A CONCEPT FOR HIGH PERFORMANCE REFLECTOR-BASED SYNTHETIC APERTURE RADAR

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1. ABSTRACT

The success of current spaceborne Synthetic Aperture Radar (SAR) is boosting the performance requirement of next generation systems. In order to cope with the evolution of SAR, the design of the new systems will need to meet higher requirements for spacial and radiometric resolutions together with an increased availability. This tendency is recognized nearly independently of the application area and manifests itself through several study programs from different space agencies aiming at the design of future SAR systems. In this context the use of large reflectors combined with digital feed arrays for SAR is a highly attractive concept. This paper suggests a spaceborne SAR system utilizing a a deployable reflector together with a digital feed array and elaborates into the various design and operation issues together with the resulting instrument SAR performance.

2. INTRODUCTION

A review of several ongoing studies for the conception of next generation SAR systems, reveals the shared characteristic of being multi-channel systems utilizing digital beamforming techniques. Among those systems, the Tandem-L/ DESDnyI [1, 2] is a reflector based system utilizing a digital feed array designed to image a swath width of $300 - 400\,\mathrm{km}$. Such an architecture has the potential to combine both the flexibility and the capabilities of digital beamforming with the high antenna gain provided by a large reflector aperture. To lower the stowed satellite volume and weight, and therefore the launch costs, the reflector could be deployable. Unfurlable reflector antennas are a mature technology with extensive flight heritage in space telecommunications and satellites with lightweight mesh reflectors spanning diameters of more than $20\,\mathrm{m}$ deployed in space [3].

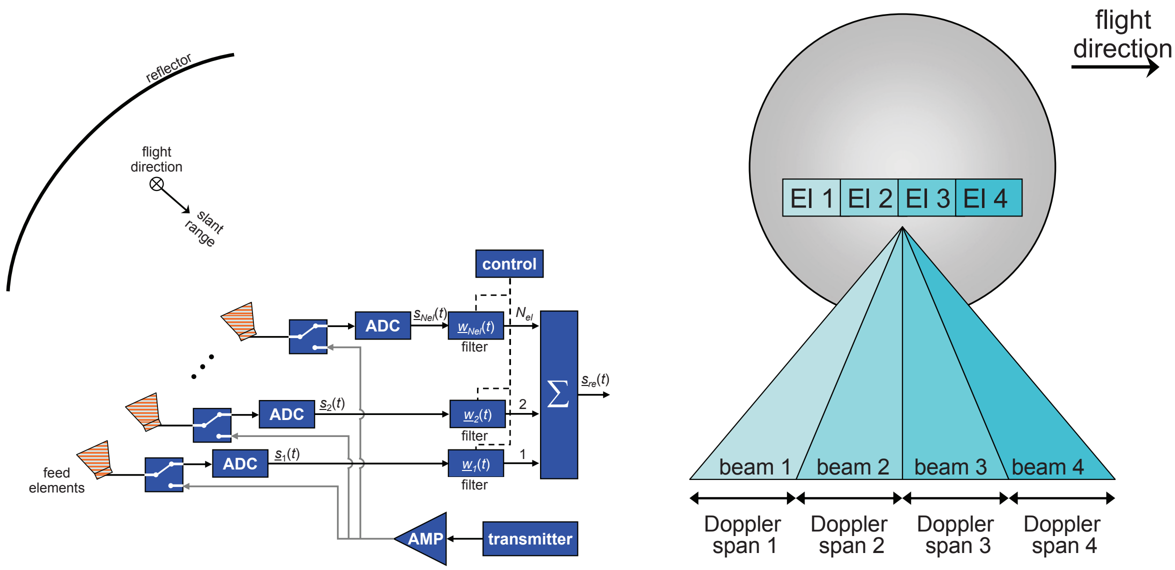
From the above it seems reasonable to consider reflector-based SAR systems for future, or at least to perform comprehensive trade analyses of reflector versus direct radiating array antennas. In [4] a planar and a reflector system were designed to a common set of performance parameters; the comparison revealed that the reflector system can be realized with a simpler hardware and shows a performance advantage of several dBs in terms of ambiguity and signal-to-noise ratio.

Nevertheless ongoing investigations also show that several particularities of reflector based systems have a non-negligible impact on the performance and for this need to be considered in the design. Among these are for example the trade trade between the elevation beamwidth versus antenna gain on one side and the purity of the resulting impulse response function versus the signal-to-noise performance on the other. It turns out that each individual performance aspect can be optimized either by adapting the hardware design, using appropriate techniques (modes), or adapting the signal processing. In case of the aformentioned gain versus beamwidth trade, for example, frequency- and time-adaptive digital beam-forming can be used to increase both parameters, however, at the expense of a higher on-board processing requirements.

Starting by an introduction of the basic design and operation of a reflector based SAR system the paper proceeds by addressing the various details of the design versus performance aspects and pointing out the interrelation between these aspects. This involves several novel techniques introduced to optimize the performance without neglecting the associated hardware complexity and the resulting data rate. The result is a reflector system design which takes into account the all performance aspects.

3. ARCHITECTURE AND OPERATION

In the following the digital beamforming technique and the corresponding system architecture is addressed. At first this will be given separately for the elevation and azimuth directions and then later combined in one system.



(a) digital beamforming in elevation

(b) digital beamforming in elevation

Fig. 1. System architecture for reflector system.

3.1. Digital Beamforming in Elevation

The system (in elevation) consists of a parabolic reflector and a feed array of transmit/receive elements, as shown in Fig. 1(a). The feed elements are arranged in the plane perpendicular to the flight direction and facing the reflector. Each element results in a beam, illuminating a region on the ground, which partially overlaps with the region illuminated by the beams of the adjacent elements. To illuminate a given angular segment in elevation the corresponding feed elements are activated. The receive beam will scan the complete swath within the time period of one PRI utilizing digital SCan-On-Receive (SCORE) mode of operation [5, 6]. Here each set of elements is only active during a subinterval of this time period.

3.2. Digital Beamforming in Azimuth

A reflector system of multiple azimuth phase channels will require multiple feeds displaced along a line parallel to the along track direction as shown in Fig. 1(b). Here each azimuth element “looks” at a different angle and by this the covers a distinct angular (Doppler) segment. Thus each element samples a narrow Doppler spectrum corresponding to the half-power-beamwidth of the corresponding pattern. The PRF must be high enough such that the spacial sampling for each channel is adequate. This is approximately given by $PRF > 2 \cdot V/D$ with the platform velocity V and the reflector diameter D. If the Doppler spectra of the elements are contiguous, they jointly yield a higher azimuth resolution $\approx D/(2N_{az})$. Here each of the N_{az} channels carries non-redundant information.

3.3. Elevation/Azimuth System Operation

The reflector SAR system will combine digital beamforming operation in elevation and azimuth through a 2-dimensional feed array consisting of $N_{el} \cdot N_{az}$ elements. The signals of the feed elements of each column (N_{el} elevation channels) are combined on-board using time variant complex coefficients $\underline{w}_i(t)$ to form the SCORE beam, which follows the pulse on the ground. Each of the resulting N_{az} data streams carry non-redundant information and are stored in the mass-memory for later on-ground processing. Actually here, since reflector based systems may be operated at high PRF values oversampling the Doppler spectrum on-board Doppler filtering may be used to reduce the data rate.

Reflector SAR systems are suitable for operation in Stripmap and ScanSAR operation modes; further they facilitate for hybrid operation modes which, for example, allow to simultaneously image a swath of high spacial resolution within an ultra-wide swath of low spacial resolution (c.f. [7] for advanced reflector operation modes). The system under consideration is operated in a multi-swath stirpmap mode.

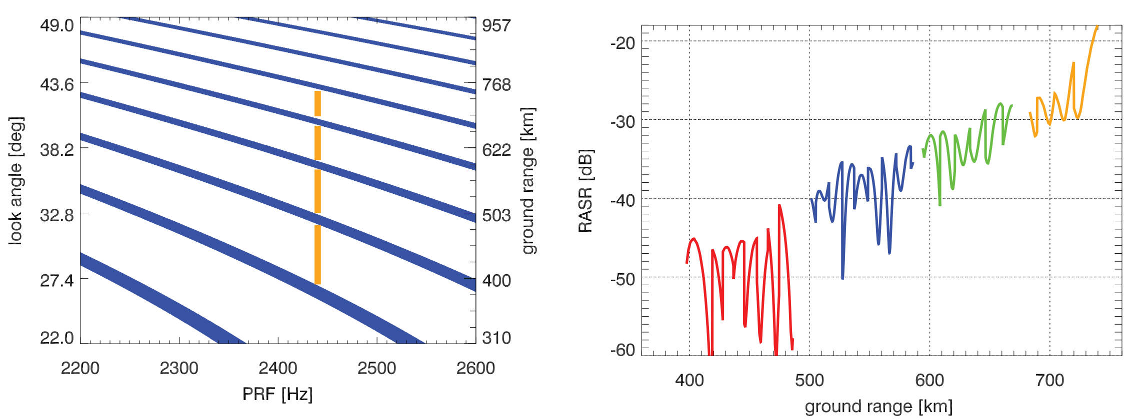
4. SAR PERFORMANCE PARAMETERS

The SAR performance of the system will is investigated in terms of the known parameters. In the following the parameters are listed and shortly commented.

- As shown exemplarily in Fig. 2(a) the timing allows to simultaneously image multiple sub-swathes. In the case that two or more sub-swathes are imaged, gaps, caused by the transmit instances, will appear in the final swath; depending on the application these gaps may be tolerated, or alternatively a variation of the PRF may be used the eliminate these gaps [7].

- Reflector Antenna Pattern: The receive and transmit antenna pattern is a crucial parameters for the performance. Different elevation beams are generated for transmit and receive. The pattern is influenced by the shape and focal length of the reflector and the offset of the feed array. Further the number of elements, separation and total length of the feed array must be optimized for a specific pattern.

- Range-Ambiguity-to-Signal Ratio: Usually reflector based SAR systems have very low range-ambiguity level, because of the low sidlobe level of the transmit beam and the narrow receive beam. This even facilitates the suppression of nadir returns to a level which allows a relaxation of the timing. On the other hand, high PRF values may be required to achieve azimuth performance, which worsens the range ambiguity performance (see Fig. 2(b) for an example).



(a) timing diagram

(b) range-ambiguity-to-signal ratio

Fig. 2. Example timing diagram and range-ambiguity-to-signal ratio for a $760\,\mathrm{km}$ orbit and four sub-swathes to cover a total swath of $355\,\mathrm{km}$.

- Azimuth-Ambiguity-to-Signal Ratio: As indicated in section 3.2 azimuth beamforming is rather different from conventional SAR systems. Further, since the flexibility available for azimuth pattern steering is not readily available for reflector systems. This requires careful design to achieve the required azimuth performance in terms of azimuth (Doppler) spectra overlap, oversampling and the processing approach.
- Noise-Equivalent Sigma-Zero: Although this performance parameter profits from the large reflector gain, but still other instrument and operation parameters influence its value. For example a small number of feed array elements would be activated to achieve a high receive antenna gain; however this would cause a narrow receive beam which –depending on the pulse duty cycle– might not cover the complete ground extension of the pulse.
- On-Board Beam-Forming: on board signal processing is required for SCORE operation. The underlying algorithms range from a very simple on/off turning of different feed elements to frequency-dependent time-varying complex weighting of the received signals. The necessary complexity to achieve a given performance depends on the instrument hardware and on-board processing/storage capabilities and is interrelated to all other performance parameters.

Further, dedicated performance parameters are introduced which are relevant for digital beamforming systems; specifically these are the pulse-extension-loss and score-pattern-loss, used to evaluate the effect of SCORE operation; and the range impulse response which characterizes the influence of the frequency dependent patterns.

5. REFERENCES

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