The 25th Satellite Design Contest / Idea Section / Analysis sheet
Origami Solar System Satellite “OS3”

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1. Mission design

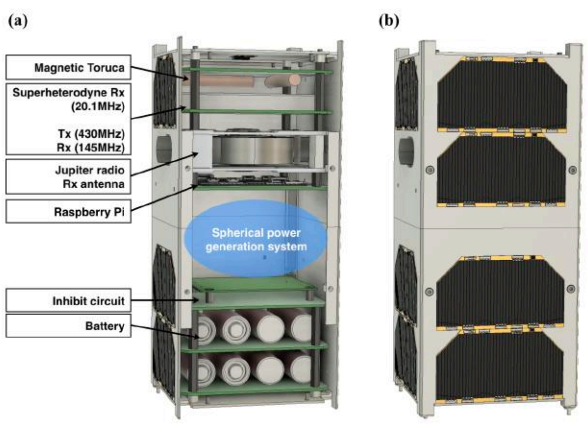
1.1 Introduction Ultra-small satellite(called as cubesat) is extremely compact and lightweight and it is very inexpensive compared to the launch cost of general satellites, making it possible for anyone to participate in development and launch from this cheapness. However, since it is ultra-small, power supply is limited and power saving is essential. Therefore, we propose a spherical power generation system that enables high-power generation even for cubesat, aiming for a full-scale science mission with ultra-small satellites, which was previously disadvantageous for science missions. As one of the ideas for realizing these, we decided to propose cubesat Origami Solar System Satellite (OS3) which solar cell generation increased by an order of magnitude compared with the conventional one. As a science mission, we propose observation of the broadband dynamic spectrum of Jupiter radio waves in the shortwave band. This is aimed at elucidating the Jupiter radio emission structure by broadband dynamic spectrum observation in the space with less influence of the ionosphere of the earth, and this science mission adopts a digital method by a high-speed A/D converter which requires power capacity. The large power for that purpose is supplied by the spherical power generation system.

1.2 Application of Origami In recent years, origami has been drawing attention in various fields such as space development, medical, design, but in space development it is being used for solar sail etc. as a model of a new exploration satellite. In addition, it is beginning to be used for folding solar cells and antennas. The greatest feature of this origami is that various solids can be made from a single piece of paper. Because of this, it has the power to attract people all over the world, and in addition to the technology which is regarded as important in the conventional space development, design side is added and it becomes more interesting.

1.3 Jupiter radio waves It is known that the L burst, which is a temporal change of the order of several seconds on Jupiter's radio waves, is due to the large modulation by the ionosphere of the Earth. In space, detailed dynamic spectrum observation with broadband without the influence of the ionosphere becomes possible.

1.4 Overview of mission The mission procedure is shown below. **1.** Release 2U CubeSat OS3 to outer space as piggyback satellite of H-IIA rocket. **2.** Expansion the spherical power generation system with the extension system. **3.** As auxiliary expansion, BMX (Biometal helix) reliable expansion is done by PWM power control of Raspberry Pi. **4.** Uplink, downlink antenna, Jupiter radio receiving antenna extension. **5.** The processing of converting the analog signal of Jupiter radio wave received using the GPS pulse of the installed GPS module to the digital signal by the A/D converter is performed by Raspberry Pi, and then the data is transmitted to the ground station. **6.** Finally, we aim to elucidate the dynamic spectrum structure of Jupiter radion from correlation analysis with simultaneous observation data on the ground. Next, the purpose of the mission is shown. **1.** Verification of reliable expansion method of spherical power generation system. **2.** Verification of reliable extension method of Jupiter radio observation antenna. **3.** Elucidation of Jupiter Radio Dynamic Spectrum Structure

1.5 Performance of satellite Fig.2 shows the layout of each unit and the state of expansion. Tab.1 shows Performance goal. Next, the Jupiter radio waves are received by the antenna for Jupiter radio observation, amplified by a preamplifier, digitized by a high-speed A/D converter, dynamic spectrum display processing by Raspberry Pi, and saved in a file. The stored data is sent to the ground station by the communication band of 435[MHz] band.



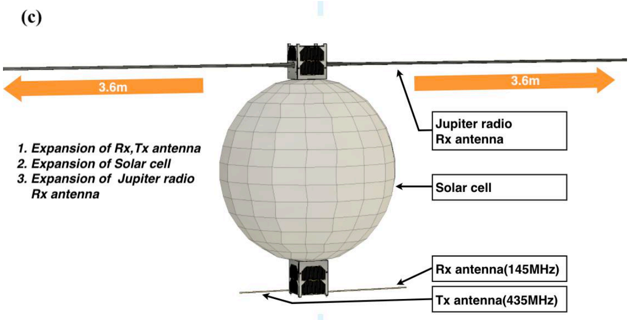


Fig.2 (a) Internal structure of satellite, (b) Appearance before expanition, (c) Appearance after expanition

Tab.1 Performance goal

Size	W100×D100×H 227.0 [mm] (2U)	
Mass	Overall	2600g
	Power system	400g
	Communication, Data processing system	250g
	Solar panel	500g
	Structure	1000g
	Mission system	450g
Release condition	500km, 97°, 192day ~ 4year	
Attitude control	Gravity gradient, Magnetic Toruca, DRW	
Main mission equipment	Solar panel, Attitude control system	
	GPS, Communication system	
	Transceiver, Data processing system	
	Jupiter radio receiving antenna	

2. Spherical power generation system

2.1 Origami

The reason for using the spherical power generation system is that the ultra-small satellite structure has a limited surface area and it is difficult to achieve high power generation. Therefore, we focused on the spherical power generation system proposed this time. As a method of folding the spherical structure, a method of folding the spherical membrane in the axial direction while contracting the spherical membrane in the radial direction was considered.[4] Fig.3 shows the situation until expansion.

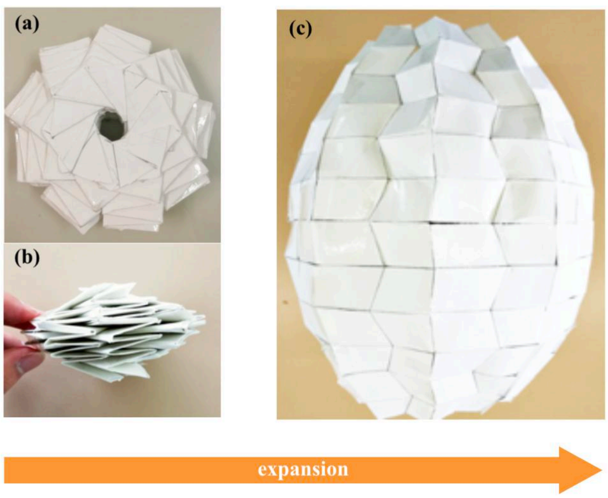


Fig.3 (a) Separation axis of satellite, (b) Before expansion, (c) After expansion

This way of folding is divided into 9 divisions in the longitude direction and 9 divisions in the latitude direction. The larger the division into the latitude direction, the more you can store it in the satellite without taking the lateral width. In addition, as shown in Fig.3 (a), space is created in the central axis, storage of springs for separating the satellites in the expansion of a spherical power generation system, use for storing shaft rods for fixing axes between the two satellites.

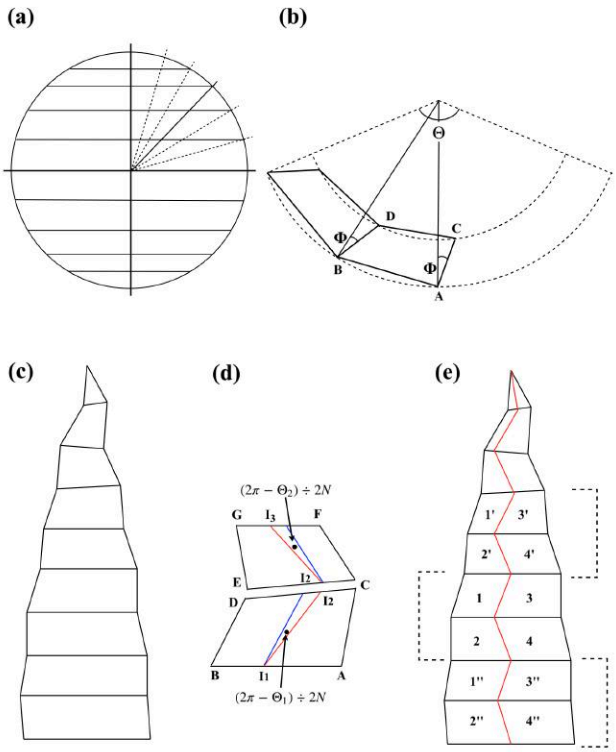


Fig.4 (a) Slicing of membrane sphere by horizontal planes, (b) fan-shaped strip-element obtained by slicing, and then divided into small trapezoidal elements by mountain fold lines, (c) packing up of small elements to produce boat-shaped element, (d) prescribed angles of valley fold lines in small element, (e) boat-shaped element with valley folding

The characteristics of the folding method used this time will be described below. At the time of storage, a spherical body having a height of 4[cm] or less, a diameter of 9[cm] or less, and a diameter of 40[cm] at the time of deployed is formed with the thickness of the strut being 1[mm]. The total power generation amount is about 10 times the solar cell light receiving panel area, so it is possible to supply several W of electric power etc. necessary for the broadband dynamic spectrum observation system of Jupiter radio waves. In this way, the spherical power generation system is considered to be very advantageous in the science mission which requires high power. The finer the division, the smaller one solar cell is, making the solar cell difficult to manufacture. For practical use, it is desirable to divide into 6 divisions in the longitude direction and 9 divisions in the latitude direction. However, in this verification, we examined the classification of longitude and latitude in 9 divisions. In addition, in order to lower the difficulty of making this solar cell, it is not a conventional flat plate cell but a solar cell using Sphelar Cell can be used to construct a free shape.

2.2 Sphelar Cell By setting the light receiving surface to spherical shape, Sphelar Cell[5] can capture about 3 times the light compared with the flat plate type. As it is designed with granular cells as a unit, it is possible to make solar panels with free shapes without having to be bound by a predetermined size and shape of conventional space solar cells. In fact, a demonstration experiment[6] using 58 series Spellar Array of 12 series and 1 parallel type using Sphelar Cell is being conducted on the satellite of Kyushu Institute of Technology, and power generation of 300[V] Is realized. Tab.2 shows its characteristics.

Tab.2 12 cell serial Sphelar Array

Open circuit voltage [V]	**7.27**
Short circuit voltage [mA]	**2.3**
Maximum output [mW]	**13.5**

This time we are planning to use this Sphelar Cell arranged in a mesh shape, and Fig.5 shows how to take the electrode.

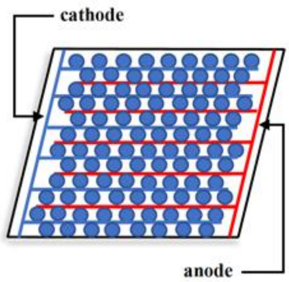


Fig.5 Sphelar Cell electrode

As mentioned at the beginning, since the light receiving surface is a spherical shape as the merit of Sphelar Cell, it is possible to capture about 3 times as much light as the flat plate type. Therefore, as shown in Fig.6, consider plating processing of the surface of the support material to which Sphelar Cell is stuck and to introduce a mechanism where by light is efficiently taken into the cell.

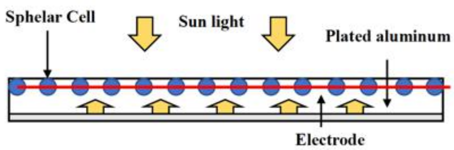


Fig.6 Use of reflected light

2.3 BMX We considered supplementary expansion of the spherical power generation system using BMX(Biometal helix)[7]. BMX is a new actuator that behaves like a muscle, and the stretched BMX shrinks powerfully and strongly to its original length with heat. The force when contracting generates a greater force than when it is stretched, and a change close to 200 [%] as a motion displacement can be obtained. Tab.3 shows physical properties of BMX.

Tab.3 Physical properties of BMX

Coil diameter [DΦmm]	**0.62**
Practical force [gf]	**20~40**
Motion displacement [%]	**200**
Drive current [mA]	**200~300**
Resistance value [Ω/m]	**400**

Assuming that the amount of shrinkage of BMX required for deployment is Δα[mm] and the thickness of the panel is t[mm], equation (1) is obtained.

$$\Delta\alpha = \pi t + 2t \tag{1}$$

2.4 Expansion of spherical structure When released to outer space, the folded spherical structure is cut by the heat generated by the Nichrome wire and developed by the extension system. Because of the nature of origami, deployment is completed by the extension system, but it is necessary to assume the case that it can not be opened. We solve this by auxiliary deployment using BMX contraction by Raspberry Pi 's PWM scheme power control. Fig. 8 shows the mechanism of expanitiont system.

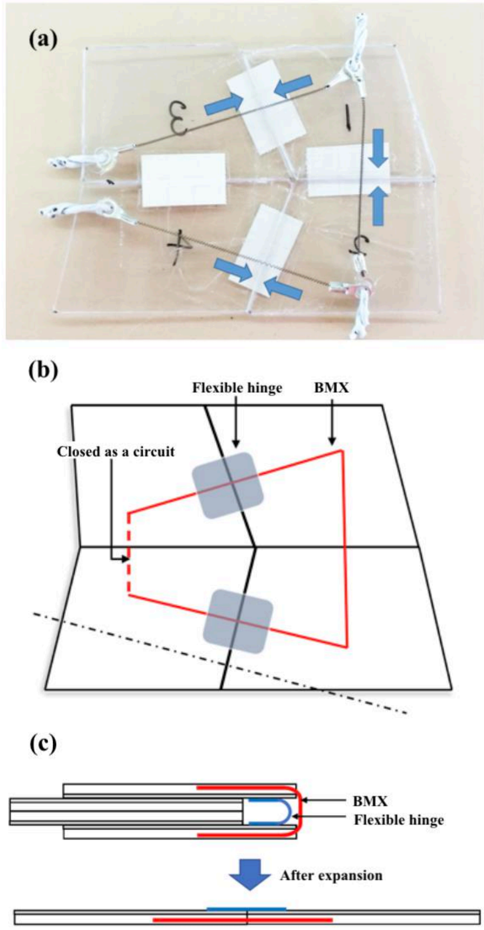


Fig.8 (a) Experiment state, (b) Details of Fig.10, (c) Dashed line sectional view of (b).

This expansion system is used for <u>1', 2', 3', 4'</u> and <u>1'', 2'', 3'', 4''</u> as well as <u>1, 2, 3, 4</u> shown in Fig. 4 (e). This is not affected by direct sunlight by incorporating only on the shaft side (the side not exposed to sunlight). For other folded parts, BMX is not used. Fig.9 shows the expansion state when three AA batteries are connected in series. The time required for expansion was found to be within 4[s]. Also, since sudden expansion is dangerous in outer space, smooth deployment is possible by controlling the interval of current flowing in BMX by power control in PWM system.

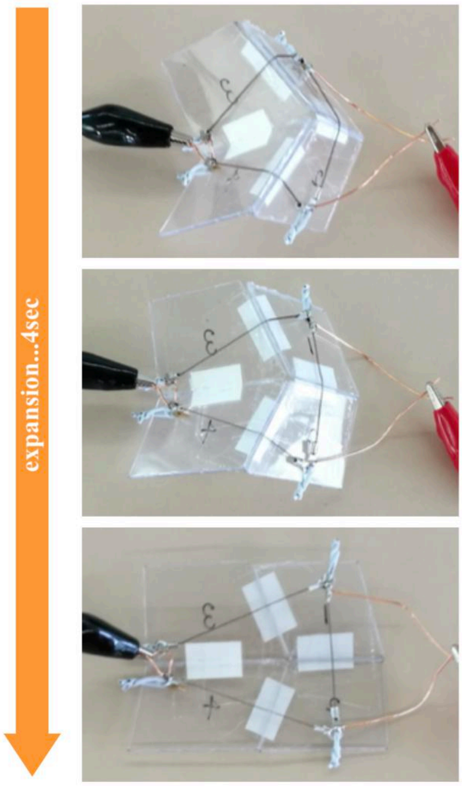


Fig.9 Solar panel development

3. Extension of antenna

In order to observe Jupiter radio waves (20[MHz]), it is necessary to extend the dipole antenna of 7.2[m] corresponding to the half wavelength of 20MHz. Therefore, from the 1980's, we decided to use Stem Boom, which was used as a posture stabilizing device for gravity gradient torque with the Space Shuttle and others. This Stem Boom is the simplest structure among the boom mechanisms and has many other merits such as storage rate etc. We decided to use it as an antenna for Jupiter radio observation as its application example. Fig.10 shows the antenna storage and extension.

Fig.10 Antenna storage and extension view

Stem Boom makes it possible to extend by using the restoring force of the rolled antenna, so no power source is necessary. As the cross section of the antenna changes with the extension as shown in Fig.11, we can overcome the strength problem.

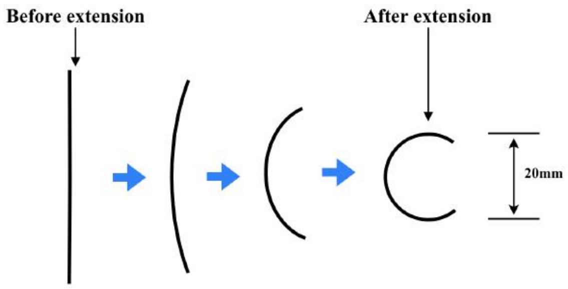


Fig.11 Cross section in antenna extension process

4. Power system

The OS3 safely charges the power obtained by the solar panel to the AA type lithium ion battery by switching control between the CV mode and the PPT mode with the controller IC. At the same time, power is supplied to each unit from the battery. Also, because the 3 junction solar cell is attached to the side of the satellite, it is always possible to generate the minimum electric power at all times. In the spherical power generation system proposed this time, with a diameter of 40[cm], the power generation amount on the side of the satellite is set to 6[W] It is 7 times as much as 42[W] electricity generation possible. After 2 years, it is expected that the power generation efficiency of Sphelar Cell (now 10 to 15[%]) will be over 30[%], so it is possible to realize more than 10 times power generation against the amount of electricity generated on the side of the satellite.

5. Conclusion

This mission enables science missions that could not be done by conventional cubesat with large electric power generation using a spherical power generation system using origami. If this can be realized, it can be used for 2U or more cubesat as a 2U size bus system. Furthermore, on the expansion for the spherical power generation system considered in this mission, it is the first attempt to use BMX and it can be expected to have a ripple effect as a model of a new cubesat. We think that these are important technical elements that will open up a breakthrough in realizing science missions by cubesat.

References

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