A DATA VOLUME REDUCTION STRATEGY BASED ON ON-BOARD DOPPLER FILTERING

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ABSTRACT

High-resolution wide-swath (HRWS) synthetic aperture radar (SAR) systems based on digital beamforming (DBF) in elevation are very attractive for the observation of dynamic processes on the Earth's surface. However, due to their resolutions and swath widths, HRWS systems are inherently associated with a huge data volume. Furthermore, a pulse repetition frequency (PRF) much higher than the required processed Doppler bandwidth is often desirable to comply with azimuth ambiguity requirements. The data volume can be significantly reduced, if on-board Doppler filtering and decimation are performed before downlinking the data. This paper presents different criteria for the design of the low-pass filter and shows that a finite impulse response (FIR) filter with a relatively small number of taps is sufficient to completely suppress the additional ambiguous components and recover the original impulse response, provided that a compensation of the filter transfer function is performed within the processing. This strategy is also applicable to staggered-SAR systems, where on-board Doppler filtering and resampling can be jointly implemented.

1. INTRODUCTION

Synthetic aperture radar (SAR) is a remote sensing technique, capable of providing high-resolution images independent of weather conditions and sunlight illumination and therefore very attractive for the systematic observation of dynamic processes on the Earth's surface. However, conventional SAR systems are limited, in that a wide swath can only be achieved at the expense of a degraded azimuth resolution [1]. This limitation can be overcome by high-resolution wide-swath (HRWS) systems based on digital beamforming (DFB) in elevation, where multiple swaths can be simultaneously imaged using multiple receive beams [2]. Moreover, if the pulse repetition interval (PRI) is continuously varied (staggered SAR), it is also possible to get rid of the "blind ranges", present between adjacent swaths, as the radar cannot receive while it is transmitting [3], [4].

Due to their resolution and coverage requirements, however, HRWS systems are inherently associated with a huge data volume, thereby increasing the demands for internal data storage, downlink, ground processing and archiving. Moreover, in order to comply with azimuth ambiguity requirements, a pulse repetition frequency *PRF* much higher than the required processed Doppler bandwidth B_p is often desirable. This determines a further increase of the data volume to be downlinked with a direct impact on the cost of the mission.

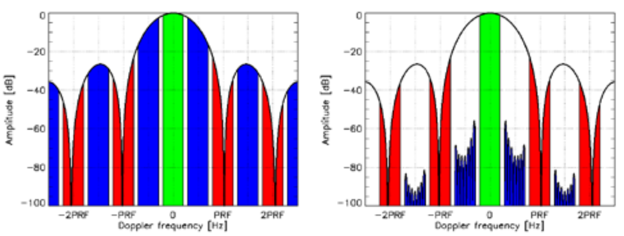
2. DATA VOLUME REDUCTION STRATEGY

If data were just decimated prior to downlink, a considerable degradation of the azimuth-ambiguity to signal ratio (AASR) would occur. Fig. 1 (a) shows the power spectral density of the azimuth SAR signal for a planar antenna of length L = 10 m and a wavelength λ = 0.2384 m (L-band). The unambiguous energy, the ambiguous energy and the additional ambiguous energy due to the decimation are highlighted in green, red, and blue, respectively. As is apparent, the additional ambiguous energy due to decimation is significant. However, if Doppler low-pass filtering is performed before decimation, the additional ambiguous energy due to decimation can be substantially reduced, as shown in Fig. 1 (b).

Due to the large amount of data, acquired by typical HRWS systems, the number of on-board operations per sample has to be minimized, while avoiding a degradation of the impulse response. The Doppler low-pass filtering can be performed in time domain using a finite impulse response (FIR) filter with a relatively small number of taps. The filter will introduce a distortion of the Doppler spectrum of the signal, which can be compensated for in the SAR processing (on ground).

3. LOW-PASS FILTER DESIGN

Different criteria for the design of the FIR low-pass filter are considered in the following, namely the FIR filter design by windowing, the FIR Wiener filter and a method based on the minimum variance distortionless response (MVDR) or Capon beamformer.



(a) (b)

Fig. 1 Power density spectrum of the azimuth SAR signal. The energy of the unambiguous component, the ambiguous components, and the additional ambiguous components due to decimation are highlighted in green, red and blue, respectively. (a) Only decimation. (b) Low-pass filtering and decimation.

The FIR filter design by windowing consists of obtaining the impulse response of the FIR low-pass filter by windowing the impulse response of the ideal low-pass filter [5]. Common windows are considered, namely rectangular, Bartlett, Hanning, Hamming, and Blackman. The transfer functions of the filters, obtained by using the five aforementioned windows and a ratio between B_p and *PRF* equal to 0.4, are represented in Fig. 2 for $M = 25$.

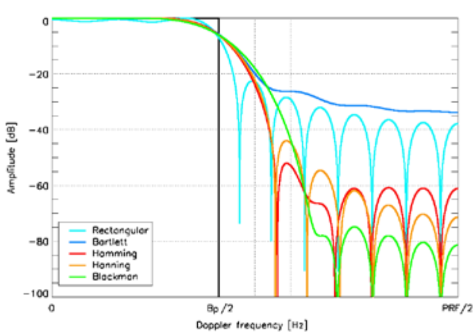


Fig. 2 Transfer functions of the filters, obtained by the five windows and using 25 taps. The transfer function of the ideal low-pass filter is shown in black.

As an alternative, the FIR filter could be also designed by exploiting the knowledge of the power spectral density (PSD) of the useful and disturbance signals. Two possibilities are the Wiener filter and the minimum variance distortionless response (MVDR) beamformer, for which the analytical derivation of the impulse response is presented in [6]. Fig. 3 shows the transfer functions of the 25-tap FIR Wiener filter and the 9-tap MVDR filter obtained for PRF = 1492 Hz and B_p = 600 Hz, assuming a uniformly-illuminated aperture of length L = 10 m and a satellite velocity v_S = 7473 m/s.

While both filters suppress the disturbance components, i.e., the frequencies which fold back when decimating, the Wiener filter also preserves the useful signal, i.e. the signal in the processed bandwidth. For that more taps are required to achieve the same attenuation of the disturbance components.

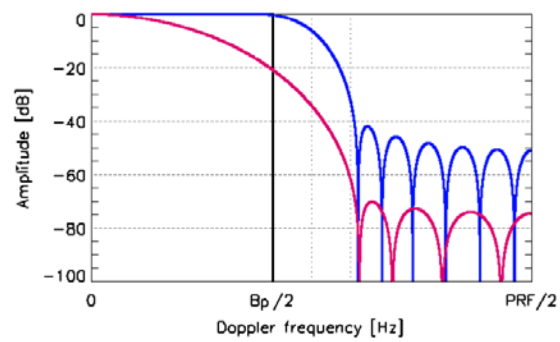


Fig. 3 Transfer functions of the 25-tap Wiener filter (blue) and the 9-tap MVDR filter (purple).

4. PERFORMANCE ANALISYS

The performance of a system, where the described data volume reduction strategy is implemented, is evaluated and compared with a reference system, where the data volume reduction strategy is not applied, i.e., all data are downlinked. A uniformly-illuminated aperture is considered. The relevant parameters of the SAR system are provided in Table 1.

Fig. 4 shows the azimuth impulse responses for the reference case (no data volume reduction) [Fig. 6 (a)] and for a reduction of the data volume by a factor of 2, where different filters have been used [Fig. 6 (b)–(d)].

The azimuth resolution and the azimuth peak-to-side lobe ratio (PSLR), are equal to 13 m and 31.3 dB, respectively, for the reference case, and remain unchanged for all filters, provided that the distortion of the Doppler spectrum of the signal, introduced by the low-pass filtering, is compensated for in the processing.

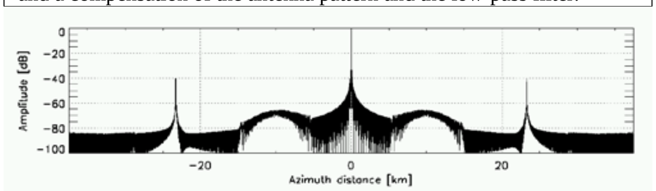
As far as azimuth ambiguities are concerned, it can be noticed that additional ambiguous peaks arise at ±11.5 km in the azimuth impulse response of Fig. 4 (b). This means that the low-pass filter does not provide a sufficient suppression of the frequency components, which fold back after decimation. In all other cases the level of the aforementioned additional peaks is lower than -60 dB, therefore negligible. An analytical expression of the AASR is provided in [6], where it is shown that the AASR composed of two terms, where the first term is the AASR for a system, where no data volume reduction is performed, while the second one represents the AASR degradation due to the on-board filtering.

Furthermore, it has to be remarked that no scaling of the signal-to-noise ratio (SNR) is associated with the proposed data volume reduction strategy, as also apparent from simulations.

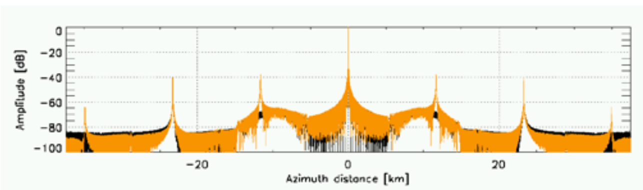
Although the transfer function of the filter is compensated for in the SAR processing, an increase of the noise level is however foreseen for some of the filters, if the signal is further quantized prior to downlink.

TABLE I. RELEVANT SYSTEM PARAMETERS FOR THE 1-D SIMULATION

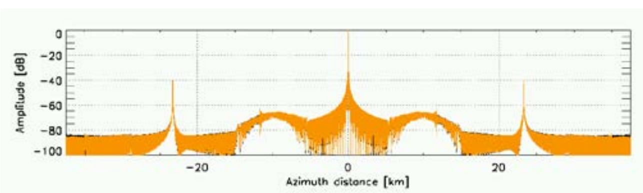
Parameter	**Value**
Wavelength	0.2384 m
Orbit height	770 km
Closest slant range approach	1000 km
Antenna length	10 m
PRF	1492 Hz
Processed Doppler bandwidth	600 Hz
Decimation factor	2
A processing window is applied, which includes a Hamming weighting and a compensation of the antenna pattern and the low-pass filter.	



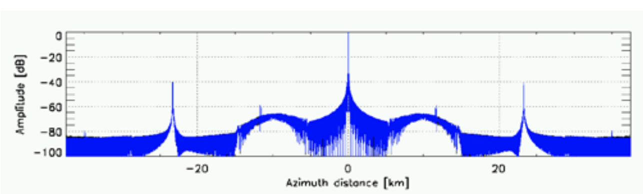
(a)



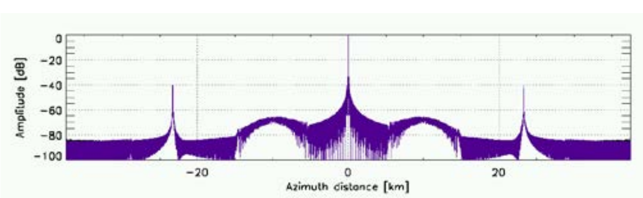
(b)



(c)



(d)



(e)

Fig. 4 Azimuth impulse responses. (a) Reference case (no data volume reduction). (b) Hanning filter with $M = 9$. (c) Hanning filter with $M = 17$. (d) Wiener filter with $M = 25$. (e) MVDR filter with $M = 9$.

The quantization noise, in fact, is amplified, when compensating for the transfer function of the filter within the processing. Filter characterized by a flat response in the processed Bandwidth, such as the presented Wiener filter (cf. Fig. 3), are robust to this problem, while other filters, such as the MVDR filter of Fig. 3, may lead to an increase of the noise level. In a context of data volume reduction, data are likely to be quantized, therefore it is worth to use a filter with a slightly higher number of taps, but robust to the amplification of quantization noise. This issue is further analyzed in [7], where raw TerraSAR-X data have been used and quantitative results are provided.

Two-dimensional simulations (for conventional SAR with constant PRF and staggered SAR) are provided in [6].

5. CONCLUSION & OUTLOOK

A strategy for data volume reduction in spaceborne SAR system has been presented, where on-board Doppler filtering and decimation are performed on raw data prior to downlink. Different criteria for the design of the FIR filter have been proposed. It has been furthermore shown that a filter with a relatively small number of taps suffices to completely suppress the additional ambiguous components and recover the original impulse response. This strategy is also applicable to staggered-SAR systems, where on-board Doppler filtering and resampling can be jointly implemented.

Although further analyses with simulations and real raw data are needed to better assess the performance for different scenarios. From the first results the proposed strategy already shows a great potential for data volume reduction and should be therefore considered for the design of future spaceborne SAR systems.

REFERENCES

[1] G. Krieger, N. Gebert, M. Younis, F. Bordoni, A. Patyuchenko, A. Moreira, “Advanced concepts for ultra-wide-swath SAR imaging,” Proceedings of EUSAR, Friedrichshafen, Germany, 2008.

[2] M. Villano, G. Krieger, and A. Moreira, “Staggered SAR: high resolution wide-swath imaging by continuous PRI variation,” IEEE Trans. Geosci. Remote Sens., in press.

[3] M. Villano, G. Krieger, and A. Moreira, “A novel processing strategy for staggered SAR,” IEEE Geosci. Remote Sens. Lett., in press.

[4] J. C. Curlander and R. N. McDonough, “Synthetic Aperture Radar: Systems and Signal Processing,” New York: Wiley, 1991.

[5] A.V. Oppenheim, R.W. Schafer, J.R.Buck, “Discrete-Time Signal Processing. Upper Saddle River,” NJ, USA: Prentice Hall, 1999.

[6] M. Villano, G. Krieger, V. Del Zoppo, “On-Board Doppler Filtering for Data Volume Reduction in Spaceborne SAR Systems”, International Radar Symposium, Gdansk, Poland, 2014, accepted.

[7] M. Villano, M. Martone, V. Del Zoppo, and G. Krieger, “Joint effects of on-board Doppler filtering and quantization in spaceborne SAR systems,” IEEE GOLD Remote Sensing Conference, Berlin, Germany, 2014, accepted.