# Development of Space borne X Band SAR for 100kg Satellite

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## Abstract
We have started development of small synthetic aperture radar (SAR) compatible to 100kg class small satellites with about 3m ground resolution and multi-polarization, aiming for constellation SAR observations. This technology enables us to realize high frequency SAR observations with only several hours observation interval. This paper describes key technologies of this development such as deployable slot array antennas, waveguide feeder with a small gap at a deployment point, and GaN HEMT X band amplifier. Also we show an integration design result of this SAR system to 100kg class bus system.
***Keywords*** **:** X band SAR, 100kg Small Satellite, slot array antenna, SAR constellation

## 1. Introduction
Synthetic Aperture Radar (SAR) is a well known remote sensing technique with reliable capabilities that offer advantages over an optical sensor. 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.

In this paper, we propose a synthetic aperture radar sensor compatible with 100kg class piggy-back satellites. A 100kg satellite may cost roughly ten million US dollars. Furthermore it can be injected into an orbit as a piggy-back, resulting in total mission cost of less than twenty million US dollars..

In the next section, we discuss on the system goal and specifications of SAR that is suitable for a small satellite. Finally, the conclusion and future research will be summarized in section 3.

## 2. Small SAR Compatible with Piggy-Back Satellite
### 2.1 System Goal of Small SAR
Piggy-back launch is inexpensive method to inject a small satellite to an orbit. We have started development of a small satellite with a SAR sensor, which is compatible to piggy-back launch. Japanese H2A vehicle afford a maximum piggy-back satellite with 70x70x70 $cm^3$ volume and around 100kg mass.

Recently a medium or large SAR sensor has a high resolution of 1 meter or less. However, in most cases, a SAR sensor can operate for 5-10minutes in an orbit period of around 100 minutes because of power constraint. At present, a few number of medium or large SAR satellites can observe the earth in a limited time for example less than 10%.

Therefore, an advantage of a piggy-back satellite with a SAR is to increase in observation frequency with relatively low resolution observations. Piggy-back launch is a cost saving way to inject in different orbits many piggy-back satellites with SARs. A system of 12 piggy-back satellites with SARs affords a short revisit time of less than 10 hours. Probably the total cost is less that one of single large SAR satellite.

Candidates of applications that require short revisit time are disaster managements and maritime security to observe objects exposed at earth surface without covering vegetation. It implies that X-band observation is adequate for a small SAR compatible with a piggy back satellite.

### 2.2 System Description of Small SAR
We have performed a preliminary parameter design of a piggy-back satellite with a SAR [1]. It is concluded that X band is a good choice for a compact SAR antenna. Also X-band is adequate to observe objects exposed on the ground, which is the main target of a small SAR with a short revisit time. A transmitting RF power is 573W.We are developing a high efficiency GaN RF power amplifier, in which we improve to increase operational duty ratio up to 20-30%. The ground resolution is 6.1m in a case of noise-equivalent sigma zero $\sigma^{\circ}_{NE}$= -20dB and the duty ratio 20%.

A key technology of the small SAR compatible with a piggy-back satellite is a deployable plane antenna array. Maximum envelop size of a piggy back satellite is 70 x70 x 70$cm^3$ and size of one antenna panel is selected to be 70

cmx70cm. Waveguides have the lowest transmission in this frequency region. Single layer slotted waveguide antennas are a good candidate for this application [2]. We are developing a RF feeder system based on waveguide, which is compatible with deployment and has low loss. The satellite deploys two wings each of which consist of three antenna panels. Antenna arrays are also on the satellite body and the total size of the antenna is 0.7m x 4.6m. Figure 1 shows a preliminary outlook of the satellite.

A SAR sensor radiates high RF power in a short observation time. Time profiles of power and heat of this satellite have a very high peak-average ratio. This satellite has to manage the issue of a high peak-average ratio under severe constraint of mass and volume. In addition to conventional satellite technologies, several advanced technologies would be applied to solve these issues. A solution of the power management is to apply olivine-type lithium-ion batteries compatible for high discharge rate.

## Conclusions

This paper describes the goal and system description of a piggy-back satellite with a small SAR. The system analysis shows that a ground resolution of several meters is possible with X-band. Possible applications are to form a constellation of several piggy-back SAR satellites for disaster managements and maritime security, which require short revisit time.

A preliminary satellite design is in progress. The total mass of satellite is 100kg mass and the satellite is zero-momentum 3-axis stabilized. The details will be reported in the conference.

## References

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**Table 1 Main Parameters of Small SAR**

| Parameter | Value |
|---|---|
| Frequency (GHz) | 9.65 |
| Altitude (km) | 510 |
| Off Nadir (°) | 21 |
| Pulse Bandwidth (MHz) | 40 |
| $\sigma^{\circ}_{NE}$ (dB) | -25 |
| Resolution (m) (Number of look = 4) | 9.8 |
| Swath Width (km) | 23 |
| Antenna size (m) | 4.9 x 0.7 |
| Peak Power (W) | 573 |
| Average Power (W) | 230 |
| System Noise Temperature (K) | 589 |
| Noise Figure (dB) | 4.8 |
| System Loss (dB) | 4 |
| Antenna Efficiency | 0.6 |
| Transmitter Duty Cycle | 0.4 |
| SAR Battery Capacity (Wh) | 127 |
| SAR Battery Mass (kg) | 1.26 |
| Operational Battery Capacity (Wh) | 26.39 |
| Operational Battery Mass (kg) | 0.26 |
| Power Control & Converter Unit Mass(kg) | 5 |
| Operational | 9.57 |
| SAR Observation | >0.67 |
| Solar Paddle Area ($m^2$) | |

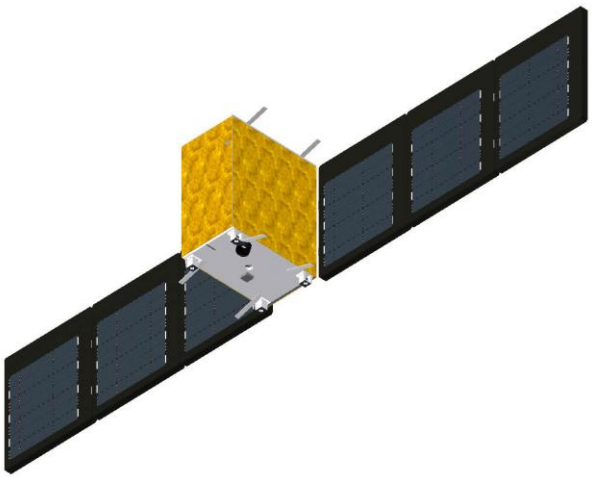

**Fig.1 Outlook of Piggy-back Satellite with Small Synthetic Aperture Radar. Mass is 100kg and body size is 0.7x0.7x0.4m3. Two wings of SAR antennas are deployed and each antenna panel is 0.7x0.7m2. Back side of SAR antenna is partially solar cell.**