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DESIGN OF TOKYO TECH NANO-SATELLITE Cute-1.7 + APD II AND ITS OPERATION

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ABSTRACT

Cute-1.7 + APD II is the 3rd satellite developed by the Laboratory for Space Systems at the Tokyo Institute of Technology. Cute-1.7 + APD II is a successor to the Cute-1.7 + APD. This new satellite is based on its predecessor but has some modifications to increase its reliability and robustness against radiation effects, electrical power shortage and so on. The satellite was launched by ISRO PSLV-C9 rocket on April 28, 2008 and has operated for more than 4 months. Through its operation, many missions such as attitude determination and control experiments, scientific observations, photographing and communication expriments have been conducted. In this paper an overview of the Cute-1.7 series and configurations, modifications and operation results of Cute-1.7+APD II are introduced.

FULL TEXT

1. INTRODUCTION

The Laboratory for Space Systems (LSS) at the Tokyo Institute of Technology (Tokyo Tech) has developed and launched three satellites.

The 1kg pico-satellite named CUTE-I, which is the first CubeSat in the world, was launched by Eurockot's Rockot launch vehicle on June 30, 2003[1)]. CUTE-I was developed in a student-lead program, managed to fully conduct its missions and is still transmitting its house keeping data to the Earth. The flight model of CUTE-I is shown in Fig. 1.

Based on this satellite development procedure and acquired nano-satellite bus technology, the LSS began its next satellite project, "Cute-1.7 + APD", pursuing innovation in small satellite systems. This satellite was launched by JAXA M-V-8 launch vehicle on February 22, 2006, and had operated for a little more than a month[2)]. After achieving success in some of its missions, the satellite stopped replying to any uplink commands from the ground station at Tokyo Tech. Cute-1.7 + APD is now transmitting a continuous wave that is not modulated. While the recovery operation has been continuing for a year, the problem from its housekeeping data has been thoroughly investigated and ground experiments have concluded that it was the result of a kind of a space radiation hazard. Fig. 2 shows the flight model of Cute-1.7 + APD.

The "Cute-1.7 + APD II" project, the successor to the Cute-1.7 + APD, began in April 2006 to complete the missions which Cute-1.7 + APD was, unfortunately, not able to accomplish[3)]. Cute-1.7 + APD II is essentially a modification of Cute-1.7 + APD, with changes not only to prevent the radiation hazard but also to conduct the missions more effectively. This satellite was launched by an Indian rocket PSLV-C9, on 28th April, 2008.

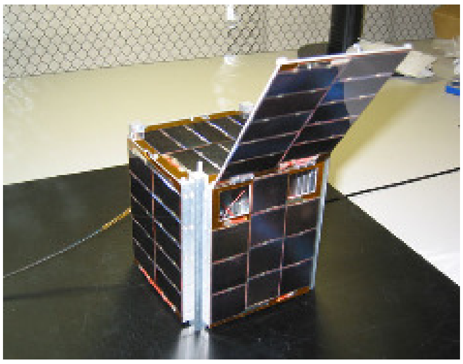

Fig. 1. CUTE-I

Fig. 2. Cute-1.7 + APD

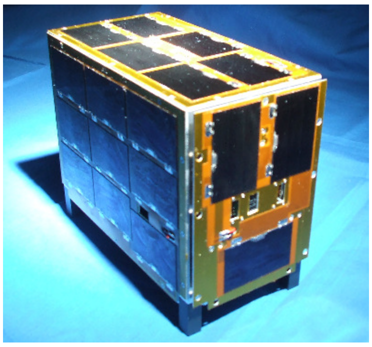

Fig. 3. Cute-1.7 + APD II

In this paper, an overview of the Cute-1.7 series, modifications, some special features of Cute-1.7 + APD II and its current status are introduced.

2. OVERVIEW

In this chapter the objectives and missions of the Cute-1.7 + APD series are introduced.

2.1. Objectives

The Cute-1.7 + APD project has two objectives.

The first objective is to facilitate future micro-satellite development projects by demonstrating a new design methodology. The methodology, aiming toward rapid and low-cost development, includes proactive use of high performance and low cost commercial devices in orbit. The Cute-1.7 + APD series are equipped with several COTS (Commercial Off-The-Shelf) devices including widely used PDAs (Personal Digital Assistants) as their OBC (On-Board Computer) and amateur radio transceivers as communication devices.

The secondary objective is to provide flight experiment opportunities to space engineering researchers and students by developing a highly versatile satellite. To this aim, this satellite contains an engineering mission shared with researchers in the field of control engineering. On-board devices for attitude determination and control such as three magnetic torquers and a software upload function which can update software inside the PDAs from the ground enable on-orbit experiments of advanced attitude control algorithms. In addition, the Cute-1.7 was designed to provide other researchers an opportunity to demonstrate their devices using a simple interface between the satellite bus system and themselves. A scientific observation device, APD (Avalanche Photo Diode) sensor, is implemented on the Cute-1.7 + APD series to demonstrate it in orbit.

2.2. Missions

In an effort to search for a rapid and low-cost satellite design, one mission was assigned to demonstrate the use in space of PDAs as the primary computers in this satellite. This approach comes from advances in PDA technology which have resulted in low cost, high computing performances and a wide range of software development environments. In addition to these functional advantages another objective is to acquire the necessary engineering knowledge to adjust commercial devices to a space environment. For one, the Cute-1.7 + APD series uses two PDAs which can be switched over in case of malfunction for the purpose of redundancy. The PDA used in the satellites is shown in Fig. 4.

Fig. 4. Hitachi NPD-20JWL

Cute-1.7 + APD II will also conduct three missions for the purpose of providing space experiment opportunities using nano-satellites.

One is a three-axis attitude control experiment using the magnetic torquers whereby the satellite's control algorithms can be demonstrated. A conceptual diagram is shown in Fig. 5.

In another experiment the satellite demonstrates a new APD sensor, developed by the Laboratory for Experimental AstroPhysics at the Tokyo Institute of Technology, to observe the density of low energy charged particles in LEO (Low Earth Orbit). This sensor is planned to be used in the LSS's next satellite as a part of a scientific observation device after passing this flight experiment[4]. Fig. 6 shows the APD sensor.

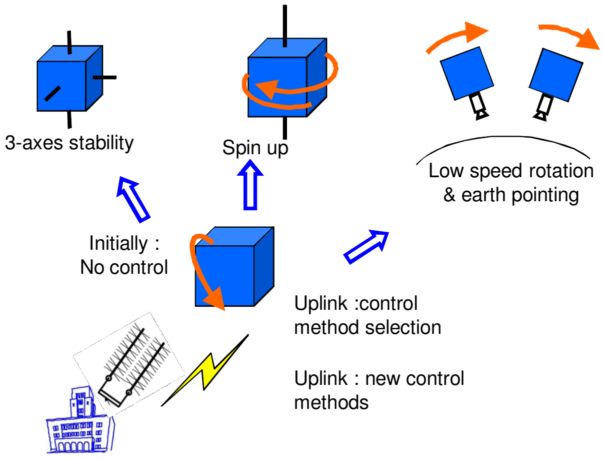

Fig. 5. Attitude Control Mission

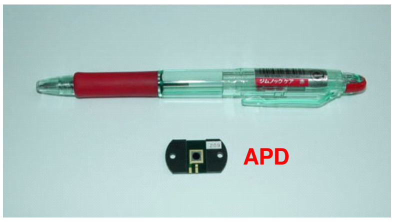

Fig. 6. Attitude Control Mission

This satellite also provides a digital repeater function which is a public message box to ham operators. By using this function ham operators can upload their message to this satellite and the messages can be downlinked in a certain period. This enables them to exchange messages with not only close operators but also distant operators such as an operator who is on the other side of the Earth.

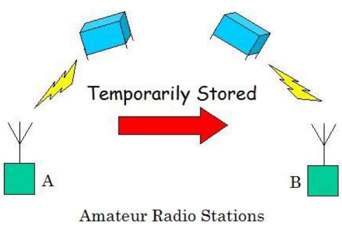

Fig. 7. Amateur Service Mission

In order to expand the use of nano-satellites in space, Cute-1.7 + APD is also managed to conduct an experiment in deorbit technology using electrodynamic tethers. Based on the concern over space debris from inactive satellite, deorbitting technology composed of small components can be an important factor for the future of nano-satellite development. As a first step for the development of this technology, this satellite deploys 10m of an electrodynamic tether. This mission, shown in Fig. 8 was conducted only in Cute-1.7 + APD because the orbit of Cute-1.7 + APD II is too high to conduct the deorbitting experiment.

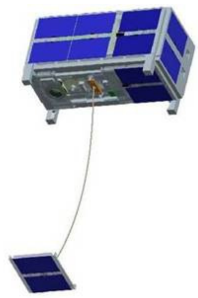

Fig. 8. Tether Deployment Mission

3. DEVELOPMENT

In this chapter the configurations and modifications of the Cute-1.7 + APD II and the results of environmental tests are introduced.

3.1. Configurations

Fig. 9 shows the functional diagram of Cute-1.7 + APD II. Thirteen blocks out of the total thirty ones employ commercial products including PDAs, memory cards, USB (Universal Serial Bus) hubs, digital cameras and handheld amateur radio transceivers. Most subcomponents are connected to a PDA through the USB interface that enables plug and play. The connectivity contributes to designing each subcomponent as a module and expanding versatility of this satellite by providing easy connection to various mission devices.

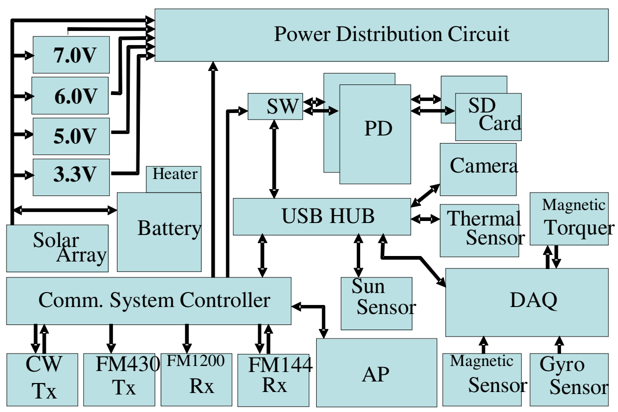

Fig. 9. System Block Diagram of the Cute-1.7 + APD II

The development of the Cute-1.7 + APD II was advanced by categorizing it into nine subsystems: ADCS (Attitude Determination and Control Subsystem), C&DH

(Command and Data Handling), Communication, EPS (Electrical Power Subsystem), Camera, Structure, Separation System, Ground Station and Science (APD). Details of each subsystem are described below.

3.1.1. Attitude Determination and Control

As the satellite is very small and has been developed within the university, small-size and low-cost sensors have been employed. Although they have an advantage of size and cost, their accuracy is not high enough to satisfy the mission demands. Consequently, the system is constructed using a combined sensor system that is composed of multiple attitude determination sensors, as shown in Fig. 10: sun sensors, magnetic sensors and gyroscopes. In addition to these, attitude determination algorithms such as the QUEST (Quaternion Estimation), REQUEST (Recrusive QUEST), EKF (Extended Kalman Filter) and UF (Unscented Kalman Filter) methods were implemented to improve the accuracy of the attitude determination.

Fig. 10. Attitude Determination Sensors (Left: Sun sensor, Center: Gyroscope, Right: Magnetic Sensor)

S6560, which is manufactured by Hamamatsu Photonics, has two photo-diodes per unit whereby a difference of currents between them indicates, via a known correlation, the incident angle of light. They, therefore, were used as sun sensors. Two units each are mounted on five of the sides except for the top side of the satellite. The sensor's coverage is 84% of the whole sky.

The Analog Devices' ADXRS150 was used as a gyroscope. It can measure an angular velocity around a single axis and output the measured value as analog data. This analog data is acquired by an A/D converter of a DAQ (Data Acquisition Device) controller. The temperature of the gyroscope is also determinable and enables appropriate calibration of the instrument to compensate for temperature dependency.

HMR2300, produced by Honeywell, was used as the magnetic sensors. It consists of Honeywell's subcomponent of magnetic sensors (HMC1001 and HMC1002) and a digital interface. A performance test was conducted using a magnetic shield facility with the support of JAXA.

Data from these sensors are gathered by the PDA and used for the calculations for attitude determination or to downlinking to the ground station.

The satellite has four algorithms for attitude determination: QUEST, REQUEST, EKF and UF. The use of a high-performance PDA enables a real-time attitude determination of the satellite using these advanced algorithms. An attitude estimation will also be done on the ground by recalculating using the sensor data from the satellite and its result will be used to confirm the result of on-orbit attitude determination experiment by comparing them.

A magnetic torquer is employed, shown in Fig. 11, for three axis attitude control. Specifications of the magnetic torquer are shown in Table 1.

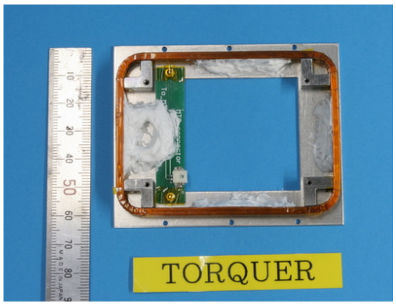

Fig. 11. Magnetic Torquer (1 Axis)

Table 1. Specification of the Magnetic Torquer

Type	Air Core Coil
Dimensions	58.5 x 78.3 x 1.6 [mm^3]
Weight	5 [g]
Resistance	180 [ohm]
Power Consumption	900 [mW]
Output Magnetic Dipole	0.15 [Am^2] (per coil)

3.1.2. Command and Data Handling

The primary MPU consists of two PDAs for redundancy. Hitachi's NPD-20JWL, shown in Fig. 4 and Table 2, was selected because of its small-size which can be put inside the two-unit CubeSat (100 x 100 x 200 mm^3).

Table. 2. Specification of the PDA

Model	NPD-20JWL
Manufacturer	Hitachi
Dimensions	70 x 100 x 5 [mm^3]
Weight	100 [g]
CPU	ARV4I 400MHz
OS	Microsoft Windows CE.NET
RAM	32 [MByte]
Flash Memory	SD Card 128 [MByte]
Interfaces	USB, MMC/SD Card Slot

Data that cannot be handled by the PDA such as analog data is gathered by the DAQ controller. By the commands from the PDA, it acquires the analog data, configures a data frame and sends it to the PDA through a USB interface. Fig. 12 shows a block diagram of the C&DH subsystem.

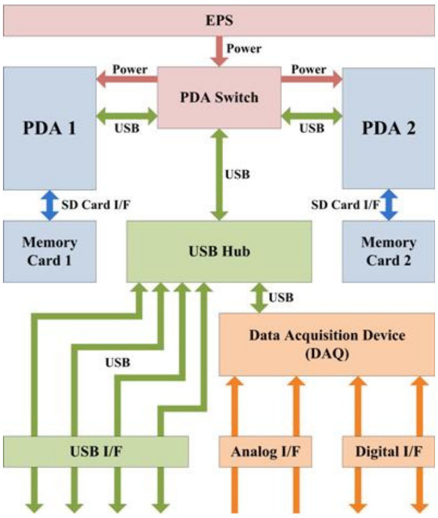

Fig. 12. C&DH Subsystem Block Diagram

3.1.3. Communication

The communication module has four channels; 144MHz AFSK (Audio Frequency Shift Keying) for a command uplink, 1.2GHz GMSK (Gaussian filtered Minimum Shift Keying) for a public message uplink, 430MHz CW (Continuous Wave) for a beacon downlink and 430MHz AFSK and GMSK for a packet downlink. Amateur handheld transcievers are employed as onboard transiverers.

Four monopole antennas were used for these four bands. The antennas were made of teflon-coated iron steel to provide insulation, environmental resistance and attenuation.

As the communication subsystem is a minimum configuration of the satellite, it has responsibility for a crisis-management. Two communication controllers monitor all important conditions of the satellite, e.g. bus voltages, and power off or reset a device when the satellite is in danger. In addition, the microcontroller can mutually monitor the other one and both microcomputers can reset each other when one of them stops working.

Fig. 13. Amateur Transcievers used in Cute-1.7

(Left : ALINCO DJ-C5, Right : Kenwood TH-59)

3.1.4. Electrical Power

The EPS uses 4 Li-ion batteries, shown in Fig. 14, in parallel and 33 GaAs solar cells that generate a 4W power supply on average. The EPS provides four stabilized buses; 3.3V, 5V, 6V and 7V for various components of the satellite.

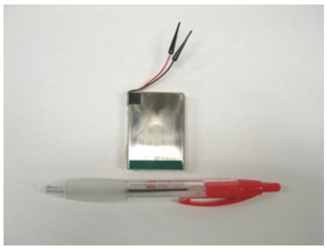

Fig. 14. Li-Ion Battery

3.1.5. Camera

The Cute-1.7 + APD II has a compact CMOS camera module which is designed for a mobile phone. The camera module is controlled by Renesas' H8 microcontroller and its data is temporally stored in a FIFO (First Input, First Output) memory before it is sent to the PDA via USB as shown in Fig. 15. A sample picture taken by the on-board camera is shown in Fig. 16.

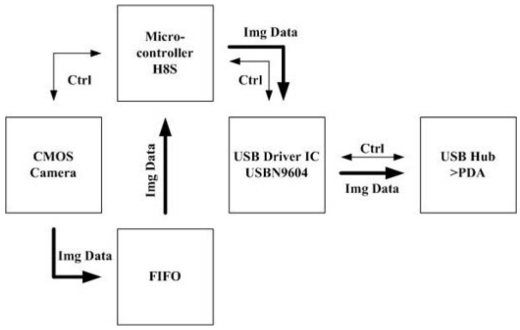

Fig. 15. Camera Subsystem Block Diagram

Fig. 16. Picture Taken by the On-Board CMOS Camera

3.1.6. Structure

Cute-1.7 + APD II measures 115 x 180 x 220 mm^3 and weighs 3kg. The main structure of the satellite is made of aluminium. Layouts of components are shown in Fig. 17.

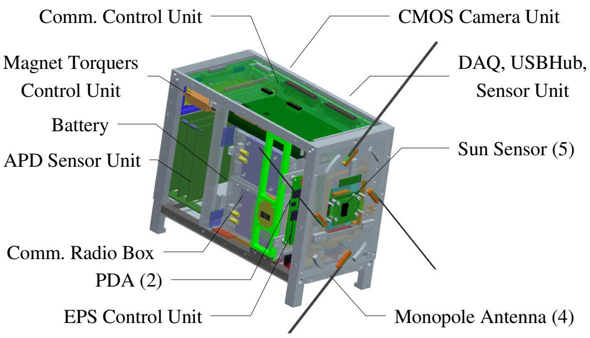

Fig. 17. Components Layout

3.1.7. Separation System

The LSS's separation system, shown in Fig. 18, has been demonstrated for three times in orbit to prove a very reliable system. The satellite's four legs are tightly held by four latch levers of the separation system during a launch, and the latch levers are tied with two nylon strings, as shown in Fig. 19. When the separation signal is given by the launch vehicle the circuit of the separation system begins a count-down. After waiting for a given duration the heat wire inside the separation system is heated to cut the nylon string. Then the finger (latch lever) rotates with a torsion spring so that it removes itself from the notch on the pillars of the satellite. Finally the spring inside the separation system pushes the satellite up and releases it from the launch vehicle.

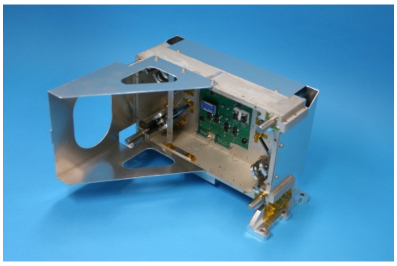
Fig. 18. Separation System

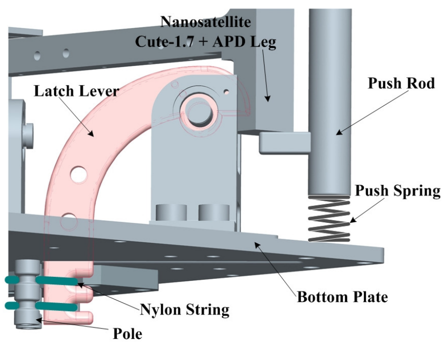

Fig. 19. Detail of Latch&Deploy Mechanism

3.2. Modifications

Some modifications were implemented to the satellite to increase its reliability.

3.2.1. Radiation Tolerance

In the first satellite, because of the SEL (Single Event Latch-up) occurred in the microcontroller of the communication subsystem, the satellite became unable to conduct all missions.

Cute-1.7 + APD has a single auto-power reset function to automatically restart damaged components before it totally breaks up when a SEL occurs. In addition to this, Cute-1.7 + APD II is equipped with distributed auto-power reset functions as shown in Fig. 20. With the functions, it can detect slight current increase caused by a radiation effect. The circuits showed effective tolerance to radiation in a ground experiment.

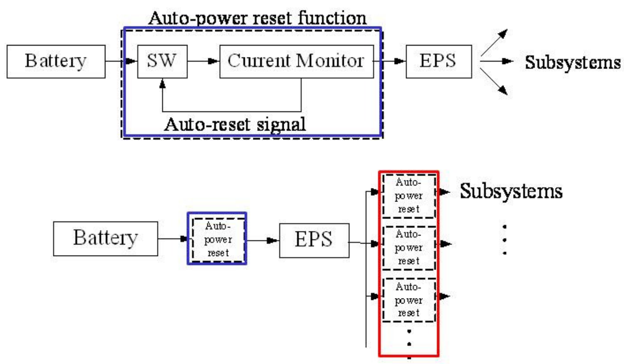

Fig. 20. Layout of Radiation Tolerant Circuit
(Top: Cute-1.7 + APD, Bottom: Cute-1.7 + APD II)

3.2.2. Crisis Management

Battery voltage, current and temperature are always monitored by MPU and if unusual value was observed, the satellite autonomously turns into a minimum power consumption configuration.

All mission devices can be turned on only for preset duration and if the time passed, they will be turned off as shown in Fig. 21.

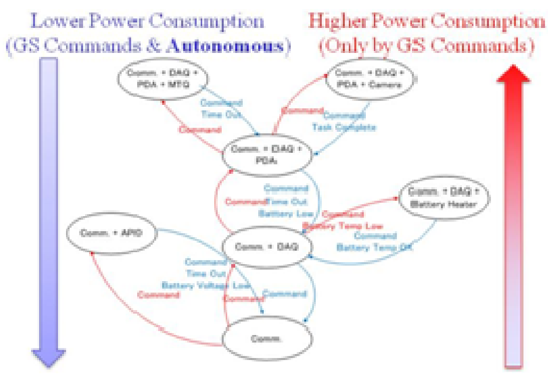

Fig. 21. Transition of Operation Mode

These functions ensure optimal power consumption for all the time and highly reliable crisis management system.

3.2.3. EPS

Another modification was to increase the power generation of the small satellite. The orbital operation of the former satellite showed relatively low power compared to the estimation, which affected the satellite's operation procedures. The power generation is enhanced by increasing the dimension of the satellite. As a result, mean generated power is increased from 3W to 4W.

Satellite's configuration was reconsidered and reconfigured to output maximum result with minimum power consumption.

3.2.4. Structure

The satellite is about 1.5 times larger than the former satellite to increase its power generation as described. In addition to this, the structural change also contributes to the assembly process. As many missions were installed to the former satellite, the high density of components required a long time to assemble them. A mother board which has an external access port also helps assembling and debugging.

3.2.5. Attitude Determination and Control

Improvements over Cute-1.7 + APD were made. For example, an output torque of the actuator is tripled, to control the satellite in its residual field, by dividing a coil into three segments and connecting them in parallel, which leads to an increase in its consumption of the current.

3.2.6. Communication

The transceiver circuit and the software inside the communication controller were improved far more reliable than Cute-1.7 + APD.

3.3. Tests

Many environmental tests had been conducted on the Cute-1.7 + APD II to make sure it will work well during launch and in orbit.

3.3.1. Vibration Test

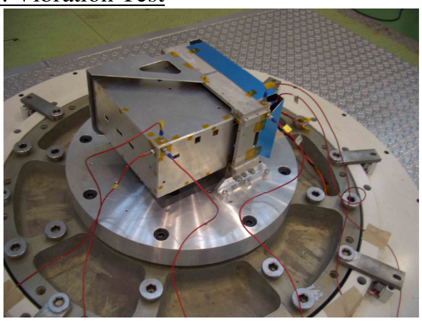

Fig. 22. Vibration Test

A vibration test was conducted with the support of JAXA. The level of the vibration was the QT (Qualification Test) Level of the PSLV. From an appearance and electrical check, it is confirmed that the satellite is tolerable for the predicted vibration during the launch.

3.3.2. Radiation Test

As it was expected that the microcontroller of the communications subsystem had stopped working in the former satellite because of a radiation hazard, a radiation test was conducted at the Research Center for Nuclear Physics at the Osaka University. When protons, which have energy of 60MeV, were emitted against the microcontroller an SEL frequently occurred and large-currents were detected. This result led the satellite to have an over-current monitoring circuit per one microcontroller.

3.3.3. Thermal Test

Severe temperature change is expected in orbit because one third of an expected orbit of the Cute-1.7 + APD II is umbra. Therefore, a thermal test was conducted by using the LSS's thermostatic chamber for the subcomponents and the whole satellite, and confirmed the satellite's nominal behaviour for -20 to 60 degree C.

3.3.4. Vacuum Test

Antenna deployment, high voltage application to the APD module and demonstrations of other devices under vacuum condition were totally successful.

3.3.5. Attitude Determination and Control Simulation

A simulator for the attitude determination and control, shown in Fig. 23, was made to conduct ground experiments to demonstrate their algorithms. MATLAB on the computer calculates an orbit of the satellite and obtains pseudo values of the attitude sensors. Orbital calculations including perturbations and magnetic fields were calculated by using the IGRF (International Geomagnetic Reference Field) model.

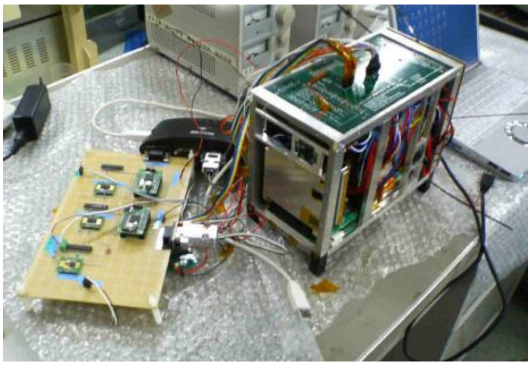

Fig. 23. ADCS Simulator and the Satellite

4. OPERATION

4.1. Launch

Cute-1.7 + APD II was shipped to India via Canada in January 2008. In April 2008, a launch campaign team went to India to conduct final checks of the satellite and confirmed its perfect performance as shown in Fig. 24. During the launch campaign, we discussed and checked about launch readiness of our satellite with ISRO (Indian Space Research Organization). Finally, the satellite was assembled to the 4th stage of the launch vehicle, as shown in Fig. 25, with other nanosatellites: SEEDS from Japan, CanX-2 and CanX-6/NTS from Canada, Delfi-C3 from Netherlands, AAUSat-II from Denmark and COMPASS-I from Germany.

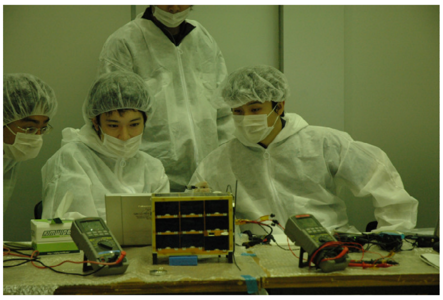

Fig. 24. Final Checks for the Cute-1.7 + APD II

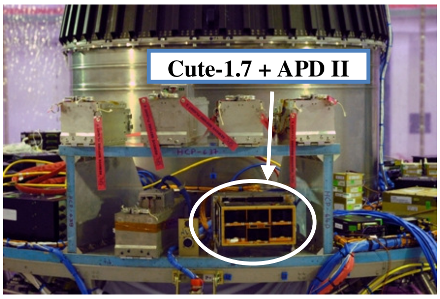

Fig. 25. Satellites Assembled with the Launch Vehicle

Fig. 26. Launch of the PSLV-C9 (Courtesy of ISRO)

The satellites were successfully launched into space together with 6 university satellites in an Indian rocket, PSLV-C9 (Polar Satellite Launch Vehicle) as shown in Fig. 26. Its orbit is a circular sun-synchronous with an altitude of approximately 630km and inclination of about 98 degrees. Cute-1.7 + APD II is now at the initial operation phase and is being checked the basic functions such as power generation and communication.

4.2. Operation Result

In this section, results of the initial operations of the Cute-1.7 + APD II will be introduced.

4.2.1. Attitude Determination Experiment

When the satellite was separated from the launch vehicle and activated, it starts to acquire gyro data for 4 minutes in 10Hz resolution and store them inside FRAMs. These gyro data indicates the initial rotation of the satellite. After the separation, the satellite rotates at a slow speed, 0.4rad/s as shown in Fig. 28.

Antenna deployment was conducted at 3 minutes after the separation and the rotation of the satellite indicates the deployment was success.

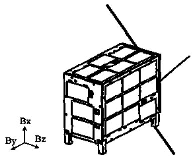

Fig. 27. Body-Fixed Coordinates

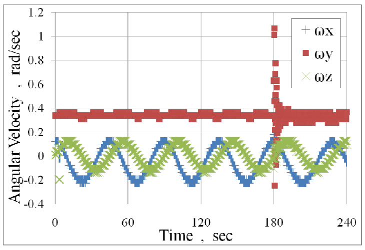

Fig. 28 Rotation Data

4.2.2. Camera

15 photos were taken by the satellite as shown in Fig. 29. Accurate attitude of the satellite can be known from the pictures. Currently,

The satellite also can take a movie for 20 frames with the rate of 15 fps (frames per second). One of the results is shown in Fig. 30. From this movie, rotational speed of the satellite was obtained as 0.24 rad/sec.

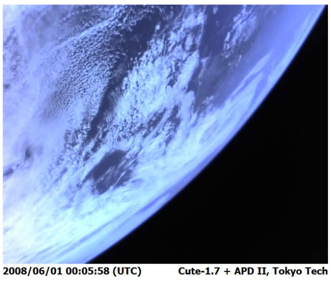

Fig. 29. Picture

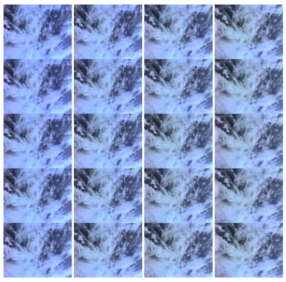

Fig. 30. Movie

4.2.3. APD Observation

APD observations were also conducted. Through 2 times of short-term observation, normal behavior of the APD was confirmed. Then, we tried to conduct a long-term observation and succeeded as shown in Fig. 31. This was the 1st global observation of charged particles in the world. In addition to these, time variation of charged particles distribution had been monitored through 5 times of short-term observation and confirmed that distribution of the SAA is stable.

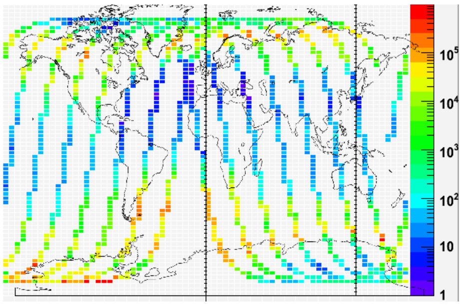

Fig. 31. APD Observation Result

4.2.4. Communication Experiment

Most of the existing university nano-satellites are equipped with the AX.25 protocol and AFSK (Audio Frequency Shift Keying) modulation which are frequently used in amateur radaio. In addition, Cute-1.7 + APD II has another protocol called SRLL, which is Tokyo Tech's original protocol, and GMSK modulation. The SRLL protocol has an error correction function and it makes the protocol robust and suitable for satellite communication. The data rate of the GMSK modulation is 8 times faster than that of the AFSK modulation. Both uplink and downlink using SRLL and GMSK were succeeded in orbital operation and these method led to faster communication.

Over 60 amateur radio operators have reported their signal reception as shown in Fig. 32.

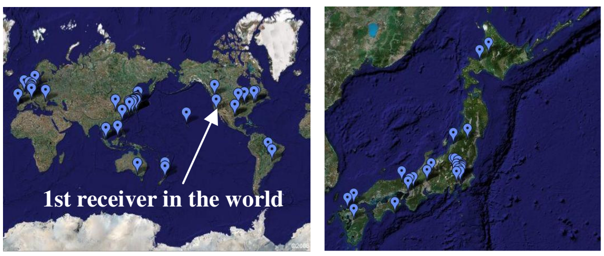

Fig. 32. Reception Maps (Japan : 27 Sta., Overseas : 36 Sta.)

5. CONCLUSION

The development of the 3kg nano-satellite Cute-1.7 + APD II was introduced. The configurations and modifications of the on-board devices over Cute-1.7 + APD are described. In addition to this, many environmental tests and simulations were conducted throughout its development to make sure that the satellite can accomplish its missions whilst withstanding space environments such as space radiation. It was launched into orbit, and is in the operation phase. Attitude experiments, camera missions, APD observations and communication experiments have been successfully conducted and the results are briefly introduced. The development of Cute-1.7 was finished and invaluable experiences can be obtained by the development of the satellite. The LSS just has begun to develop a next small satellite which will conduct novel engineering and scientific missions.

References

1) Koji Nakaya, Kazuya Konoue, Hirotaka Sawada, Kyoichi Ui, Hideto Okada, Naoki Miyashita, Masafumi Iai, Tomoyuki Urabe, Nobumasa Yamaguchi, Munetaka Kashiwa, Kuniyuki Omagari, Ikutaro Morita and Saburo Matunaga: Tokyo Tech CubeSat: CUTE-I - Design & Development of Flight Model and Future Plan -, *AIAA 21st International Communications Satellite Systems Conference and Exhibit*, Yokohama, 2003, AIAA 2003-2388.
2) Naoki Miyashita, Masafumi Iai, Kuniyuki Omagari, Katsutoshi Imai, Hideyuki Yabe, Kei Miyamoto, Thomas Iljic, Takeshi Usuda, Ken Fujiwara, Shinji Masumoto, Yasumi Konda, Saori Sugita, Tomio Yamanaka, Kazuya Konoue, Hiroki Ashida and Saburo Matunaga: Development and Flight Report of Pico-Satellite Cute-1.7 + APD, *25th International Symposium on Space Technology and Science*, Kanazawa, June 4-11, 2006, 2006-f-08.
3) Ken Fujiwara, Kuniyuki Omagari, Thomas Iljic, Shinji Masumoto, Yasumi Konda, Tomio Yamanaka, Yohei Tanaka, Masaki Maeno, Taihei Ueno, Hiroki Ashida, Junichi Nishida, Takuro Ikeda, and Saburo Matunaga: Tokyo Tech Nano-Satellite Cute-1.7 + APD Flight Operation Results and The Succeeding Satellite, *The 17th IFAC Symposium on Automatic Control in Aerospace*, Toulouse, June 25-29, 2007.
4) Junichi Nishida, Yoshihiro Tsubuku: Tokyo Tech's Technology Demonstration Satellite "TSUBAME", *21st Annual Conference on Small Satellite Student Competition*, Utah, 2007.
5) Masaki Maeno, Kuniyuki Omagari, Thomas Iljic, Shinji Masumoto, Ken Fujiwara, Yasumi Konda, Tomio Yamanaka, Yohei Tanaka, Taihei Ueno, Hiroki Ashida, Junichi Nishida, Yusuke Hagiwara, Kota Fujihashi, Takuro Ikeda, Shinichi Inagawa, Yoshiyuki Miura, Saburo Matunaga: Development of Tokyo Tech Nano-Satellite Cute-1.7 + APD II, *The 17th Workshop on JAXA Astrodynamics and Flight Mechanics*, Sagamihara, 2007
6) Kuniyuki Omagari, Naoki Miyashita, Saburo Matsunaga: Development, Launch and Operation

of Tokyo Tech's Nanosatellite Cute-1.7 + APD, *The 16th Workshop on JAXA Astrodynamics and Flight Mechanics*, Aug 1-2, 2006, Sagamihara, pp.209-214

7) Yasumi KONDA, Takeshi USUDA, Tsuyoshi SAGAMI, Kuniyuki OMAGARI, Munetaka KASHIWA, Saburo MATUNAGA: Development of Attitude Determination and Control System for Pico-Satellite Cute-1.7 + APD, *The 16th Workshop on JAXA Astrodynamics and Flight Mechanics*, Aug 1-2, 2006, Sagamihara, pp.242-247

8) Hiroki ASHIDA, Junichi NISHIDA, Kuniyuki OMAGARI, Ken FUJIWARA, Yasumi KONDA, Tomio YAMANAKA, Yohei TANAKA, Masaki MAENO, Kota FUJIHASHI, Shinichi INAGAWA, Yoshiyuki MIURA and Saburo MATUNAGA: Flight Model Development of Tokyo Tech Nano-Satellite Cute-1.7 + APD II, *26th International Symposium on Space Technology and Science*, Hamamatsu, June 1-8, 2008, 2008-f-22.