# WIDE SWATH SAR INSTRUMENT FOR GLOBAL MONITORING BASED ON DIGITAL BEAM FORMING

*Martin Suess, Michael Ludwig*[(1)], *Christoph Schaefer*[(2)], *Marwan Younis*[(3)]

[(1)] European Space Agency, ESTEC
2200AG Noordwijk, The Netherlands

[(2)]Astrium GmbH
88039 Friedrichshafen, Germany

[(3)]Microwaves and Radar Institute, German Aerospace Center (DLR)
82234 Weßling, Germany

## 1. INTRODUCTION

The European Space Agency undertakes the development of the European Radar Observatory Sentinel-1 as part of the 'Global Monitoring for Environment and Security (GMES)' program in a joint initiative together with the European Commission (EC) to support Europe's goals regarding sustainable development and global governance of the environment by providing timely and quality data, information, services and knowledge. The focus of the multi satellite constellation Sentinel-1 is to provide a continuation of SAR image data in C-band for user services which have developed from ESA's ERS and ENVISAT missions. The crucial requirements for operational sustainable services are continuity of data supply, frequent revisit, geographical coverage and timeliness which translates into a high operation duty cycle of 25% per orbit and a wide imaged swath of 250 km in the nominal operational imaging mode.

Based on the imaging requirements for the Sentinel-1 constellation [1] a study was performed to investigate what improvements could be achieved through new instrument concepts based on digital beam forming and to identify the technologies that have to be developed to be able to realize such an instrument in the following generation of Sentinel-1 satellites.

## 2. SENTINEL-1 IMAGING REQUIREMENTS

The Sentinel-1 SAR will have 4 different imaging modes operating the nominal frequency of 5.405 GHz. These are Interferometric Wideswath, Stripmap, Wave and Extra-Wideswath mode.

- The Interferometric Wideswath mode is the main imaging mode which will be nominally operated 25% of each orbit. It has a moderated geometric resolution of 5m x 20m (range x azimuth) combined with a large swath width of 250 km.
- The Stripmap mode has a high geometric resolution of 5m x 5m over a swath width of 80 km and an access range of 375 km.
- The Wave mode is based on single Stripmap operations with different elevation beams (between 23 and 36.5 mid incidence angle) and a fixed on/off duty cycle to generate of vignettes of 20 km x 20 km size in regular intervals of 100 km.
- The Extra-Wideswath mode has a huge swath width of 400 km which is imaged at the low resolution of 20m x 40m.

The Interferometric Wideswath as well as the Extra-Wideswath mode are implemented as ScanSAR modes with a progressive azimuth scanning (TOPS operation). Except for the Wave mode, which is single polarization (HH or VV), all other modes operation in dual polarisation (HH-HV, VV-VH). The Sentinel-1 satellites take their images from a Near-Polar Sun-Synchronous orbit with a 12-day repeat cycle and a height of 693 km. To fulfill this imaging requirements Sentinel-1 is equipped with an active phased array antenna of 12.3m x 0.821m in size.

The objective of the study was to take the orbit and the image performance requirements from Sentinel-1 and to design a SAR instrument that has the high geometric resolution of 5m x 5m like Sentinel-1 in Stripmap mode combined with the huge swath width of 400 km like Sentinel-1 in Extra-Wideswath mode!

## 3. HIGH RESOLUTION WIDE SWATH SAR INSTRUMENTS

As described e.g. in [2] the azimuth resolution and the swath width in a continuous mode are contradicting parameters which can not be improved both at the same time with a conventional SAR instrument. This is also illustrated by the different Sentinel-1 modes described before which show three different optimum combinations between along track resolution and swath width.

Only by using different antenna beam characteristics in transmit and receive this constraint can be overcome. In [3] a system is described which uses a transmit antenna adapted to the along track resolution and with a wide beam in elevation combined with a separate, large receive only antenna that allows to record the signals from several phase centers in along track. It uses digital beam forming in elevation to produce a thin pencil beam that follows the echo on the ground in a scan on receive operation to allow the combination of a wide swath width with a high along track resolution. Other works [4], [5] have investigated the use of reflector antennas with the same objective. Based on the this SAR system design described in [3] the receive antenna would have to be at least 36m long which is considered as not feasible.

## 4. INSTUMENT DESIGN OPTIONS

In order to reduce the required receive antenna length the high resolution wide swath (HWRS) principle described above has to be combined with a ScanSAR operation. In this particular case at least three sub-swaths are required to meet the overall swath width of 400 km.

The two principle design options shown in Figure 1 have been investigated. The first option shown uses a dedicated offset reflector based transmit antenna (3.5m x 1.5m) with an array of feed horns capable to illuminate three different sub-swaths and which are powered by a total of 6 TWTAs. The separate planar receive only antenna has a height of 1.18m and a total length of 12.8m. It is organized in 7 receive sub-apertures in azimuth containing each 28 receive arrays in elevation which are combined to perform a dispersive SCORE operation.

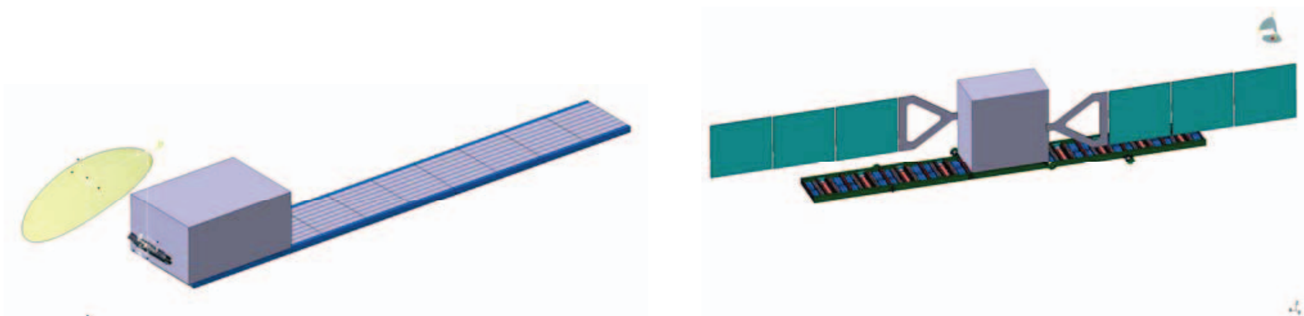

**Figure 1: Satellite configurations, option 1 on the left with a reflector based transmit antenna and the large planar receive only antenna and option 2 on the right with a single antenna for transmit and receive.**

The second option shown in Figure 1 on the right uses the same antenna size as for the receive antenna in the first option but the antenna includes also the transmit function in the form of T/R modules. In order to achieve the wide required beam pattern in azimuth and elevation a very strong phase taper is used. The size of the transmit and receive antenna is the same as the size of the receive only antenna in the first option.

Design option 2 was selected after trade-off. This decision was mainly based on the built-in ability of the active antenna in option 2 to scan the beam in along track direction and therefore enable TOPS mode for a more homogeneous imaging performance. Taking this into account the required RF power of option 2 is only about 10% higher than for option 1. The satellite configuration with a single antenna appears simpler and the solar array attachment and deployment concept is proven. The disadvantage of option 2 is the higher thermal power density in the antenna which requires a careful thermal design.

In both HWRS SAR systems the height of the receive antenna aperture is a degree of freedom which can be traded-off. A higher antenna allows to reduce the required transmit power and therefore the overall power consumption of the instrument. On the other side this will lead to an increased instrument mass and at some point difficulties to accommodate the antenna during launch.

## 5. COMPARISON WITH SENTINEL-1

In the following table, the DBF-SAR instrument performance is compared to state-of-the-art performance values of the Sentinel-1 instrument.

| Parameter | HWRS-SAR | Sentinel -1 | Comment |
|---|---|---|---|
| radar band | 5.405 GHz | 5.405 GHz | C-Band |
| orbit height | 693 km | 693 km | |
| on-ground resolution cell | < 5m × 5m | < 5m × 5m | single look |
| swath width | > 400 km | > 80 km | instantaneous coverage |
| incidence angle range | 20°-50° | 20°-45° | access range |
| polarisation | single/dual/quad | single/dual | |
| noise-equivalent σ0 (NESZ) | < -22 dB | < -22 dB | |
| distributed target ambiguity ratio (DTAR) | < -22 dB | < -22 dB | |
| point target ambiguity ratio | < -25 dB | < -25 dB | |
| antenna length | 12.80 m | 12.3 m | |
| antenna height | 1.18 m | 0.82 m | |
| average RF transmit power | 900 W | 448 W | |
| no. of TRM (1 TX + 2 RX channels active) | 392 | 280 | |
| instrument power consumption | 6650 W | 4075 W | |
| thermal power load on antenna | 355 W/m² | 236 W/m² | |
| antenna mass | <1600 kg | 945 kg | |
| instrument mass | <1650 kg | 990 kg | |
| proposed launcher | Soyus | Soyus | |

**Table 1: Comparison of HWRS SAR in option 2 and Sentinel-1 key instrument and performance parameters**

## 6. CONCLUSION

The study has demonstrated the general feasibility of achieving the high resolution of 5m x 5m provided by the Sentinel-1 Stripmap mode over an instantaneous swath with of 400km by using a HRWS SAR based on digital beam forming on receive. The study is used to identify the critical technologies [6] which need to be developed further to make such sort of instruments realty in the future.

## 7. REFERENCES


[1] E. Attema, "Mission Requirements Document for the European Radar Observatory Sentinel-1", ES-RS-ESA-SY-0007, Issue 1.4, 11 July 2005. (http://esamultimedia.esa.int/docs/GMES/GMES_SENT1_MRD_1-4_approved_version.pdf)

[2] J. C. Curlander and R. N. McDonough, Synthetic Aperture Radar Systems and Signal Processing, New York: Wiley, 1991, p. 21 ff.

[3] M. Suess, B. Grafmueller, and R. Zahn, "A novel high resolution, wide swath SAR system," Proceedings of IGARSS '01, vol. 3, pp. 1013–1015, Sydney, Australia, July 2001.

[4] N. Gebert, G. Krieger, A. Moreira, "Digital Beamforming on Receive: Techniques and Optimization Strategies for High-Resolution Wide-Swath SAR Imaging", IEEE Transactions on Aerospace and Electronic Systems, vol. 45 (2), pp. 564-592, Apr 2009.

[5] M. Younis, S. Huber, A. Patyuchenko, F. Bordoni, G. Krieger, "Performance Comparison of Reflector- and Planar-Antenna Based Digital Beam-Forming SAR," International Journal of Antennas and Propagation, vol. 2009, Article ID 614931, 13 pages, 2009.

[6] C. Fischer, C. Schaefer, C. Heer, "Frontend Development for the High Resolution Wide Swath SAR", Proc. EUSAR 2008, Friedrichshafen, Germany, June 2-5, 2008, vol. 4, pp. 71-74

[7] N. Gebert, G. Krieger, M. Younis, F. Bordoni, A. Moreira, "Ultra Wide Swath Imaging With Multi-Channel ScanSAR", Proceedings of IGARSS '08, Boston, Massachusetts, USA, July 2008.