L BAND CIRCULARLY POLARIZED SAR ONBOARD MICROSATELLITE

Josaphat Tetuko Sri Sumantyo[1], Nobuyoshi Imura[1], Shunsuke Onishi[2], Tetsuo Yasaka[2], Robertus Heru Triharjanto[3], Koichi Ito[1], Steven Gao[4], Kazuteru Namba[1], Katsumi Hattori[1], Fumio Yamazaki[1], Chiharu Hongo[1], Akira Kato[1], Daniele Perissin[5]

[1] Chiba University, [2] Institute for Q-shu Pioneers of Space, [3] Indonesian National Institute of Aeronautics and Space, [4] University of Kent, [5] Purdue University

ABSTRACT

Center for Environmental Remote Sensing, Chiba University develops L Band circularly polarized synthetic aperture radar (SAR) sensor for microsatellite (150 kg class). This paper explains the project, specification, antenna deployment, RF system, and experiment of circularly polarized SAR in anechoic chamber. In the future, this sensor will be employed to monitor global land deformation.

Index Terms— Synthetic Aperture Radar, Circularly Polarized SAR, Microsatellite

1. INTRODUCTION

Synthetic Aperture Radar (SAR) is well-known as a multi-purpose sensor that can be operated in all-weather and day-night time. As our laboratory roadmap for microsatellite, aircraft, and unmanned aerial vehicle development (refer Fig. 1), our laboratory develops SAR, especially Circularly Polarized Synthetic Aperture Radar or Elliptically Polarized Synthetic Aperture Radar (Patent Pending 2014-214905) to monitor global land deformation. The sensor is designed to transmit and receive left-handed circular polarization (LHCP) and right-handed circular polarization (RHCP). The main mission of circularly polarized SAR is to hold the basic research on elliptically polarized scattering and its application developments [1].

The circular polarization's mission has benefit, as circular polarization performs better than the HH polarization at lower incidence angle [2]. Circular polarization exhibits multiple benefits over linear polarization including avoiding polarization losses due to TX and RX antenna misalignment, where it also has the ability to reduce interference between direct and reflected signal due to multipath propagation [3]-[4].

Fig.2 shows concept of circularly polarized SAR, where circularly polarized SAR transmits only one polarization (RHCP or LCHP), then this sensor will receive RHCP and LHCP scattering waves simultaneously, as shown on Fig.2(a). Fig.2(b) shows when we transmit RHCP in L Band (1.275 GHz) with axial ratio (AR) of incident wave is 0 dB.

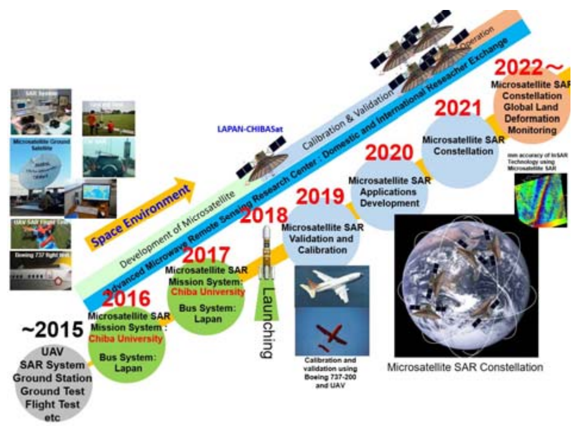

Fig.1. Roadmap of Chiba University Microsatellite

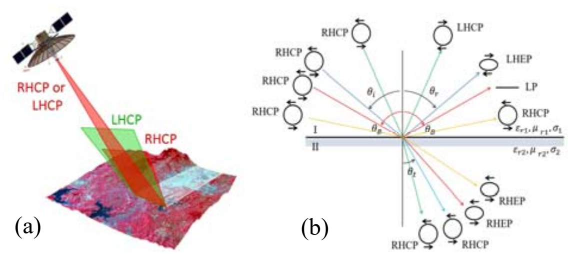

Fig.2. Scattering polarization of circularly polarized wave

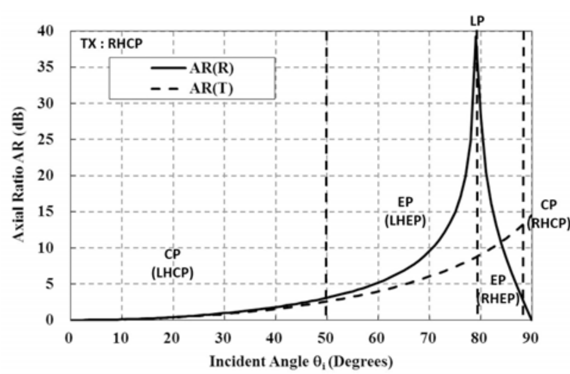

Fig.3. Axial ratio of circularly polarized scattering

In Fig.2(b), at incident angle θ_i closes to 0°, sense of wave change to opposite sense or change to be cross polarized wave, and the axial ratio of scattered wave closes to 0 dB or closes to circular polarization. But at incident angle θ_i is larger than 50°, as shown on Fig. 3, the axial ratio is larger than 3 dB, polarization of scattered wave is elliptical polarization (EP) at incident angle $50° < \theta_i < \theta_B$, where θ_B is Brewster's angle. Axial ratio is largest at $\theta_i = \theta_B$, it means elliptical and linear polarization (LP), where only perpendicular wave scatters and linear polarization with perpendicular direction remains after scattering. At $\theta_i > \theta_B$, scattering wave closes parallel to scattered plane, axial ratio decreases to be circular polarization. In this case, rotation direction or polarization of scattered wave is same to polarization of incident wave or main wave.

The transmission or penetrated wave has same polarization as incident wave with axial ratio less than 3 dB at incident angle of less than 50° as shown on Fig. 3. Based on these result, design of our circularly polarized SAR must be efficient on power consumption and keep stable axial ratio for circular polarization, where we must employ low nadir angle (less than 50°) to reduce the transmitting power, particularly on mission of low frequency as L band.

2. STRUCTURE OF MICROSATELLITE

2.1. Structure of Microsatellite

Fig. 4 shows structure of circularly polarized SAR onboard microsatellite. Cruising direction is X axis (roll), Earth pointing direction is Z axis (yaw), and pitch direction is Y axis. As shown on Fig.4, this antenna is composed by 24 ribs to fix mesh sheet with parabolic shape, where mesh grid is 1mm. Flatness of the mesh surface is 0.5mm~0.8mm (RMS). Interface of each module employs 12V and 24V of power interface. Communication between SAR mission unit and satellite bus uses RS422 and TCP/IP. Communication between sensor, actuator, and other control devices uses I2C.

Payload of circularly polarized SAR sensor is 53.9kg, and satellite bus system is 64.8kg, totally 118,7kg, therefore the microsatellite is 150kg class of satellite. Power consumption during the microsatellite is whole system on mode, rough control mode, high accuracy control mode, communication to ground mode, and SAR observation mode is 705W, 37W, 58W, 88W and 658W respectively.

The orbit is sun synchronize with altitude about 550 km with inclination 97.6°. Based on power budget calculation in each season, every five rotations of the Earth, SAR sensor could be operated 0.25 minutes of Earth observation mode (800W~1400W), and 10 minutes of SAR sensor adjustment mode (120W). Every eight rotations of the Earth, microsatellite could have communication with ground station in maxiumum 15 minutes (120W), and adjustment mode (90W). In normal mode, microsatellite consumes 90W. For this purpose, we employ Nickel–metal hydride (NiMH) battery (8kg).

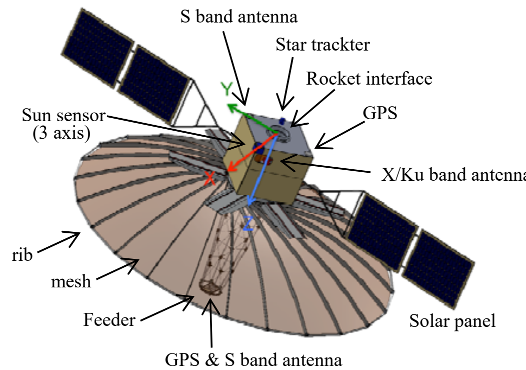

Fig. 4. Stucture of microsatellite

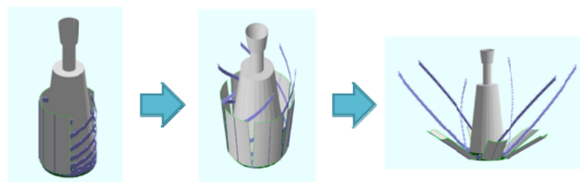
Fig.5. Microsatellite and deployment of antenna

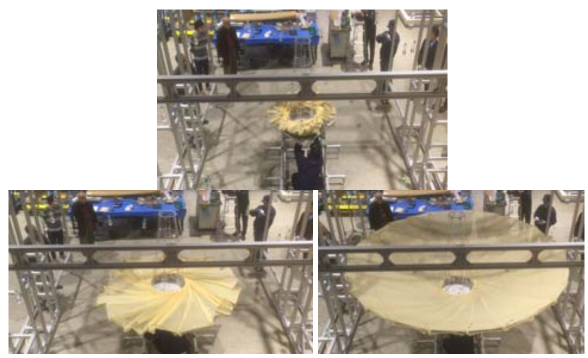
Fig.6. Antenna deployment test in our laboratory

2.2. Reflector of L Band Mesh Antenna

As shown on Fig.5, main antenna of circularly polarized SAR onboard microsatellite is proposed by Wrap-Rib type, where parabolic antenna employs gold coated mesh spreads on ribs with diameter and depth of antenna is 3600mm and 650mm respectively. Size of deployed antenna is diameter 3600mm × height 1450mm, and weight 15kg. The deployment mechanism is shown in Fig. 5, and deployment test in our laboratory has been done as shown in Fig.6. Envelope of microsatellite when launching is 800mm × 800mm × 1450mm.

2.3. Attitude Control

Accuracy target of attitude control is less than 0.1° using three axis attitude control. We employ sun sensor, magnetic field sensor, Earth sensor or horizon sensor, Micro Electro-Mechanical System (MEMS), Fiber Optics Gyro (FOG) or

Ring Laser Gyro, and star tracker to collect the attitude data with accuracy about $\pm 2^{o}$.

We employ active magnetic torquer and reaction wheel. Active magnetic torque is used for rough controller and unloading reaction wheel. Magnetic torque has characteristic to obtain local direction of magnetic line and horizon, but magnetic line around Earth has large curve at high latitude, therefore it could control three dimension. High accuracy control with attitude accuracy 0.1^{o} is realized by using Quaternion. Rough accuracy controller with attitude accuracy $\pm 2^{o}$ using magnetic torque by employing Bang-Bang controller or Pulse-Width Modulation (PWM).

2.4. Position of Instruments

As shown on Fig.4, satellite has four solar panel paddles with each size is 620mm×700mm that designed for sun synchronize orbit with altitude 549.6km and local time 10:00 AM. Earth pointing direction is +Z and cruising direction is +X. –X and +Y planes always on shadow plane as radiating surface. X or Ku band antenna is installed on +X direction. Sun sensor is installed at five direction, except +Z direction where the SAR antenna is located. GPS and S band antenna is installed at –Z and +Z direction with width received area. Star tracker is installed at –X and –Z direction for continuous observation. Fig.7 shows position of each module of microsatellite.

2.5. Electronics of SAR System

Fig.8 shows electronic system of SAR sensor that composed by SAR Transmitter (TX) Unit, SAR Receiver (RX) Unit, SAR Signal Generator Unit, SAR Controller Unit, and Power Supply Unit. Center frequency of SAR system is 1.275GHz and maximum bandwith 35MHz. Maximum output peak power is 1400W. I/Q of RX has 14bit and memory 4GB. Fig.9 shows two microstrip antenna as feeder of parabolic antenna.

3. EXPERIMENT IN ANECHOIC CHAMBER

The investigation of scattering of linear polarization and circular polarization has been done in this research by using N219 aircraft model and employing inverse SAR (ISAR) technique in our anechoic chamber. The objective of this research is to simulate scattering wave by employing Circularly Polarized SAR. We studied the scattering with various modes, e.g. HH, VH, VV, and HV modes for linear polarization (LP mode). The circular polarization (CP mode) considered RR, RL, LR, and LL modes.

Fig.10(a) shows that linear polarization depicts co-polarization (HH and VV modes) has strong scattering, but cross polarization (HV and VH modes) has weak scattering. Cross polarization shows volume scattering, and co-polarization shows surface scattering and double bounce. This figure shows that linear polarization has weak scattering by cross polarization or volume scattering,

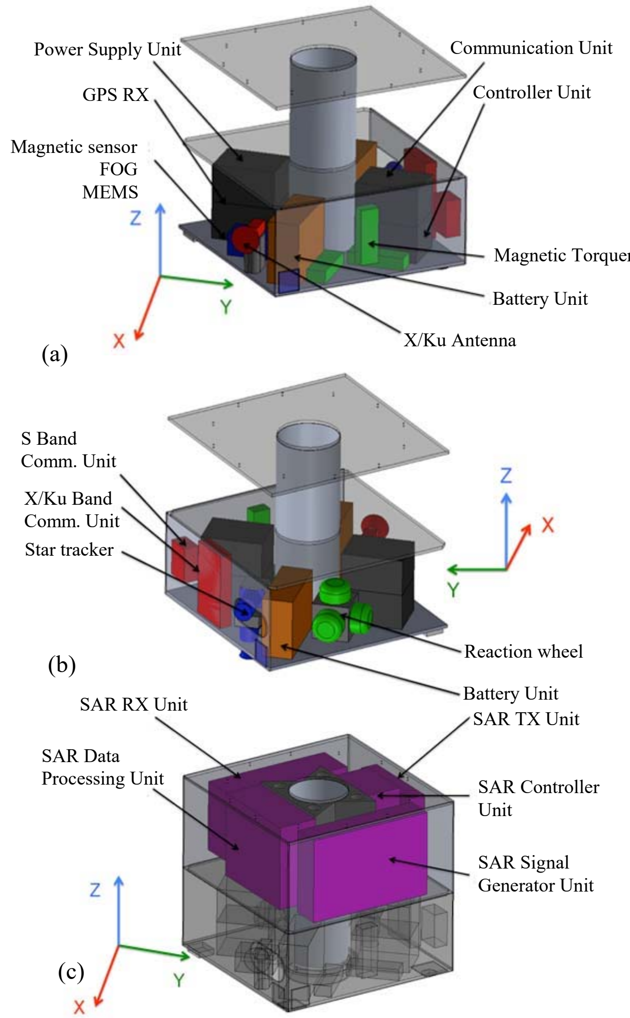

Fig.7. Position of each module of microsatellite

Fig.8. Electronic system of SAR sensor

especially scattering by main body of object. The co-polarization or surface scattering and double bounce shows strong intensity of scattering from main body, main wing, nose, tail, and propeller.

Fig.10(b) shows circular polarization has strong scattering from the main body of model on both co-polarization (LL and RR) and cross-polarization (LR and RL), but different scattering from tail. Co-polarization shows even-scattering (double bounce) and cross-polarization shows odd-scattering (surface scattering). It means the circular polarization could avoid the effect of antenna misalignment and orientation angle of the antenna when installed on the side body of platform (UAV and aircraft), especially Circularly Polarized SAR could reduce the effect of air drag and platform's attitude during the observation using UAV as main discussion in this paper.

Fig.11 shows images of ellipticity and axial ratio of circular polarized scattering of N210 aircraft model from Fig.10(b). The ellipticity ε (unit : radian) in Fig.11(a) is calculated by using intensity of LHCP and RHCP of scattering wave (EL and ER). Zero radian of ellipticity means linear polarization (LP), positive value (0 ~ 0.25π) means LHCP, and negative value (-0.25π ~ 0) means RHCP. Fig.11(a) shows that LHCP scattering wave scattered from tail wing and propellers. The main body scattered RHCP wave. We can use this information to classify the structure of targeted object as shown in this result.

Fig.11(b) shows axial ratio (AR) image with input of ellipticity ε shown in Fig.11(a). Zero value of ε means perfectly circular polarization (CP). We define elliptical polarization (EP) for ellipticity from 0 to 20 dB, and linear polarization (LP) for ellipticity with value more than 20 dB. This figure shows various value of elliptical polarization of scattering wave from some parts of model, where main body has low value and tail has high scattering close to linear polarization. This result shows the axial ratio and ellipticity could be employed to classify the object characteristics, i.e. shape, roughness, thickness, height etc by using Circular Polarized SAR.

5. SUMMARY

Chiba University develops L Band circularly polarized SAR sensor for microsatellite (150 kg class). This paper explains the project, specification, antenna deployment, and RF system of circularly polarized SAR for microsatellite, and experiment of circularly polarized SAR in anechoic chamber.

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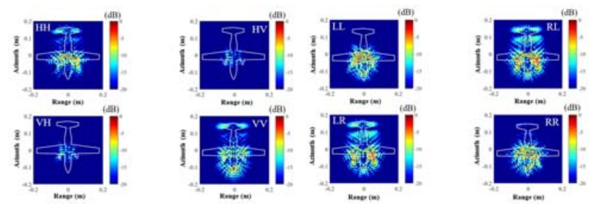
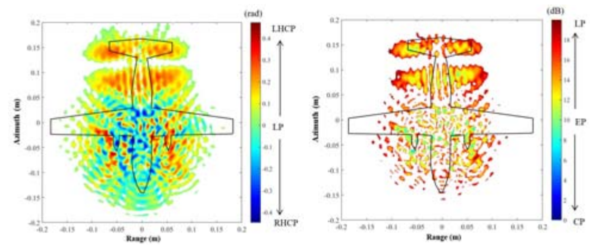
(a) Two microstrip antenna (b) Radome of feeder

Fig.9. Microstrip CP antenna as feeder of parabolic antenna



(a) Linear Polarization (b) Circular Polarization

Fig.10. Scattering of linear and circular polarizations



(a) Ellipticity image (b) Axial ratio image

Fig.11. Axial ratio and ellipticity images

REFERENCES

[1] J.T. Sri Sumantyo, V.C. Koo, T.S. Lim, T. Kawai, T. Ebinuma, Y. Izumi, M.Z. Baharuddin, S. Gao and K. Ito, "Development of circularly polarized synthetic aperture radar onboard UAV JX-1," Intern. Journ. Rem. Sens., July 2017 – Accepted (DOI : 10.1080/01431161.2016.1275057)

[2] S. Angelliaume, P. Martineau, Ph. Durand, Ph. Cussac, T., "Ship Detection and Sea Clutter Characterisation Using X&L-Band Full-Folarimetric Airborne SAR Data," Proc. the SeaSAR 2012, ESA-SP, 709, id.15, Tromsø, Norway, 18-22 June 2012.

[3] R. Touzi, J. Hurley, and P. W. Vachon, "Optimization of the Degree of Polarization for Enhanced Ship Detection Using Polarimetric RADARSAT-2." IEEE Trans. Geosci. Rem. Sens., 53, 10, 5403–5424, 2015.

[4] R. Touzi, and P. W. Vachon, "RCM Polarimetric SAR for Enhanced Ship Detection and Classification." Canadian Journ. Rem. Sens., 41, 5, 473–484, 2015.