First demonstration of Azimuth Phase Coding Technique by TerraSAR-X

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Abstract

The disturbance generated by ambiguous echoes is at the origin of a basic limitation of Synthetic Aperture Radar (SAR) spaceborne imaging: the trade-off between spatial resolution and swath extension. A tool to overcome this limitation is provided by ambiguity suppression techniques. Among these techniques, the Azimuth Phase Coding (APC) shows the appealing properties of having a low complexity and being effective against ambiguities originated by both point and distributed targets. Despite the number of investigations on the APC concept published in the last years, a proof of its capability based on real data is still missing in the literature. This paper focuses on the first APC test experiment based on real spaceborne SAR data. The experiment, realized by using the satellite TerraSAR-X, is described and its principal numerical results are presented.

1 Introduction

The key role played by spaceborne Synthetic Aperture Radar (SAR) in remote sensing and Earth observation is testified by the amount of missions started in the last years and planned for the future, e.g. ALOS-PALSAR, TerraSAR-X, COSMO-SkyMed, RADARSAT, TanDEM-X, Sentinel-1, PAZ [1]-[5]. In fact, SAR images are today an established essential tool for geological, hydrological, oceanographic, agricultural, urban and environmental applications, such as ice and water dynamics analysis, vegetation classification, biomass and moisture retrieval, environmental threats and disasters monitoring. Nevertheless, a basic limitation still affects current SAR imaging: high spatial resolution and wide coverage are contradicting requirements, which cannot be simultaneously satisfied without a degradation of the other image quality parameters [6]. In particular, a disturbance due to range and azimuth ambiguities arises.

In order to solve this basic limitation of current SAR systems a number of methods have been proposed, which enable mitigating the effect of the ambiguities [7]-[9]. Among the techniques for ambiguity suppression, the one proposed by Dall and Kusk [9], denoted as Azimuth Phase Coding (APC), stands out for its indiscriminate applicability to point and distributed range ambiguities and its low implementation complexity. In more detail, the APC is based on three main steps: i) azimuth phase modulation on transmission; ii) azimuth phase demodulation on reception; iii) filtering of the SAR azimuth signal over the processed Doppler bandwidth. The modulation and demodulation produce a frequency offset between the spectrum of the useful signal and that of the range ambiguity. Then, in presence of Doppler oversampling, the final step (iii) allows eliminating the range ambiguous signal power located outside the processed Doppler bandwidth [9].

The appealing properties of the APC have motivated theoretical investigations on the applications of the technique for future multichannel SAR systems [10], [11], and suggest the necessity to evaluate the inclusion of the APC technique in the forthcoming or even, if possible, in the currently operational SAR missions.

In April 2013 an experiment was executed by the German Aerospace Center (DLR) using TerraSAR-X to demonstrate the APC ambiguity suppression capability, for the first time with real spaceborne data. This paper describes the implementation of this experiment (concept, SAR system parameters, choice of acquisition scenes) and reports its first results.

2 Experiment Description

The experiment is conceived in order to evidence the APC capability of suppressing range ambiguities in SAR images. Accordingly, proper acquisition scenarios were defined, where conventional SAR images characterized by strong range ambiguity disturbance could be obtained. Over each of the selected sites a couple of SAR acquisitions, with a separation of few days, were

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made: one with APC and one without APC, i.e. conventional. For this couple of images all the acquisition parameters (except for the time) are equal. Consequently, it is expected that an eventual SAR image quality improvement, observable in the APC image with respect to the conventional one, could only be due to the APC.

All the acquisition parameters (radar and hardware settings, imaged regions) were accurately selected in order to obtain a conventional SAR image with a very poor range ambiguity-to-signal ratio (RASR). First of all, the imaged swath was located in far range and the Pulse Repetition Frequency (PRF) chosen to be as high as possible. In fact, this brings the range ambiguities angularly closer to the useful signal, i.e. stronger, since weighted in average with a higher power. Moreover, the high PRF makes an eventual disturbance induced by azimuth ambiguities negligible. This is important in order to ensure that the disturbance seen in the conventional SAR image is indeed due to range ambiguities. Then, the imaged area and the radar polarization were selected such that the imaged swath has a low backscatter coefficient with respect to that of the area producing the ambiguous echo.

The TerraSAR-X parameters of interest used for the experiment are summarized in Table 1. The selected acquisition test sites are two strips of about 17 km x 60 km, located on the coasts of the Victoria and Titicaca lakes. They are shown in shown in Fig. 1 und Fig. 2: the white central rectangle delimits the imaged swath of interest, the two laterals the ambiguous regions, i.e. the areas where the range ambiguous echoes are originated.

The imaged swath comprises in both cases mainly calm water, with corresponding ambiguous areas consisting of land and cities. The difference in backscatter between signal of interest and ambiguity was amplified by the choice of a HH po-larization

Acquisition operational mode	Stripmap
Swath look angle [deg]	41,3 – 42,4
PRF [Hz]	6442
Polarization	HH
Processed Doppler Bandwidth [Hz]	2762

Table 1: TerraSAR-X parameters.

Regarding the APC implementation, the APC was designed to suppress the range ambiguities of odd order, since the first-order ambiguities provide the dominant disturbance [9]. Accordingly, the APC modulation phase assumes alternately the values 0 and $-\pi/2$. This phase modulation has been implemented in TerraSAR-X by switching, from pulse to pulse, between two azimuth patterns having the same amplitude but a phase difference of $\pi/2$. The APC phase demodulation has been implemented in software, including it at the very beginning of the SAR processing chain.

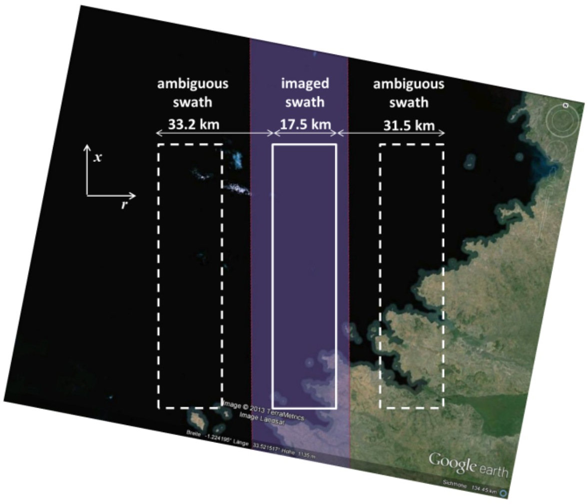

Figure 1: Acquisition area over Lake Victoria. Range, *r*, and azimuth, *x*, directions are reported.

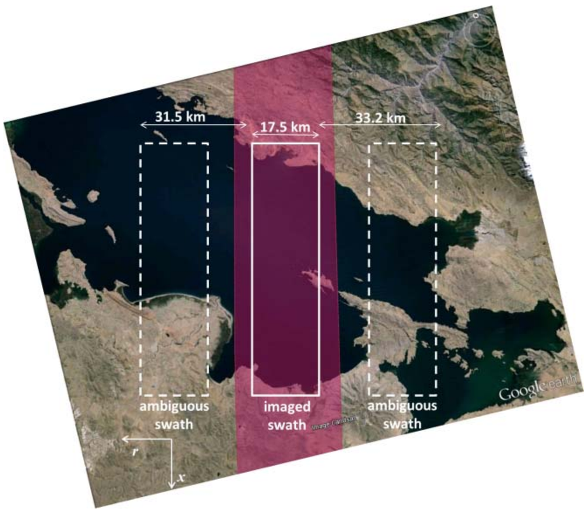

Figure 2: Acquisition area over Lake Titicaca. Range, *r*, and azimuth, *x*, directions are reported.

The suppression performance of APC depends on the Doppler oversampling, i.e. the ratio between PRF and processed Doppler bandwidth. For the experiment, the nominal processed Doppler bandwidth of TerraSAR-X (2762 Hz) was considered, which corresponds with an oversampling of 2.3.

3 Experiment Results

Fig. 3 shows TerraSAR-X images over Lake Victoria, obtained from standard Single Look Complex (SLC) products by mooltilook processing: the conventional image is on the left, the one with APC on the right. A comparison of the conventional SAR image (Fig. 3, left)

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with the acquisition area reported in Fig. 1 allows distinguishing the land surface within the imaged swath of interest (white region on the lower-right part of the image) from the sea (dark grey) and range ambiguities (bright grey regions). Moreover, it is easy to recognize that the ambiguous echoes are generated, as expected, from the land surface in the rectangle on the right in Fig.1. The comparison between the two images in Fig. 3 demonstrates that in the image obtained with APC (Fig. 3, right), the ambiguities have completely disappeared.

Fig. 4 shows the other realization of the experiment, over Lake Titicaca. Also in this case the APC suppression capability is confirmed: the ambiguities, well visible in the conventional image, disappear completely in that with APC.

As explained in the introduction, the APC produces a frequency displacement between the spectrum of the useful signal and that of the range ambiguity [9]. In particular, the useful signal is not modified by the APC, whereas the ambiguity is shifted. In our case a shift of PRF/2 is expected. In order to verify this property of the APC, the azimuth spectrum of the acquired TerraSAR-X data was analyzed. In particular, the SLCs were generated by processing the raw data with a bandwidth equal to the PRF (not with the 2762 Hz of the previous results). This was done in order to have access to the entire unambiguous spectrum. Then, three different blocks of samples of the SLC data were selected: one corresponding with the water, one with the ambiguity, one with the actual land. Then the azimuth spectrum, Power Spectral Density (PSD), was evaluated as modulus square of the Fourier Transform (FT) of the azimuth samples within the block, averaged in range direction.

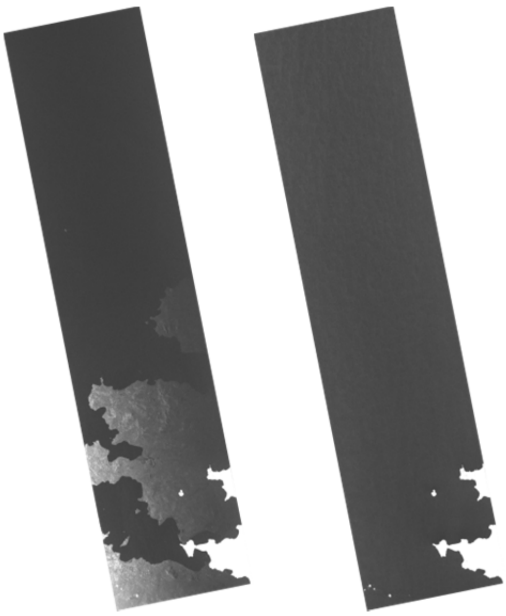

Figure 3: TerraSAR-X images at Lake Victoria: left conventional, right with APC.

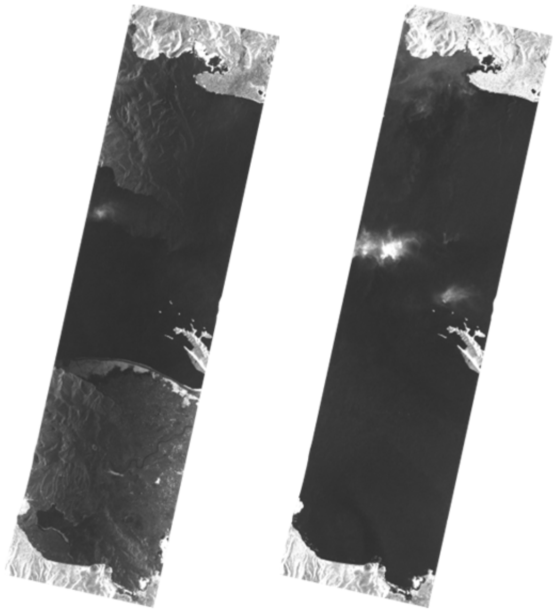

Figure 4: TerraSAR-X images at Lake Titicaca: left conventional, right with APC.

The results for the acquisition over Lake Victoria are shown in Fig. 5 and Fig. 6 for the conventional and the APC data, respectively. The represented unambiguous frequency interval corresponds to the PRF = 6442 Hz. The shadow in the center represents the Doppler processed bandwidth, 2762 Hz. The azimuth spectrum of the water is denoted by the blue, dash-dotted line; that of the ambiguity by the green dashed; that of the actual land in by the red, solid. The comparison between Fig. 5 and Fig. 6 shows clearly the shift of PRF/2 of the spectrum of the ambiguity, as also the invariance of the actual land and the water. (The other differences in the shapes of the spectra are assumed to be due to the fact that the couple of SAR acquisitions over Lake Victoria were performed with a few days of delay). The fact that the ambiguous spectrum, with APC, falls outside the processed bandwidth justifies the suppression of the disturbance.

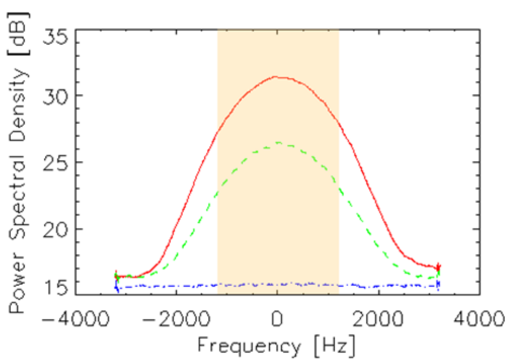

Figure 5: Spectra from the SAR SLC data without APC: land (red, solid), ambiguous land (green, dashed) and water (blue, dash-dotted). Lake Victoria.

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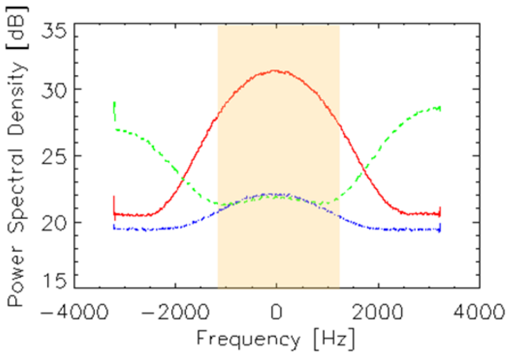

Figure 6: Spectra from the SAR SLC data with APC: land (red, solid), ambiguous land (green, dashed) and water (blue, dash-dotted). Lake Victoria.

In order to evaluate the entity of the ambiguity suppression, homogeneous blocks in correspondence with the ambiguities, were selected in the SLC images, for the case of conventional acquisition and APC acquisition. Then, the ratio between the average intensity of the samples within the blocks was computed in the two cases. A maximum suppression of about 15 dB (depending on the local backscatter coefficient) was measured.

4 Conclusions

In April 2013, an experiment was developed by DLR using TerraSAR-X to demonstrate the APC ambiguity suppression capability, for the first time with real spaceborne data. For this experiment two sites were considered: one at Lake Titicaca and the other at Lake Victoria. Both the characteristics of these imaged sites as also the radar system parameters were accurately selected in order to obtain high range ambiguity disturbance in a conventional SAR image. On each site both a conventional SAR acquisition and an acquisition based on the APC technique were performed. The obtained SAR images, as well as the analysis of their spectral and intensity properties, confirm the high suppression capability of the APC technique in presence of oversampling and its suitability for relaxing the system design constraints. This suggests the convenience to provide with the APC the forthcoming or even the currently operational SAR missions.

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