Digital Beamforming: A Paradigm Shift for Spaceborne SAR

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Abstract: *Spaceborne Synthetic Aperture Radar (SAR) provides high-resolution, day-and-night and weather-independent images for a multitude of applications ranging from geoscience and climate change research, environmental monitoring, global 2-D and 3-D mapping, change detection, 4-D mapping (space and time), security-related applications up to planetary exploration. By means of the development of new digital beamforming and waveform diversity technologies in combination with large reflector antennas, future SAR systems will outperform the imaging capacity of current systems by two orders of magnitude. This paper provides an overview of the state of the art in spaceborne SAR and describes the technological developments that will open the door to a future global remote sensing system for the continuous observation of dynamic processes over the Earth surface.*

1. Introduction

Synthetic Aperture Radar (SAR) has entered into a golden age. More than 15 spaceborne SAR sensors are being operated today and 10 new SAR systems will be launched within the next 5 years. SAR is unique in its imaging capability: It provides high-resolution two-dimensional images independent from daylight, cloud coverage and weather conditions. It is predestined to monitor dynamic processes on the Earth surface in a reliable, continuous and global way [1].

With the launch of the bi-static SAR satellites TerraSAR-X and TanDEM-X (X-band), the COSMO-SkyMed satellite constellation (X-band) as well as Radarsat-II (C-band) a new class of SAR satellites was introduced providing images with resolution in the meter regime. Fig. 1 shows a comparison of a SAR image with moderate resolution corresponding to the state of the art in the 90s and a SAR image obtained with the new generation of high-resolution SAR satellites.

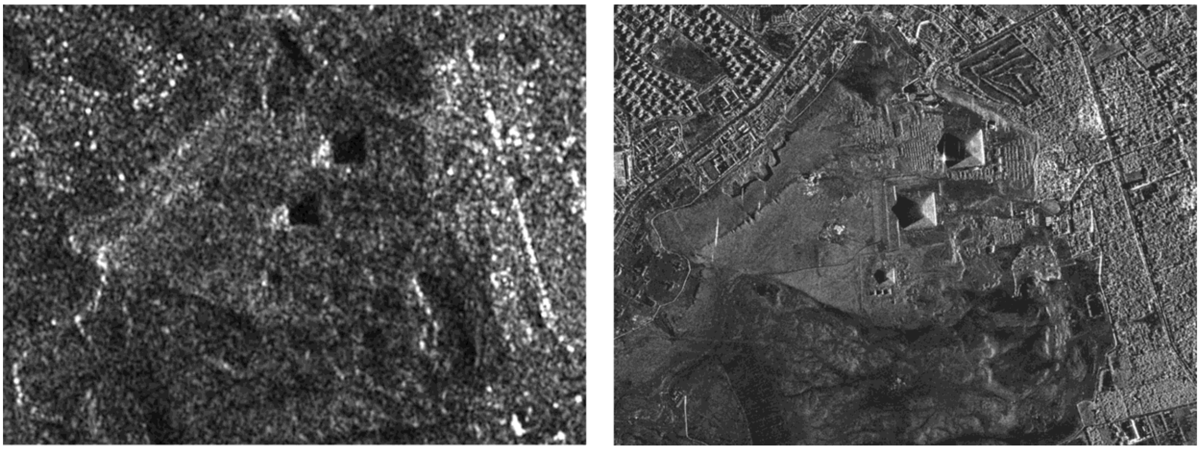

Figure 1 – Comparison of a SAR image corresponding to the state of the art during the 90s (left: ca. 20 m resolution, C-band, radar illumination from the left) and the current generation of SAR satellites available since 2007 (right: 1 m resolution, X-band, radar illumination from the right). The images show the pyramids of Giza, Egypt.

2. State of the Art

A summary of the state of the art of spaceborne SAR systems is given in Table 1 which are, expect for HJ-1C, based on a planar antenna with transmit/receive (T/R) module technology. This allows the steering of the antenna beam at different incidence angles and a great flexibility in the implementation of imaging modes for a wide range of user requirements. Typically a few hundred T/R modules are employed, with their settings being controlled by software. As seen in Table 1 there is also a trend for constellations of SAR satellites in order to fulfill the demanding user requirement for a short revisit time.

Sensor	Operation	Freq. Band (Polaris.)	Comments	Institution/ Country
TerraSAR-X/ TanDEM-X	2007 – today 2010 – today	X (quad)	First bi-static radar in space, resolution up to 1 m, global topography available by end of 2014	DLR/Astrium, Germany
Radarsat-2	2007 – today	C (quad)	Resolution up to: 1 m x 3 m (azimuth x range), swath width up to 500 km	CSA, Canada
COSMO-SkyMed-1/4	2007…2010 – today	X (dual)	Constellation of 4 satellites, up to 1 m resolution.	ASI, MiD, Italy
HJ-1C	2012 – today	S (VV)	Constellation of 4 satellites, first satellite launched in 2012	CRESDA/CAST/ NRSCC, China
Sentinel-1a/1b	Launch sched.: 2013/2015	C (dual)	Constellation of 2 satellites, swath width up to 400 km	ESA, Europe
ALOS-2	Launch sched.: 2013	L (quad)	Resolution up to: 1m x 3m (azimuth x range), swath width up to 490 km	JAXA, Japan
Kompsat-5	Launch sched.: 2013	X (dual)	Korea Multi-Purpose Satellite 5, resolution up to 1 m	KARI, Korea
PAZ	Launch sched.: 2013	X (quad)	Constellation with TerraSAR-X and TanDEM-X planned	CDTI, Spain
RISAT-1	2012 – today	C (quad)	Follow-on satellite (RISAT-1a) to be launched in 2016, RISAT-3 (L-band) in development	ISRO, Indien
Radarsat Constellation	Launch sched.: 2017	C (quad)	Constellation of 3 satellites, swath width up to 500 km	CSA, Canada
SAOCOM-1/2	Launch schedule: 2014/2015	L (quad)	Constellation of 2 satellites, fully polarimetric	CONAE, Argentina

Table 1. Overview of spaceborne SAR sensors and their main characteristics [2].
More than 10 SAR satellites will be launched in the next 5 years.

Of particular interest in Table 1 is the German satellite mission TanDEM-X, the first radar interferometer in space that employs two satellites operating in a closely controlled formation flight. The primary objective of TanDEM-X is the generation of the Earth’s topography with unprecedented accuracy as the basis for a wide range of commercial applications as well as for scientific research. It is expected that this data set will become a reference in geosciences and remote sensing applications [3], [4], [5].

TanDEM-X has an ambitious time schedule to reach the main mission goal. The operational bi-static data acquisition has started in December 2010. Two global digital elevation model (DEM) acquisitions have been performed until April 2013 which are followed by six months of additional acquisitions to cover difficult terrain with extreme topography. The distance between the satellites are optimized in each mission phase for DEM performance and varies between 150 and 500 meters. The global DEM data set will be available by mid-2014.

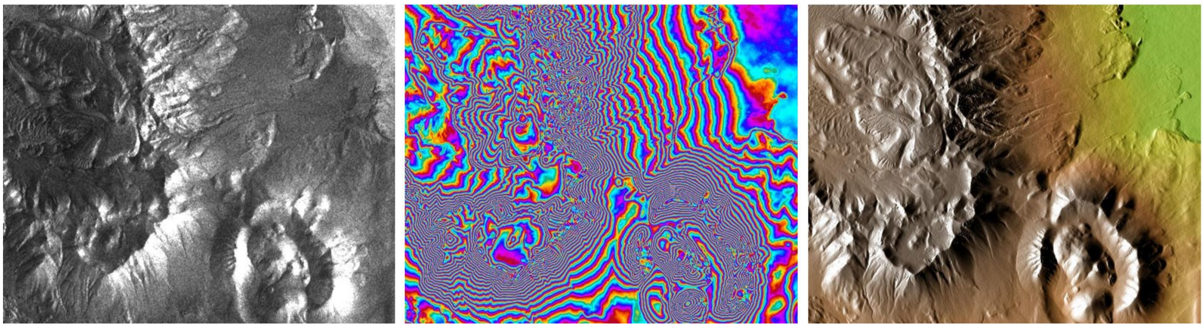

Figure 2 – TanDEM-X data acquisition over the Atacama desert in Northern Chile. Left: radar image, middle: phase interferogram (a color cycle corresponds to 360 degrees phase change), right: digital elevation model (DEM).

3. Digital Beamforming: A Paradigm Shift for Spaceborne SAR

The trend for future systems shows the need for an increased information content in SAR images that are achieved by polarimetric operation, multi-frequency radar systems, improved range and azimuth resolution, time series (frequent revisit of the same area) as well as observation angle diversity (interferometry and tomography).

A conventional spaceborne SAR system has however a main intrinsic limitation: It is not possible to achieve high azimuth resolution and wide swath coverage at the same time. This constrain arises from the pulsed operation of SAR systems and the sampling requirement for the Doppler bandwidth. Radar systems with very high resolution have a high Doppler bandwidth which leads to a high value for the pulse repetition frequency (PRF). This high PRF value reduces on the other hand the maximum allowable size of the swath. An increase of the swath width implies therefore in a deterioration of the azimuth resolution.

A paradigm shift is however taking place in spaceborne SAR systems: New digital beamforming concepts will boost the performance of future SAR systems by at least one order of magnitude. A prominent example is the high-resolution wide-swath (HRWS) SAR demonstrator [6] which is currently under development at EADS Astrium with support from the German Aerospace Center (DLR). This system has been specified to map a 70 km wide swath with a resolution of 1 m, thereby exceeding the number of acquired ground resolution cells of the TerraSAR-X stripmap mode (3 m resolution at 30 km swath width) by a factor of 21. Advanced concepts includes additionally a ScanSAR image mode (Figure 3 left) or simultaneous multi-beam on receive which are illuminated by a broad Tx beam (Figure 3 middle left). The broad Tx beam can be achieved by applying phase tapering, spectral Tx diversity or an illumination with a sequence of sub-pulses [8]. Moreover, digital beamforming in combination with waveform diversity and large reflector antennas will outperform the imaging capacity of current systems by two orders of magnitude (cf. Figure 3 middle right and right). One example is the mission proposal Tandem-L which is distinguished by the high degree of innovation with respect to the methodology and technology. Examples are the polarimetric SAR interferometry, multi-pass coherence tomography, the utilization of the latest digital beamforming techniques for increasing the swath width and imaging resolution, as well as the close formation flying of two cooperative radar satellites with variable adjustable spacing. The Tandem-L mission concept is based on the use of two radar satellites operating in L-band and offers the ideal basis for the continuous observation of dynamic processes on the Earth's surface. The goal of Tandem-L is to image the land mass interferometrically once a week and by this to provide urgently needed information for solving pressing scientific questions in the areas of the biosphere, geosphere, cryosphere, and hydrosphere [9], [10].

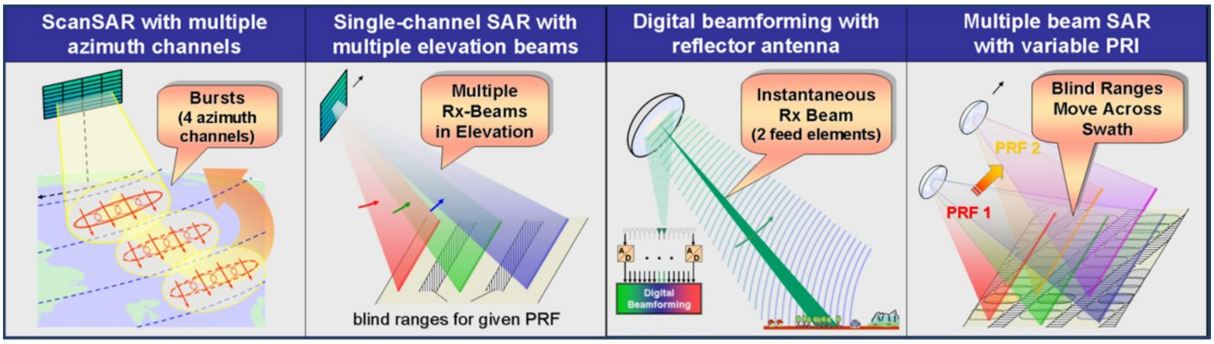

Figure 3 – Advanced concepts for high-resolution wide-swath imaging based on digital beamforming. Left: large planar array, right: multichannel feed array and large reflector antenna.

3. Outlook

The vision for spaceborne radar remote sensing looks exciting. New spaceborne radar technologies will enable the implementation of a constellation of radar satellites for reliable and systematic monitoring of the Earth's surface. These concepts will provide the means for the global observation of dynamic processes on the Earth's surface with hitherto unknown quality and resolution. A future remote sensing system, a sensor web, will allow the continuous observation of dynamic processes over the Earth, as it currently exists for weather prediction, where a network of geostationary satellites is used.

References

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