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Nano-JASMINE: A Small Infrared Astrometry Satellite

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ABSTRACT

The University of Tokyo and National Astronomical Observatory of Japan have been developing a small infrared astrometry satellite named "Nano-JASMINE". This is about 50cm cubic and 15kg size satellite and it aims to achieve 1 milli arcsecond astrometry data for stars of magnitude of 7.5. And this is traditional large satellite scientific data class. Therefore Nano-JASMINE has advanced specification compared to past small satellites. It can achieve 1 arcsecond attitude control accuracy using customize fiber optical gyros and mission telescope and also 0.1[K] thermal stability by multilayer adiabatic structure. Also new centralized information architecture is adopted to simplify the system. Nano-JAMINE satellite system and missions are described in this paper.

OBJECTIVES AND BACKGROUND

Intelligent Space Systems Laboratory, The University of Tokyo (ISSL) and National Astronomical Observatory of Japan JASMINE team (NAO) have been developing a small infrared astrometry satellite "Nano-JASMINE". A CG image is shown in Figure 1-1. This project starts with NAO and JAXA astrometry satellite JASMINE[1,2] (Figure 1-2). It is to measure astrometric parameters of stars at the disk and the bulge part of the Milky Way Galaxy to an accuracy of ten micro arcsecond. However the satellite is planned to be launched in 2014, there has been only one astrometry satellite named HIPPARCOS[3,4] by ESA in the past. And JASMINE requires new advanced technologies for its precise observations. Therefore NAO proposed a precedent technical demonstration satellite project Nano-JASMINE together with ISSL that has experience in small satellites[5]. In this project, NAO can learn about satellite, try some technologies for JASMINE and ISSL can develop new satellite technology taking advantage of short term development, low cost and risk tolerability of small satellite. ISSL is in charge of bus part and ground segment development and system integration. NAO is in charge of observation equipment and mission data analysis.

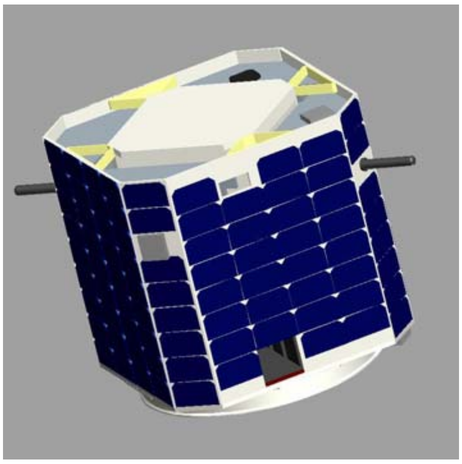

Figure 1-1: Nano-JASMINE Outlook

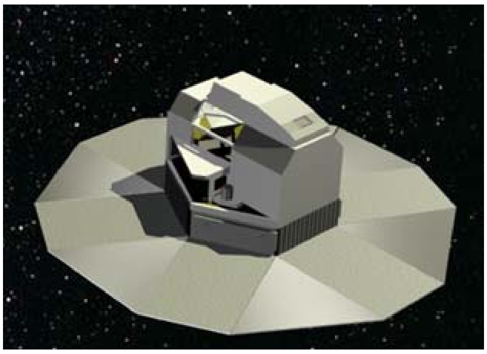

Figure 1-2: JASMINE Outlook © NAO

NANO-JASMINE PROJECT MISSIONS

The satellite missions are selected from the point that this project is linked to JASMINE satellite.

Astrometry Data Acquisition

HIPPARCOS is the only astrometry satellite and ended its missions in 1992. So Nano-JASMINE is planned to update whole celestial globe astrometry data, position, annual parallax and proper motion, at HIPPARCOS level precision: 3 milli arcsecond (mas) at 7.5 magnitude stars. Especially by combining the HIPPRCOS catalogue, Nano-JASMINE can make 0.1[mas] per year accuracy proper motion catalogue, which will be the world best record.

Demonstration of a Beam Combiner

A beam combiner (Figure 2-1) is the key component which guarantees the precision of astrometric measurement. The mirror planes and its cross angle stabilization will be tested on orbit.

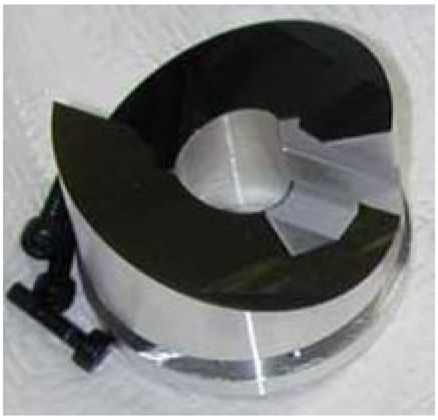

Figure 2-1: Beam Combiner

Demonstration of a CCD

JASMINE observes the bulge part of the Galaxy in which visual wavelength light absorb by dusts. Then JASMINE monitors near infrared light at a wavelength of 0.9 micrometers (z-band). Since there is not a CCD which has enough sensitivity at z-band, a new type full-depleted CCD is developed for JASMINE. Nano-JASMINE uses this CCD and its characteristics and deterioration data will be collected.

It is used in time delayed integration (TDI) mode in which CCD transfers a pixel's electrons to next pixel and integrates charge to suppress read-out-noise. A method to use a CCD in TDI mode is the first attempt in astrometry and its work will be tested.

Demonstration of Precise Attitude and Temperature Control

However Nano-JASMINE adopts newly created high sensitivity sensors, its small size telescope requires precise attitude control at 1[arcsec] precision. This is a challenging problem for current small satellites. New attitude control devices and control algorisms are considered to fulfill this demand. As for the thermal control, there are also strict requests from the infrared CCD cooling and the beam combiner thermal stability at 0.1[K] level. So development of an epoch-making bus system is one of the missions.

Integrated Satellite Simulator Development

A satellite simulator is developed in order to confirm design feasibility and data analysis validity. This simulates from behavior of a single photon from one star to the satellite attitude dynamics on orbit. Mission part is coded by NAO and bus part is programmed by ISSL. This simulator will be used not only for Nano-JASMINE Project, but also for follow-on JASMINE Project as a design information transfer tool.

ASTROMETRY AND OBSERVATIONS PRINCIPALS

Astrometry is to measure six parameters of stars on celestial globe: position, distance (annual parallax), crossing velocity (proper motion) and line of sight velocity. Observation is based on triangular surveying of yearly circuit around the sun as shown in Figure 3-1. If a star stops in the universe, it moves on an ellipse from the earth observation. On the contrary when it moves it shows intricate movement like Figure 3-2. Astrometry parameters of position, distance, crossing velocity are estimated from these star trajectories of two years observation. To measure line of sight velocity spectrographic analysis is needed, so JASMINE and Nano-JASMINE don't measure it.

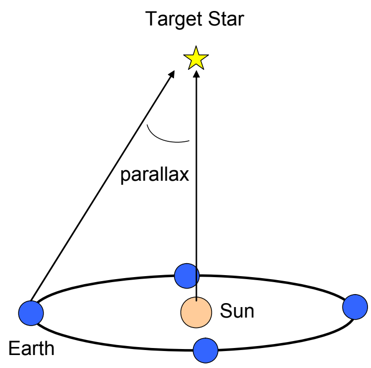

Figure 3-1: Triangular Survey

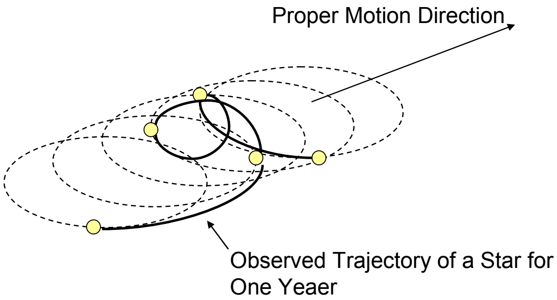

Figure 3-2: Observed Trajectory of a Star

Since the scientific output must exceed the current star map precision, a satellite can't finally decide its attitude using a star tracker. Nano-JASMINE adopts simultaneous large angled two way observation method to determine astrometric parameters and the satellite attitude self-consistently. The satellite is designed to spin and scan zonal area of the celestial sphere. When the satellite observes in one direction, star density fluctuation and attitude motion perturbation can't be separated from the data (Figure 3-3). But the degeneration of both parameters can be solved by simultaneous two way observation (Figure 3-4). And the basic angle of two fields of view is decided as 99.5 degree to achieve most ergodic observation with a few numbers of great circles.

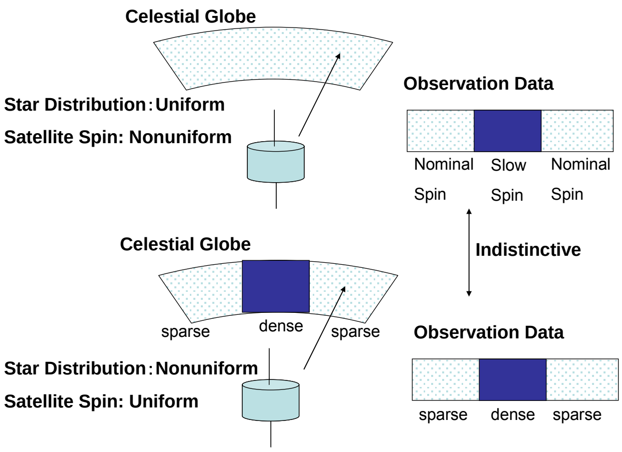

Figure 3-3: One Way Observation

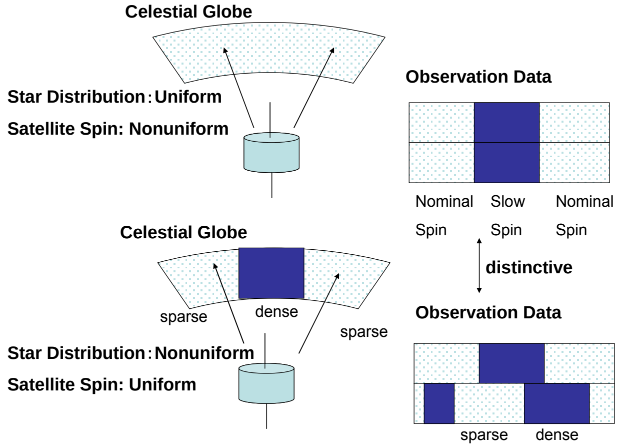

Figure 3-4: Two Way Observation

There are commonly three shooting procedures when the satellite is spinning. TDI mode is adopted from these methods because of long exposure time and little intermission. In this mode, electric charge is transferred to next pixel synchronized with a star in the field of view and charge is read out at the edge of CCD so that read-out-noise will be suppressed (Figure 3-5). But this requests the satellite spins exactly on be half of data precision.

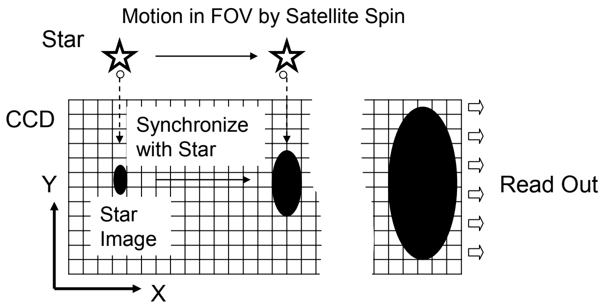

Figure 3-5: TDI mode

Nano-JASMINE is expected to be launched into a sun-synchronous orbit in view of piggyback launch opportunities and observation method. High altitude orbit such as GEO or Lagrange point L2 is not suitable for equipments will grow in size. When the satellite is launched into sun-synchronous orbit, its spin rate should synchronize with orbit period to avoid the telescope seeing the Earth. Then the satellite scan stars on a great circle during one spin. The satellite spin axis motion aligns with orbit plane rotation and scans the entire sky in half year (Figure 3-6). To be more exact, the scanned great circle is little shifted from the circle which contains the Sun. And the direction of the spin axis of rotation is precessed around the sun direction to disperse observation time and direction of a single star to improve measurement (Figure 3-7).

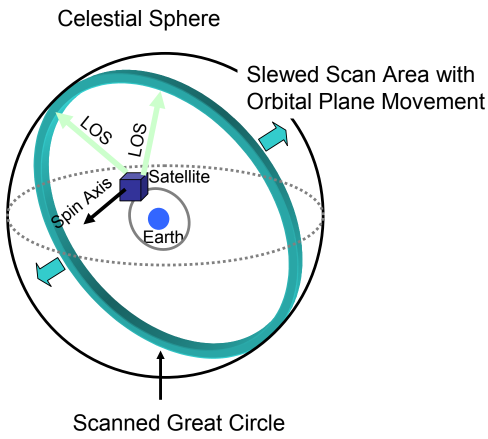

Figure 3-6: Scan Method

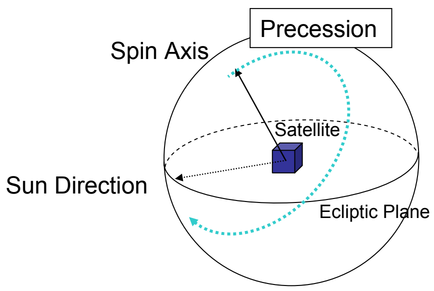

Figure 3-7: Spin Axis Precession

NANO-JASMINE SATELLITE SYSTEM AND SUBSYSTEMS

General Specifications

Nano-JASMINE outlook is shown in Figure 1-1 and general specifications are shown in Table 4-1. Mission sequence plan is shown in Figure 4-1 and this detail is explained in attitude control section.

Table 4-1: Satellite Specs

Size	485*485*412[mm]	Separation mechanism is not included. Maximum envelope size.
Mass	14[kg]	Separation mechanism is not included.
Mission	Infrared Astrometry	3[mas] accuracy at 7.5 magnitude.
Mission Life	Two[Years]	
Orbit	Sun-synchronous Orbit	Any LTAN can be adoped.
Attitude Control	Three Axis Stabilization	
Power	Peak Power Tracking	
Communication	S-band Up:1[kbps] Down:100[kbps]	

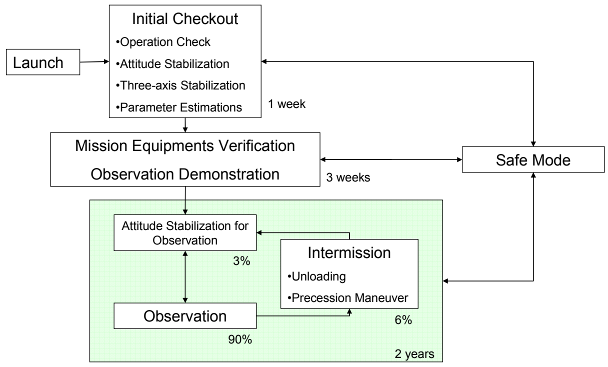

Figure 4-1: Mission Sequence

Satellite Architecture

The functional block diagram is shown in Figure 4-2. Nano-JASMINE adopts a typical centralized information processing style. The main OBC collects data from mission part, sensors and receiver then sends commands to mission OBC, actuators and transmitter. This hierarchy makes components' interface simple.

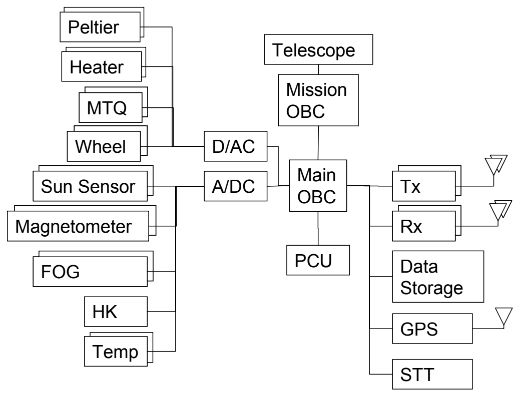

Figure 4-2: Functional Block Diagram

Telescope

The telescope has two fields of view and combines these images on one CCD. Focal length 1.66[m] is folded by plane mirrors and the optical characteristics are shown in Table 4-2 and equipment picture is shown in Figure 4-3. NAO is in charge of mission part development.

Table 4-2: Telescope Specs

Telescope Type	Korsch
Diameter	5[cm]
Focal Length	1.66[m]
Detector	z-band:1K×1K
Num. of Detector	1
1pixel size	15[μm]
FOV	0.53[°]×0.53[°]
Airy Disk	4[pixels]
Mirror Material	Aluminium
Structure Material	Aluminium
Exposure Time	8.8[s]

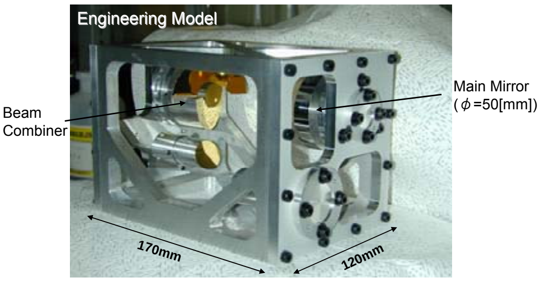

Figure 4-3: Telescope (Engineering Model)

Mission OBC

Mission OBC is a FPGA base data processing circuit. Its functions are as follows.

- Analog-digital conversion of CCD output.
- TDI clock control to synchronize with satellite spin.
- Star image cutout from continuing CCD output for data compression.

C&DH Subsystem

C&DH is a centralized system using a CPU core embedded FPGA.

- Potential radiation tolerance by using a FPGA.
- Computation power is up to 100[MIPS].
- House keeping functions are implemented at logic level to maintain robustness and advanced functions are running by the OS on CPU so that reprogramming can be easy.

Structure Subsystem

Special requirements for structure are as follows.

- Stiff structure is suitable for attitude stability.
- Large surface area for solar cells.
- Symmetric structure is preferable to suppress disturbance torque caused by air drag and solar wind pressure.
- Long light shielding food enough to absorb stray light for the telescope.

Structure is designed as Figure 1-1 from above demands. Nano-JASMINE has low density as a small satellite since outer panels are set to cover the optical food and increase power generation. Internal configuration is shown in Figure 4-4.

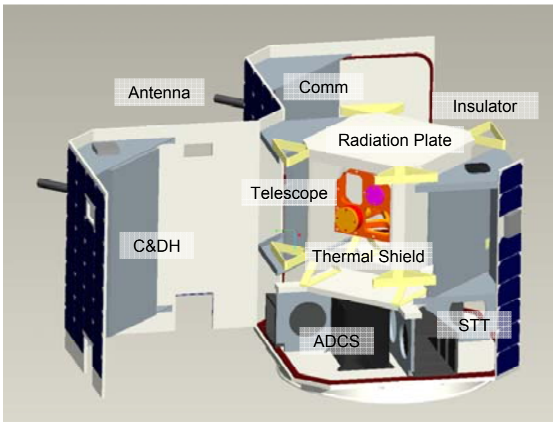

Figure 4-4: Inside Components Arrangement

ADCS Subsystem

Requirements for attitude controls are as follows.

- Short period stabilization is 1[pixel] per detector transit time 8.8[sec]: This means that the taken image will not blur. It is equivalent to 740[mas] / 8.8[sec].
- Middle period stabilization is 0.05[degree] per orbit period 100[min]: It aims that the spin axis follows the orbit rotation and scans the celestial sphere.
- Long period stabilization is 10[degree] per few days: This is for the spin axis precession maneuver.
- Absolute attitude determination accuracy is 0.1[degree]: To identify observed stars.
- Shooting time determination accuracy is 10[microsec]: For astrometry.
- Satellite orbit determination accuracy is 15000[km]: For triangular survey.
- Satellite velocity determination accuracy is 15[cm/sec]: To compensate aberration.

Attitude stabilization requirements are plotted in Figure 4-5.

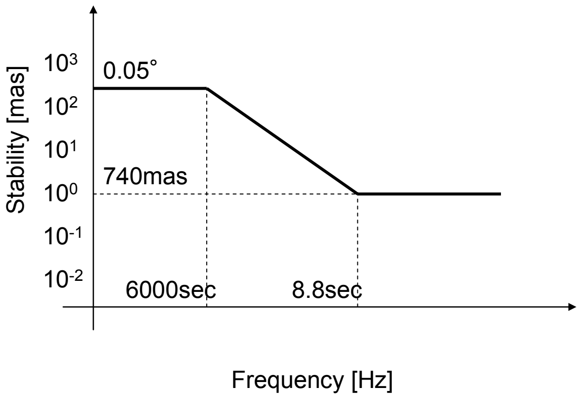

Figure 4-5: Frequency and Attitude Stability Requirements Relationship

Especially short period stabilization requirement is strict for small satellite. So Nano-JASMINE gradually stabilizes its attitude step by step as shown in Figure 4-6.

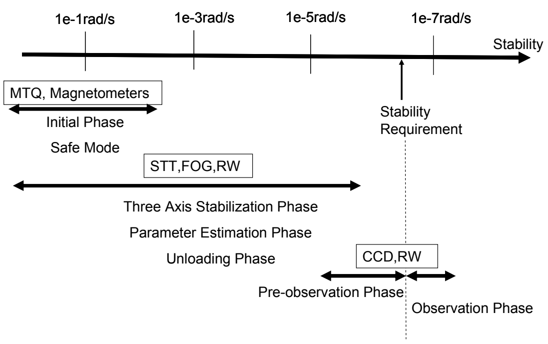

Figure 4-6: Attitude Control Strategy

Parameter Estimation Phase

In this phase, the satellite estimates its moment of inertia, sensors and actuators alignment and residual magnetic moment (RMM) using extended Kalman filter. RMM is the most serious attitude disturbance source, so its estimation and cancellation is a major issue. Attitude determination is made by traditional inertial navigation using star trackers, fiber optical gyros. The FOG is special made. It can work in limited narrow dynamic range but its error is within 1E-6[rad/sec].

Pre-observation and Observation Phase

After the parameters are tuning in three axis stabilization, the telescope starts taking star images. So in this phase, mission CCD output is used as a fine attitude sensor. A star image is distorted by attitude instability from ideal ellipse style and this distortion rate is feedback to the controller.

All phase control feasibility is verified using the satellite simulator (Session 5). Observation phase control example is shown in Figure 4-7.

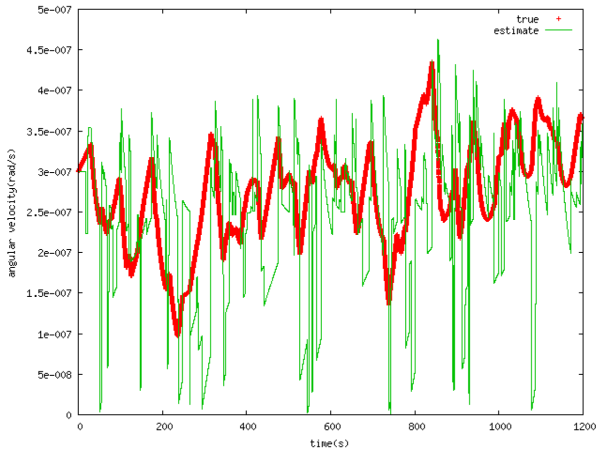

Figure 4-7: Attitude Control Example

Thermal Control Subsystem

Special requirements for thermal control are as follows.

- Beam combiner angle stability is within 1[mas] per two orbit periods. It is equivalent to 0.1[K] temperature stability. This angle guarantees the measurement accuracy.
- Telescope frame temperature stability is within 1[K] in order to be in focus.
- CCD unit is at temperature of -50[C] or lower for infrared detection.

The design point is thermal insulation as shown in Figure 4-8. Temperature stability is achieved by covering the telescope with a thermal shield. The telescope and the shield are hold by adiabatic columns which don't transfer heat and release heat stress. CCD is cooled by emission from the radiation plate on the top. This estimation is difficult due to orbit uncertainty and radiation plate is inevitable to see the Earth because of the observation method. This part is calculated by using FEM model and verifies the feasibility (Figure 4-9).

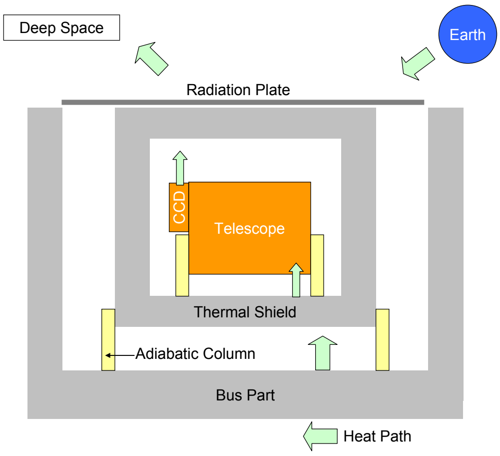

Figure 4-8: Thermal Design Model

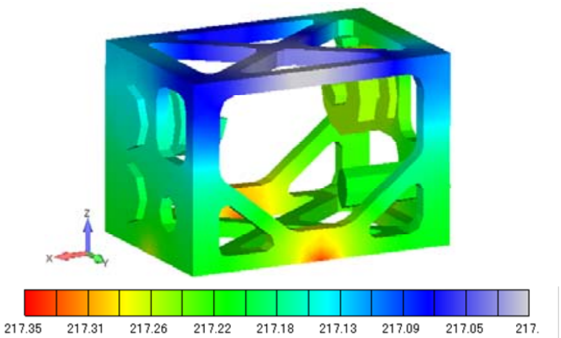

Figure 4-9: Telescope Part Precise Temperature Analysis

Communication Subsystem

S-band radio communication is used and its device specifications are shown in Table 4-3. Average generated data rate of mission part is 900[bit/sec] and bus part is 1000[bit/s]. The BBM model of transceiver is shown in Figure 4-10.

Table 4-3: Radio Specs

	Uplink	Downlink
Band	S-band	S-band
Data Rate [kbps]	1	100(Nominal) 10(Safe Mode)
Modulation	PCM-PSK-PM	BPSK
Output Power [W]	1	0.2

Figure 4-10: Communication Unit (BBM)

On board antenna is a backfire helical type and uplink and downlink share the same one. Earth pointing side antenna is the main one and an antenna which is branched by 10[dB] coupler is mounted on the opposite side for attitude loss case. This configuration is shown in Figure 4-11.

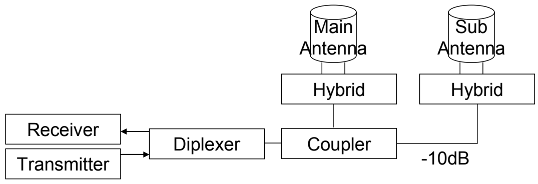

Figure 4-11: Antenna Configuration

Power Subsystem

Power subsystem inherits ISSL satellite bus system.

- GaAs solar cell
- Lithium ion battery
- Peak power tracking
- Power control unit and main OBC mutually monitor each other to respond for single event effects. CPU of PCU has been tested on orbit several times.

Body mount type solar cell arrangement is adopted because solar paddle could be an attitude disturbance source. Large body has advantage to power consuming satellite. Power generation is estimated at about 20[W].

Ground Station

Nano-JASMINE is basically operated only above Japan. Each ground station and control room is connected via networks and data is shared. Entire picture is shown in Figure 4-12.

ISSL ground station (3[m] dish, Tokyo, Univ. of Tokyo jurisdiction) is used to send commands and receive low speed telemetry.

Mizusawa ground station (10[m] dish, Mizusawa, NAO jurisdiction, Figure 4-13) is used to receive high speed telemetry.

An overseas station is also planned to be used at initial operation phase.

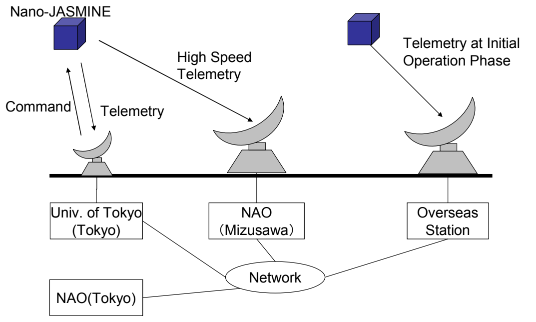

Figure 4-12: Ground Station Relationship

Figure 4-13: Mizusawa Ground Station

SATELLITE SIMULATOR

Since Nano-JASMINE adopts new observation methods and the satellite bus system is also very advanced, the optimal design point is unknown. Therefore, a simulator which has precise modules of bus and mission part is developed to clarify the design problems, check design feasibility and verify data analysis.

The mission part simulates one photon trajectory from a star to the detector and output of CCD data. The bus part calculates satellite status, attitude, position, et al. for the mission part input. Down link data during mission life span can be generated to check whether it can yield enough accuracy astrometry data.

A CCD output example is shown in Figure 5-1 and link margin case is in Figure 5-2.

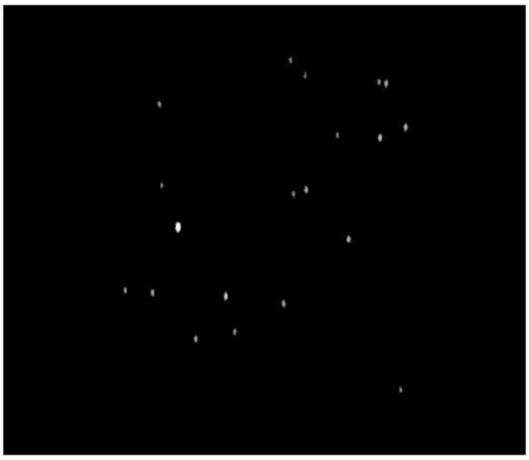

Figure 5-1: CCD Output Example

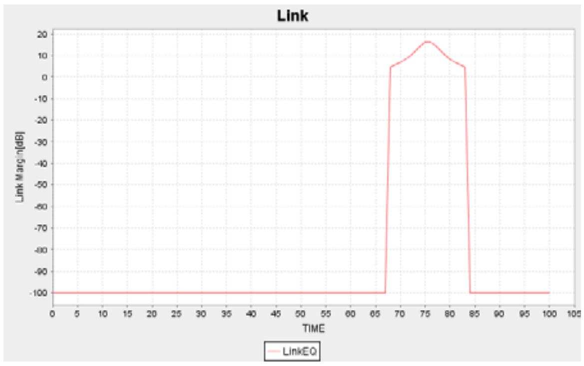

Figure 5-2: Link Margin Calculation Example

Software development language is JAVA, and source code is uploaded to a CVS server to develop this simulator simultaneously at each organization. The development environment display is shown in Figure 5-3.

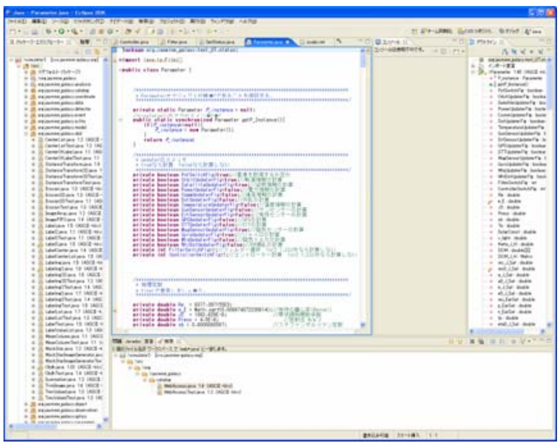

Figure 5-3: Development Environment.

SCHEDULE

The current status of the project is detailed development phase. Some components are under development from the previous phase and attitude control algorism refining is ongoing. The process of past and future plan is shown in Table 6-1.

Table 6-1: Schedule

Date	Events
Apr./2003	First meeting between NAO and ISSL Small astrometry satellite is examined.
2003	50kg class infrared astrometry satellite "ASAGAO" conceptual design
2004	10kg class infrared astrometry satellite "Nano-Jasmine" conceptual design
Apr./2005	Nano-JASMINE is authorized as a project
Sep./2005	Prototype of satellite simulator
Nov./2006	PDR
2009	Launch of Nano-JASMINE (TBD)
2011	End of obeservation (TBD)
2014	Launch of JASMINE

CONCLUSIONS

A small infrared astrometry satellite Nano-JASMINE developed by ISSL and NAO is described in this paper. It is a small but has enough ability to satisfy astrometry scientists. The bus technology can be used for not only for space science but also for other practical use and will boost demand for small satellites.

Acknowledgments

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