SAR Cross-Ambiguities in SAOCOM-CS Large Baseline Bistatic Configuration

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Abstract

The evaluation of the ambiguity-to-signal ratio (ASR) plays a key role in the Synthetic Aperture Radar (SAR) design and performance prediction. In conventional SAR acquisition scenarios, the computation of the ASR is based on the evaluation of the range and azimuth ambiguous contributions. Though appealing for its simplicity, this approach could be inaccurate in case of complex SAR acquisition geometries. In this paper we focus on the ASR performance of the SAOCOM-CS system in large baseline bistatic (LBB) configuration, extending a previous performance analysis by investigating the effect of cross-ambiguities.

1 Introduction

Synthetic Aperture Radar (SAR) ambiguities denote disturbing echoes, intrinsically associated with the SAR pulse transmission and Doppler processing [1]. The power of the ambiguities superimposes that of the useful signal, producing a degradation of the SAR imaging performance. Accordingly, the ambiguous power level must be limited below a proper value in order to guarantee a satisfactory quality of the generated SAR image. As a matter of fact, the power of the ambiguities is strictly related to the most important SAR parameters, such as antenna size, pulse repetition frequency, acquisition geometry. This explains the relevance of the evaluation of the SAR ambiguity level, in order to properly design a SAR system and predict its achievable imaging performance.

The SAR ambiguity level is usually expressed in terms of ambiguity-to-signal ratio (ASR) [1]. The value of the ASR has a simple mathematical expression for the conventional acquisition scenario, i.e. based on a monostatic SAR system with planar antenna and negligible squint. Specifically, in this case, the ASR could be decomposed in range and azimuth ambiguity-to-signal ratio (RASR and AASR). The range ambiguities account for echoes from preceding and succeeding pulses, which arrive at the antenna simultaneously with the echo of interest. The azimuth ambiguities account for a backfolding (aliasing) of the Doppler spectrum of the signal of interest over the processed bandwidth, associated with the *discrete-like* pulse transmission and reception. In the conventional acquisition scenario, each of these components can be easily evaluated independent of each other by considering a simple two-dimensional geometrical model [1]. Nevertheless, this simple approach could provide only a first approximate evaluation when a more complex acquisition configuration is involved, such as in the case of long baseline bistatic (LBB) or high-squinted geometries [2, 3]. In this case in fact, the location of the ambiguous sources (iso-range and iso-Doppler lines) as well as the shape and symmetry of the pattern change with respect to the conventional acquisition scenario. As a consequence, the RASR and AASR could provide only a partial description of the ambiguous returns. A more accurate evaluation should account also for the influence of cross-ambiguities, i.e. of the disturbance generated from preceding and succeeding pulses, received concurrently with the signal of interest, and having a Doppler frequency folding back over the processing bandwidth due to the azimuth sampling.

In a previous paper [4], we analyzed the overall SAR imaging performance achieved in a LBB configuration by SAOCOM-CS, the spaceborne mission proposal based on the Argentinian L-band system SAOCOM and the European Space Agency (ESA) companion satellite (CS) [5]. This configuration is characterized by a baseline of about 250 km and a squint angle on receive up to 50°. Moreover, due to cost constraints, the receive pattern is much larger than the imaged swaths. Under these conditions, the effect of the cross-ambiguities can become no more negligible. In [4], a first evaluation of ASR was provided, based on the range and azimuth ambiguities. In this paper we extend the analysis in [4], by investigating the effect of cross-ambiguous echoes. First, the considered SAR system parameters and acquisition geometry are recalled. Then, with reference to this scenario, the issue related to an accurate computation of the ASR performance in complex acquisition configurations is discussed and numerically analyzed.

2 Reference Scenario

The geometrical and instrumental parameters of interest for the considered reference SAOCOM-CS formation are summarized in Table 1: both satellites fly in the same orbit, with the same velocity, separated by a 250 km along-track-only baseline. The swaths, illuminated by SAOCOM and imaged in stripmap mode, are located along SAOCOM 0-Doppler. On receive (Rx), the CS antenna is mechanically pointed toward the swath of interest. Specifically, the Rx antenna squint varies between 50° and 30° from near to far range.

Fig. 1 shows the considered timing diagram: the swaths (brown vertical segments) cover the interval ranging from 17.6° to 35.6° incidence angle, with a swath extension between 20 and 27 km except in the very far range where the swath extension reaches only 14 km; the PRF used to illuminate them belongs to the interval 3400 Hz - 4350 Hz. A fully polarimetric operation is assumed.

A remarkable characteristic of the formation is that the antenna length and height on Rx are more than three times shorter than on transmit (Tx). As a consequence, the Rx pattern embraces a much wider area than the illuminated swath of interest. Moreover, the high-squint on Rx affects the pattern symmetry. This can be seen in Figs. 2 and 3, which show the Tx and Rx pattern plane projection versus the SAOCOM look angle at 0-Doppler and the along-track distance (SAOCOM is at 0° look angle and 0 km along track distance, CS in 0° and 250 km; the pattern level is normalized and expressed in dB). These aspects make the system possibly vulnerable to undesired echoes, generated outside the swath of interest. Specifically, cross-ambiguities can become critical.

PARAMETER	UNIT	VALUE
Orbit Height	[km]	627
Along-Track Baseline	[km]	250
Polarization		quad
RF Center Frequency	[MHz]	1275
Proc. Dop. Bandwidth	[Hz]	1050
Tx Antenna Height x Length	[m] x [m]	3.47 x 9.97
Rx Antenna Height x Length	[m] x [m]	1.10 x 2.92

Table 1: SAOCOM-CS formation main parameters.

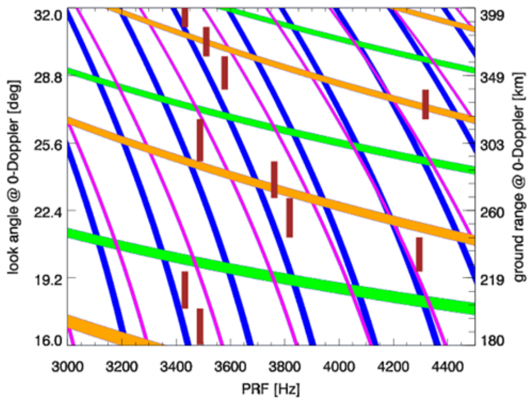

Figure 1: Timing diagram. Green stripe: nadir echo at SAOCOM; blue stripe: Tx event; orange stripe: specular-nadir echo; magenta stripe: direct-signal; brown segments: swaths. Look angle and ground range at SAOCOM 0-Doppler. (The considered swath allocation is based only on SAOCOM constraints [4].)

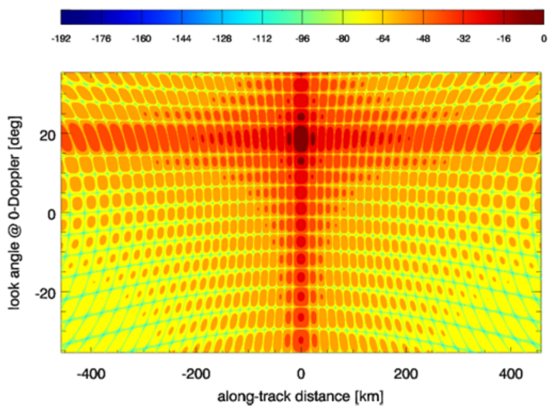

Figure 2: Swath 2. Transmit pattern plane projection vs look angle at SAOCOM 0-Doppler and along-track distance from SAOCOM.

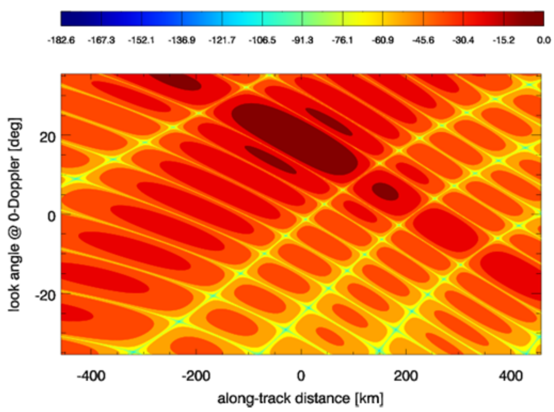

Figure 3: Swath 2. Receive pattern plane projection vs look angle at SAOCOM 0-Doppler and along-track distance from SAOCOM.

3 Cross-Ambiguities Analysis

A qualitative evaluation of the effect of cross-ambiguities in SAOCOM-CS LBB can be derived from a map of the ambiguous bistatic iso-Doppler and iso-range lines over the antenna two-ways pattern plane projection. This representation provides a useful tool since the ambiguous sources are located along the iso-Doppler and iso-range lines [1, 4], and the power received from the ambiguous sources is weighted from the antenna two-ways pattern.

Such a map is shown in Fig. 4 with reference to the 2nd swath. The black solid lines denote the bistatic two-ways iso-range lines, whose distance differs by a multiple of 87 km = c_0/PRF (c_0 denoting the light speed). The black dotted lines denote the bistatic iso-Dopplers, whose frequency differs by a multiple of the effective pulse repetition frequency (PRF) of 1716 Hz (the effective PRF is half of the Tx PRF, due to the assumed fully polarimetric operation). As further evidenced in Fig. 5, the useful signal, at the center of the illuminated swath, is located at the intersection of the bistatic iso-Doppler and iso-range, with Doppler frequency -10.418 kHz and two-ways range distance 1364 km, respectively. The corresponding range ambiguous sources are located along the bistatic iso-Doppler (-10.418 kHz) passing through the center of the swath, at the intersection with the iso-range lines. The azimuth ambiguous sources are located along the bistatic iso-range line (1364 km) passing through the center of the swath, at the intersection with the iso-Doppler lines [1, 4]. All the other intersections between iso-range and iso-Doppler lines correspond to cross-ambiguities.

Fig. 5 remarks also the effect of the polarization. In fact, due to the fully polarimetric operation (pulse-to-pulse polarization switch in transmission), the ambiguities are received in co- or cross-pol, depending on their order of ambiguity. This influences the disturbance level induced by the ambiguity. Specifically, the co-pol return has a much higher backscatter coefficient with respect to the cross-pol.

The inspection of these maps for all the imaged swaths suggests that the cross-ambiguities are not critical. Specifically, they are definitely much weaker than the azimuth ambiguities. Moreover, they are generally weaker or comparable with respect to the range ambiguities. Though, in this case, exceptions are possible. This is highlighted in Fig. 6, which shows two pattern cuts, extracted from Fig. 4, respectively for the iso-Doppler at -10.418 and -8.702 kHz, as well as the corresponding ambiguous sources. As it can be seen, at 1451 km and 1539 km two-ways slant range, the cross-ambiguities are weighted by a much stronger (about 15 dB and 30 dB, respectively) pattern than the corresponding range ambiguities.

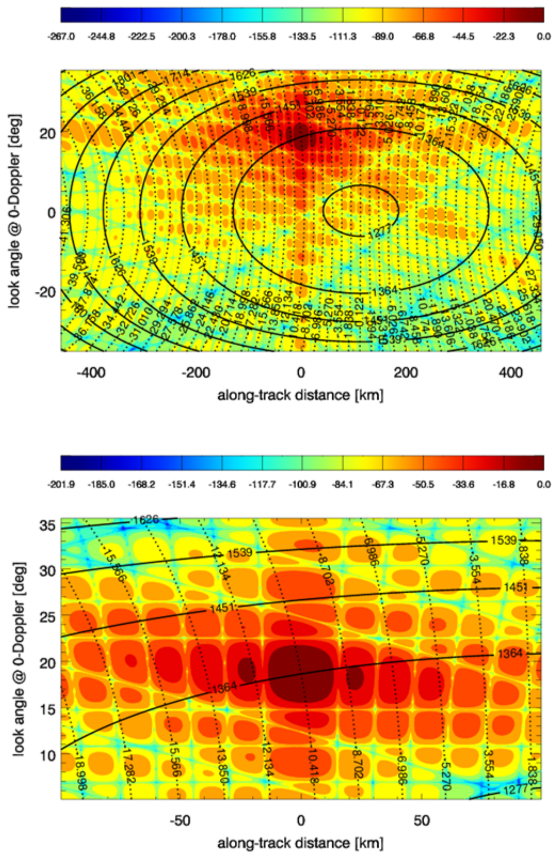

Figure 4: Swath 2, wide (top) and zoomed (bottom) vision. Two-ways pattern plane projection vs look angle at SAOCOM 0-Doppler and along-track distance from SAOCOM. Iso-range lines (solid lines) and iso-Doppler (dotted lines). Pattern level in dB.

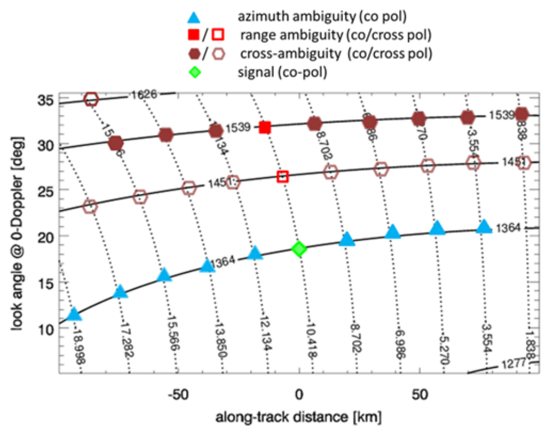

Figure 5: Swath 2, zoomed vision. Iso-range lines (solid lines) and iso-Doppler (dotted lines). Useful signal and corresponding ambiguities are marked by symbols. The symbols are empty for cross-pol reception, full for co-pol (with reference to the co-pol SAR image).

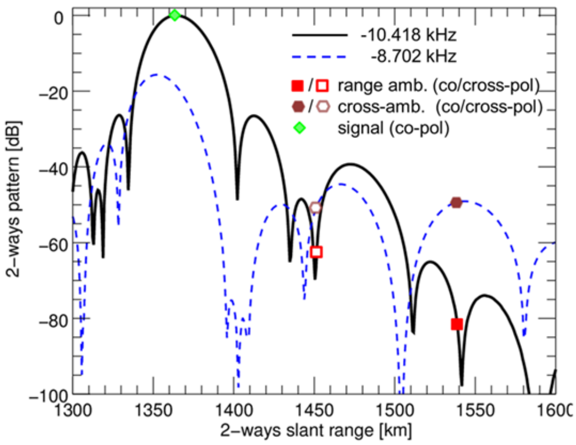

Figure 6: Swath 2. Two-ways pattern cuts over the signal iso-Doppler -10.418 kHz (solid black line) and over the ambiguous iso-Doppler -8.702 kHz (dashed blue line). The pattern values weighting the useful signal and the ambiguous sources are marked by symbols.

A quantification of the effect of the cross-ambiguities in terms of ASR requires the computation of the ratio between the power of the ambiguities and that of the useful the signal. In the following, the ASR for the cross-ambiguities and range ambiguities is computed and compared. It is worth to remark that this computation is not based on isolated vertical cuts of the pattern, as those represented in Fig. 6, but an integration over the processed Doppler bandwidth is involved [2]. In fact, isolated cuts allow computing the RASR in the conventional acquisition scenario [1]. Nevertheless, for a LBB geometry, the stated integration is involved even for the RASR, due to the more complex spatial distribution of the pattern and of the iso-range and iso-Doppler lines.

Fig. 7 shows the RASR and, as comparison, the RASR increased by the cross-ambiguities along the imaged swaths. Both the co-pol and cross-pol SAR images are considered. In both images, the disturbance induced by the cross-ambiguities is evident for the first two swaths in near range, but becomes less marked proceeding to far range. Indeed, for the last far range swaths, it is almost negligible. The main reason is related to the acquisition geometry. In fact, starting from the 3rd swath, the range ambiguity of order +1 (the first in far range) starts to be mapped in the first sidelobe of the two-ways pattern. Moreover, the range ambiguity of order -1 (the first in near range) appears and is weighted by a comparatively strong pattern. As a consequence, the RASR contribution gains dominance. This effect is even more accentuated starting from the 7th swath. Here in fact, the range ambiguity of order -1 starts to be mapped in the first sidelobe of the two-ways pattern, and a range ambiguity of order -2 appears (Fig. 8).

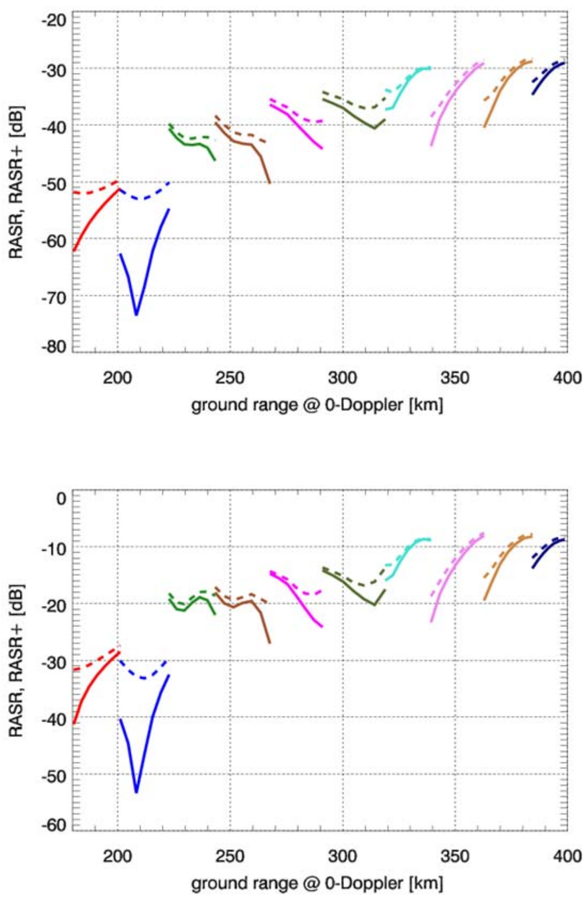

Figure 7: RASR (solid lines) and RASR+ (dashed lines), i.e. RASR increased by the cross-ambiguity contribution, vs ground range at SAOCOM 0-Doppler. Co-pol (top), cross-pol (bottom) SAR image.

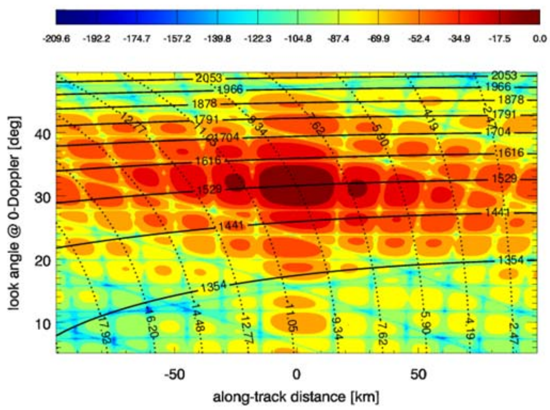

Figure 8: Swath 10. Two-ways pattern plane projection vs look angle at SAOCOM 0-Doppler and along-track distance from SAOCOM. Iso-range lines (solid lines) and iso-Doppler (dotted lines). Pattern level in dB.

4 Conclusions

The effect of cross-ambiguities on SAOCOM-CS SAR imaging performance in LBB configuration has been discussed and analyzed with reference to an acquisition scanario based on a 250 km along-track-only baseline, and a stripmap full polarization operational mode.

The obtained results show that the cross-ambiguities are negligible with respect to the azimuth ambiguities, but are not always negligible with respect to the range ambiguities. Specifically, a comparison between the RASR and the RASR increased by the cross-ambiguities contribution evidences a performance degradation until 20 dB in the near range swaths; whereas the degradation is almost negligible in far range. It must be remarked, that the far range swaths are those characterized by the worst RASR performance, and indeed they set the limit on the achievable performance over the full access range. As a consequence, the limit on the ASR achievable performance over the full access range is not affected by the cross-ambiguities.

References

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