FUTURE SPACEBORNE SAR TECHNOLOGIES AND MISSION CONCEPTS

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ABSTRACT

In the last decade we entered into a golden age for spaceborne synthetic aperture radar (SAR) systems with the number of satellites increasing in a quasi-exponential way. The reason is obvious: SAR data utilization and associated services are making a most important contribution in addressing societal challenges of global dimension since spaceborne SAR is the only sensor technology that is able to provide high-resolution images on a global scale independent of weather conditions and sunlight illumination. This paper provides a short overview on the latest developments including new technologies and progress on digital beamforming in azimuth and elevation, bistatic and multistatic mission concepts as well as NewSpace SAR satellites.

***Index Terms*—** Synthetic Aperture (SAR), Digital Beamforming, High Resolution Wide Swath (HRWS), Bistatic and Multistatic SAR, NewSpace SAR

1. INTRODUCTION

In a changing and dynamic world, high resolution and timely geospatial information with global coverage and access is becoming increasingly important. Spaceborne synthetic aperture radar (SAR) plays an essential role in this task, as it is the only sensor technology which provides high-resolution imagery on a global scale independent of the weather conditions and sunlight illumination [1], [2], [3]. Current spaceborne SAR systems have, however, an inherent limitation: The system design can be either optimized for a high azimuth resolution or wide swath imaging, i.e., it is not possible to achieve high resolution and wide swath simultaneously [4]. This poses several constraints in fulfilling the user requirements for global scale observations. Table 1 shows the trade-off in imaging performance in terms of swath width, resolution and orbit duty cycle for the state-of-the-art SAR systems as well as the user requirements for future SAR systems.

2. MULTICHANNEL SAR WITH DIGITAL BEAMFORMING

A paradigm shift is taking place in the development of SAR systems, as digital beamforming allows for the implementation of innovative imaging modes with high azimuth resolution and wide swath width [5], [6], [7]. For example, ESA's Sentinel-1NG mission, currently in Phase B1 with two competing industry consortia, has a SAR instrument specification to achieve a 400-km swath width and 5-m azimuth resolution [8]. By means of 2-3 satellites with azimuth and elevation digital beamforming, a global coverage in ca. 4 days is achieved with a much higher spatial resolution than it would be possible with conventional spaceborne SAR systems operating in the classical single-channel ScanSAR or TOPS mode. Figure 1 shows the imaging performance of the current and next generation of spaceborne SAR systems with digital beamforming as well as the realization options of multichannel SAR systems with digital beamforming using direct radiating arrays and a large reflector with a digital feed array. The latter option becomes attractive for low-frequency SAR (e.g., L band) due to the

State of the Art (e.g., Sentinel-1)	Imaging Mode (**single/dual pol.**)		
	EW	IW	SM
Resolution	**40 m**	**20 m**	**5 m**
Swath Width	**400 km**	**250 km**	**80 km**
Orbit Duty Cycle	**25 minutes per orbit**		

a)

Future Requirements	Imaging Mode (**quad pol.**)		
	Mode X	Mode Y	Mode Z
Resolution	**5 m**	**2 m**	**1 m**
Swath Width	**500 km**	**200 km**	**100 km**
Orbit Duty Cycle	**> 50 minutes per orbit**		

b)

Table 1 – a) Trade-off of imaging performance in terms of swath width, spatial resolution and orbit duty cycle for the state-of-the-art SAR systems, b) User requirements for the next generation of spaceborne SAR systems.

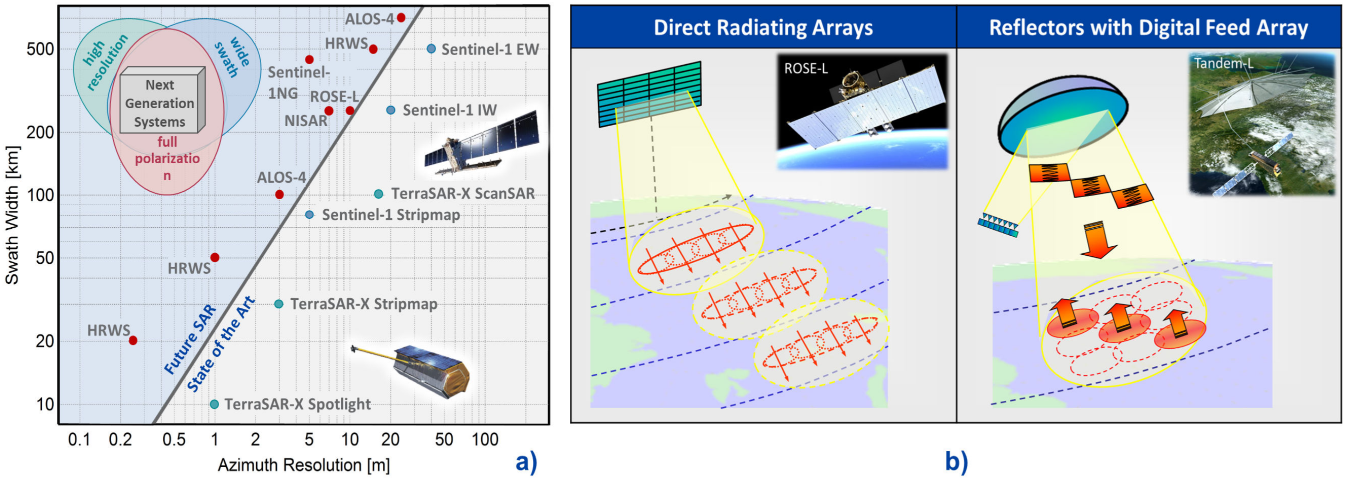

Figure 1 – a) Imaging performance of the current and next generation of spaceborne SAR systems with digital beamforming. b) Implementation of multichannel SAR systems with digital beamforming using direct radiating arrays and a large reflector with a digital feed array.

large antenna dimensions required for the implementation of multichannel SAR systems with digital beamforming [9], [10]. For example, ROSE-L, ESA/EC's L-band mission of the Copernicus program, scheduled for launch in 2028, will have a planar antenna size of 11 m x 3.6 m, the largest planar antenna for a spaceborne SAR mission to date [11].

3. BI- AND MULTISTATIC SAR MISSIONS

The trend for future SAR systems shows the need for an increased information content in SAR imagery, which can be achieved by polarimetry, multi-frequency and/or improved range and azimuth resolution. In addition, bi- and multistatic SAR imaging increases the information content in the multi-dimensional data space and opens the door to a new class of information products [12]. While repeat-pass interferometry is a well-established technique and is widely used by current space-based SAR systems, across-track interferometry, 3D differential SAR interferometry as well as polarimetric SAR interferometry and tomographic SAR are shaping the future development of several SAR missions [13], [14], [15], [16], including Harmony (3D DinSAR, [17], [18]), HRWS MirrorSAR [23], Biomass and Tandem-L (PolinSAR and TomoSAR, [19], [20]). Although TanDEM-X has been operational since December 2010, it is still the only bistatic radar consisting of two satellites in close formation flight. TanDEM-X has already generated a global digital elevation model (DEM) of the Earth with unparalleled quality and resolution. A second edition of a global DEM is being processed and will be available by mid-2023. All topographic changes on the Earth's surface that have occurred between the two DEM acquisitions will then be measurable for the first time on a global scale [21], [23], [22].

4. NEWSPACE SAR MISSIONS

Augmenting complex SAR missions with global coverage, low-cost, lightweight systems based on NewSpace concepts are being implemented with the objective of imaging small areas with a very short revisit time. The combination of fully-fledged SAR systems with disruptive NewSpace SAR concepts offers a wealth of new system approaches for multistatic SAR missions with enhanced imaging capabilities. One example is the High-Resolution Wide-Swath (HRWS) SAR mission with the MirrorSAR concept, which consists of a main X-band satellite and three small receive-only satellites using the MirrorSAR concept of a space transponder [23], [24]. Further opportunities arise for distributed SAR system concepts with a multistatic configuration [25], [26], [27].

5. CONCLUSIONS

The ultimate goal for spaceborne SAR remote sensing is the deployment of a space-based radar observatory with a satellite constellation capable of providing real-time geospatial information in a reliable way, thus making an essential contribution to solving societal challenges of global dimension. Digital beamforming, bi- and multistatic systems as well as cost-efficient NewSpace developments are key for the realization of this vision.

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