

RECENT STATUS OF SMALL SATELLITE STUDY IN JAPAN

Takashi Iida*, Ryutaro Suzuki*, and Atsushi Nakajima**

*Communications Research Laboratory,
Ministry of Posts and Telecommunications
4-2-1 Nukui-Kita, Koganei, Tokyo, Japan 184

**National Aerospace Laboratory,
Science and Technology Agency
7-44-1 Jindaiji-Higashi, Chofu, Tokyo, Japan 182

Abstract

This paper describes the recent status of small satellite study in Japan focusing on the activities of the Small Payload WorkShop (SPWS) which was established in January, 1990. The objectives of SPWS are to review the development of small satellite and its launching system, to study the possible mission, to exchange information, to pick up and study the issues to be solved and to contribute to the good and efficient development of the future plan of small satellite utilization in Japan. The discussion to initiate the SPWS is reviewed briefly. The paper describes the recent studies of small satellites missions and launching systems as well as the Japanese small satellites which have been launched so far.

1. Introduction

In parallel with the development of the large satellites, the research and development of small satellite is attracting interest of many researchers in various fields of science and engineering. In this context, the study group targeting small satellites and their related technology, whose name is Small Payload WorkShop (SPWS), was established in Japan in January, 1990, and the SPWS has played important role in reflecting their opinion to the small satellite study in Japan through the activities.

In this paper, the recent studies on the small satellite and its related technology in Japan are described focusing on the activities of the SPWS.

2. Brief Review of Discussion to Initiate the Small Satellite Study in Japan

There are some key reasons why the small satellite has been highlighted recently as an important new option. These include advancements in micro-electronics development, low costs for small satellite launch services, fast turnaround time, low total project cost, multiple discrete satellites which can exactly match satellite capacity to traffic de-

mand, and even the psychological reason of having one's "own" satellite.

The following questions for studying small satellites are raised, even after the above-mentioned merit and motivation of study on the small satellite were asserted⁽¹⁾⁽²⁾.

(a) What is the merit of small satellite in comparison with the large satellite?

(b) Is the large satellite unnecessary for the future?

(c) Is there any new technology specialized to the small satellite?

(d) What is the merit of developing small satellite for the people?

(e) Is the small satellite technology promising in the future?

(f) Does any government organization need to study the small satellite?

The question (a) can be answered by the background of studying small satellite as mentioned above. With regard to the question (b), we consider that the advanced function including multi-mission, high reliability and reduction of cost per channel bring the large satellite. The small satellite should be applied to the field of demonstrating the merit such as short period of development and application and test of advanced devices. We should not understand that the small satellite opposes the large satellite.

To answer the question (c), there are technologies which are not used for the large satellite, such as inter-multi-satellite communications and store-and-forward transmission and protocol, very large scale integration circuit, and the launch technology for the small satellite. The newly developed onboard large scale integration circuits can be tested in space before they are applied to a large satellite.

We can answer to the question (d) as follows: We can expect to offer a simple and inexpensive system using small satellites and to reduce the turnaround time of space technology to the people.

Concerning the question (e), the future small satellite technology will include the simple communication system, the observation by multiple satellites, the reduction of propagation delay by using multi-satellite system, and the emphasis of developing the launch method dedicated to the small satellite.

The question (f) is the most important to us. We should develop small satellite technologies, such as optimization of communication system, miniaturization of onboard equipment and the development of deploy and extension technology, from the viewpoint of technology including optimization, standardization, high risk technology and prevention and mitigation of space debris. We believe that these developments should be conducted by the government organization.

Through the above mentioned discussions, the Small Payload WorkShop (SPWS) has been established, whose objectives are to review the development of small satellite and its launching system, to study the possible mission, to exchange information, to pick up and study the issues to be solved and to contribute to the good and efficient development of the future plan of small satellite utilization in Japan. The member consists of researchers from National Aerospace Laboratory (NAL), Communications Research Laboratory (CRL), National Space Development Agency of Japan (NASDA), 6 universities and more than 30 companies. Since 1990, the SPWS has studied the small satellite bus technology, launch system and utilization. These items are discussed in a regular meetings planned once a month and Small Satellite Symposium sponsored by SPWS once a year.

3. Japanese Piggyback Satellites

Many small scientific satellites have been launched by the Institute of Space and Astronautical Science (ISAS) in Japan so far. The weight range of the satellites are between 24 kg in the early 1970s and 420 kg in the recent years. In this paper, the examples of the activities other than ISAS are described briefly in the following.

The first Japanese piggy back satellites were launched in 1986 by the H-I rocket test flight No. 1. They are JAS-1 and MABES (Magnetic Bearing Flywheel Experimental Satellite). The second Japanese satellite, DEBUT and JAS-1b were successfully launched with the main satellite MOS-1b (Marine Observation Satellite) on 7 Feb. 1990. DEBUT, the nick name "ORIZURU" after launch, was developed in a short period of 1.5 years, jointly by NAL, NEC Corp., Nissan Motor Co. and Japan Aircraft Manufacturing Co.⁽³⁾ Fig. 1 shows DEBUT at deployed mode. The main features of DEBUT are, 50.3 kg in weight, 440 mm (dia) x 790 mm (launch mode) and 900 mm (dia) x 1935 mm (deploy mode) in dimension, up/down link is 148/137 MHz, power supply is 95 Ah lithium battery for 10 days mission life. The experimental objective of DEBUT was the in-orbit verification of mechanical subsystem of boom and umbrella like aerodynamic break (ADB), which are possible candidates of the important subsystems of tether/boomerang satellite. During 10 days planned mission life time, the boom was deployed and retracted and open/closed motions of ADB were repeated 52 times. The functions of both mechanisms were verified by means of the in-orbit repeated operation.

JAS-1b (Fuji-2), which was modified its shape and solar cell capacity compared with JAS-1 (Fuji-1) was developed by JARL (Japan Amateur Radio League Inc.)⁽⁴⁾. Fig. 2 shows JAS-1b. The main features of JAS-1b: 50 kg in weight, 440 mm x 470 mm in dimension, up/down link is 146/436 MHz, 10 W power output with GaAs solar cells and mission life will be 3 years. The objectives of JAS series were experiment of worldwide amateur radio communications, study of the satellite tracking and operation techniques and confirmation of performance of transponders developed by radio amateurs.

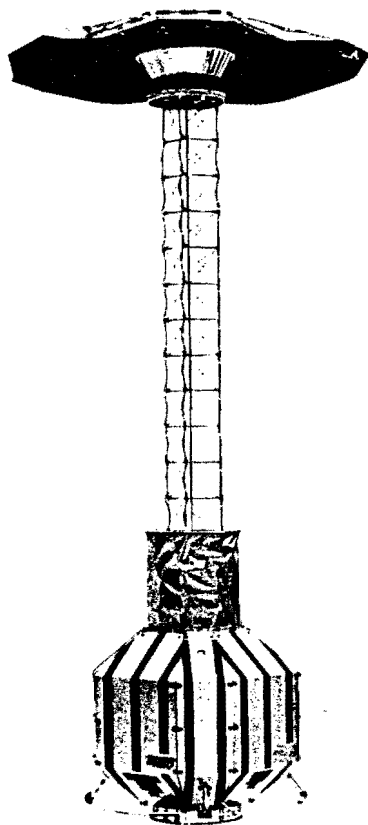


Fig. 1 DEBUT Configuration.

4. Study on Small Satellite⁽⁵⁾⁻⁽⁸⁾

4.1 Small Satellite Missions

In the fields of communication and global positioning, remote sensing, scientific observation and technology experiment, small satellites will also be expected to act an important role. In the past 2 years, the SPWS has studied and proposed many mission ideas. Some of them are listed in Table 1. These ideas were presented in the Small Satellite Symposium sponsored by the SPWS. A few proposals are briefly introduced here.

(1) Communication System

The key communication technology will be the store-and-forward transmission and inter-multi-satellite communication. We understand that the store-and-forward transmission technology includes not only the message store-and-forward type simple repeater but also some intelligent type

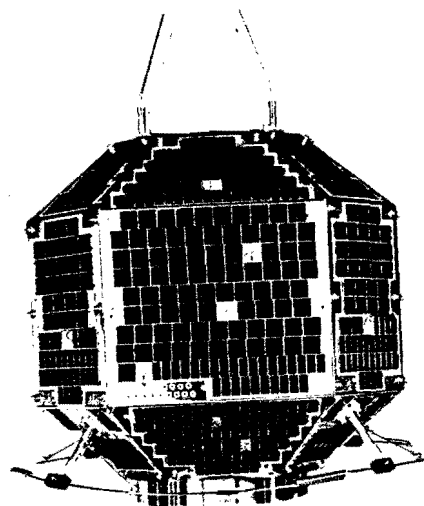


Fig. 2 JAS-1b Satellite.

transponders including regenerative type, routing capability and very high speed and high capacity transmission. These technologies stem from the limitation of satellite visibility.

CRL and NEC Corp. cooperative team is currently designing a store-and-forward type of digital message delivery system with the microsatellites as shown in Fig. 3⁽¹⁰⁾. All satellites in the system are put into the same orbit. The orbital position of each satellite is selected in order that the coverage of each satellite can overlap the other. Then, the earth terminals covered by one satellite zone can communicate with each other through the satellite in real-time basis with data and/or voice. Also, the earth terminals covered by different satellite zone at the same time can communicate with each other through the inter-satellite link among the satellites in real-time basis. The data and/or voice packet transmission to the earth terminals outside the zones of the satellites can be carried out by the store-and-forward communication.

The satellite features twin structures (barbell type) of twenty-six-hedron using the state-of-the-art JAS-1 microsatellite bus. The twin buses are connected to each other by an expanded mast. The solar cells are mounted on the each panel of the twin structures are fixed 2.5 meter apart by expanding the mast as shown in Fig. 3.

Table 1 Mission Ideas for Small Satellites.

| Category | Mission Objectives | Orbit (km) | No. of Sat. | Mass (kg) | Remarks |
|-------------------------------|----------------------------|------------|--------------------|-----------|----------------|
| Communication and positioning | Store-and-forward | 900-2,000 | 1-3 | 50 | |
| | Mobile comm. and Posit. | 27,000 | 3/3orb. 8/3orb. | 50 | 12-hr period |
| Observation | Store-and forward | 42,000 | 2/2orb. | 50 | 24-hour period |
| | Worldwide comm. network | 900 | 2 | 50 | |
| | Emergency medical sat. | 1,700 | 24 | 100 | |
| | Cosmic-ray observation | Tundra | 3 | 400 | Moving image |
| | Solar flare | 1,000 | 5 | 50 | |
| | Ionosphere | 1,000 | >2 | 200 | i=25 deg. |
| Lifesat | Life science experiment | 2,000x400 | 2/1orb. | 70 | |
| | Plant, algae, fish, etc. | 1,000 | >1 | 500 | Recovery |
| Material Exp. Technology | Material process under 0-g | 1,000 | 1 | 100 | |
| | Deployable antenna | 400 | >1 | 200 | Recovery |
| | | GEO | 1 | 300-400 | |
| | | 2,700 | 1 | 150-200 | |
| | Deploy and stowage | 1,000 | 1 | 150 | |
| | Docking/separation mech. | 1,000 | 2 | 200 | |
| | Tether release/recovery | 1,000 | 1 | 50 | |
| | Low altitude observation | 250 | 3 | 100 | |
| | Telescience | 1,000 | 1 | 100 | |

The stowed configuration size during launch phase is 440 mm (dia) by 2970 mm (length). The merits of this structure are as follows: (1) There are two areas to install onboard equipment, and it corresponds to versatile requirements. (2) The structure strength is kept by a central tube, then the outer frame shape can change easily, depending in mission requirements.

The satellite attitude is controlled by using a gravity gradient torque. The microstrip antenna with solar cells is designed⁽¹¹⁾. The transponder consists of RF units, which are 400 MHz band unit for the up/down link, and 2.5 GHz band unit for the inter-satellite link

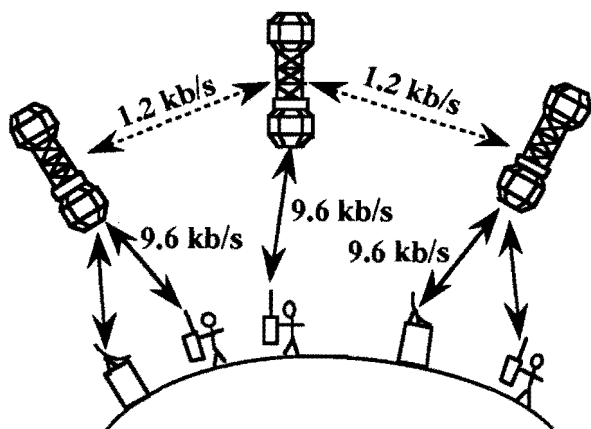


Fig. 3 Image of Experimental Satellite Communication System Using Bar-bell Type Small Satellites.

and the store and forward data control unit. A memory size of 4 to 16 MByte is essential in order to store up to three minutes length of the voice packet which is coded to 9.6 kb/s data.

(2) **Optical Inter-Satellite Link⁽¹²⁾**

NASDA and CRL study the optical inter-satellite link experiment using a small satellite which is launched by J-I rocket (described later).

(3) **Communication and Positioning System**

It seems to be effective to use the non-geostationary orbits with large inclination angle for the satellite mobile communication system in the high latitude area. For 24 hour satellite communication network with high elevation look angle from the ground, 12-hour orbital period satellite system and 24-hour system were studied. The numbers of orbit and satellite for each case were calculated under the condition that the elevation angle from Japan is larger than 60 deg. They are: 3 orbits-3 satellites system for 12-hour orbital period and 2 orbits - 2 satellites for 24 hour period. For the communication and positioning, 3 orbits with 12-hour period - 8 satellite system will satisfy the requirements.

(4) **GPS Receivers on Microsatellites**

The possibility of mounting GPS (Global Positioning System) receivers on microsatellites were examined using software simulation. The following simulation results are obtained: The position covariance is 10 m

or less, 5-10 GPS satellites are always visible from a microsatellite with 90 deg inclination and 800 km altitude, the maximum Doppler shift is about 45 kHz and Doppler rate is about 70 Hz/s, the GDOP (Geometrical Dilution of Precision) values are always 5 or less. To realize this system, onboard lightweight GPS receiver must be developed.

(5) Emergency Medical Satellite

Medical information transmission system utilizing satellites was investigated. The needs of this system is strongly desired as a transmission of the moving images from a moving ambulance. To receive a real-time image from a transmitter moving along the ground requires that "shadowing" like interference from buildings, trees, pedestrian overpasses, mountains, etc. be suppressed as much as possible. MOLNIYA and TUNDRA type orbits are, for example, candidates to avoid this problem. The frequency of Ka band (30/20 GHz) will be used and the mobile transmitter will require 25 dBi planar antenna to transmit 1.5 Mb/s moving image to the satellite with 3.3 m antenna.

(6) Technology Experiment

These are many mission ideas to perform the technology demonstration. One-dimensional deployable structure employing telescopic members is one of the proposals. Various box type truss structure will be used for supporting structures of platform type spacecraft. It is also available for deploying experiment missions or can be used as supporting structures of payloads on small satellite. A functional model, the side length of which is 200 mm, was manufactured to confirm the basic movement of deployment and retraction.

4.2 Bus Technology

For reducing both the cost and the development time, it is necessary to standardize the bus system and its equipment. In order to clarify the constitution equipment and its required characteristics, small satellites considered in this paper are divided into 25 kg, 50 kg and 100 kg-class satellite. The classification results are shown in **Table 2**.

The mass property is estimated by referring to a number of satellites data launched in the past. The average percentage of weight

for each subsystem is as follows: 30% for mission payload, 23% for structure and thermal control mechanism, 28% for power subsystem, 13% for attitude control subsystem and 5% for TT&C subsystem.

A body-mounted solar cell array is used for a low-cost, small satellite, as a principle. Deployable solar panel without sun-pointing system will also be used. For TT&C subsystem, microprocessor will be necessary for data handling, in a specific mission. Three-axis attitude control system will be chosen for a 100 kg-class satellite attitude stabilization, if the high precision pointing accuracy is required. On the contrary, a gravity gradient stabilization is suitable for low pointing missions.

The estimated cost for each satellite is \$4-2M for 25 kg-class, \$8-4M for 50 kg-class and \$14-7M for 100 kg-class satellite. The calculation is based on the cost of the communication satellites launched in the past.

4.3 Launch System

Various type of rockets will be available for small satellites' launcher in the near future. After the phase-out of H-I rocket, newly developing H-II rocket will be expected to give the flight opportunities for the small satellites as piggyback payload, will be operational in the next year. A new concept J-I rocket will also be available within a few years as a low earth orbit (LEO) launch system. The Mu series have launched small scientific satellite of ISAS (The Institute of Astronautical Science) and next generation M-V is underdevelopment and will be available in a few years. Another small rocket, TR-X series, will be possible to launch a small satellite into LEO. In this chapter, some features of these launchers are described.

(1) H-II Rocket

H-II rocket is a two stage launch vehicle equipped with two large solid rocket boosters (SRBs) on the first stage. It will be capable of launching payload of approximately two tons in GEO. The second stage engine restart capability is possible to inject sub-payload into a various orbits, simultaneously. Sub-payload is defined as single or multiple small satellites launched with the primary satellite.

Table 2 25 kg, 50 kg and 100 kg-class Small Satellite.

| | 25kg-class satellite | Spin (cylinder) | 50kg-class satellite Spin (polyhedron) | Gravity grad | Spin (polyhedron) | 100kg-class satellite Gravity grad. | 3-axis |
|-------------------|--|---|---|---|---|---|---|
| Bus system | •Earth environment observation •Rygback launch •Mass:25kg •Power:20W | •Earth environmental •Technology verification •Rygback launch •Mass:52kg •Power:40W | •Earth environmental •Technology verification •Rygback launch •Mass:50.5kg •Power:40W | •Technology verification/scientific observation/communication experiment •Rygback launch •Mass:50kg •Power:40W | •Technology verification/scientific observation/communication experiment •Rygback or dual launch •Mass:100kg •Power:100W | •Technology experiment •Communication/positioning •Earth observation/rescue •Multi-platform •Rygback or dual launch •Mass:112kg •Power:100W | •Technology experiment •Communication/positioning •Earth observation/rescue •Multi-platform •Rygback or dual launch •Mass:102kg •Power:100W |
| Power | •Solar Panel •NiCd battery •Mass:6kg •Power:2W | •Cylindrical solar array •NiCd battery •Mass:15kg •Power:5w | •Square solar panel •NiCd battery •Mass:15kg •Power:4W | •Solar array •NiCd battery •Mass:13kg •Power:5W | •Cylindrical solar array •NiCd battery •Mass:23kg •Power:10w | •Cylindrical solar array •NiCd battery •Mass:25kg •Power:10w | •Cylindrical solar array •NiCd battery •Mass:25kg •Power:10w |
| Structure/Thermal | •Spherical polyhedron •Passive thermal control •Mass:6kg •Power:3W | •Central cylinder •Passive thermal control •Mass:12kg •Power:3W | •Polyhedron •Passive thermal control •Mass:12kg •Power:3W | •Standard modular box •Passive thermal control •Mass:12kg •Power:3W | •Central cylinder •Passive thermal control •Mass:20kg •Power:5W | •Cylindrical frame/multiplatform •Cylindrical solar panel •Passive thermal control •Mass:20kg •Power:5W | •Cylindrical frame/multiplatform •Cylindrical solar Panel •Passive thermal control •Mass:20kg •Power:5W |
| Attitude/Orbit | •Spin stabilization •Nutation dumper •Mass:0.2kg •Power:0W | •Spin stabilization •Nutation dumper •Mass:2kg •Power:7W | •Spin stabilization •Nutation dumper •Mass:0.5kg •Power:0W | •Gravity gradient stabilization/ Magnetic torquer •Mass:5kg •Power:5W | •Spin stabilization Magnetic torquer •Attitude/orbit control •Mass:10kg •Power:9W | •Gravity gradient stabilization Magnetic torquer •Mass:10kg •Power:10W | •Momentum wheels Attitude sensor Magnetic torquer •Mass:10kg •Power:10W |
| TT&C | •Central TT&C •VHF transmitter/receiver •Telem command •Mass:4kg •Power:8W | •Central TT&C •VHF transmitter/receiver •Telem command •Mass:6kg •Power:10W | •Central TT&C •VHF transmitter/receiver •Telem command •Mass:6kg •Power:10W | •Onboard computer (Laminating architecture) •96kb/s ISK data transmitter •Mass:8kg •Power:10W | •Central TT&C •VHF transmitter/receiver •Telem command •Mass:12kg •Power:16W | •Depend on mission requirement •CFU dispersion/central TT&C •Mass:12kg •Power:15W | •Dispersed TT&C •Mass:12kg •Power:16W |
| Integration | •2-stage platform •Mass:2kg | •2-stage platform •Mass:2kg | •2-stage platform •Mass:2kg | •Central box type •Laminated modules •Mass:2kg | •2-stage platform •Mass:5kg | •2-stage platform •Mass:15kg | •Multi-stage platform •Mass:5kg |
| Mission equipment | •Observation sensors •Mass:7kg •Power:7W | •Observation sensors •In-orbit experimental hardware •Mass:15kg •Power:30W | •Observation sensors •In-orbit experimental hardware •Mass:15kg •Power:20W | •Observation sensors •In-orbit experimental hardware •Communication experiment •Mass:10kg •Power:15W | •Observation sensors •In-orbit experimental hardware •Communication experiment •Mass:30kg •Power:60W | •Observation sensors •In-orbit experimental hardware •Communication experiment •Mass:30kg •Power:60W | •Observation sensors •In-orbit experimental hardware •Communication experiment •Mass:30kg •Power:60W |

(2) J-I Rocket⁽¹²⁾

J-I rocket will be compared of a SRB of H-II rocket for the first stage and the upper stages of M-3SII for the second/third stages. It will be possible to launch about one-ton class small satellite into LEO. The J-I rocket is expected to be available in 1995.

(3) Mu Series

M-3SII launch vehicle, an improved version of the M-3S, is capable of carrying a 770 kg satellite into a 250 km circular orbit. In 1990, it launched a double lunar swing-by testing satellite and at the same time, orbited another micro-satellite "HAGOROMO" around the moon. M-V, the next generation launch vehicle, is now under development and the first flight is scheduled in 1995.

(4) TR-X Series

TR-X series is a TR rocket family based on TR-I rocket system, which is a 1/4 scale simulation rocket of H-II launcher, and possible to launch 100-300 kg class small satellite into LEO. A 3-stage solid propellant TR-X will transport a 100 kg satellite into 250 km circular orbit.

(5) Air-Launch Vehicle

The baseline vehicle is a winged 3-stage rocket as a derivative of M-V launcher. The vehicle, weighting about 52 tons, is to be launched from the B-747 at 10 km altitude with 200 m/s initial velocity and can deliver 1,270 kg of payload into a 250 km circular orbit.

Table 3 Summary of Japanese Launchers.

| | H-II | J-I | M-3SII | M-V | TR-X | | H-I | Air Launch |
|--------------------|--|--------------------------|---------------------------|--|-------------------------------|--------------------------------|------------|-----------------|
| | | | | | TR-X1 | TR-X2 | | |
| Overall length (m) | 48 | 33 | 28 | 31 | 13 | 13 | 40 | 17 |
| Total weight (ton) | 260 | 87 | 62 | 128 | 14 | 14 | 140 | 52 |
| Number of stages | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Payload capacity | 2.2 tons/GEO 10 tons/250 km i=30 deg | 1 ton/250 km i=31 deg | 770 kg/250 km i=31 deg | 1.8 tons/250 km 800 kg/600 km i=31 deg | 100 kg/250 km 50 kg/600 km | 300 kg/250 km 150 kg/600 km | 550 kg/GEO | 1.3 tons/250 km |
| Operation time | 3.8 tons/GTO 1994 | 250 kg/GTO 1997 | 510 kg/GTO 1985 | 1995 | 1986-1992 | | | |
| Status | Under develop. | Under develop. | In operation | Under develop. | Propose | | Phase-out | Propose |

Table 3 summarizes the main capabilities above-mentioned launchers. Some of them are under development and will be available for launch in a few years.

5. Concluding Remarks

This paper has presented briefly the activities of the study on small satellites and related technologies in Japan focusing on the activity of the SPWS. The usefulness of small satellites are recognized by the researchers, engineers and other users in various fields such as communications, scientific observations, remote sensing like resource and disaster observations, technological R&D. We believe that the SPWS has contributed to stimulate the atmosphere of developing small satellites and related technologies in Japan.

Finally, the authors give their thanks to the members of SPWS for their contribution.

References

- (1) T. Iida: "Small Satellites and Their Significance", 1990 Autumn National Conv. IEICE, SB-2-1, Oct. 1990 (in Japanese).
- (2) T. Iida, K. Kondo, Y. Ohkami and A. Nakajima: "Activities of Small Payload WorkShop of Japan", IEICE Tech. Report, Vol.90, No.452, pp.25-30, Feb.27, 1991.
- (3) A. Nakajima, M. Abe, Y. Nishio and H. Yahagi: "Space Experiments of Deployable Boom and Umbrella Test Satellite (DEBUT)", IAF-90-008, 1990.
- (4) F. Yamashita, I. Matsuo, T. Kondou, T. Machida, M. Matsui and T. Ikeda: "Amateur Satellite JAS-1b (FUJI 2)", 1990 Autumn National Conv. IEICE, SB-2-5, Oct. 1990 (in Japanese).
- (5) SPWS Annual Report, SPWS-90-02, Feb. 1991 (in Japanese).
- (6) SPWS Annual Report, SPWS-91-01, Mar. 1992 (in Japanese).
- (7) Proceedings of Small Satellite Symposium, SPWS-90-01, Apr. 1990.
- (8) Proceedings of Small Satellite Symposium, SPWS-91-01, Apr. 1991.
- (9) A. Nakajima, T. Iida, K. Kondo and Y. Ohkami: "A Concept Study of Low-Cost, Small Satellites", 18th ISTS, 1992.
- (10) K. Kondo, Y. Hashimoto, R. Suzuki, M. Tanaka, T. Ikegami, T. Obuchi, O. Nakagawa and M. Matsui: "Study of Microsat Communication System", IAF-92-0431, 1992.
- (11) M. Tanaka, R. Suzuki, Y. Suzuki and K. Araki: "Microstrip Antenna with Solar Cells", IEICE Tech. Report, Vol. 92, No.175, pp.35-38, Aug. 20, 1992.
- (12) A. Tsuiki, T. Doura and Y. Suzuki: "Missions of Small Satellites Launched by the J-I Launch Vehicle", 6th Annual AIAA/USU Conf. on Small Sat., Sept. 1992.