TerraSAR-X TOPSAR and ScanSAR comparison

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Abstract

TOPSAR is a recently proposed SAR mode for wide swath acquisition, which is intended to replace the conventional ScanSAR mode. TOPSAR will be used by the ESA Sentinel-1 SAR sensor in its main interferometric wide swath mode. TerraSAR-X has demonstrated the TOPSAR mode in space by acquiring and processing TOPSAR images for the first time. The paper reports the results of the image scalloping analysis performed on TOPSAR, inverse TOPSAR and ScanSAR images.

1 Introduction

TOPSAR is a recently proposed acquisition mode for wide swath imaging which aims at reducing the drawbacks of the ScanSAR mode. TOPSAR has been proposed by Attema (ESA-ESTEC) and Rocca (POLIMI) and successively developed in [1]. It has been demonstrated in space by DLR Microwave and Radar Institute producing first TOPSAR images and interferometric results [2] with TerraSAR-X data for an ESA contract. TOPSAR will be used by the ESA Sentinel-1 SAR sensor in its main interferometric wide swath mode.
TOPSAR is very interesting for TerraSAR-X due to the performance advantages compared to ScanSAR. TOPSAR may substitute the ScanSAR mode in TerraSAR-X. Within the commissioning phase it has been demonstrated that high quality TOPSAR imaging is possible with TerraSAR-X. A possible operational implementation is now only a question of resources and priority.
TerraSAR-X, in fact, is able to electronically steer the antenna azimuth pattern. This capability, together with the high flexibility of the satellite commanding, has offered the opportunity to implement on the satellite the TOPSAR acquisition mode.
The azimuth resolution reduction in both ScanSAR and TOPSAR (compared to the stripmap mode) is caused by a shorter target illumination time. In ScanSAR this is achieved by illuminating targets with only a small portion of the antenna pattern [3]; in TOPSAR the shorter target illumination is obtained by steering the azimuth antenna pattern from back to forth, in an opposite fashion as in spotlight. The aim of using a sweeping azimuth pattern is to have each target being seen under the same antenna pattern, independently from its azimuth position in the burst image. By using this approach, the scalloping effect is drastically reduced and the distributed target ambiguities noise ratio (DTAR) and the signal-to-noise ratio (SNR) become nearly constant in the azimuth direction within the burst image [1].
In this paper, after a short TOPSAR and inverse TOPSAR introduction, scalloping analysis performed on TOPSAR, inverse TOPSAR and ScanSAR images acquired by TerraSAR-X are reported. The measured values are then compared with respect to theoretical values.

2 TOPSAR and inverse TOPSAR

The basic principle of TOPSAR is the shrinking of the azimuth antenna pattern as seen by a target on ground. This is obtained by steering the antenna in the opposite direction as for Spotlight.
For the resolution, SNR and DTAR performance, the driving parameter is the shrinking factor. However, since the antenna gain is symmetric, the same antenna shrinking can be obtained steering the antenna in the

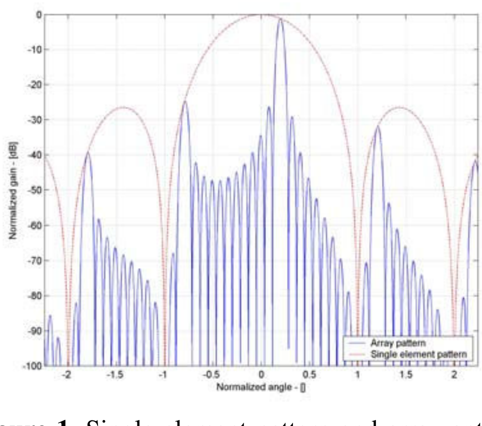


Figure 1. Single element pattern and array antenna pattern for a pointing angle corresponding to a normalized angle of 0.2. The array antenna pattern is amplitude weighted by the single element pattern and grating lobes are present.

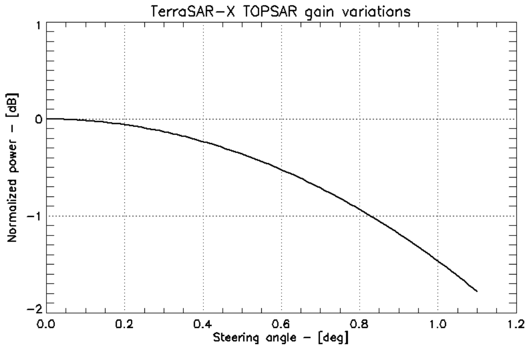


Figure 2. TOPSAR main lobe gain variation depending on the steering angle for TerraSAR-X. The power variation is normalized to the boresight case.

same direction as in Spotlight (but with a rotation center in between platform and illuminated scene). Therefore, wideswath images can be acquired also in an inverse TOPSAR mode.

Both TOPSAR and inverse TOPSAR have the same burst length for a given resolution and integration beamwidth [4], therefore larger steering angles are required in inverse TOPSAR, which results in an increased scalloping effect when compared with nominal TOPSAR mode. In fact, the larger the steering angle, the bigger the scalloping effect.

3 Scalloping analysis

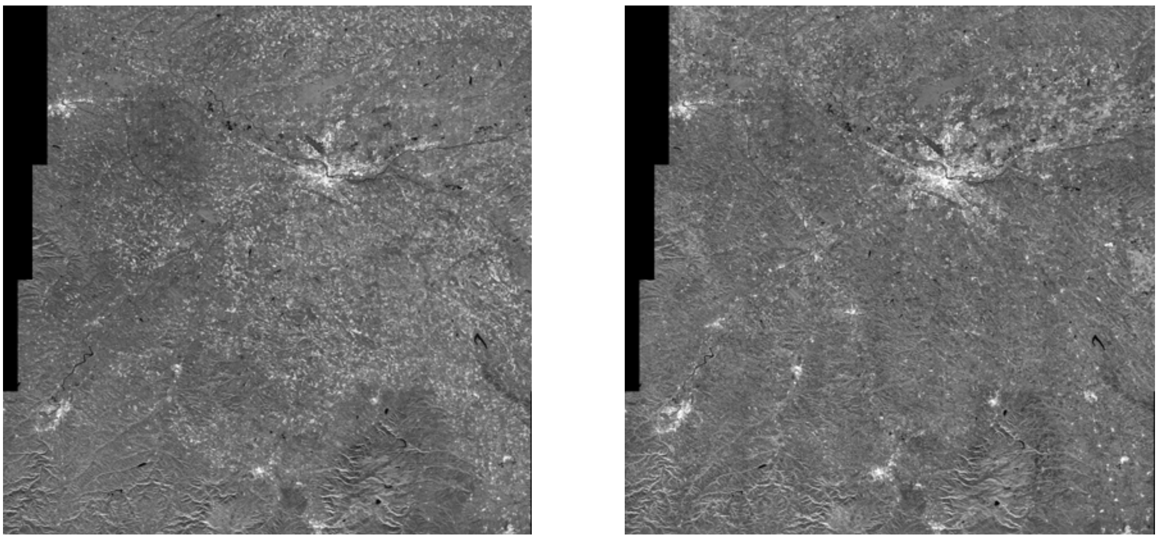
In TOPSAR mode, the scalloping effect is induced by the reduced gain of the main lobe for squinted angle, when phased array antennas are used to perform the steering of the azimuth pattern, (see Fig. 1) and this value is usually much smaller than in ScanSAR [2]. Typical values for TerraSAR-X are shown in Fig. 2. Residual TOPSAR scalloping can be removed with conventional techniques, i.e. Doppler centroid based azimuth pattern correction. Furthermore, being TOPSAR bursts much longer than in ScanSAR, scalloping removal is less sensible to inaccuracy in the Doppler centroid knowledge. In order to have TOPSAR raw data with negligible scalloping, an increased number of transmitting modules are required in the antenna array, given a certain total antenna length. This aspect should be an element to take into account in the design of future spaceborne SAR payload.

An experimental phase preserving TOPSAR processor has been developed at DLR-HR [5][6] and it has been used for the processing of the images shown in this paper.

3.1 TOPSAR image

A nominal TOPSAR image is shown in Fig. 3a. It has been acquired over Toulouse, France on August 7th, 2007. The scene size is approximately 90 km in azimuth and 75 km in slant range. Azimuth resolution is 16 m. The data take has been commanded with four subswaths and nine bursts. In all the pictures shown in this paper, slant range is on vertical direction, azimuth on the horizontal direction.

The commanded steering angle is between plus and minus 0.52 degree. However, a burst overlap has been introduced during the commanding as safety margin; therefore the burst image without overlap has been



a) b)

Figure 3. TOPSAR image (a) acquired by TerraSAR-X over Toulouse, France. Over the same area and with the same geometric and system configuration, an inverse TOPSAR (b) data take has been acquired. Scalloping is hardly visible in the TOPSAR image, while instead it is possible to notice intensity gain variation at the edges of the bursts in the inverse TOPSAR image. This is due to the lower variation of the burst image steering angle in the TOPSAR image compared to the inverse TOPSAR mode.

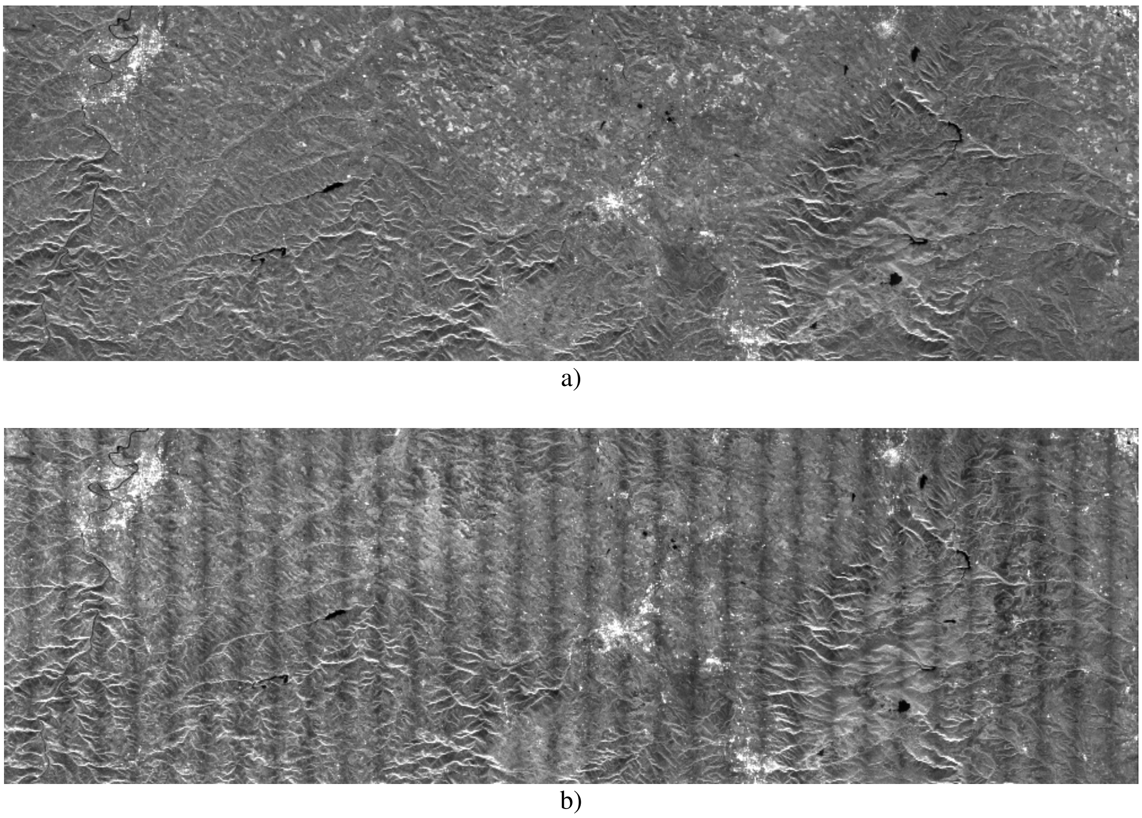
acquired with an azimuth steering angle variation of plus minus 0.47 degree.
No weighting has been applied in the overlapping region nor has scalloping correction (antenna azimuth pattern correction) been performed; therefore the picture shown is the "true" TOPSAR image.
Due to the low variation of the steering angle, the scalloping effect is hardly visible and it has been quantified to approximately 0.3 dB, see Fig 5a.

3.2 Inverse TOPSAR image

An inverse TOPSAR data take has been acquired by TerraSAR-X on September 9th, 2007, over the same Toulouse area and with the same geometric (orbit, look angle, range and cross-range extension) and system configuration (number of swaths, PRFs, transmitted bandwidth). The processed inverse TOPSAR image is shown in Fig. 3b.
The commanded steering angle is between plus and minus 0.73 degree and a burst image without overlap has been acquired with an azimuth steering angle variation of plus minus 0.68 degree. Also this picture is showing the "true" TOPSAR image without scalloping correction. A small scalloping effect is visible in the inverse TOPSAR image. A variation of approximately 0.7 dB has been measured from the generated azimuth profile (reported in Fig 5b) and this value corresponds well to the expected performance from Fig.2. Therefore, as shown from this comparison and as expected from theoretical evaluations [5], TOPSAR mode is always preferable to inverse TOPSAR mode in systems with electronic steering array antennas.

3.3 ScanSAR image

In order to have a consistent data set for image analysis, a ScanSAR image has been acquired over Toulouse area, again with the same system and geometric configuration, on September 20th, 2007. To cover the same azimuth extension, thirty-three ScanSAR bursts were necessary, compared with nine used in the TOPSAR and inverse TOPSAR mode.
The first subswath has been extracted from both the ScanSAR and TOPSAR data take and processed without any scalloping correction. The results are shown in Fig. 4. The measured scalloping in the ScanSAR intensity image is around 1.2 dB. Figure 5 reports a comparison of the intensity azimuth profile of the images analyzed in this paper. The advantage in using TOPSAR technique in terms of scalloping and therefore signal to noise ratio is clearly visible.



a)

b)

Figure 4. TOPSAR (a) and ScanSAR (b) comparison. The first subswath of the two data take acquired over Toulouse has been processed. No scalloping correction has been performed. The measured scalloping in the ScanSAR image is around 1.2 dB, compared to 0.3 dB in the TOPSAR image. Thirty-three ScanSAR bursts were necessary in contrast to only nine required by the TOPSAR. The advantage in using TOPSAR technique in terms of scalloping and therefore signal to noise ratio is clearly visible.

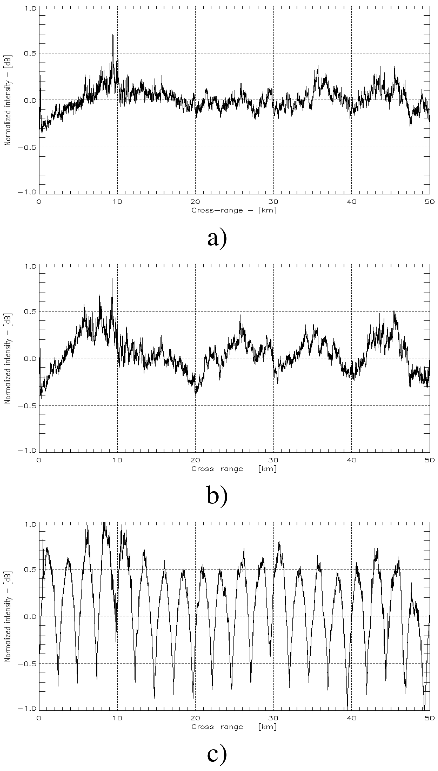


Figure 5. Intensity azimuth profiles extract from part of the first subswath of the TOPSAR (a), inverse TOPSAR (b) and ScanSAR image (c).

4 Sentinel 1 TOPSAR simulation with TerraSAR-X

Sentinel-1, the European Space Agency SAR satellite [7], is foreseen to use TOPSAR acquisition mode as baseline for wide range interferometric applications. TerraSAR-X has demonstrated in space the performance of TOPSAR mode. A Sentinel-1 like mode has been implemented with TerraSAR-X and a wide coverage TOPSAR data take having more than 250 km swath ground coverage (Sentinel-1 configuration) has been simulated with three TerraSAR-X TOPSAR acquisitions with 20 m resolution in cross-range. The mosaicked image is shown in Fig.6. The TOPSAR data takes have been acquired over the northern area of France.

5 Conclusions

The paper has reported on the latest TOPSAR results obtained with TerraSAR-X. A comparison of TOPSAR, inverse TOPSAR and ScanSAR images has been quantitatively analyzed in terms of scalloping. The measured values of the intensity variation of the analyzed images correspond very well with the expected theoretical values. Scalloping in the TOPSAR image is 0.3 dB against 1.2 dB in the ScanSAR image. Additionally, fewer bursts are required in TOPSAR, which also positively affects the image quality.

Figure 6. Simulated Sentinel-1 TOPSAR image obtained with three TerraSAR-X TOPSAR acquisitions in order to cover a ground range swath of 250 km with a cross-range resolution of 20 m.

An operational TOPSAR implementation into TerraSAR-X is technically feasible.

Acknowledgments

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