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Aerospace Science and Technology 6 (2002) 451–457

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Performance analysis of spaceborne SAR systems ☆

Reinhard Schroeder *, Helmut Suess, Karl-Heinz Zeller

DLR Oberpfaffenhofen, Institute of Radio Frequency Technology and Radar Systems, P.O. Box 1116, D-82230 Wessling, Germany

Received 10 October 2001; received in revised form 12 August 2002; accepted 30 August 2002

Abstract

This paper describes a software tool for performance analysis and parameter prediction for conventional and special SAR modes. Several aspects of design, performance analysis and parameter optimization for Spotlight and interferometric SAR systems are examined. After the description of relevant principles the synthesis of antenna dimensions and efficient modeling of parabolic reflector antenna patterns are demonstrated. The influences of range migration and yaw steering on the PRF selection are shown along with a design example. The tool presented here was used on the Shuttle Radar Topography Mission (SRTM) flown on the Shuttler Endeavour for the X-SAR performance prediction in the preparation phase and was also used in near realtime during the mission.

Keywords: Spotlight SAR; Interferometric SAR; SAR performance analysis; High resolution SAR

1. Introduction

After the end of the cold war the request for global reconnaissance systems increased due to the growing number of smaller but dangerous conflicts which are widespread over the various continents. Imaging systems for reconnaissance and surveillance on spaceborne platforms are able to fulfill most of the frequently requested user requirements:

- the information acquisition is non-harming and without geographical limitation,
- areas of interest can be observed continuously,
- the information age can be very short depending on the number of satellites and available data links.

The use of SAR sensors beside optical and infrared sensors yields further the advantages:

- the independence of the image acquisition on day time and weather conditions,
- the independence of the spatial resolution on the distance between target and sensor and the wave length,
- the wide accessable regions.

These facts make SAR sensors on spaceborne platforms a suitable candidate for a considerable part of the military user spectrum.

On the other hand, design and realization of SAR sensors on spaceborne platforms also reveal serious problems. The main problems are the enormous costs caused by the high technological requirements (e.g. space-qualification) and the overall complexity (e.g. launch of the satellite, ground segment, satellite control, ...). Another cost driving element are the phased array antennas which were succesfully used in previous SAR systems such as SIR-C/X-SAR and Radarsat to increase the flexibility and the efficiency of the system. As an alternative, reflector antenna systems can also be used which provide a sufficient radio frequency bandwidth for a much lower price.

The goal of this paper is the introduction of a design and analysis tool and the investigation of possible design examples with their limitations due to the constraints of the user requirements. Design efforts are complicated by the necessity to achieve an optimal efficiency of the SAR system with respect to the overall costs. As an example based on typical military requirements, the following data set for the most important image quality parameters has been used:

Spatial resolution < 1 m
Radiometric resolution < 2 dB
Ambiguity level < 25 dB
Dynamic range > 70 dB.

☆ This article was presented at ODAS 2001.

* Corresponding author.
E-mail address: helmut.suess@dlr.de (H. Suess).

1270-9638/02/$ – see front matter
PII: S1270-9638(02)01188-4

These specifications shall be valid for a system working in X-band (frequency $f_0 = 9.6$ GHz).

2. General approach of performance analysis

A fundamental step in the development and optimization of a SAR system is usually performed by an analytical assessment of the following image quality parameters: Spatial and radiometric resolution, signal-to-noise ratio, ambiguity ratios and dynamic range. The typical performance calculation is an iterative optimization process, which is depicted in Fig. 1. For the X-SAR/SRTM mission a special focus had to be directed of course to the interferometric performance. Two important parameters defining this performance are the relative height error and the absolute height error in the digital elevation model.

The different levels of performance calculations are characterized by the corresponding system features and software modules, respectively. The software tool used in this paper is embedded into a graphical user interface and offers a variety of visualization tools to support the optimization process (Fig. 2).

To reduce the necessary number of iterations, the first set of system parameters should be close to the final solution. This can be performed with a separate software tool for parameter synthesis. A possible concept for deriving the first system parameter set is given in [1]. This concept was derived for the conventional Stripmap SAR mode. A similar approach is also applicable to the Spotlight SAR mode which we illustrate here.

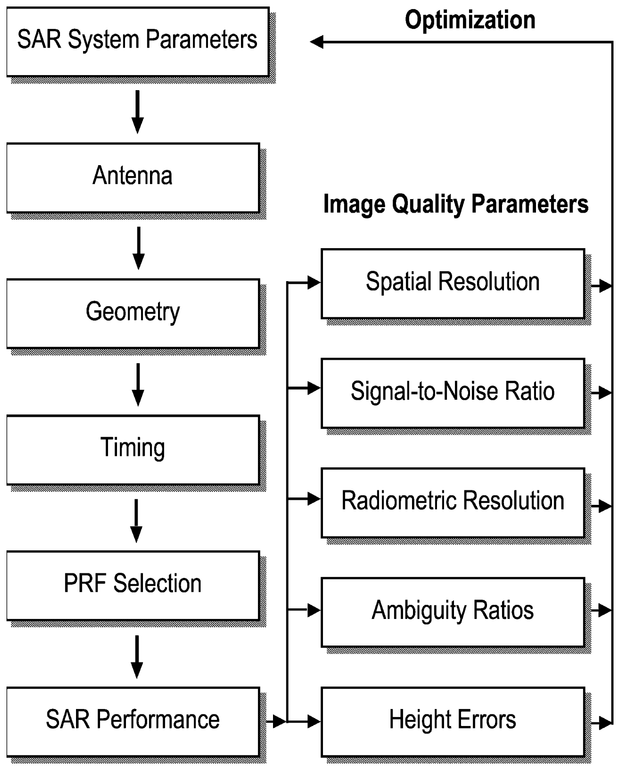

Fig. 1. Approach of performance analysis.

3. Antenna design aspects for spaceborne Spotlight SAR

For an example of a Spotlight SAR system (Fig. 3) some important design aspects will be demonstrated. Based on [1] the antenna dimensions for a Stripmap SAR can be derived as depicted in Fig. 4. For the case of a spaceborne Spotlight SAR the driving factor for the antenna length is not the azimuth resolution but the swath length S_a. A simplified approach to get the antenna dimensions is shown in Fig. 5.

As a design example, we assume the following parameters: Frequency $f_0 = 9.6$ GHz ($\lambda = 3.125$ cm), orbit height $H_{orb} = 666$ km, a range for the off-nadir angle from $\gamma_{near} = 25°$ to $\gamma_{far} = 45°$ and a swath length of $S_a = 5$ km.

If S_a is considered as the final image size, we have to account for pointing inaccuracies during the synthetic aperture. So we assume a 3-dB azimuth footprint $F_a = 1.4 \cdot S_a = 7$ km.

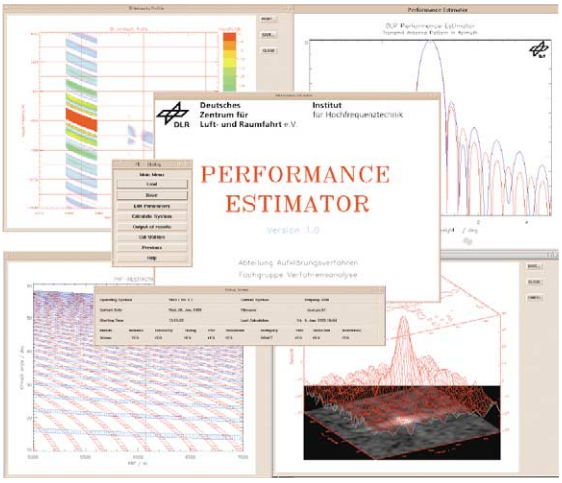

Fig. 2. Graphical user interface.

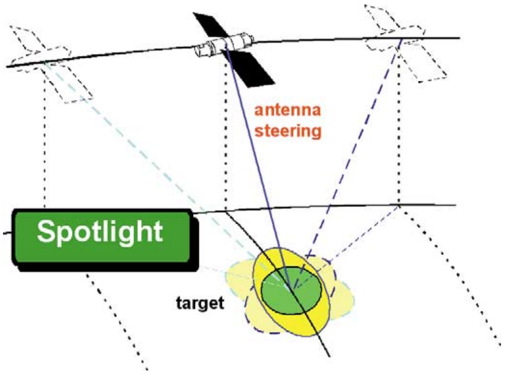

Fig. 3. Spotlight SAR geometry.