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The Development Status of the First Demonstration Satellite of Our Commercial Small Synthetic Aperture Radar Satellite Constellation

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ABSTRACT

Expectations for SAR (Synthetic Aperture Radar) satellites that can observe a target area through clouds and during nighttime are emerging, especially in Asia where high cloud cover rate prevent from the satellite monitoring with optical sensors. We are now developing a small SAR satellite based on technologies of ImPACT (Impulsing PAradigm Change through disruptive Technologies) program. This program aims to develop a responsive earth observation system with the small SAR satellite, originally target for disaster monitoring. We will build a constellation of the small SAR satellites to realize short term revisits, shorter than one day to take advantage of SAR sensor that can acquire data regardless of weather and time in a day. We expect the constellation expands needs of the SAR data to business and private decision making, and develop a market for commercial use. We have almost completed the development of mission FM components of the first demo satellite. The bus system is under EM testing and FM procurements. We will launch the first demo satellite in Q1 of 2020. We are already preparing to build the second satellite and will make six satellite constellation until 2021. Our final goal is to build a constellation of 25 satellites.

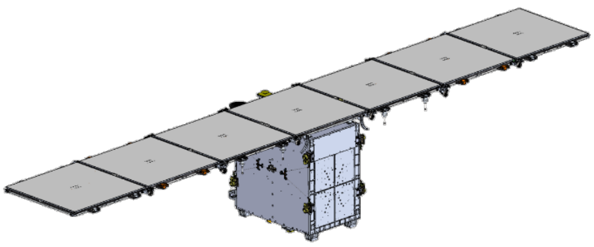
INTRODUCTION

Expectations for SAR (Synthetic Aperture Radar) satellite that can observe a target area through clouds and during nighttime are emerging, especially in Asia where high cloud cover rate prevent from the satellite monitoring with optical sensors. However, because the SAR data is expensive and the number of SAR satellites is limited, main users of the SAR data are governments and agencies. So, the SAR data market is still limited. In recent years, the development of small SAR satellites aimed at commercial use in the private sector has been active. Moreover, they are trying to improve revisit time and increasing the amount of SAR data by building a constellation of them. Therefore, offering a low cost, high frequency, and a large amount of SAR data is getting more feasible, especially for users who have not use the SAR data.

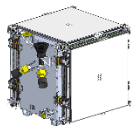
We are now developing the small SAR satellite in collaboration of ImPACT (Impulsing PAradigm Change through disruptive Technologies) program. The ImPACT is a Japanese government's high-risk and high-impact research and development program that aims to bring industry and society revolutionary changes by innovative science and technology such as cyber, chemistry, material and robotics with big funding. 16 programs have been selected and our responsive observation satellite program is one of them.

In the ImPACT program, development of the mission system was carried out. The items developed within the ImPACT program are a SAR Antenna, a Power Amp, a SAR Electronics, a Data Recorder, a Data Transmitter and so on.1),2)

We also developed technologies for the bus system in the ImPACT program, related to the EPS (Electrical Power Subsystem), which are unique ones to the SAR mission. We have developed a Power Control & Destruction Unit and a Battery to realize 700 W class power generation and 1.6kW peak power consumption



(a) On-orbit Configuration



(b) Launch Configuration

Figure. 1. Satellite Configurations

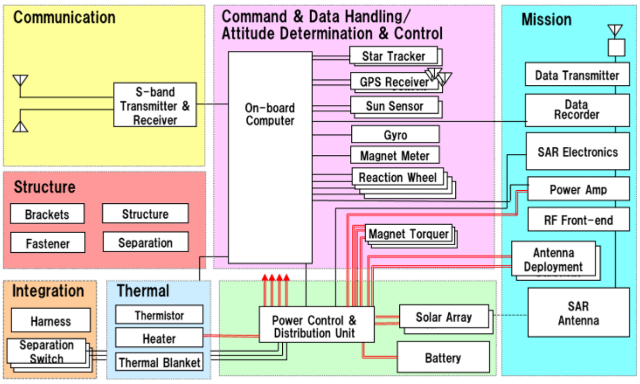


Figure. 2. Block Diagram

in a 100kg class satellite, which has usually 100 W class power generation and power consumption.

A whole satellite development began in April 2018, as we have successfully gained private funding to procure and develop the rest of satellite components and procure its launcher.

THE DESIGN OF THE SMALL SAR SATELLITE

Key Issue on Design

One of the key functions is a deployable planar SAR antenna. Unlike the conventional active phased array antenna or the parabola antenna, it can be compactly stored in a simple configuration. Thin film solar cells are mounted on the back side of the antenna to generate high power that is necessary for small SAR satellites.

Figure 1 shows the on-orbit configuration and the launch configuration of our satellite.

When we build the satellite constellation for commercial use, satellite mass reduction is important to reduce launch cost and to maximize the number of satellites in a single launcher. We have to realize unique key functions for the SAR satellites in a 100kg class small satellite. Those required functions are usual for SAR satellites that weigh 300kg to 1 ton, however, it is a challenge to realize them in the 140kg small satellite.

Since the satellite consumes peak power of 1.6 kW during SAR observation, it has a battery with large capacity and capable outputting large current. In order to charge the large battery in a short period of time to enable frequent observation, it has solar cells with 700 W power generation. We mount the solar cells on the back side of the large SAR Antenna.

Block Diagram

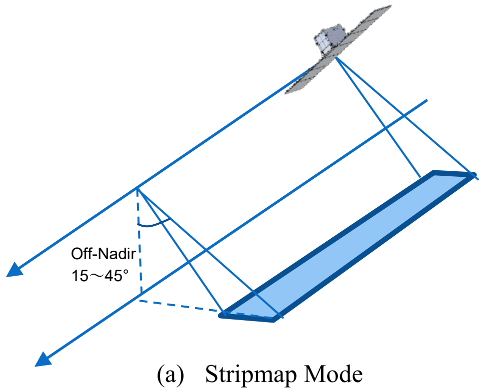
A block diagram is shown in Figure. 2. The development speed and fewer risks to achieve it is important for commercial use, so we selected our heritage components from Hodoyoshi satellites3) as much as we can.

Attitude and Orbit Determination and Control

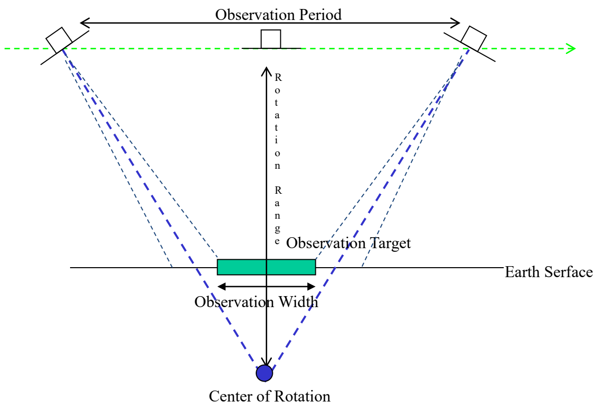
For attitude control, there are two Star Trackers (STT), four Reaction Wheels (RW) and a Gyro (FOG). The reason for having two STTs is that attitude determination accuracy is necessary for SAR observation. The reason why four RWs are needed is that angular velocity is required to change the attitude before, after and during the observation. Because the antenna for SAR observation is large, the inertial moment of the satellite is larger than that of a normal small satellite, and the angular momentum of RW needs to be large.

An orbit determination accuracy is also important for observation. Therefore, two different GPS Receivers (GPSR) are also mounted. One is a device that has been used in the past project and is capable of highly accurate orbit determination, and one is an affordable device. We will use them on the same satellite and determine which one is adequate for the future GPSR by comparing the accuracy of the two.

The accuracy of estimated satellite time is also important. If the observation timing is only 10ms off, it will result in a positioning error of about 80 m. The satellite has a new function to estimate the time accurately and synchronize it with the time of the SAR Electronics based on the time obtained from GPSR.



(a) Stripmap Mode



(b) Sliding Spotlight Mode

Figure 3. Observation Modes

Operation

After the separation of the satellite, the antenna is automatically deployed and the satellite is directed to the sun to enable power generation with the solar cell.

The reference attitude during normal operation is a sun pointing. The satellite changes the attitude for the observation to point the antenna to the target.

There are two observation modes (Figure. 3), a stripmap mode and a sliding spotlight mode. Both of them requires high rate attitude pointing with high accuracy.

Basically, it is a single strip system, however, because of high attitude control ability requirements in a SAR mission, it has two Star Trackers and four Reaction Wheels.

In the event of an abnormality, all but the minimum required components are turned off as safety, and the satellite point to the sun. The satellite can achieve the sun pointing in a short time and robustly using STTs, GYRO, and RWs, which they are redundant. Even if the sun pointing with those components is not achieved during a certain period of time, we prepared a second phase of the sun pointing where the satellite use Magnet Torquer (MTQ) and Magnet Sensor (MAGS) to achieve the sun pointing.

Autonomous operation is important for achieving complicated observation operations with the constellation of multiple satellites. It is also important to realize the mission while coping with off-nominal conditions. In order to realize these, we developed autonomous operation functions using state transition models and successfully demonstrated on-orbit using CubeSat in February 2018.4)

Constellation Orbit

The orbit selection of multi-satellite constellations is important for commercial use. Since the first few satellites are demonstration ones, they will be launched as one of piggybacks. Therefore, their orbit will be mainly the sun-synchronous orbit. The first demonstration satellite will be launched into the Dawn-Dusk orbit. This orbit becomes a characteristic orbit as a radar satellite because it enables us imaging a time zone which can't be observed by normal optical satellites since the local sun time becomes 6:00 or 18:00.

In the future, we will launch our satellite into a 60 ° inclination orbit using dedicated rockets. This is because our potential customers are interested in frequent monitoring of the big cities in Japan and Asia. Therefore, it is the optimal orbit that can maximize revisit while covering Japan and Asia.

Ground System

The development of a ground system is also important for the observation satellites constellation for commercial use. Especially the needs of the ground system are not fixed from the beginning. Every time a new satellite is launched into orbit, every time a satellite's performance becomes clear and every time we acquire a new customer, the needs for the ground system are added. As such, the ground system should be extensible and modifiable.

We build the satellite's ground system on the cloud services to achieve the extensibility and modifiability.

In addition, we think that the freshness of the observed date is important, so the data downlink ground stations overseas are important so that the satellite can downlink the observation data over Japan and Asia in a short time without waiting the satellite come again over Japan ground stations.

As it is a high-performance earth observation satellite, it is also important to obey the remote sensing act. We apply certain security measures such as encryption for observation commands and downlinked data.

DEVELOPMENT STATUS

Figure 4 shows the test configurations we have conducted until April 2019. We have almost completed the development of mission components FM (SAR antenna, SAR Electronics, Power Amp, Data Transmitter and Data Reorder) for the first demo satellite during the ImPACT program. The bus system is under EM phase testing and FM procurements. After an interface verification of the mission system and the bus system, we will conduct assembly, integration, and test of satellite FM.

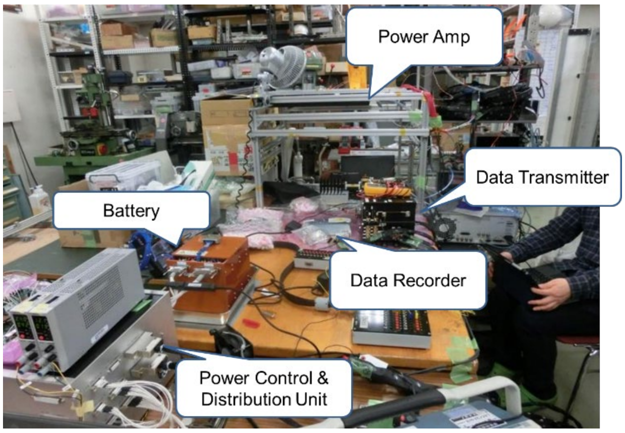
One of the biggest issues in verifying the system functions is the power interfaces associated with the high power required by the SAR. We confirmed them between the Power Control & Distribution Unit and other SAR mission specific components like the Power Amp, SAR Electronics, the Data Transmitter and the Data Recorder at an early stage.

The other issue is the dissipated heat during the observation operation. A thermal vacuum test was conducted to verify the thermal mathematical model of the satellite structure. In March, we conducted the FlatSat, the electrical interface tests where all the components were on the table and connected via harnesses to confirm electrical interfaces, power interfaces, and operation procedures. In April, we conducted through electrical tests with all the components mounted on the satellite structure and confirmed that issues in the design and the manufacturing. We also conducted those test under temperature conditions to confirm all the functions and the interfaces work correctly under high temperature and low-temperature conditions.

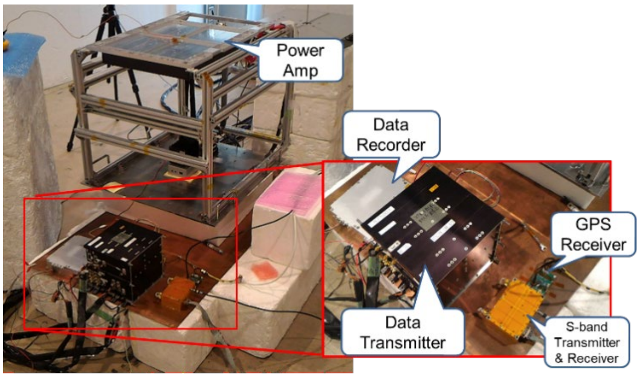
After those tests, we will make some modifications to fix issues founded during the tests. The first integration for the Initial Electrical Test for Flight Model will start in May.

We use the ISAS (Institute of Space and Astronautical Science) facility for the first demonstration satellite development and the testing under the collaboration agreement with JAXA.

We will develop the first demonstration satellite until the end of 2019 and will launch it in Q1 2020 (Figure.5).

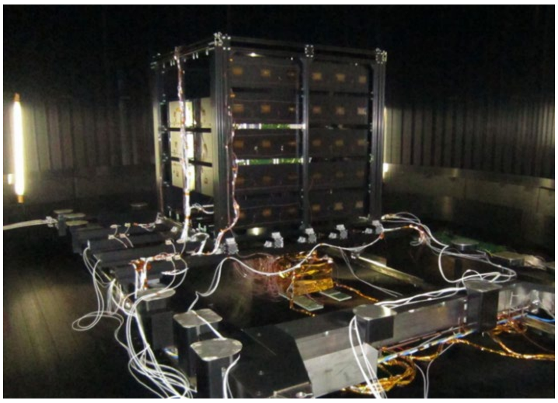


(a) Power Interface Test



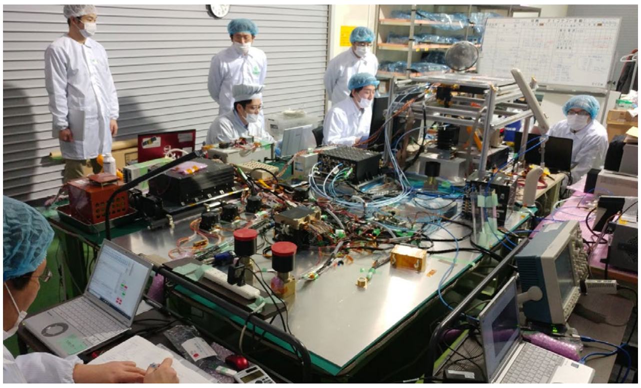
(b) Electromagnetic Interference Test

(c) Structural Vibration Test

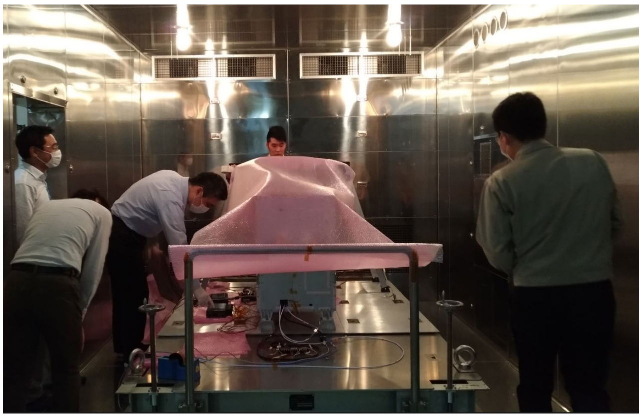


(d) Thermal Balance Test

Figure. 4. Test Configurations (1/2)



(e) FlatSat Test



(f) Thermal Cycle Test

Figure. 4. Test Configurations (2/2)

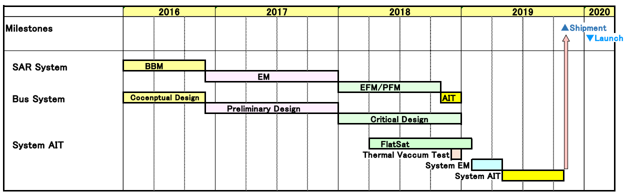


Figure. 5. Development Schedule

CONCLUSION

We are developing the small SAR satellite and will deploy a lot of them on orbit to enable frequent and persistent observations. We expect the constellation expands needs of the SAR data to business and its data is used to solve social problems symbolized by SDGs (Sustainable Development Goals).

We will launch the first demo satellite at Q1 of 2020. We are already preparing to build the second satellite and will make six satellite constellation until 2021. The first two satellites are demonstration satellite and the third satellite will be designed and developed as a mass-production model. Our final goal is to build a constellation of 25 satellites that enable daily or shorter revisits at some specific targets especially in Japan and Asian area.

Acknowledgments

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