.3V converter output runs about 3.34V with 0.3% of error.

5. CONCLUSIONS

The detail design of electrical power subsystem for Phoenix has been presented, ranging from COTS product purchase to functional testing. In addition, a comprehensive of pre-mission analysis in terms of lifetime, ground station accesses, sunlight periods, and power generation are illustrated. The proposed architecture stand for recommendation approach for EPS designer to have a quick understand in space mission as well as design the whole bench system.

ACKNOWLEDGEMENT

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