Conceptual design for On-demand small satellite for SAR mission

Kei-ichi Hirako[1)], Shin-ichi Nakasuka[2)], Masahiro Koyama [2)], Ken-ichi Anma[3)],
Seiko Shirasaka[1)], Shinobu Nakamura [4)], Takeshi Tohara [4)]
1) Graduate School of System Design and Management, Keio University, Japan.
2) Intelligent Space System Laboratory, The University of Tokyo, Japan.
3) Mitsubishi Heavy Industries, Ltd, Japan.
4) Japan Science and Technology Agency, Japan.

Abstract: Synthetic aperture radar (SAR) is useful for observing the earth from space without restriction of the cloud. These SAR mainly apply frequency band such as L-band, S-band and X-band. A working group of JAXA studies possibility of X-band SAR which fits with a small satellite of 100kg class[1)]. And the X-band SAR program has been initiated and funded for 2015-2018 by Japanese government. This program is one of the ImPACT, " Impulsing Paradigm Change through Disruptive Technologies Program", and titled as "On-demand small satellite for SAR mission". This paper describes about initial concept of bus system of small satellite for X-band SAR mission.
Key Words: Small Satellite, X-band, SAR, ImPACT

1. Introduction

There are many users of earth observation image data from space with optical sensor and synthetic aperture radar (SAR). Generally S-band, L-band and X-band are applied to SAR, and weight of these satellites is up to few thousands kilo-grams, and small one is around three hundreds kilo-grams. In Japan, a researcher of JAXA began to study X-band micro SAR which fits with small satellite of 100kg class[1)]. In case of disaster such as flood, earthquake and eruption of volcano, on-demand rapid observation of the damaged area with optical sensor or RF sensor which generally means SAR sensor is useful to direct recovery activity. This action is important to assure civilian safety. Based on above back ground, some researchers applied to a government's program named "ImPACT", Impulsing Paradigm Change through Disruptive Technologies Program, which is one of the activity of Science and Technology Policy of Japanese Government and has been selected. A theme applied to above program is "On-demand small satellite with X-band SAR mission", and has three projects.

(1) X-band SAR System Project to study and evaluate mission performance with flight equivalent system.
(2) Bus System Project to evaluate the performance of bus equipment having strong relation with SAR mission and conceptual system design.
(3) Integrated System Project to study relation between the launch site, observing area and data down link station. And also feasibility study of model-based system design approach.

Conceptual design of the small satellite bus system with SAR mission has been started by Keio University, The University of Tokyo, Mitsubishi Heavy Industries Ltd. and Japan Science and Technology Agency. Mission of this satellite is compact X-band SAR with deployable panel antenna. This paper reports conceptual design status of the small satellite.

2. Compact X-band SAR System

Synthetic Aperture Radar (SAR) is a generally known remote sensing technique with reliable capabilities that offer advantages over an optical sensor with cloud. However, SAR sensors require relatively large antennas with several meters and high RF power of hundreds watts or more. Up to now, only large or medium size satellites with hundreds kilo-grams or more can afford SAR sensors. These large or medium satellites cost hundreds million US dollars including launching cost. SAR system for this satellite has been studied by few researchers[1,3,5)]. Before describing the design policy of the satellite system in following section, over view of the SAR System with deployable antenna panels is introduced. Fig. 1 shows rough image of the satellite. SAR antenna is constructed with six deployable panels and one fixed panel on the satellite center body. Many feeder waveguides and radiating slots are allocated in the SAR Panel as indicated in Fig. 2. In order to evaluate structural feasibility, one layer honeycomb panel slot array antenna with 1/1 scale, which size is 70cm x 70cm x 6cm was manufactured.

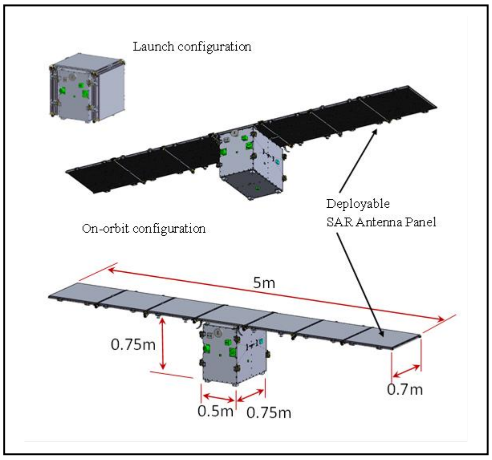

Fig. 2.1. Overview of small satellite with X-band SAR

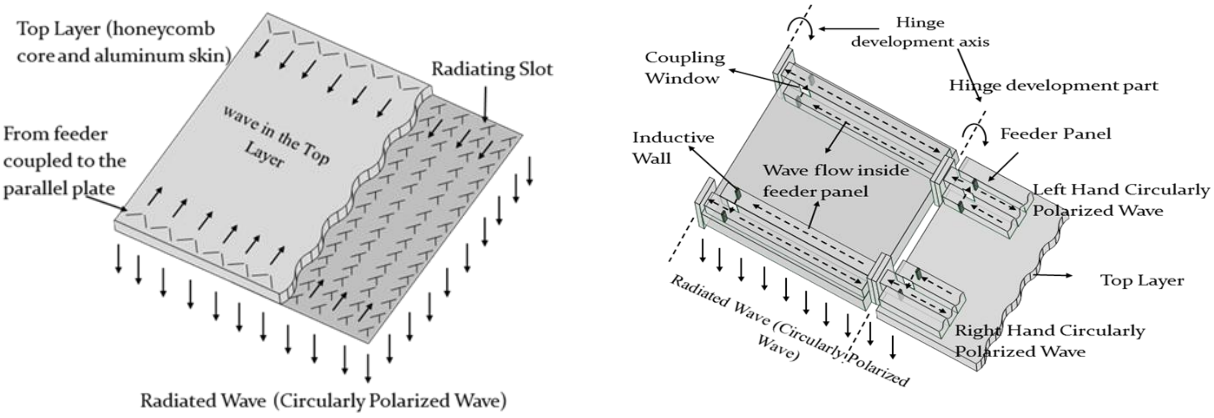

Fig.2.2. (a) Antenna panel from feeder side. (b) Antenna panel without feeders

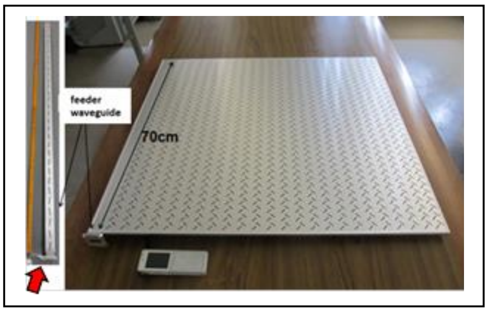

Fig.2.3. Structure model

Table 2.1.Performance of SAR System for Ground Resolution 3m &10m

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Parameter	3m resolution	10m resolution
Frequency (GHz)	9.65	9.65
Altitude (km)	618	618
Off Nadir (degrees)	21	21
Pulse Bandwidth (MHz)	127	38
σ°NE(dB)	-15	-20
Resolution (m)	3	10
Swath Width (km)	28.55	28.55
Antenna Size (m)	4.6x0.7	4.6x0.7
Peak Power (W)	581	592
Transmit Duty Cycle	0.29	0.278
System Noise Temperature (K)	589	589
Noise Figure (dB)	4.8	4.8
System Loss (dB)	4.5	4.5
Antenna Efficiency	0.6	0.6

Fig. 2.3. shows a structural model including feeder waveguide inside. Right picture is a honeycomb panel slot array antenna. Left picture is a feeder waveguide before installed in the panel. There are periodic coupling slots at bottom wall[3,5)].

When this small SAR satellite is injected to typical earth observation orbit with 500-600km altitude, its ground resolution is expected to be 3-10m that is useful for earth observation and monitoring. Evaluation of the performance is shown in table 1.If this satellite is injected to a low earth orbit with Table 2.1. Performance of SAR System with 300km altitude, the ground resolution can be for Ground Resolution 3m &10m 1m, however life time of the satellite will be very short because of large air drug caused by big SAR antenna panel. Detail description about compact X-band SAR System for small satellite of 100kg class is presented in the referenced paper by Prof. Hirobumi Saito et al[1,3,5)].

3. Small Satellite System

In the Bus System Project, conceptual system design has been initiated to realize above compact X-band SAR mission. As for system design, following design conditions are supposed.

- Assumed altitude of a technology demonstration satellite is 500km.
- The mission life is 6 months.
- Candidate of launch vehicle is Epsilon rocket of JAXA.

Generally SAR system requires high power and thermal control of mission equipment. The power amplifier of this SAR system consumes more than 1300W which is extremely high power for small or micro satellite of 100kg class. Also, in order to develop with low cost and short period, COTS based electrical parts are applied, and simple management approach will be introduced like as Small Demonstration Satellite (SDS) [2)]. System survivability is important for users to operate the satellite effectively, which design policy is took over the philosophy of "HODOYOSHI"-satellites and "SDS" satellites.

Main requirement from user is to observe a requested ground or ocean area with the SAR and down link the SAR data to the ground within short period[4)]. Considering above requirement and condition, significant system design problem and policy are defined as follows.

- To manage high temperature of the amplifier of SAR including cooling method.
- To avoid thermal distortion of SAR antenna panel during eclipse.
- To achieve autonomous function in order to observe designated point and down link the data within short time after separation from launch vehicle.
- To develop with low cost and short period, COTS part is usable. However any evaluation is necessary for critical parts for space environment.

- The reliability is not defined because of COTS parts or equipment are applied.
- To obtain survivability, function redundancy is considered using single system with permitting degradation of performance.

Even if the satellite is constructed with COTS base parts or equipment, it is important to obtain certain probability of mission assurance for on-demand requirement. Equipment of satellite bus is selected from units having flight heritage such as “HODOYOSHI”, “SDS” and other micro satellites. Estimated mass of the small satellite with compact X-band SAR weights around 120kg. Fig. 3.1. shows current arrangement of equipment inside of the satellite.

Definition of the axis is indicated in Fig. 3.2. In the cruising mode during day time, satellite takes sun pointing attitude, orientating body Z axis towards the sun. During eclipse, satellite orients Z axis to the earth in order to obtain infrared heat energy from the earth and prevents thermal distortion of SAR antenna panel. Therefore, attitude maneuver is necessary between night time and day time.

Concept of operation of this satellite is as follows.

(1) Separation from launch vehicle.
(2) Reduction of tip off rate with cold gas jet followed by deployment of SAR antenna.
(3) Attitude maneuver to orient the SAR antenna toward targeted point or area.
(4) Monitoring with SAR and store great amount of data into on-board data recorder.
(5) Cruising with sun pointing until data down link contact with ground station.
(6) Attitude maneuver to look at ground station within X-Band antenna FOV[4].
(7) Down load SAR data to ground.
(8) Attitude maneuver to orient toward the sun.
(9) Attitude maneuver to orient toward the earth when satellite comes into night time.

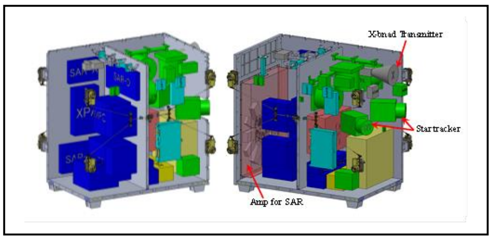

Fig. 3.1. Equipment arrangement inside of the satellite

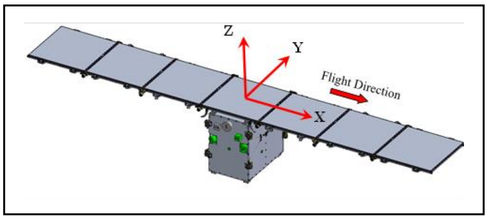

Fig. 3.2. Definition of body coordinate

Cold gas jet will be applied considering a standby situation of the satellite for ”On-demand” request. In order to fine attitude determination, two star trackers (STT) are onboard. Therefore, it constructs functional redundant system against one STT failure and sun or earth interference Fig. 3.2. permitting degradation of performance. Few on-orbit campaign of “On-demand operation” will be planned during mission period of 6 months. Number of the campaign is defined based on quantity of fuel for cold gas jet.

4. Conclusions

System design of Compact X-band SAR mission has been initiated, and typical technical risks are recognized. Basic system configuration and operational sequence is defined followed by detail design which makes it possible to develop hardware in the future.

Acknowledgments

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