

# MetaSensing StarSAR-X: design and performance analysis of the phased array SAR payload for the NOCTUA programme

Adriano Meta, Filippo Speziali, Julien Marini  
MetaSensing Italia Srl, Milan, Italy

Simone Placidi  
MetaSensing AP Pte Ltd, Singapore

Emails: [name.surname@metasensing.com]

## Abstract

In October 2019 Lombardia region in Italy awarded the NOCTUA programme, aiming at monitoring ground infrastructure and natural hazards by means of a dedicated X band Synthetic Aperture Radar satellite. MetaSensing Italia is providing the StarSAR-X, its platform agnostic phased array X band SAR payload, which will be hosted on the ION2 platform built by D-Orbits. This combination results in high performance SAR small satellite designed for repeat pass Differential interferometry at X band. The paper describes the design and performance of the StarSAR-X.

**Keywords:** SAR, SmallSat, NOCTUA, MetaSensing, D-Orbit, DInSAR, Infrastructure monitoring, ship detection.

## 1 Introduction

NOCTUA is a programme financed by Lombardia region in Italy for the development and manufacturing of an X band SAR small satellite mission for monitoring infrastructures and natural hazards. MetaSensing Italia is part of a consortium of six members that includes D-Orbits S.p.A., Beta 80 S.p.A. Software e Sistemi, Fondazione EUCENTRE, Istituto Universitario di Studi Superiori, TRE Altamira s.r.l., with the advice of Fondazione Politecnico di Milano and the support of Lombardia Aerospace Cluster and Fondazione Cluster Tecnologie per le Smart Cities & Communities.

The spaceborne segment is composed by the ION2 bus platform developed by D-Orbits and the X band phased array SAR payload, the StarSAR-X, developed by MetaSensing.

This paper details the design and performance analysis of the StarSAR-X used in the NOCTUA programme.

## 2 The StarSAR-X

The StarSAR-X is MetaSensing spaceborne multi-mode SAR payload for small satellite platforms. It is platform agnostic and it provides high performance characteristics in terms of swath size and spatial resolution keeping flexibility and scalability thanks to its design. The SAR transmitter/receiver system implements electronic steering of the antenna in elevation and in azimuth.

The StarSAR-X features a transmitted peak power of 2.2 kW distributed over a total of 480 TRMs (Transmit/Receive Modules).

The main design characteristics of the StarSAR-X are:

- Large instantaneous bandwidth
- Electronic beam steering in elevation and azimuth
- Arbitrary waveform generation (linear and not linear waveforms, programmable PRF, pulse width and bandwidth)
- Multiple imaging modes: Stripmap, ScanSAR, TopSAR and Spotlight
- Maritime mode for ship detection over large area
- Integrated hardware for amplitude and phase calibration
- Integrated data compression processing techniques

The instrument is composed of two major elements:

- a phased array antenna subsystem: SAS (SAR Antenna Subsystem),
- a central electronics module, the SES (SAR Electronics Subsystem), consisting of a fully integrated Digital Tx/Rx Unit with analogue Front-End and Back-End sections.

The SAS provides the distributed power amplification, beam steering capabilities and low noise reception of the radar pulses through beam forming. The SES is responsible for the electronics power supply, Tx signal generation, Rx signal acquisition and data formatting.

The main design blocks of the instruments are the waveform generation, the active antenna and the RF Direct Sampling ADC followed by an onboard selectable compression algorithm based on BAQ (Block Adaptive Quantizer).

The waveform generator produces an arbitrary waveform based on preloaded signal, which includes linear chirp waveforms with selectable pulse duration and bandwidth depending on the specific configuration mode. An arbitrary waveform generator also allows the possibility to predict the signal to compensate the effects of the H/W distortions versus the frequency.

The digital system is based on a configurable high sampling rate A/D converter (up to 3 Gsps) followed by the pre-processor (digital band pass filter and decimator) and the Block Adaptive Quantizer (BAQ).

The BAQ implements different compression rates, 8:4, 8:3, 8:2, and 8:1 or by-pass the compression.

The data formatting is not defined yet but one option under investigation is a CCSDS like standard packets formatting. However, the data formatting can be optimized for the platform, in relation to the operations and for the data link to download the data to the ground-segment.

## 2.1 Antenna

The SAR Antenna Subsystem (SAS) is a deployable planar phased array operating in single vertical linear polarization, able to generate and to steer the Tx/Rx beams, capable of assuming many different shapes along the antenna elevation plane. The SAS is thermally isolated from the satellite bus.

The TRMs mounted in the SAS can be operated with different phase and amplitude coefficient which allows the beam-steering capability but also the possibility to compensate for any degradation of the antenna itself or of any inflight small misalignment of the antenna panels during deployment.

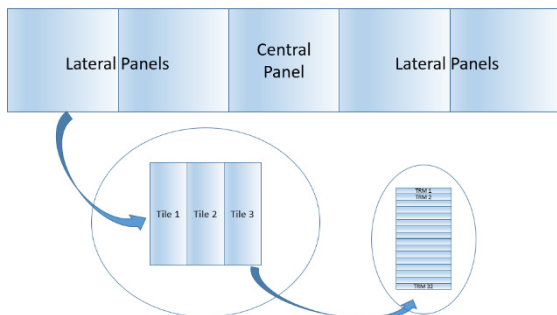


Figure 1 Schematic of the SAS panel configuration

The SAS enhances the StarSAR-X instrument with the following features:

- Beam steering in the elevation and in the azimuth antenna plane
- High speed selection of different elevation beam (to implement the ScanSAR/TopSAR modes)
- High peak power at X-band for irradiating the radar signal and low noise amplification of the backscattered echo

The SAS antenna has dimensions of 5.0 m x 0.8 m, consisting of 5 mechanical panels. Each panel includes three tiles composed of:

- 32 TRMs (Transmit/Receive Modules), grouped in 8 electronic front ends (EFE), to amplify and control the RF signal
- 1 DC/DC tile power supply units (TPSU) to supply the required energy to the modules
- The intermediate digital controller (SBC) to control the modules settings. Each SBC is then commanded via a CAN bus.

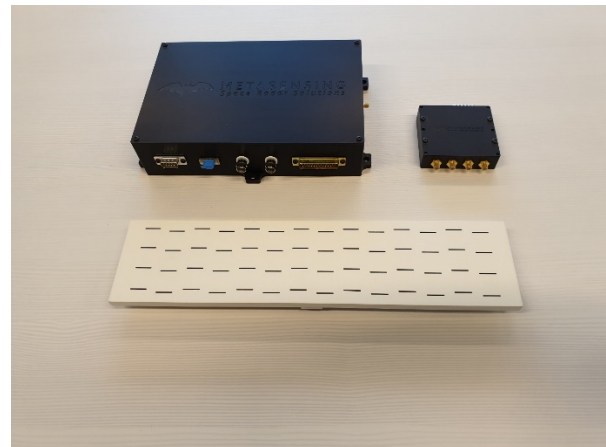


Figure 2: EFE subsystem including 4 TRM for a total of 16-watt peak power at X band, Digital module and a slotted waveguide antenna element.

Within a tile there are all functions needed for beam forming and reception. Each tile is a self-consistent active antenna element including all functional support (thermal, RF, digital and power).

The antenna has a total of 480 TRMs. The tiles are mounted on the panel frame which provides the mechanical stability. The StarSAR-X features two advanced beamforming networks, one for the distribution of the X-band Tx / Rx signal and one for the calibration.

The StarSAR-X is designed to operate in Interferometric Spotlight, Stripmap, TopSAR and ScanSAR mode for imaging. While a large area maritime surveillance mode is programmable for ship detection.

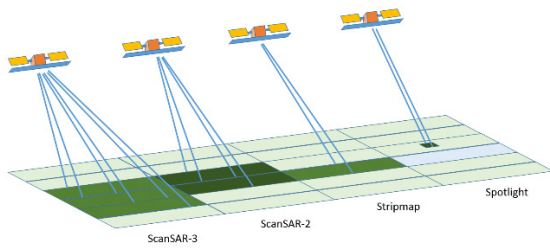


Figure 3 StarSAR-X SAR operational modes

The total power consumption is kept below 2400 W peak and it is distributed for a maximum of 2200 W for the SAS and 200 W for the SES.

Table 1: StarSAR-X Swath, slant range and azimuth resolution for the imaging modes

Mode	Swath	Slant range resolution	Azimuth resolution
Spotlight	10 km	0.3 m	0.5 m
Stripmap	30 km	0.5 m	2.5 m
ScanSAR-2	60 km	0.5 m	5.0 m
ScanSAR-3	90 km	0.5 m	10.0 m
ScanSAR-4	120 km	0.5 m	20.0 m

## 2.2 SAR instrument calibration:

The designed radiometric stability is set to 0.5 dB and it is achieved through compensating the radio frequency system fluctuations. The compensation is achieved by the characterization of the transmitting and receiving gain through the internal calibration and through the antenna characterization (which must be performed during the commissioning phase of the satellite and during regular calibration data takes).

The most important subsystem to monitor is the SAS.

The instrument stability is based on two mechanisms:

- a) the compensation of the TRM variations versus temperature, and
- b) the internal calibration.

Experience shows that often the inflight compensation of the TRM settings is not necessary and the calibration line information is enough to perform an accurate calibration. Nevertheless, the StarSAR-X will implement both.

The internal calibration is performed by sending dedicated pulses along the signal path, according to the specific system timeline. Two different calibration pulses are used:

- CalTx is used to perform the calibration of the transmit path,
- CalRx is used to perform the calibration of the receiving path.

Those pulses are transmitted in a warmup period and ending period before and after the actual SAR acquisition in a much shorter interval are also sent in between regular acquisition pulses.

## 3 Performance Analysis

MetaSensing has built an advanced spaceborne SAR performance simulator to assess and predict the quality of the achievable images varying certain typical parameters of the spaceborne SAR missions like flight altitude, irradiated peak power, antenna size, beam steering capability, etc..

The following parameters of the StarSAR-X have been used for the performance analysis of the payload when flying at 510 km altitude.

Table 2: StarSAR-X radar characteristic

Parameter	Specification
Frequency	X-band
PRF	Up to 20 kHz
Bandwidth	Up to 500 MHz
Slant Range resolution	From 0.3 m
Antenna size	5.0 x 0.8 m (scalable)
Antenna efficiency	70%
Antenna polarization	Linear Vertical
Technology	Transmit/Receive Modules (TRM)
RF Peak power	< 2200 W
RF Pulse duty cycle	< 20%
Number of TRM	480
Acquisition modes	Stripmap, Spotlight, ScanSAR, TopSAR, Maritime
Ground imaging swath	Up to 120 km
Ground range coverage	Up to 400 km
Total payload mass	< 80 kg
Power supply	< 2400 W @ 30 V DC

The performance has been calculated for an orbit altitude of 510 km and varying the transmitted bandwidth (and hence the range resolution). For each selected transmitted bandwidth, several performances are calculated. The main goal is to identify the regions which meet the main requirements of having a ground resolution finer than 3 meter and a ground swath larger than 20 km. A spherical Earth has been assumed for these performance calculations.

The following plots illustrate the NESZ with respect to the ground range in km calculated when transmitting 100, 150, 300 and 500 MHz, corresponding respectively to 1.5, 1.0, 0.5- and 0.3-meter slant range resolution.

As shown in Figure 4, the NESZ decreases with increasing look angle since the distance between the radar and the area to be observed increases. Ground resolution on the other hand improves with increasing look angle because of the slant range projection on the ground.

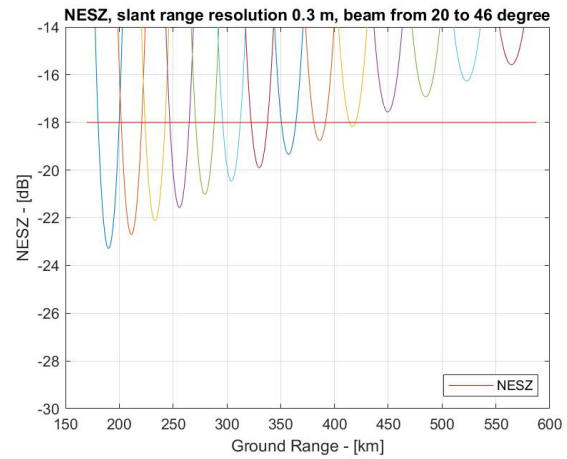
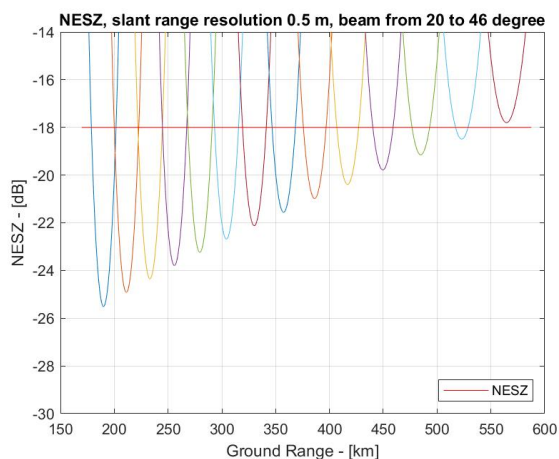
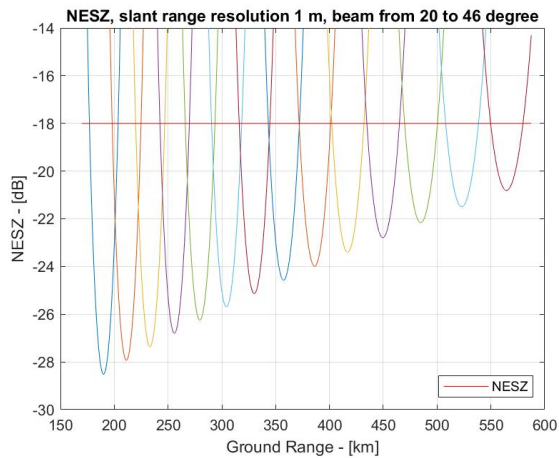
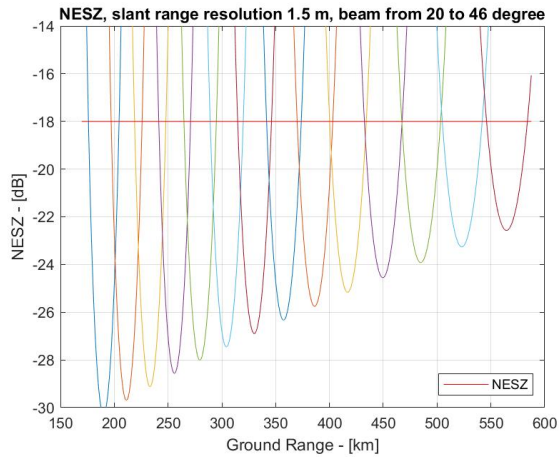


Figure 4: NESZ versus Ground Range for different slant range resolutions

## 4 Conclusion

The paper illustrates the design and performance analysis of the StarSAR-X, the MetaSensing phased array spaceborne SAR payload which will be carried on the ION2 by D-Orbit platform within the framework of the NOCTUA project.

NOCTUA is a programme financed by Lombardia region and aims at providing ground infrastructure and natural hazard monitoring with space Differential Interferometric SAR technology.

The StarSAR-X is a platform agnostic payload with scalable design which can be installed on different small satellite platforms or larger.

## 5 Literature

- [1] Walter G. Carrara, Ron S. Goodman, Ronald M. Majewski, Spotlight synthetic aperture radar: signal processing algorithms, Artech House, c1995
- [2] John C. Curlander, Robert N. McDonough, Synthetic Aperture Radar: Systems and Signal Processing, ISBN: 978-0-471-85770-9
- [3] Ian G. Cumming, Frank H. Wong, Digital Signal Processing of Synthetic Aperture Radar Data: Algorithms and Implementation, Artech House Remote Sensing Library
- [4] Ferretti A., Satellite InSAR Data. Reservoir Monitoring from Space, EAGE Publications
- [5] Jakowatz, Charles VJ, Daniel E. Wahl, Paul H. Eichel, Dennis C. Ghiglia, and Paul A. Thompson. Spotlight-Mode Synthetic Aperture Radar: A Signal Processing Approach. Springer Science & Business Media, 2012.