# Precise SAR Antenna Pointing Determination using Phase Coherent Difference Images

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## Abstract

Most modern spaceborne SAR systems are equipped with a phased array antenna to adjust the antenna beam to the acquisition geometry to gain best performance and to increase the access area. An antenna model can be used to predict the radiation pattern of the SAR antenna based on the selected antenna excitation coefficients which reduces the effort and time compared to verifying each single antenna pattern individually. The predicted patterns only need to be verified for certain samples after the model is initially aligned with the real SAR antenna. One challenge for future SAR missions employing large deployable reflector antennas, like ESA's BIOMASS or DLR's Tandem-L is that due to the large antenna structure the antenna alignment is no longer fixed but may change within a short period of time. This makes traditional antenna pointing determination using homogenous distributed targets like the Amazon Rainforest inapplicable, as pointing variations along the orbit are untraceable due to a lack of suitable targets which are not evenly spread over the Earth. A novel technique is proposed which allows precise pointing determination also over inhomogeneous areas using phase coherent difference images to extract the elevation antenna pointing. First results using TerraSAR-X acquisitions will be shown to verify the technique.

## 1 Introduction

The antenna model approach is widely used ([1], [2]) to minimize the verification effort during commissioning phase. One important step is the alignment of the antenna model to the real SAR antenna called antenna pointing determination. While for most planar phased array antennas the antenna pointing can be assumed fixed to the spacecraft body (e.g. as seen on Sentinel-1 [3]) large deployable reflectors (LDRs) as proposed for BIOMASS [4], NiSAR [5] or Tandem-L [6] add additional pointing uncertainties due to finite stiffness of their huge structure. Traditionally SAR antenna pointing measurements in elevation direction are performed over homogeneous distributed targets like the Amazon Rainforest using an elevation notch pattern applied to the SAR antenna [7]. The homogenous nature of the target allows retrieving the notch pattern which is then averaged over azimuth to gain lower uncertainty.

This kind of homogeneous targets is unfortunately rarely spread over the Earth and cannot be used to monitor pointing variations over the orbit. A novel technique will be introduced using the phase coherent difference between images acquired with both a notch beam and a regular beam to mitigate the underlying heterogeneous scene reflectivity in the recorded antenna patterns. It is furthermore possible to benefit from the phase information between the images to detect the characteristic 180 degree phase jump of the notch pattern for precise elevation pointing determination.

## 2 Elevation Pointing Determination from Difference Images

Homogeneous distributed targets like the Amazon Rainforest are ideal targets for antenna pattern retrieval as they have only little intrinsic structure. This can be used to detect the steep null characteristic for a notch antenna pattern. After masking of interfering features like rivers and averaging in azimuth direction, a gamma profile can be derived from which the pointing is estimated [7]. When applied to non-homogeneous areas this approach fails due the inherent structure and unknown scattering mechanisms of the underlying scene.

Future advanced spaceborne SAR missions will employ digital beam forming (DBF) techniques to create the desired antenna beam. Digital beam forming uses the individual sampled signals from each antenna element to create one or more individual antenna beams using signal processing techniques. This allows a greater flexibility in optimizing the antenna beams [8]. Furthermore individual beams can be processed from one acquisition pointing to different areas. This feature will be employed by the novel technique to form a notch beam in addition to the regular beam over one scene. This allows using the regular beam to mitigate the influence of the underlying scene and to extract the characteristic features of the notch pattern.

A difference image can be formed from two recorded acquired images using the following expression:

$$S_{Difference} = S_{Notch} / S_{Regular} \tag{1}$$

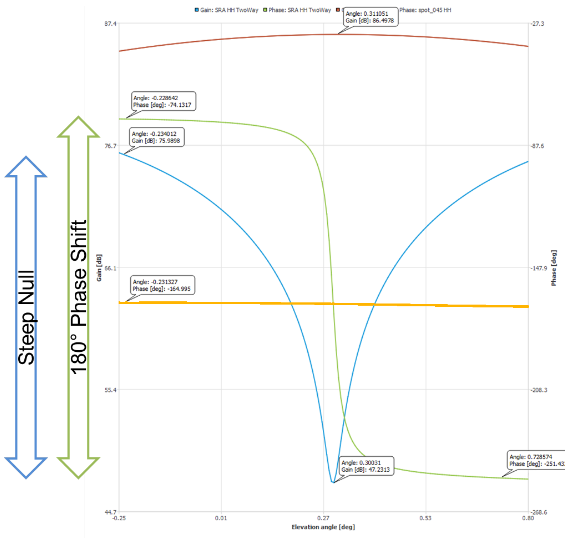


**Figure 1:** Theoretical antenna pattern of TerraSAR-X for a regular antenna beam (spotlight beam, power: red, phase: orange) and a notch beam (power: blue, phase: green). The logarithmic power scale is on the left and the phase scale in degree on the right.

where $S_{Notch}$ and $S_{Regular}$ are the complex-valued amplitudes of the focused notch and regular beam image, and $S_{Difference}$ is the resulting difference image. It can be easily seen that this operation results in a difference of the power in a logarithmic scale and a difference of the image phases. In case both images are generated from the same acquisition i.e. at the same instant of time,in addition to the proper image scene most effects like the propagation path, image geometry or instrument effects cancel out and purely the differences between the two commanded antenna pattern remains:

$$S_{Difference} = \frac{S_{Target} \cdot A_{Notch} \cdot A_{Propagation}}{S_{Target} \cdot A_{Regular} \cdot A_{Propagation}} = \frac{A_{Notch}}{A_{Regular}} \tag{2}$$

Eq. (2) describes simplified how effects like the target properties ($S_{Target}$) and the common propagation path ($A_{Propagation}$) cancel out while the complex antenna pattern amplitude ($A_{Notch}$ and $A_{Regular}$, $A_{Pattern} = \sqrt{g_{Pattern}} \cdot e^{\phi_{Pattern}}$, with $g_{Pattern}$ the antenna gain pattern and $\phi_{Pattern}$ the antenna phase pattern) remains.
From a practical point of view it is very advantageous to choose antenna patterns with characteristic differences for this method, like the proposed notch and high gain patterns. Figure 1 shows the theoretical notch and regular beam antenna pattern for the TerraSAR-X system used later. Besides the steep null in the notch pattern (blue curve), its characteristic 180 degree phase jump (green curve) is clearly visible. The difference image is expected to show both the notch and the phase jump while the effects of the underlying scene are significantly reduced.

# 3 Experimental TerraSAR-X Acquisitions

DLR's SAR satellites TerraSAR-X and TanDEM-X are equipped with very flexible SAR instruments which also allow the demonstration of advanced SAR techniques for future missions. To test the proposed pointing determination technique the aperture switching mode was utilized. In this mode the receive antenna pattern will be toggled for each radar pulse. This feature was used to simulate the acquisition of two images (regular beam and notch beam) with current hardware by an interleaved acquisition of the two required datasets.
The two acquired co-registered L1a images are shown in Figure 2. The impact of the notch is shown by the brighter edges compared to the mid. Additionally many (range) ambiguities appear due to the none optimized antenna pattern for the used timing (doubled PRF to acquire two images). The extraction of phase information from a single of the acquired images would not be meaningful since the unknown phase of the target is dominant.

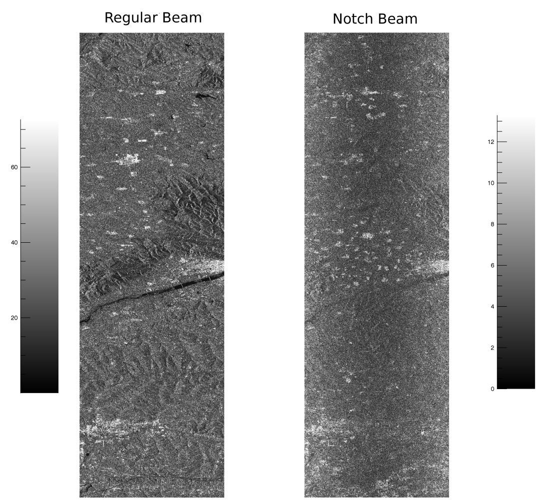


**Figure 2:** Image amplitudes over a non-homogeneous area in China using TerraSAR-X's aperture switching mode to acquire images using a regular (left) and a notch beam (right) simultaneously.

The difference image is shown in Figure 3 in amplitude and phase. In this plot the antenna pattern notch is better visible and the phase image clearly shows the location of the notch. The quality of the measurement becomes even more obvious when calculating the range profile i.e. averaging in azimuth as shown in Figure 4. A steep null of several 10 dB can be found in the power profile and also the 180 degree phase shift is at the expected location in the phase profile. The shown outcome results from a relatively short data take of only 57.6 km and with a setup producing many ambiguities. The performance of an optimized DBF SAR system is expected to be even superior. Nevertheless, the shown results already allow an elevation pointing determination down to an accuracy of only a few 10 milli degrees.

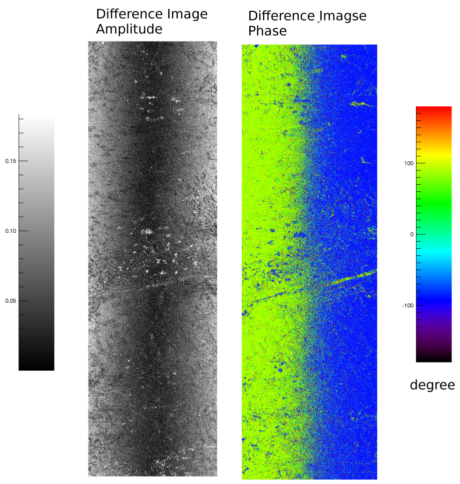


**Figure 3:** Difference image from the same scene as Figure 2. Left: amplitude, right: phase difference in degree.

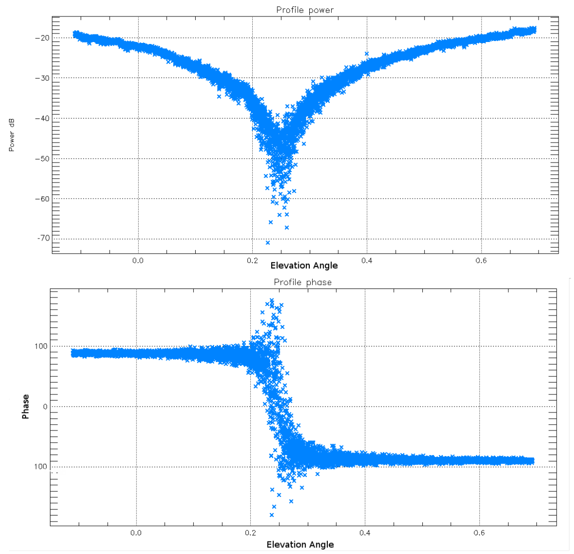


**Figure 4:** Range profile of the difference image acquired over a non-homogeneous area. Top panel: logarithmic power, bottom panel: phase in degree.

## 4 Conclusions

A novel approach for antenna pointing determination in elevation has been introduced. It uses phase coherent images acquired with different antenna beams, preferable with characteristic differences like a regular high gain beam and a notch beam. The approach allows also to exploit the phase information between the antenna beam patterns while mitigating the influence of the underlying scene significantly. The proposed method and the theoretical background has been introduced and first results using the fast switching capability of TerraSAR-X show the potential of the technique to monitor the beam pointing over non-homogeneous areas. This will enable future missions like BIOMASS, NiSAR and Tandem-L with not completely fixed antenna pointing to monitor the elevation beam pointing over small periods of time e.g. during an orbit.

## References

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