System outline of small standard bus and ASNARO spacecraft

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ABSTRACT
ASNARO (Advanced Satellite with New system ARchitecture for Observation) system outline including payload characteristics and bus architecture is presented in this paper. ASNARO, which is being developed by NEC and USEF under the contract with NEDO, is a LEO satellite for the earth observation by optical sensor in sub-meter class. The bus module of the ASNARO is highly adaptive for various missions such as remote sensing by optical sensor or Synthetic Aperture Radar (SAR) sensor, and for the future small satellite market. ASNARO imaging capability of Ground Sample Distance (GSD) from 504km altitude is less than 0.5m for the panchromatic band. The new silicon carbide mirror, named NTSIC, is employed for the primary mirror of the telescope.

1. INTRODUCTION
After first launch of Japanese satellite OHSUMI, which was manufactured by NEC in 1970, NEC has been developing more than 60 satellites with Japan Aerospace Exploration Agency (JAXA), Institute for Unmanned Space Experiment Free Flyer (USEF) and New Energy and Industrial Technology Development Organization (NEDO). During 40 years, not only the large satellites, such as DAICHI (ALOS), KAGUYA (SELENE) and KIZUNA (WINDS), but also many small satellites, such as HAYABUSA (MUSES-C), TSUBASA (MDS-1) and KIRARI (OICETS), have been successfully launched.

NEC also has long history of optical sensor development. For example, our first sensor for MOMO-1 (MOS-1) satellite was launched in 1987 and PRISM sensor for DAICHI (ALOS) satellite was launched in 2006.

Considering the recent trend of increasing of the small satellite market, NEC has decided to bring new small observation satellite to the market using our heritage mentioned above.

ASNARO, which is being developed by NEC Co. and USEF under the contract with NEDO15, is a first small satellite using NEC standard bus with our small and high resolution optical sensor (OPS).

This paper presents outlines of ASNARO system, NEC standard bus and Optical mission.

2. ASNARO SPACECRAFT SYSTEM OUTLINE
ASNARO spacecraft is a small low earth orbit (LEO) satellite (total mass of 450kg) for the earth observation by precise 3-axes pointing control. The orbit of ASNARO is Sun Synchronous Polar Orbit at 504 km, local time of descending node is 11:00 AM and design life is 3 years.

ASNARO payload consists of high resolution imager, data recorder and X-band transmitter. The Ground Sample Distance (GSD) of the imager from 504km altitude is expected to be less than 0.5m at panchromatic band. The output images non-compression data from optical sensor are transferred to 120Gbyte (at the end of life) flash memory data storage and stored. The stored data is transmitted to the ground
station by the X-band transmitter and the directional antenna, placed on X-band Antenna Pointing Module (X-APM) which is 2 axis gimbals mechanism, with 16QAM modulated X-band frequency by 800Mbps data rate. ASNARO maneuver range is +/- 45 degree from nadir direction. The configuration of the ANSARO on orbit is shown in Fig. 1, and the expected performances and characteristics are summarized in Table 1.

![On-orbit configuration diagram](image)

**Table 1: Performance and Characteristics**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Sensor</td>
<td>Pan/Multi</td>
</tr>
<tr>
<td>GSD</td>
<td>&lt;0.5m/2m (Pan/Multi, from 504km)</td>
</tr>
<tr>
<td>Swath</td>
<td>10km</td>
</tr>
<tr>
<td>Data Transmission</td>
<td>X-band 16QAM, App. 800Mbps</td>
</tr>
<tr>
<td>Mass Memory Size</td>
<td>&gt;120GB(EOL)</td>
</tr>
<tr>
<td>Coverage</td>
<td>+/- 45deg (from Nadir)</td>
</tr>
<tr>
<td>Agility</td>
<td>1deg/sec average</td>
</tr>
<tr>
<td>Launch Rocket</td>
<td>JFY2011(Expected)</td>
</tr>
<tr>
<td>JAXA New Solid (Assumed) (Compatible with H-IIA, Dnepr, etc.)</td>
<td></td>
</tr>
<tr>
<td>Orbit Altitude</td>
<td>Sun Synchronous Polar Orbit 504km Nominal</td>
</tr>
<tr>
<td>Inclination</td>
<td>97.4deg</td>
</tr>
<tr>
<td>Local Time</td>
<td>AM 11:00 at Descending Node</td>
</tr>
<tr>
<td>Design Life</td>
<td>3 Years</td>
</tr>
<tr>
<td>Mass</td>
<td>Bus 250kg (without propellant)</td>
</tr>
<tr>
<td></td>
<td>Payload 150kg</td>
</tr>
<tr>
<td></td>
<td>Propellant 50kg</td>
</tr>
<tr>
<td></td>
<td>Total App. 450kg</td>
</tr>
<tr>
<td>Size</td>
<td>App. 2.5m x 3.5m x 3.2m (On orbit)</td>
</tr>
<tr>
<td>Power</td>
<td>SAP Power: &gt;1300W (400W for Payload)</td>
</tr>
</tbody>
</table>

**Bus system configuration**

ASNARO bus system consisted of Telemetry Tracking and Command subsystem (TTC) which include S-band RF communication system, Electrical Power subsystem (EPS), Thermal Control subsystem (TCS), Satellite Management system (SMS), and Attitude and Orbit Control subsystem (AOCS) which include Reaction Control subsystem (RCS). The precise and swift control for the earth observation maneuvers are performed by Reaction Wheels (RW), IRU, Star Trackers (STT), GPS receiver (GPSR) and the control S/W in AOCS. This bus system applied to ASNARO was developed by NEC as first model of standard LEO satellite bus.

The system network block diagram of ASNARO is shown in Fig. 2. This network applies to SpaceWire network which is described in the following paragraph.

![ASNARO system network diagram](image)

**Operational aspects**

The on orbit operational scheme is shown in the Fig.3. Various imaging requirements from the users will be integrated and coordinated, and flight operation plan, such imaging task definition, of the spacecraft will be defined. The operation plan will be uploaded through the ground station prior to the spacecraft fly over the area of concerns for the imaging. Captured image data will be transmitted to the ground, and stored and processed in the ground facility for the distribution.
Figure 3: ASNARO spacecraft operation outline
There are four kind of imaging capability as follows.

1) Snap shot mode
Acquire nominal 10 X 15 km area covered image for one shot. (Covered 10 km X 10 km area effectively)

2) Wide view mode
Acquire image by snap shot mode mentioned above in succession to cover wide area.

3) 3D mode
Acquire same area from different time to obtain 3 dimensional information of the concerned area.

4) Strip map mode
Up to 850 km along track of continuous image of 10 km width

An example of the image capture operation simulation is indicated in the Fig. 5. This example is simulated to take 7 snap shot images of Japan during the spacecraft flying over Japan.

Figure 4: ASNARO observation mode
(a) Snap Shot mode (b) Wide View mode
(c) 3D mode (d) Strip Map mode

Figure 5: Snap shots simulation example over Japan

The sequence started from the Sun pointing mode of the spacecraft attitude. The maneuver operation started prior to the spacecraft approaching Wakkanai where the first shot will be captured from almost zenith direction above. The maneuver time included the time necessary to be stabilized after the target angle maneuver achieved. After the image of the Sapporo has been taken, the spacecraft maneuver a lot of angle to target forward direction to capture image of Akita. The arrows indicate the direction of the target from the spacecraft. After the planned capture operation of the target over Japan, the captured image data will be down linked to the ground station located in Okinawa Island as an example.

This simulation resulted that the ASNARO spacecraft has ability to take images of the area concerned in practical use.

Agility
To obtain sufficient information of the interesting areas, the agility performance is important to guarantee the efficient observing operation. The satellite configuration is designed to reduce the moment of inertia of the satellite body to realize a high agility performance. The average agility performance of the satellite is about 1 [degree/s] (45degree/45second). The radar chart of Fig. 6 shows the maneuver time which is defined as the needed time to acquire the final shot attitude from initially earth pointing.
attitude condition. The phase zero (0deg) of the chart means that the 45 degrees maneuver around the roll axis.

![Figure 6: Required time for attitude maneuver from nadir to 45 degrees off nadir](chart)

According to Fig. 6, the time takes to do this maneuver is about 70 seconds from 55 seconds. It is one sample of simulation.

3. STANDARD BUS SYSTEM

Concept of Standard bus

NEC has been developing commercial LEO standard bus system based on the concept of ISAS/JAXA small scientific satellite standard bus. This bus system is highly adaptive for various missions. As the payload interface, including mechanical, thermal, electrical and RF interface, is standardized, bus system can be applied not only for optical observation mission but also for the radar sensor, hyper spectral sensor, infrared sensor, and other observation missions. (See Fig. 7)

ASNARO use this standard bus as a variation of optical sensor model.

![Figure 7: Standard bus system and various missions (planned) (a) Optical Sensor](image)

(b) SAR Sensor

(c) Hyper Spectral Sensor

(d) Infrared Sensor

When the new satellite is developed using this standard bus, payload system shall be designed according to its interface rule, manufactured and tested independently to the bus system, and then mated with the bus mechanically and electrically. Between the payload and the bus, only SpaceWire, time lines (1pps, 1Mpps), power lines and the thermal control lines are existed. As a result, development duration can be reduced.

This Standard bus system is designed to correspond to the environmental condition of various rockets, such as...
JAXA new solid rocket, H-2A, DNEPR, ARIANE5 and etc.

**Figure 8: Launch configuration**

**Introduction of SpaceWire Network**

SpaceWire established by the European Cooperation for Space Standardization (ECSS 3) is the one of protocol for network in spacecraft. Innovative feature of the standardized bus system is the adoption of the SpaceWire for the telemetry and control data signal exchange network within the system.

SpaceWire network is a main network to link the bus subsystems which are SMS, AOCS, TTC, EPS and TCS. This network consists of main computers (Network masters), routers and units with SpaceWire interface (Target). The standard bus system has two CPUs for the Data Handling (DH) system and the AOCS system. Each subsystem’s target units are connected with each CPU through the SpaceWire router.

JAXA/ISAS and NEC have been engaged in developing SpaceWire network technology 4, which include small computer 5, router, interface LSI and software, for scientific satellites. These technologies apply to our new standard commercial bus to be compatible with several kinds of the earth observation payload or bus units without design change, to customize the bus architecture with low non-recurrent cost, and to reduce the recur cost and the lead time of the satellite.

The first merit of the SpaceWire is its standardized physical interface and network protocol. This standardization of physical interface and network protocol make the system configuration and the performance flexible. This flexibility gives best solution for the customer’s requirements with only a few additional changes and verifications at the system level (See Fig.10). For another instance, when redundancy is required, the additional unit is connected to the router, and then ID is defined in the flight software (See Fig.11). No additional system verification or H/W design modification is required.

**Figure 9: Small on-board computer 5 (Flight model of SDS-1 satellite)**

**Figure 10: Flexibility of mission requirement by SpaceWire**
The second merit of the SpaceWire is to simplify the test configuration of the data handling system. The standardization of telemetry and command data interface makes it possible to use identical testing facilities and testing procedure from unit level to the satellite system level.

Additionally, the third merit of the SpaceWire is to be able to simplify the harness of satellite. The flexibility of the equipment layout in a satellite increases if the harness is simplified by using SpaceWire.

According to these advantages, SpaceWire as standardized physical interface, network and testing set, make it possible that small venture companies participate in developing modules, because they can design the part of the module independently. As a result, it is expected that the development of the unit of satellite becomes active, and the development cost can be reduced.

5. OPTICAL MISSION

Table 2 shows the specification outline of OPS. It provides visible and near-infrared band high resolution ground image of more than 10km square for each scene. Panchromatic band data makes a high resolution image though the image is black and white. Multi-spectral bands data make several color images though GSD of the images is larger than panchromatic band image. And pan-sharpen images can be easily produced by those data which are taken at the same time and the same place.

### OPS Instruments Overview

Fig.12 shows overview of OPS. Telescope Optics is three-mirror anastigmatic telescope (TMA) and consists of a primary, a secondary, a tertiary and two folding mirrors. The primary mirror is made of New Technology silicon Carbide (NTSIC) \(^6)^7\). One of the folding mirrors is mounted on the linear drive mechanism for focus adjustment which can be used in ground test as well as in orbit re-focusing. The temperatures of each mirror and telescope structure are active-controlled by heaters to maintain optical performance of optics. A halogen lamp calibration source is used for on board calibration. The halogen lamp has an advantage for its broad spectral emission from visible to near infrared, though it requires power consumption and heat dissipation of some tens of watts. The calibrating light is projected a part of the primary mirror though a small optics in order to irradiate focal plane. The change of the response of the every spectral channel, including the telescope and the detectors, can be monitored by this internal calibration sources though the mission life.

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation Method</td>
<td>Push-Bloom Scan</td>
</tr>
<tr>
<td>Observation Bands</td>
<td>Panchromatic Band</td>
</tr>
<tr>
<td></td>
<td>Multi-spectral : 6 Bands</td>
</tr>
<tr>
<td>Grand Sample Distance (GSD)</td>
<td>Panchromatic: &lt; 0.5m</td>
</tr>
<tr>
<td></td>
<td>Multi-spectral: &lt; 2.0m</td>
</tr>
<tr>
<td>Swath Width</td>
<td>&gt; 10km</td>
</tr>
</tbody>
</table>

Figure 11: Flexibility of Higher-reliability requirement by SpaceWire

Table 2: Performance and Characteristics
Silicon Carbide Mirror

New Technology Silicon Carbide (NTSIC) is employed for the Primary mirror of the telescope. The silicon carbide is believed to be the most suitable material for space applications because of the high specific stiffness and thermal stability which is characterized by the parameter of CTE (Coefficient of Thermal Expansion)/thermal conductivity. NTSIC is fabricated by reaction sintering and has two times higher tensile strength than other silicon carbide material without any pore. Since the bare NTSIC can be polished to be a good roughness of a few nano meters, it requires no additional coating such as CVD (Chemical Vapor Deposition) in visible nor infrared applications. Therefore the true monolithic uniform silicon carbide mirror is available by NTSIC. Fig.13 shows the NTSIC flight substrate for primary mirror. The ASNARO telescope is a first space application of the NTSIC mirror to demonstrate the advantage of its performance.

Image Quality Improvement

ASNARO has a compact optics and its Modulation Transfer Function (MTF) performance is limited by the aperture size of optics. In order to obtain best performance of optics itself, OPS employs optimized Charge Coupled Device (CCD) driving method to minimize the degradation of MTF. For Signal Noise Ratio (SNR) improvement, OPS employs high sensitive CCD with Time Delayed Integration (TDI) function to obtain enough SNR. As radiance from earth surface changes by conditions of season and latitude, number of TDI stages for each band is properly selected to keep the signal level within the dynamic range of the sensor and suitable for the radiance level of a observation point. Figure 14 shows simulation image with nominal SNR.

6. CONCLUSION

For ASNARO small earth observation satellite, NEC has been developing standard bus system and high-resolution optical imager.

By using various technologies such as standardizations, SpaceWire, 16QAM transmitter, NTSIC and new CCD, ASNARO system is expected to be a pioneer of next-generation, small, low cost and high-performance earth observation satellite.

Currently the development is going well. Manufacturing of flight model has already started. ASNARO satellite is scheduled to be launched in FY2011.

Acknowledgments

ASNARO Project has been executed by USEF and NEC under the entrustment of the NEDO, and under the direction of the METI. OPS is an integral part of the ASNARO mission. Its development is performed in cooperation with the engineering committee consisted of expert members from various organizations such as ISAS, universities and government institutions.

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References

1. Koichi Ijichi, Shoichiro Mihara, Masatsugu Akiyama, Keita Miyazaki, Toshiaki Ogawa,


