A PRELIMINARY STUDY OF A NEW X-BAND SAR SATELLITE MISSION FOR TAIWAN

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ABSTRACT: Taiwan often suffers significant disasters (i.e., mud/land slide, flooding, etc.) from monsoons and typhoons which bring along heavy precipitation in addition to the earthquake disasters. In spite of daily revisit of Formosat-2, its data acquisition operation in Taiwan cannot obtain the needed imagery data during the monsoons and typhoons, unfortunately. A small satellite Synthetic Aperture Radar (SAR) mission was defined in 2009 and it has been analyzed for a few years for seeking a payload development solution. A C-band SAR satellite payload for disasters management was successfully defined in 2013 by flying the satellite in a mission architecture familiar to the satellites operators of NSPO. At the same time, the X-band SAR satellite mission was also studied. The mission objectives have been scoped in two main categories and these objectives are to provide 1) Disasters Management (DM) operations support in Taiwan, and 2) Earth Observations (EO) by providing routine land and near sea surface targets assessment with imaging swaths of about 8, 20 and 75 km at the 1-m resolution for SpotLight mode, 3-m resolution for StripMap mode and 12-m resolution for ScanSAR mode, respectively. To reduce development risk, aerial validation of some key parameters has been planned for the mission.

1. INTRODUCTION

Taiwan is located in the Western Pacific typhoon zone, the average number of typhoons passing Taiwan area is about 3 to 4 times each year. Not only the strong winds threaten the lives of people, the accompanied heavy rain will cause significant flooding or mud/land slide. According to statistics, the annual economic loss caused by typhoon is about 20 billion NT dollars. Typhoon Morakot, occurred during the day of August 6 to August 10, 2009, caused 681 deaths and 18 people missing in Taiwan. After the disaster, a special fund up to 116.5 billion NT dollars has been set up to reconstruct the destroyed area in 5 years. So, to apply knowledge and technology effectively for the remote sensing mitigation and contingency of the disaster is one of the emergency issues for Taiwan people and government.

In general, starting from the beginning of a typhoon, bad weather condition will last a few days. It causes optical remote sensing satellite difficult to take images. However, it is the most critical period to get information for before, during and after a disaster. Accordingly, SAR satellite becomes one of the most effective instruments to penetrate clouds and to provide useful satellite images. The problem of SAR imaging is the first scheduled time and frequency for a disaster. For Typhoon Morakot case, the first day scheduled to take SAR image of Taiwan after Morakot is on August 11 by Advanced Synthetic Aperture Radar (ASAR). Even FORMOSAT-II has the opportunity to image Taiwan once every day, the available data started from August 11 for the poor weather conditions. After the weather condition improved, a quick-look of the optical image was finally mosaicked with five stripes and presented to the public till August 13. To overcome the suffering and losses caused by a strong typhoon in Taiwan, it is very important to get satellite imagery in the critical period of the disaster. Therefore, a daily revisit orbit SAR satellite has been recognized as the very urgent one needed in disaster management operations in Taiwan.

Other than significant disasters (i.e., mud/land slide, flooding, etc.) from monsoons and typhoons which bring along heavy precipitation in addition to the earthquake disasters, many abused and illegal activities cause residents living in implicitly dangerous surroundings. Satellite Earth Observations can provide by providing routine land and near sea surface targets assessment with imaging swaths of about 8, 20 and 75 km at the 1-m resolution for SpotLight mode, 3-m resolution for StripMap mode and 12-m resolution for ScanSAR mode, respectively. Furthermore, if we change to the wide beam mode, we will be able to double the swath at the 1-m resolution for SpotLight mode and 3-m resolution for StripMap mode.

To reduce development risk, some key parameters of the SAR payload are under planning to validate in two steps, such as, at ground and on an aircraft before we will conduct a space SAR program. The aerial validation method is addressed in this paper.

2. MISSION AND PAYLOAD DESCRIPTION

A complete set of spaceborne SAR data application requirements was surveyed in Taiwan by gathering information in the domestic expert informal discussion and user requirement conferences in 2009. The mission objectives are (1) to support the disaster management services and operations in Taiwan (especially for disasters early warning), (2) to perform the environmental watch and monitoring over the oceans neighboring the Taiwan island, and (3) to perform international cooperation activities. The StripMap and SpotLight modes will be employed mainly for supporting disaster management services and operations especially over the landmass targets of Taiwan. The ScanSAR mode will be employed mainly for performing ocean surface monitoring near the Taiwan. Later, an expert meeting was called to provide guidelines for key parameters for mission definition in November, 2011. The advices from the expert committee are listed in the following table.

Table 1 Key mission guidelines

Applications / SAR Parameters	Domestic User Requirements		Expert Advices
	Cartography/Geology & Agriculture/Forestry	Disaster Management & River/Ocean Observation	
Frequency	Cartography/Geology (X/C/L-band) Agriculture/Forestry (L/C/X-band)	X/C/L-band	X-band
Ground resolution	1m is the best 3-8 m is acceptable	5-10 m for DM	3-8 m
Observation period	Forestry(Seasonal)；Agriculture、Land subsidence (Monthly)；Cartography (on demand)	Daily revisit for DM	Daily revisit is the best; 13-day revisit is secondary
Incident angle	35°-40°	40°-45° for DM 20°-50° for river/ocean	30°-45°
Swath	200km is the best; 30-50 km is acceptable	30-50 km for DM; 200 km for river/ocean	30-50 km
Polarization	Full-pol. is the best; dual-pol. is acceptable	---	Full-pol. is the best; dual-pol. is acceptable

Based mainly on the recommendations from the committee, NSPO did some iterations in the trade study, the converged mission requirements are adopted as follows.

Table 2 Key mission requirements

Parameters		X-band
Carrier frequency		9.65 GHz
Incidence angle		32°-45°
Polarization		At least dual (HH & HV)
Ground range resolution	StripMap	3 m
	ScanSAR	9-18 m
	SpotLight	1-3 m
Swath	StripMap	> 20 km
	ScanSAR	55-110 km
	SpotLight	~ 8 km
Swath (Wide Beam mode)	StripMap	> 40 km
	ScanSAR	-
	SpotLight	~ 16 km
Multi-beam Antenna		3-6 beams (TBR)
Radiometric Sensitivity (NESZ)		≤ -20 dB (clear sky) (TBR)

A sun-synchronous orbit with 97.6° inclination was selected for the simulations of Taiwan island imaging which can be performed twice per day (altitude ~ 561-582 km). The Mission lifetime is at least 5 years.

The Antenna, High-gain Power Amplifier (HPA) and SAR Electronics (SARE) are three key elements affecting the radiometric performance of a spaceborne SAR instrument. The critical HPA parts to be used in the payload design will employ suitable power combining techniques using the enabling technology products of GaN SSPA. An existing project initiated in 2013 mid-year is to develop a GaN SSPA power amplifier module (≥ 600W). In addition, a development project of the high-gain large antenna (HLA) is also under planning. The SARE provides transmission and receiving of RF signals, as well as data handling. The SARE subsystem requirements, flown down from mission requirements parameters, are listed in Table 3.

Table 3 SARE subsystem requirements

Subsystems		Parameters	X-band
SAR Electronic (SARE)	Tunable Signal Generator	RF waveform	LFM-chirp & Chu-sequence
		RF Bandwidth	20-300 MHz
		PRF	~ 4 KHz (TBR)
		Pulse width	40 μs
		Pulse duty cycle	20 % (TBR)
	STALO	Frequency stability	(TBD)
		Phase stability	(TBD)
	Digital Receiver	Channels	I/Q
		ADC resolution	8 bits
		Sampling rate	24-360 MHz
		Data compression ratio	≥ 2:1 (TBR)
	Transmitter	Low Power Amplifier	(TBD)
	Receiver	Sensitivity	< -91 dBm
		Noise figure	< 3.5 dB (TBR)
		Equivalent noise temperature	290 K
		Radiometric dynamic range	≥ 60 dB

3. MISSION OPERATION CONCEPT

The mission imaging shall serve the needs of Taiwan first not only before and after the crises but also during the crises especially when the local rain rate can be significant for the disaster area. Three baseline scenarios shall be considered, either by NSPO spontaneous execution or by responding to special request by the government agencies and academic circle, in Taiwan. The urgent events can be: (1) disaster monitoring by StripMap and then SpotLight mode, (2) typhoon and air-sea interactions monitoring by ScanSAR mode, and (3) maritime (including the ships and/or oil Spill) surveillance by ScanSAR mode. Figures 1 and 2 below show the partial coverage capability of the Taiwan island based on the right-looking condition with a four-beam antenna design. About 10% of covering area is overlapped in the two adjoining beams. These beams can also be used as different StripMap mode or to form the ScanSAR mode.

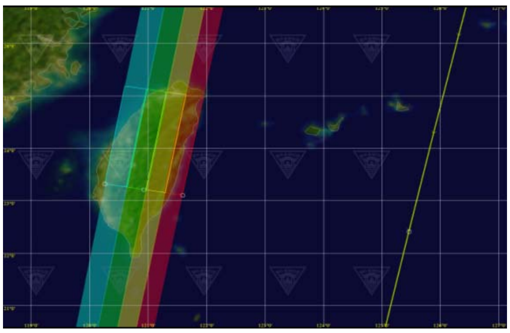

Fig. 1 Simulation of Taiwan imaging on 582-km orbit (descending)

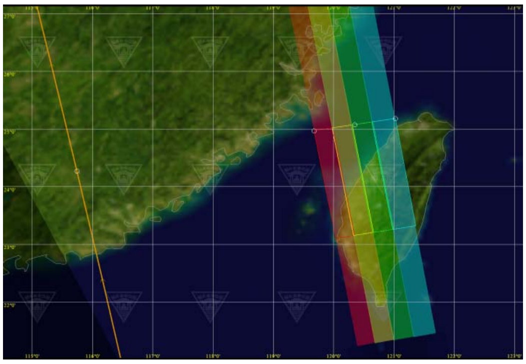

Fig. 2 Simulation of Taiwan imaging on 582-km orbit (ascending)

The SAR payload relies on key technology development of the GaN SSPA power combining and the HLA performance. As long as spaceborne SAR providing enough signal intensity to the outer beam along the slant range, Fully covering Taiwan can be realized by either building more beams in the antenna design or by satellite rolling.

Besides the urgent operations mentioned above, two elementary operation scenarios are capable of performing routine Taiwan monitoring. Case 1 is to perform StripMap operation in daytime (descending) and ScanSAR operation in nighttime (ascending) for odd weeks. It is inversely executed for even weeks. Case 2 is to assume that FORMOSAT-2 (and future FORMOSAT-5) always tasks the daily image acquisition of Taiwan territory. Therefore, the ScanSAR imaging shall be a routing operation in clear sky weather conditions. The StripMap imaging in cloudy days can be under an integrated management scheme together with the planning and scheduling of FORMOSAT-2 and FORMOSAT-5 imaging. In addition, the SpotLight acquisition is carried out for special request or disasters..

4. AERIAL VALIDATION METHOD

Prior to satellite payload development, an airborne SAR project is an effective aerial validation approach. Like The Airborne Science Program does for NASA, these activities make a stepping-stone to reduce risk. The planned aerial validation will use a piloted airplane serving as the platform for validation of SAR key parameters. This project will achieve the following objectives : (1) Satellite SAR calibration and validation, provides essential calibration measurements and the validation of data processing algorithms; (2) Sensor development and integration, creates sub-orbital flight opportunities to test and refine instrument technologies/algorithms; (3) Training of SAR scientists and engineers, makes ready our future workforce with the hands-on involvement of participating scientists/engineers in all aspects of the system.

The airborne SAR will be dual-polarimetric with specific-selected antennas for fitting the pods carried by the airplane. Single-pass interferometry will be achieved by using 2 pods under both wings. SARE prototype will be the major part of this airborne instrumental system. While this airborne SAR can justify the system design of space SAR, it can also be used for DM operation during emergency. Refer to space SAR Key mission requirements (Table 2) & Key payload requirements (Table 3), the Scaled-down parameters & Selected SARE parameters for aerial validation are as in Table 4 & Table 5, respectively. An integrated GPS/IMU will be added and required for motion compensation.

Table 4 Scaled-down parameters for aerial validation

Parameters		X-band
Carrier frequency		~9.65 GHz
Platform altitude / speed		2-5 km / ~165 m/s
Incidence angle		45° (TBR)
Polarization		At least dual (HH & HV)
Ground range resolution	StripMap	1 m
	ScanSAR	---
	SpotLight	(TBD)
Swath	StripMap	1 km
	ScanSAR	---
	SpotLight	(TBD)
Multi-beam Antenna		---
Radiometric Sensitivity (NESZ)		≤ -20 dB (clear sky) (TBR)

Table 5 Selected SARE parameters (tunable signal generator) for aerial validation

Parameters	X-band
RF waveform	LFM-chirp & Chu-sequence
RF Bandwidth	~ 250 MHz (TBR)
PRF	~ 2000 Hz (TBR)
A/D Resolution	8 bits
A/D Sampling Rate	~300MHz
Pulse width	~15 µs (TBR)
Pulse duty cycle	< 10 % (TBR)

5. CONCLUSION REMARKS

Taiwan is a wonderful place to live for people and other different lives. Unfortunately, she often suffers significant disasters (i.e., mud/land slide, flooding, etc.) from monsoons and typhoons as well as earthquakes. To apply knowledge and technology effectively for the remote sensing mitigation and contingency of the disaster is one of the urgent issues for Taiwan people and government. Since 2004, Formosat-2 has provided a rich imagery database for clear sky weather. Another daily revisit orbit SAR satellite is very urgently needed in DM and EO operations for cloudy and disaster conditions. This preliminary study presents a new X-band satellite mission mainly for the Taiwan needs. To reduce development risk, some key parameters of SAR payload will be validated in two steps, such as, at ground and on an aircraft.

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