Development of Mini Space Elevator Demonstration Satellite SATRS-Me

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ABSTRACT

STARS (Space Tethered Autonomous Robotic Satellite) project in Shizuoka University purposes to evaluate and to verify a space mechanical control system by a university satellite, whose characteristics are: it consists of a mother and a daughter (and grandchildren) satellites; it becomes a large scale space system using tether; and also robotic mechanical system performs dynamic motion on orbit. Currently, the project is developing space elevator demonstration satellite “STARS-Me,” whose primary objective is to demonstrate orbital space elevator. The experiment is planned to be performed at lower altitude than that of the International Space Station (ISS). SATRS-Me a 2U CubeSat, and two 1U satellites are connected by tether. The gravity gradient stabilization cannot be considered, tether should be tape convex and high stiffness by metal material. Off course, a climber should be stowed in the CubeSat body, and then translate on the tether. This paper describes such a 2U CubeSat named STARS-Me, which will be launched in this year 2018.

1 Introduction

STARS (Space Tethered Autonomous Robotic Satellite) project in Shizuoka University purposes to evaluate and to verify a space mechanical control system by a university satellite, whose characteristics are: it consists of a mother and a daughter (and grandchildren) satellites; it becomes a large scale space system using tether; and also robotic mechanical system performs dynamic motion on orbit. The first satellite of the project was “STARS” in figure 1, which was launched by the H-IIA rocket on January 23rd, 2009 [1], [2]. It was a mother-daughter satellite, a tethered satellite, and also a robotic satellite. These three main characteristics have been evaluated and verified successfully on orbit, though attitude control for a tethered space robot could not be performed due to shorter tether extension than that expected. On August 31th, 2010, TSR-S (Tethered Space Robot -S) was launched by the sounding rocket S-520-25 from Uchinoura Space Centre [3]. One of S-520-25 experiments is for a tethered space robot. The proposed attitude control approach for disturbances suppression and change of the desired attitude of a tethered space robot have been evaluated and verified. The second satellite of the project was “STARS-II” as shown in figure 3, which was launched by the H-IIA rocket on February 28th, 2014 [4], [5]. It was also a mother-daughter satellite, a tethered satellite, and a robotic satellite as well as STARS. However, tether was 300m long (5m long on STARS) and Electro Dynamic Tether (EDT). The 300m tether deployment was evaluated by orbital altitude change, though telemetry data from the satellites was not sufficient. The third satellite of the project is “STARS-C” as shown in figure 4, which was released from the ISS (International Space Station) on December 19th, 2016 [6]. And now it is under operation. It is a 2U CubeSat, and one is a mother and the other is a daughter. They are connected by 100m long Kevlar tether. Its primary purpose is to analyze basic tether dynamics motion on orbit experimentally.

Currently, the project is developing space elevator demonstration satellite, whose primary objective is to demonstrate orbital space elevator. Note here that long tether extension is potentially dangerous with respect to space debris problems. It is difficult to extend long tether under the requirement of the process for Limiting Orbital Debris. Then, the first space experiment for space elevator is proposed as follows. The experiment is planned to be performed at lower altitude than that of the International Space Station (ISS). Tether length is considered to be short, because life time of a long tether system is extremely short at the lower orbit, and also because putting method in the lower orbit is considered as release from the ISS. A satellite for such an experiment is 2U CubeSat, and two 1U satellites are connected by tether. The gravity gradient stabilization cannot be considered, tether should be tape convex and high stiffness by metal material. Off course, a climber should be stowed in the CubeSat body, and then translate on the tether. This paper describes such a 2U CubeSat named STARS-Me, which will be launched in this year 2018.

Figure 1. STARS.

Figure 2. TSR-S on the sounding rocket S-520-25.

Figure 3. Debris removal by a tethered space robot.

2 Outline of STARS-Me

Figure 4 shows image of STARS-Me. STARS-Me is categorized as a 2U CubeSat, which is 100 X 100 X 227 mm, with weight less than 2.66kg. STARS-Me consists of two CubeSats having basic functions independently, and each satellite communicates with the ground station independently.

Figure 4. STARS-Me image.

One of them is called CV, and the other is called HT. The two CubeSats are connected by a rigid tape tether. CV has a climber and approximately 3m tether, and HT has the tether deployment mechanism consisting of approximately 11m tether. STARS-Me has a total of 14m tether. External views of STARS-Me in its stowed and after-deployment configuration are shown in Figure 5 to Figure 7, respectively. Internal views of STARS-Me is shown in Figure 8.

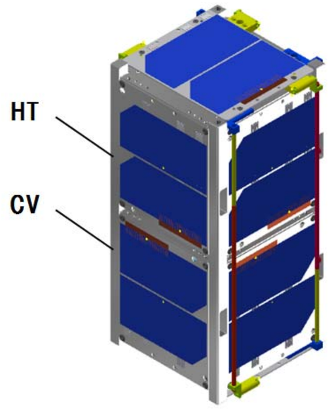

Figure 7. External View (Stowed Configuration).

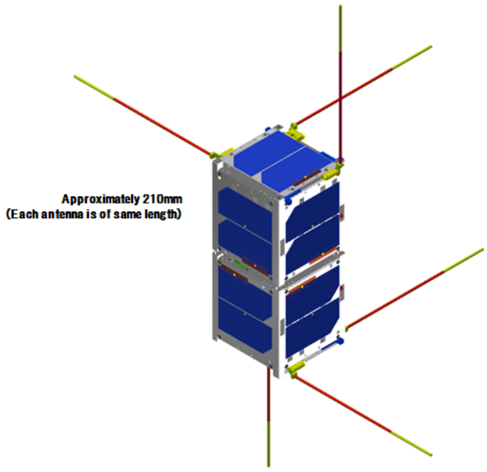

Figure 8. Antenna deployment Configuration.

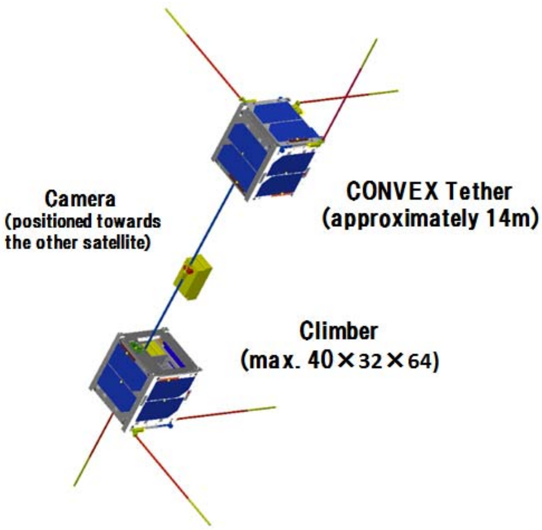

Figure 9. Tether deployment and Climber traverse.

The mission sequences of STARS-Me are divided into the following:

(i) Initial operation mode
Two satellites are first secured together and put into orbit. Thereafter, they will be unlocked. Each satellite will simultaneously deploy their antenna and start to transmit CW beacon. Then we will confirm that each device equipped in each satellite are working normally by the command from the ground station.

(ii) STARS-Me separation mode
By the command from the ground station, two satellites will deploy their tether using motors. We will acquire the mission data and confirm that STARS-Me has been separated. Furthermore, after acquiring each detailed data, the separation distance and the stability are analyzed.

(iii) Climber traverse mode
The climber will traverse on the tether after being unlocked from the CV. The climber has a Bluetooth and communicates with the CV. From the data of the climber and each satellite, we analyze the behavior of the mini elevator. We also confirm that the climber has traversed on the tether.

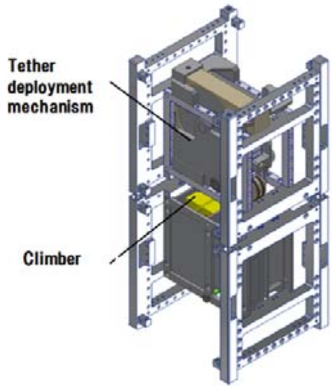

Figure 10. Internal View (Climber and Tether deployment mechanism).

3 Mission System

3.1 Antenna deployment mechanism

STARS-Me will deploy the antenna automatically 30minutes after it's been released from the J-SSOD. CV and HT consist of three antennas each, mounted on opposite sides. The two Nylon wires for fixing two satellites is cut using a self-timed nichrome wire heating element. Thereafter, the antennas are displaced slightly from their respective pockets by a spring force and a pressure caused by the joint of the two convex tethers (The two convex tethers are joined between each satellite by adhesion with an auxiliary and a tape, see the tether fixed point in Figure 12. When the two satellites are fixed, a bending stress is applied on the two convex tethers because each tether deployment point is different) which together amounts to less than 0.5[N]. The antennas are deployed using torsion springs. Two antennas are positioned at 90 degrees and one at 180 degrees for each satellite. The tip of each antenna is curved at a 1mm radius R1.

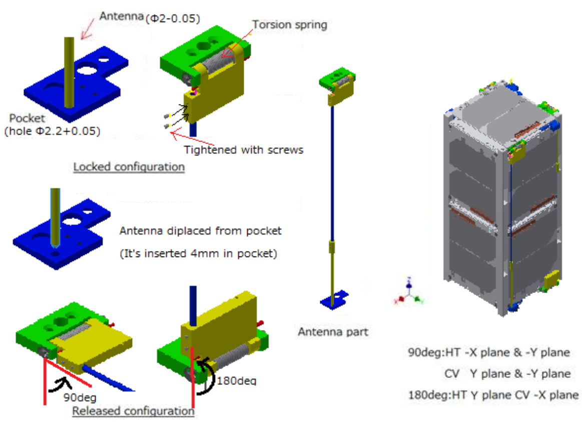

Figure 11. Antenna Deployment Mechanism.

3.2 Climber System

The climber plays two roles which deploys approximately 3m tether (The material of the tether is Steel JIS G 4802) fixed the tether of HT and traverses on the tether. Once STARS-Me reaches a stable condition, the tether deployment is carried out using motors (The material of the roller is Peek covered heat-shrinkable tubing (made by Shinetsu Kagaku). The speed of the motor is 144[rpm] constant), after the command is sent from the ground station. When the motion of the motors is outwards, the tether is deployed. After each satellite deploys tether, the commands are sent, and the motor is set to an inward motion and the climber is deployed by frictional force occurred between the motors and the tether.

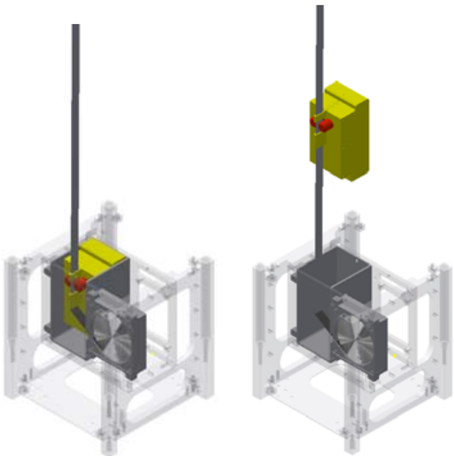

Figure 12. Separation Mechanism.

3.3 Tether deployment mechanism

Tether deployment mechanism has approximately 11m tether (The material of the tether is Steel JIS G 4802). The tether deployment mechanism in the HT is carried out by the command from the ground station. When the motion of the motor (The material of the roller is rubber. The maximum speed of the motor is 100[rpm]. The minimum speed of the motor is 30[rpm]) is outwards, the tether is deployed. When the motion of the motor is inwards, the tether is wound on the spool. The satellite that deploys the tether first depends on the attitude condition after separating CV and HT.

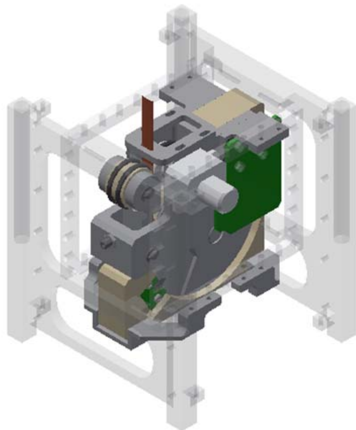

Figure 13. Tether Deployment Mechanism.

3.4 Tether deployment sequence

After separation of the two satellites, initially CV deploys the tether. After the tether deployment by CV, the climber is unlocked by a nichrome heating element and separated from CV. Thereafter HT deploys the tether after which the climber traverses on the tether.

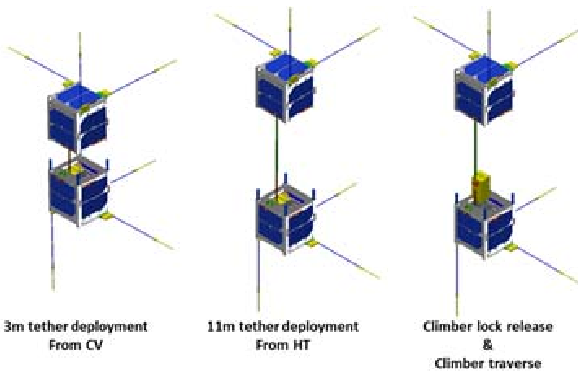

Figure 14. Tether deployment sequence.

4 Electrical System

4.1 Electrical Power System

Figure 15 shows Electrical Power System's (EPS) block diagram of STARS-Me. Each satellite has the Electrical Power System in common. Figure 16 also shows inhibit schematic of STARS-Me. The protection devices are, over-discharge protection circuit and mechanical relay (deployment switch). RBF Pin can be removed prior launch i.e., when in ground. Table 1 shows the list of the inhibit for STARS-Me.

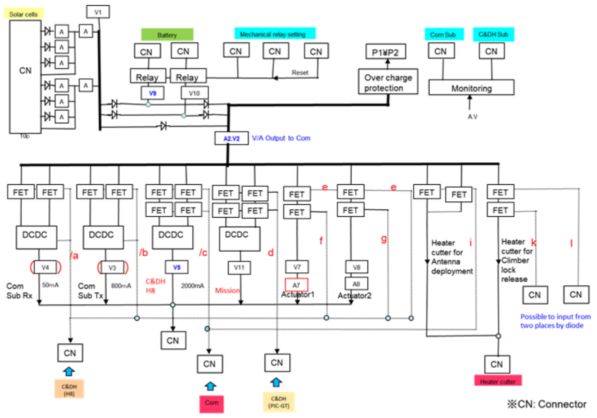

Figure 15 Electrical Power System's Block Diagram.

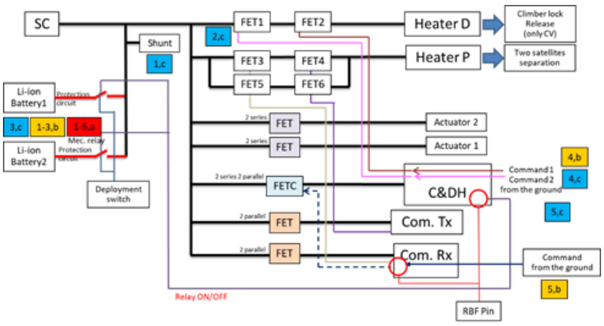

Figure 16 Inhibit Schematic.

- ✓ After removing RBF Pin (Launch, On orbit stowage and prior to deployment)
  - ➢ Battery relay is turned ON by deployment switch.
  - ➢ Com.Rx outputs high signal → FET3&5 ON (High active) and FETC OFF (Low active)
  - ➢ Com.Tx outputs high signal → FET4&6 ON (High active) → Two satellites separation
- ✓ Before removing RBF Pin (*Reference* Only ground operation)
  - ➢ Battery relay is turned ON by deployment switch.
  - ➢ Com.Rx outputs low signal when grounding RBP Pin → FET3&5 OFF (High active) and FETC ON (Low active) → C&DH is booted up
  - ➢ C&DH outputs the signal to turn battery relay OFF → Battery relay is disconnected

The circuit is in the initial state while disconnecting the battery relay.

4.2 Climber Electrical System

Figure 17 shows Electrical Power System's(EPS) block diagram of the climber. The climber has two coin cells. (P/N: CR3032, 2series, 1parallel) The satellite and the climber (Climber Board) are connected by the spring contacts. When CV outputs high signal through the spring contacts, the FET on the climber board is turned ON.

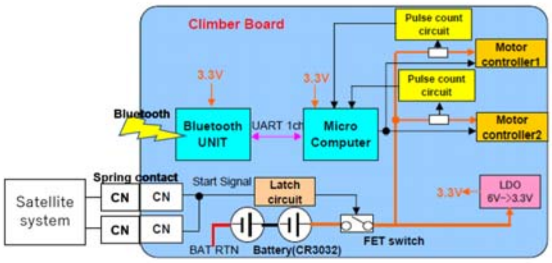

Figure 16 Electrical Power System of Climber.

4.3 Structural Bas System

Figure 17shows structural design of Bas system, which consists of circuit boards mainly.

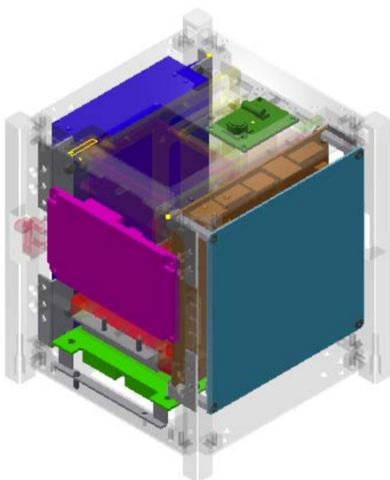

Figure 17 Structural design of Bas system.

Blue is the transceiver to communicate with the earth station. Bright green is communication control board, brown and light blue are electrical control and electrical power system boards, respectively. Pink is sensor board, which has gyro, magnet, and acceleration sensors. Red is camera control board, and dark green is camera module, respectively. Those system is mounted on each satellite, CV and HT, respectively.

4.4 Communication System

STARS-Me communicate with the ground station via amateur radio frequency band. These are FM transmission and reception and CW transmission.

I. STARS-Me conducts tether deployment, climber traverse and takes pictures via command (CMD) from Shizuoka-Univ. ground station.
II. STARS-Me transmits experiment data, photograph data and satellite housekeeping data to the ground station(TLM)
III. STARS-Me keeps transmitting Morse code and it is possible to receive them during passing through the receivable area
IV. Any ground station can receive the data of STARS-Me via amateur radio frequencies.

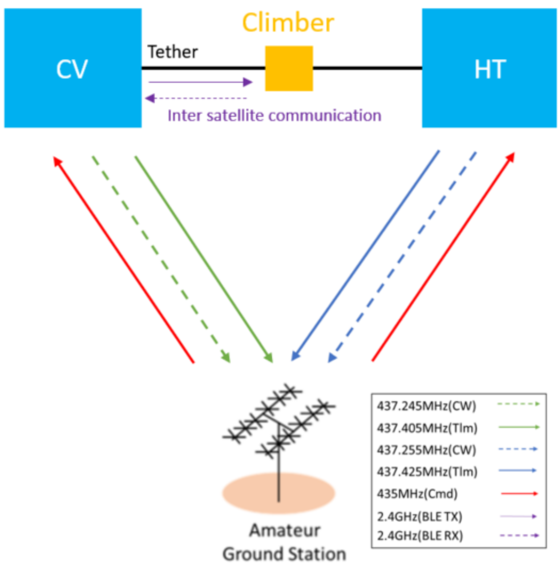

Figure 17 Communication system diagram.

5 Conclusions

This paper describes space elevator demonstration satellite "STARS-Me" to be launched in this year 2018. SATRS-Me a 2U CubeSat, and two 1U satellites are connected by tether. The tether is tape convex and high stiffness by metal material. A climber is stowed in the CubeSat body, and then translate on the tether. The detail design of the tether and the climber has been explained.

Acknowledgement

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References

[1] M. Nohmi, T. Hosoda, J. Tanigawa, and O. Itose, and A. Uchida, "Space Experiment For A Tethered Space Robot By Kagawa University, " The journal of space technology and science, vol. 26, no. 1, pp. 47-56, 2012 spring.

[2] M. Nohmi, T. Yamamoto, O. Itose, J. Saitou, "Rocket Separation Mechanism for Pico Mother and Daughter satellite "KUKAI"," Journal of System Design and Dynamics, Vol. 4, No. 6, Special Issue on D&D2009, pp. 984-995, 2010.

[3] M. Nohmi, J. Tanikawa, T. Hosoda, A. Uchida, "Evaluation Analysis of the S-520-25 Rocket Experiment for a Tethered Space Robot," International Symposium on Artificial Intelligence, Robotics and Automation in Space, Torino, Italy, Setember 4th, 2012. 5.

[4] M. Nohmi, Y. Yamagiwa, and S. Kawamoto, "STARS-II Mission Plan for Future Debris Removal by A Tethered Space Robot," 7th International Workshop on Satellite Constellations and Formation Flying, Lisbon, Portugal, March 13-15 (15), 2013.

[5] M. Nohmi, "Initial Orbital Performance Result of Nano-Satellite STARS-II," International Symposium on Artificial Intelligence, Robotics and Automation in Space, MacGill Univ., Montreal, Canada, June 17-19, 2014.

[6] M, Nohmi and Y. Yamagiwa, "Tethered 2U CubeSat Development in Space Tethered Autonomous Robotic Satellite Project," 2nd IAA Latin American CubeSat Workshop, Florianopolis, Brazil, February 28 - March 3 (Mar. 2), 2016.