Performance Investigation on the High-Resolution Wide-Swath SAR System with Monostatic Architecture

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Abstract

The High-Resolution Wide-Swath (HRWS) Synthetic Aperture Radar (SAR) system, promoted by EADS Astrium GmbH, has been object in the last years of intensive studies for his capability to overcome the conflict between azimuth resolution and swath width of conventional SAR. The original choice of a bistatic solution for the system architecture has been recently reconsidered and is currently oriented towards a monostatic approach. The paper reports a performance analysis on the HRWS SAR system with monostatic architecture.

1 Introduction

Increasing interest is currently directed toward Smart Multi-Aperture Radar Techniques (SMART) for high resolution, wide swath Synthetic Aperture Radar (SAR) imaging [1-4]. The SMART SAR systems are characterized by the employment of multiple transmit/receive channels and of Digital Beam-Forming (DBF) techniques. This allows for a relaxation of SAR system design constraints, higher imaging quality and above all a mitigation of the trade-off between swath width and spatial resolution inherent to conventional SAR.

Among SMART SAR, the system promoted by EADS Astrium GmbH, denoted as High-Resolution Wide-Swath (HRWS), merges the advantages of an extensive illumination capability with the sensitivity offered by an antenna with high gain and directivity, and combines the flexibility of a multi-channel architecture with a limited download data volume [4, 5]. The HRWS SAR system is based on an algorithm for steering of the elevation receive beam pattern, called SCan-On-REceive (SCORE): a large swath is illuminated by using a wide, static transmit beam; whereas in reception the DBF is employed in order to obtain a sharp and high gain pattern, which follows the pulse echo as it travels along the ground swath. The conflict between swath width and azimuth resolution is overcome by using multiple phase centers located along the azimuth direction, according to the Displaced Phase Center Antenna (DPCA) technique.

The different requirements on the transmit (tx) and receive (rx) patterns suggested initially the use of two physically separated antennas, in order to guarantee an independent design and optimization of the instruments [6]. Nevertheless the costs associated to the employment of an additional antenna and a reduced flexibility inherent to the bistatic architecture have brought to reconsider the monostatic option [3]. Recent studies on the possibility to obtain wide beams by using wide apertures, without degradation of the radiated power, confirm the advisability of a monostatic approach [7].

The paper reports a study on the performance of the new reference HRWS SAR system with monostatic architecture.

2 Reference Monostatic System

For performance analysis the reference HRWS SAR system described in Table 1 has been considered.

Table 1 Parameters of the reference HRWS system.

Parameter	**Value**
Orbit Height	520 km
RF Center Frequency	9.600 GHz
Average Transmit Power	2171 W
Transmit Bandwidth	<= 408 MHz
Total Losses	8.38 dB
Polarization	Full Pol.
Antenna Height	1.06 m
Antenna Length	8.75 m
Total Nr. Elevation Radiating Elem.	48 (4x12)
Total Nr. Azimuth Radiating Elem.	35 (5x7)
Nr. Elevation Receive Channels	12
Nr. Azimuth Receive Phase Centers	7

As shown in the Table, the monostatic architecture is realized by using the same planar phased array antenna both in transmission and reception. The antenna is 1.06 m high and 8.75 m long, and is uniformly subdivided along both directions in singular radiating elements. The DPCA is implemented by using 7 phase centers uniformly displaced along the length of the antenna. The large elevation size of the antenna allows, in reception, to obtain a sharp elevation pattern; SCORE algorithm is implemented by using 12 channels uniformly displaced along the elevation direction. In transmission, a broadening of the elevation and azimuth patterns is obtained by a pure phase excitation, according to the Phase Spoiling technique. A plot of the elevation and azimuth patterns is shown in Figure 1 and 2, respectively.

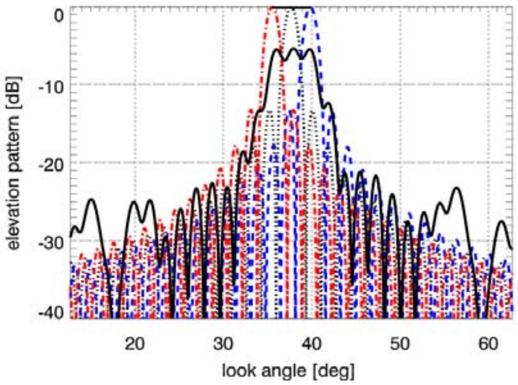

Figure 1 Normalized elevation pattern: transmit pattern (solid line); SCORE receive pattern steered in 3 different directions along the illuminated subswath (dash-dot, dotted, dashed lines).

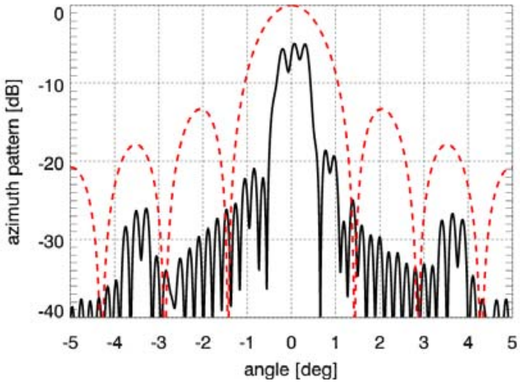

Figure 2 Normalized azimuth patterns: transmit (solid line); receive (dashed line).

3 Phase Spoiling

The use of a monostatic architecture is strictly related to the employment of the Phase Spoiling (PS) technique. In fact, the PS technique offers the possibility to utilize the whole antenna in transmission, alleviating constraints on the antenna thermal design and the radiated power [7]. Against these advantages, the PS has some peculiarities, which require to be carefully considered in SAR processing. In fact, unlike patterns obtained by typical tapering (Uniform, Hanning, Hamming, Dolph-Chebyshev), spoiled patterns are complex, with non-linear, irregular phase. Fig. 3-4 show the phase of the tx spoiled patterns, whose amplitude is represented in Fig. 1-2.

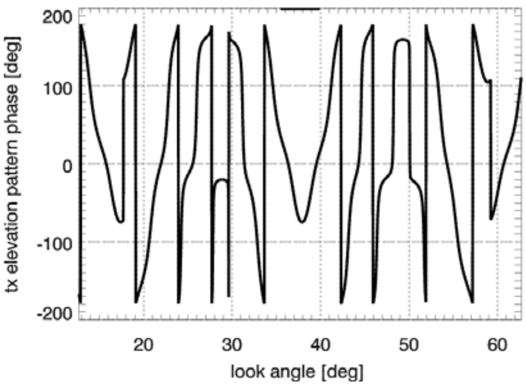

Figure 3 Transmit elevation pattern phase.

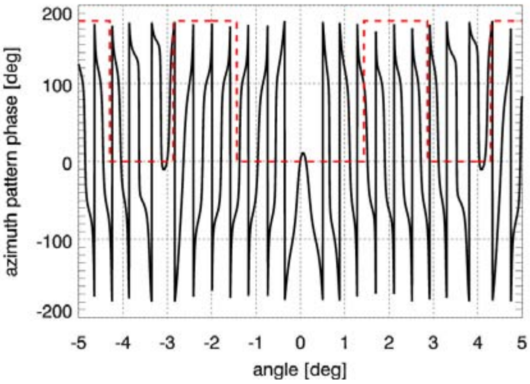

Figure 4 Phase of the azimuth patterns: transmit (solid line); receive (dashed line).

The spoiled pattern phase affects the SAR imaging. The range Impulse Response Function (IRF) of a point target, located at look angle $\bar{\vartheta}$, presents an additional phase equal to that of the elevation transmit pattern in $\bar{\vartheta}$. More in general, the SAR image shows an additional, range dependent, phase component, which is given by the phase of the mainlobe of the elevation transmit pattern. This component should be carefully considered and eventually corrected in SAR applications, such as Interferometry. In azimuth, the transmit pattern phase produces a distortion of the azimuth IRF and a degradation of the azimuth resolution. For the reference system, a degradation of the resolution of a factor approximately equal to 3 was observed. To counteract this effect a compensation for the azimuth pattern phase should be introduced in the azimuth focusing. The approach here proposed is based on the correction for the mainlobe azimuth pattern phase in the reconstructed multichannel Doppler signal before focusing. Fig. 5 shows a comparison between the distorted and corrected azimuth IRF.

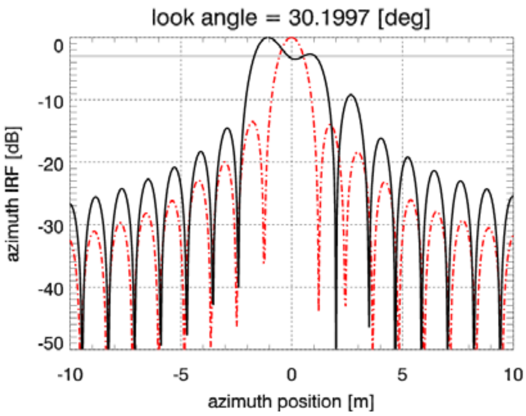

Figure 5 Azimuth IRF: azimuth tx pattern phase not corrected (solid line), corrected (dash-dot line).

The necessity to know the (mainlobe) pattern, in order to properly process the SAR data, imposes to evaluate the robustness of the spoiled pattern to possible disturbance on the taper coefficients. The spoiled pattern behavior in the presence of disturbance is investigated through Monte Carlo simulations. The amplitude/phase errors on each complex taper coefficient are modeled as additive, Gaussian, zero mean, independent and identically distributed random variables.

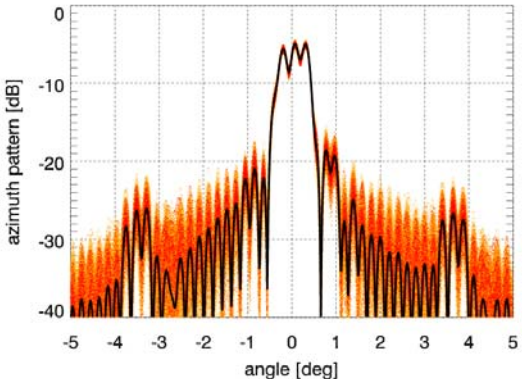

Figure 6 Azimuth pattern amplitude: noise-free (solid line); superposition of 1000 noisy realizations (dot).

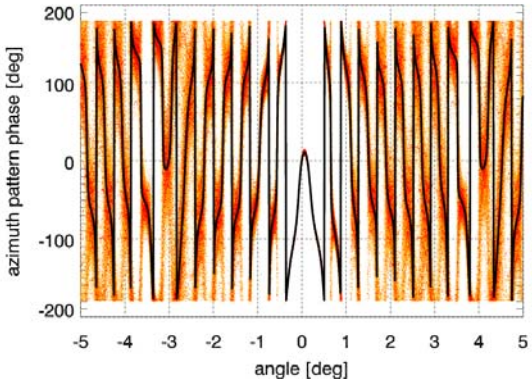

Figure 7 Azimuth pattern phase: noise-free (solid line); superposition of 1000 noisy realizations (dot).

For typical disturbance values, the main features of the spoiled patterns show negligible variations; especially the mainlobe region is stable. Fig. 6 -7 show the amplitude and phase of the azimuth pattern in the presence of an error with standard deviation on the taper phase and amplitude of 6 deg and of 0.5 dB, respectively.

4 Performance Analysis

The reference HRWS SAR system is designed in order to obtain, in Stripmap mode, a spatial resolution <= 1 m and a swath width >= 70 Km, over an access range of 20°- 50° incidence angle. The total access range is covered by 7 partially overlapping subswaths, each one associated to a specific PRF value, selected within the interval 1595 Hz -1795 Hz according to the timing constraints.

Figures 8 -11 report the performance of the reference HRWS SAR system, operating in Stripmap mode, over each subswath. As shown in Figure 8, the reference system achieves a Noise Equivalent Sigma Zero (NESZ) below -20 dB along all the access area. The curve of the distributed target range ambiguities is reported in Figure 9: a Range Ambiguity Signal Ratio (RASR) below -27 dB could be achieved over all the access range. The Azimuth Ambiguity Signal Ratio (AASR), corresponding to an azimuth resolution <= 1.05 m, is shown in Figure 10: the AASR is below -21.8 dB for all the 7 subswaths. Figure 11 shows the SCORE Pattern Loss (SPL) [8] associated to a backscattering surface with elevation of 1 km, when no topographic information is conveyed in the steering mechanism: the worst degradation is of -0.5 dB.

The reported performance results, obtained in Stripmap mode, are aligned with those assessed for the bistatic HRWS system [6]; with respect to the bistatic system, the use in reception of an antenna with shorter height, allows for an improved SPL [8].

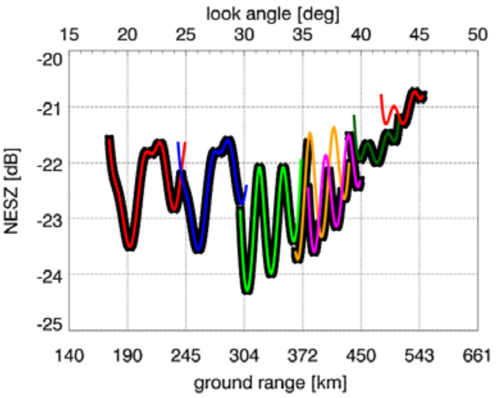

Figure 8 NESZ vs. ground range and look angle.

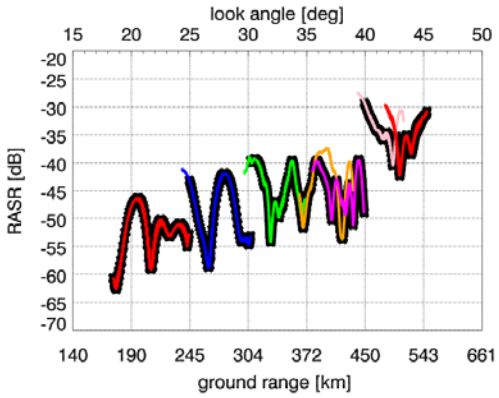

Figure 9 RASR vs. ground range and look angle.

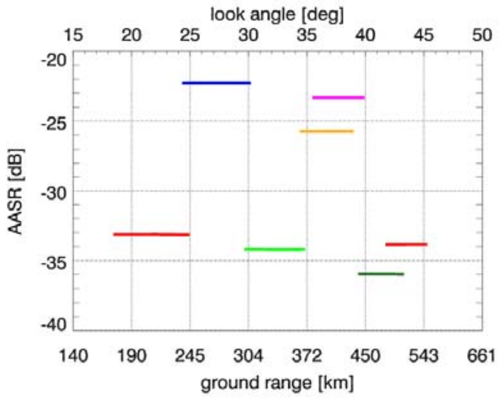

Figure 10 AASR vs. ground range and look angle.

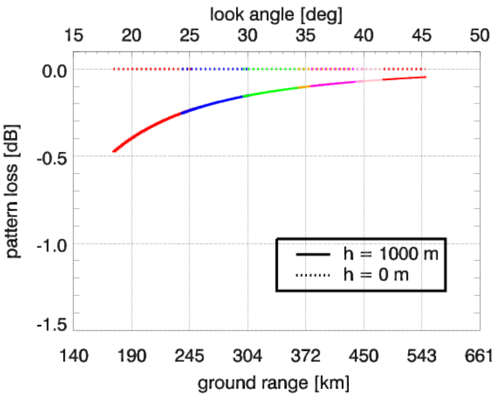

Figure 11 SPL vs. ground range and look angle.

5 Conclusions

An analysis on the achievable performance in Stripmap mode of the HRWS SAR system with monostatic architecture has been presented. The performance results obtained in Stripmap mode are aligned with that of the bistatic HRWS SAR. Moreover, insights about the impact of the Phase Spoiling technique on SAR processing have been discussed. The reported analysis confirms the advisability of a monostatic approach.

References

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