Sumantyo, J.T. Sri, Tsushima, K., Katoh, R., Kobori, T., Sumantyo, F.D. Sri, Gao, Steven, Rahardjo, E.T., Wibisono, G., Sasmita, K., Mardianto, A. and others (2018) *Hinotori-X1 Mission: X Band Walr-Sar Onboard Boeing 737–200 Aircraft.* In: 2018 IEEE International Geoscience & Remote Sensing Symposium Proceedings. . pp. 6488-6491. IEEE ISBN 978-1-5386-7150-4.

HINOTORI-X1 MISSION : X BAND WALR-SAR ONBOARD BOEING 737-200 AIRCRAFT

J.T. Sri Sumantyo[1], *K. Tsushima*[1,2], *R. Katoh*[1,2], *T. Kobori*[1,2], *F.D. Sri Sumantyo*[3], *S. Gao*[4], *E.T. Rahardjo*[5], *G. Wibisono*[5], *K. Sasmita*[6], *A. Mardianto*[6], *P. Edi*[6], *and K. Ito*[1]

[1] Chiba University, [2] Japan Radio Company, [3] Universitas Bhayangkara Jakarta Raya, [4] University of Kent, [5] Universitas Indonesia, [6] Tentara Nasional Indonesia Angkatan Udara

ABSTRACT

We developed a novel concept for X-band (center frequency 9.4 GHz, HH polarization) airborne SAR, the Wide Area Long Range Synthetic Aperture Radar (WALR-SAR) onboard a Boeing 737-200 aircraft for simultaneous air and terrestrial disaster monitoring. This paper explains the configuration of our WALR-SAR system and slotted array antenna installed on the Boeing 737-200. Ground measurements of the slotted array antenna were realized to measure the characteristics of antenna and its results are discussed in this paper. Flight test of WALR-SAR onboard Boeing 737-200 in Hinotori-X1 (Firebird-X1) mission was performed during the period of 2 to 10 August 2017 at Pare-Pare and Makassar, Indonesia. Results show good performance of the WALR-SAR system and its image acquisition that covers the depression angle 0.5 to 42.0 degrees.

Index Terms— Hinotori-X1, WALR, SAR, Boeing 737-200, HH

1. INTRODUCTION

Recently, airborne SAR systems implemented for remote sensing applications present narrow beamwidth in the range direction [1], providing narrow ground coverage observation in the order of tens kilometers. These previous SAR systems could not observe disaster events on ground surface and air area simultaneously. Josaphat Microwave Remote Sensing Laboratory (JMRSL) at Center for Environmental Remote Sensing (CEReS), Chiba University, developed a novel X band Wide Area Long Range Synthetic Aperture Radar (WALR-SAR) system onboard a Boeing 737-200 aircraft capable of wide range beamwidth for simultaneous air and terrestrial disaster monitoring, i.e. volcanic eruption (lava and volcanic ash), hurricane (landslide and rain cloud), localized heavy rain or downpour (flood and rain cloud).

The WALR-SAR system operates at center frequency 9.4 GHz, 800 MHz of bandwidth, maximum transmitter (TX) output power (peak power) 100 Watts, about 100 kg of payload, horizontal polarization (HH : transmitter and receiver has same polarization). Our SAR system has been designed to operate at altitude of 10,668 m, and about 1 m resolution. This paper discusses the configuration of the SAR system and antenna, including ground and flight tests results of the SAR system, and acquired SAR images from Hinotori-X1 (Firebird-X1) flight campaign from 2 to 10 August 2017 at Pare-Pare and Makassar cities, Indonesia.

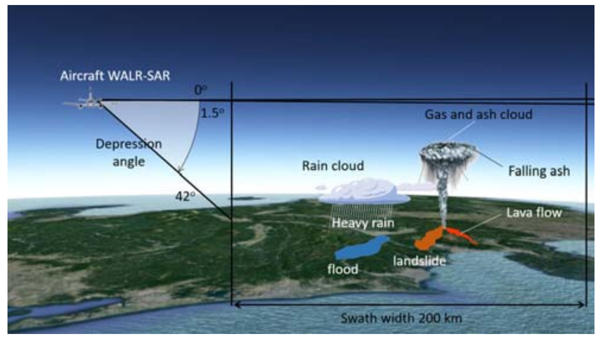


Figure 1. Proposed Wide Area Long Range Synthetic Aperture Radar (WALR-SAR)

2. MISSION

The main mission of the WALR-SAR is disaster and environmental monitoring and mitigation of wide areas, providing long range and high resolution data. In the current work, we investigate the Earth's surface from Hinotori-X1 platform, analyzing different scatterings from vegetation, snow, ice, soil etc, which aims for disaster and environmental monitoring, i.e. land cover mapping, disaster monitoring, cryosphere monitoring, oceanographic monitoring etc.

3. WALR-SAR

3.1. Concept

Figure 1 shows the concept of the WALR-SAR for simultaneous air and terrestrial disaster monitoring with wide range observation. The wide range beamwidth of the slotted array antenna for SAR system is installed on the body (left or right side) of the Boeing 737-200 to illuminate the air and terrestrial, or surface of the Earth by side looking configuration in stripmap observation mode. The transmitter (TX) and receiver (RX) has horizontal polarization (HH).

The Boeing 737-200 has length of 30.48 meters, body width 3.76 meters, wing span 28.35 meters, and SAR antenna height 5.64 meters from ground to the tail of aircraft. An antenna is mounted on each side of the aircraft's exterior to provide simultaneous detection and mapping from both sides of the aircraft. As the antennas scan left, right, or both sides of the aircraft flight path, a map of the target on air and ground surface is generated on the data processor. The signal path is as follows: an X band microwave signal is transmitted by the sensors, scattered by targets at the Earth's ground surface and above, backscattered to the receiver's antenna onboard the Boeing 737-200, and finally processed, using Range Doppler Algorithm (RDA) in order to obtain raw data as in-phase signal (I or real data) and quadrature signal (Q or imaginary data) as single look complex (SLC) image. The value of intensity, polarization and phase of scattered wave depends on structure, roughness, dielectric constant or physical characteristics of targeted material or object.

Figure 2 shows the structure and hardware system of WALR-SAR installed on the Boeing 737-200. Detailed specification and algorithms for SAR system is explained on author's chapter in [2]. The WALR-SAR system is composed by an arbitrary waveform generator (AWG) to generate chirp pulse and convert it to analog signal using digital to analog converter (DAC), transmitter (TX) unit to amplifying chirp pulse using gallium nitride (GaN) to peak power 100 watts (maximum TX output), slotted array antenna AS-1007 to transmit and receive the microwave pulses, receiver (RX) unit to receive scattering wave and amplifies it using low noise amplifier (LNA), finally, convert receives wave as raw data using analog to digital converter (ADC) using oscilloscope. SAR image processing of the raw data is performed by a dedicated computer. Local unit (oscillator) is used to generate 10 MHz signal to synchronize all subsystems. This figure shows WALR-SAR system installed onboard the Boeing 737-200.

The Boeing 737-200 is designed for operating with maximum altitude 10,668 m (35,000 feet), maximum cruising speed 906.53 km/h (0.74 Mach) or maximum ground speed 851.92 km/h. Figure 3 shows Boeing 737-200 that employed in Hinotori-X1 mission, and radome of WALR-SAR installed on tail side of aircraft. The slotted array antenna AS-1007 is employed in this mission that installed inside left side radome as shown on Figure 3, however right side radome also was installed other antenna AS-1008 with same specification for aircraft balance. The antenna has size height 0.38 meter, width 5.09 meters, depth 0.51 meter, and weight 83.92 kilograms. Both left and right antennas are functionally the same, consisting of two-

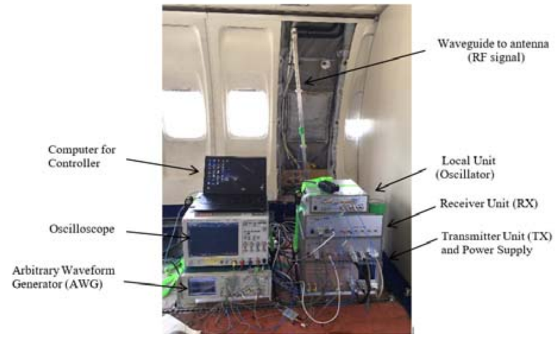


Figure 2. Structure and hardware system of WALR-SAR installed on the Boeing 737-200

Figure 3. WALR-SAR onboard Boeing 737-200 on Hinotori-X1 mission

dimensional linear array antennas, composed of sixteen slotted termination waveguides fed by a manifold at the forward end, and covered by a radome. Two identical radomes are constructed, and structure is composed of three layers of glass fabric laminated with plastic material bonded to an inner core of laminated glass and plastic honey comb material. An antenna feed waveguide assembly provides the RF energy path between the antenna and the antenna switching unit.

The antenna operates in horizontal polarisation (HH), with maximum gain (peak) 37 dBi, 3 dB beamwidth at azimuth 0.5 degrees. Beam peak depression angle at elevation angle is 0.5 degrees downward from normal azimuth plane to plane of array. Beam shaping is cosecant squared from depression angle of 0.5 degrees to 42.0 degrees below normal to the plane of array by adjusting the waveguide length of power divider to each slotted array antenna as shown on Figure 3.

3.2. Antenna Characteristics

The slotted array antenna is composed of 16 slots in vertical direction, and 200 slits in horizontal direction. Radiation pattern or far field of employed antenna was measured during 15-20 September 2016 at Hasanuddin airport, Indonesia. Far field measurements were realized using the same microwave spectrum analyzer (FieldFox, N9938A), and horn antenna with standard gain (ATM, PNR 90-442-6, frequency 8.20-12.4 GHz, gain 20 dB nominal). Figure 4(a) shows the map of measurement, where the Boeing 737-200 aircraft was positioned on the east area of taxi way of Hasanuddin airport. Microwave signals were then transmitted and its power measured at the receiver (RX) at 200 meters and 1,000 meters away.

Figure 4(b) shows the antenna radiation pattern at distance of 200 meters and 1,000 meters at center frequency of 9.4 GHz. Results show -3 dB beamwidth of our antenna is 0.5°. Our X band SAR system operates within frequency 9.0 to 9.8 GHz (center frequency 9.4 GHz). We also investigated the center beam direction as function of frequency change.

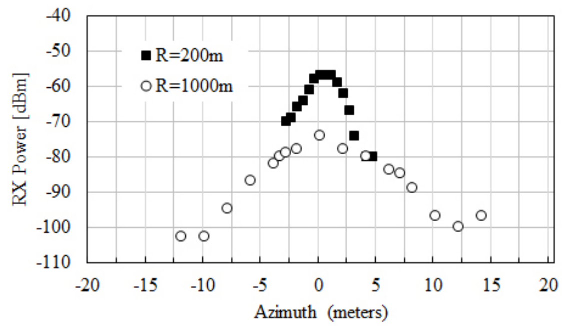
Figure 5 shows the signal processing test of our SAR system using corner reflectors (CR) on the period of 5-6 August 2017 at Hasanuddin Airport, Indonesia. Considering the beam tilting effect previously explained, we transmitted chirp pulses with bandwidth 30 MHz from TX in aircraft to CR that put at 500 and 550 meters from aircraft. This figure shows scattering wave that compressed in range direction and could processed scattering from both CR at 500 and 550 meters. Therefore this figure shows that proposed SAR system could work well.

4. FLIGHT TEST

Flight test of WALR-SAR Hinotori-X1 (Firebird-X1) mission onboard a Boeing 737-200 has been done on 7 and 9 August 2017 at Pare-pare and Makassar respectively, Indonesia. The aircraft cruised at height 610 meters (2,000 feet) and ground speed 324.1 km/h (175 knots). The SAR system operated with bandwidth 30 MHz, pulse width 2 μs, pulse repetition frequency (PRF) 1,000 Hz, and peak power 100 Watts. Figure 6 shows the result of the flight test realized on 7th August 2017 at the coastal area at Langa-langa village close to Pare-pare city. This figure shows a sample of the acquired SAR image and correspondent RGB picture, with ground range covering from 600 to 4,200 meters or depression angle 8.3 to 45.5 degrees.

Figures 7 shows urban area and sea port of Makassar city that covers ground range from 900 to 4,500 meters or depression angle 7.7 to 34.1 degrees. Figure 8 shows river site closes to Untia seaport, Makassar city that covers ground range from 1,800 to 3,900 meters or depression angle 8.9 to 18.7 degrees. The result shows that WALR-SAR system worked well and successfully collected SAR images that covers the depression angle 0.5 to 42.0 degrees. This system will be further implemented in future onboard microsatellite SAR and stratosphere platform in our laboratory.

(a) The map of measurement of WALR-SAR antenna



(b) Beamwidth of slotted array antenna

Figure 4. Characteristic of slotted array antenna at distance 200 meters and 1,000 meters

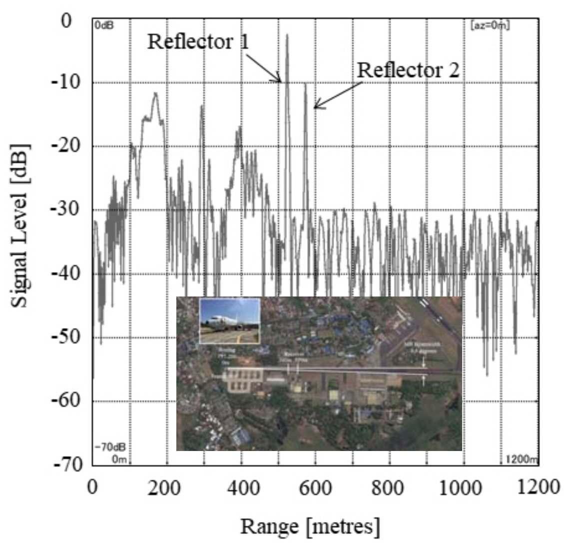


Figure 5. Signal processing test

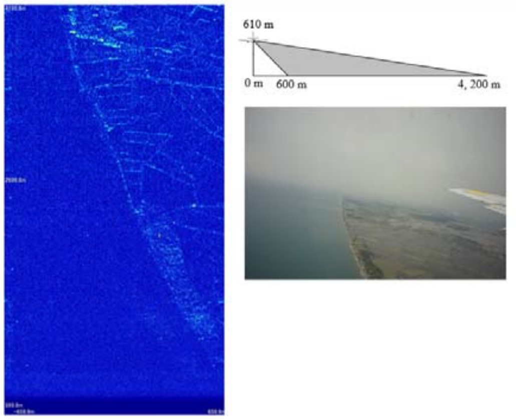


Figure 6. Flight test on 9 August 2017 Coastal area at Langa-Langa village, Pare-pare, Indonesia

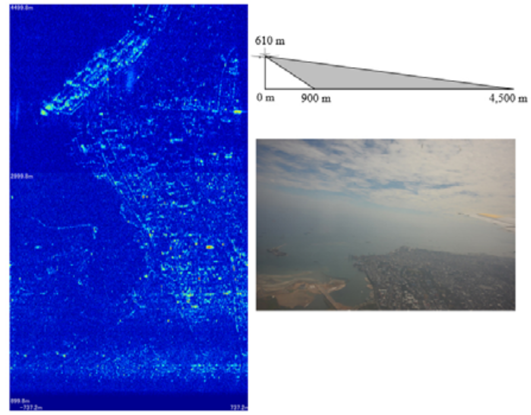


Figure 7. Flight test on 9 August 2017 Urban area at Makassar, Indonesia

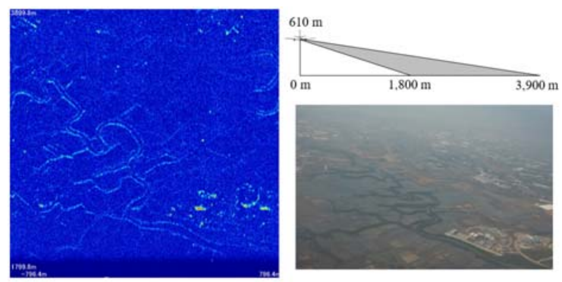


Figure 8. Flight test on 9 August 2017, River site at Makassar, Indonesia

5. CONCLUSION

We developed an X band (center frequency 9.4 GHz, HH polarization) Wide Area Long Range Synthetic Aperture Radar (WALR-SAR) onboard a Boeing 737-200 aircraft for simultaneous air and terrestrial disaster monitoring. This paper explains the configuration of our WALR-SAR system and slotted array antenna installed on Boeing 737-200. Ground measurements of slotted array antenna was done to measure the characteristics of antenna and results are discussed in this paper. Flight tests were done in 7 and 9 August 2017 at Pare-Pare and Makassar, Indonesia. The results show good operation of the WALR-SAR system for SAR image acquisition that covers the depression angle 0.5 to 42.0 degrees.

In future research, we will investigate the dependency of beam shifting and frequency for focusing techniques in SAR image processing, as wide band chirp pulse (800 MHz) was implemented. We also considered upgrading the RF system using gallium nitride (GaN) to increase output peak power to 1,500 watts as a way to improve signal to noise ratio (SNR). This system will be implemented on a circularly polarized WALR-SAR (CPWALR-SAR) system to improve the performance and support research activities in circular polarization [3] for our microsatellite and stratosphere platforms.

ACKNOWLEDGMENT

This work was supported in part by the European Space Agency (ESA) Earth Observation Category 1 under Grant 6613; the 4th Japan Aerospace Exploration Agency (JAXA) ALOS Research Announcement under Grant 1024; the 6th JAXA ALOS Research Announcement under Grant 3170; the Japanese Government National Budget - Ministry of Education and Technology (MEXT) FY2015-2017 under Grant 2101; Chiba University Strategic Priority Research Promotion Program FY2016-FY2018; Chiba University Institute of Global Prominent Research FY2016-FY2018; Taiwan National Space Organization (NSPO) under Grant NSPIO-S-105096; and Indonesian National Institute of Aeronautics and Space (LAPAN) under Lapan-Chibasat Microsatellite SAR project.

REFERENCES

[1]. S.K. Goyal, M.S. Seyfried, P.E. O'neill, Effect of digital elevation model resolution on topographic correction of airborne SAR, International Journal of Remote Sensing, 19, 16, pp.3075-3096, 2010.

[2]. K. Nonami, M. Kartidjo, K.J. Budiyono, Edn., Autonomous Control Systems and Vehicles: Intelligent Unmanned Systems; J.T. Sri Sumantyo, Chapter 12. Circularly Polarized Synthetic Aperture Radar onboard Unmanned Aerial Vehicle, 2013.

[3]. 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, International Journal of Remote Sensing, 38, 8-10, pp.2745-2756, 2017.