# JOINT EFFECTS OF ON-BOARD DOPPLER FILTERING AND QUANTIZATION IN SPACEBORNE SAR SYSTEMS

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**ABSTRACT**

A novel strategy for data volume reduction in spaceborne synthetic aperture radar (SAR) system has been recently proposed, which consists of low-pass filtering and decimating the data prior to downlink and compensating for the filter's transfer function in the processing. However, if data are further quantized prior to downlink, an amplification of the quantization noise may occur, when compensating for the transfer function of the filter. In a context of data volume reduction, data are likely to be quantized. This paper analyzes the joint effects of on-board Doppler filtering and block-adaptive quantization (BAQ) in spaceborne synthetic aperture radar (SAR) systems. For the present analysis, SAR raw data acquired by the German satellite TerraSAR-X are used. As is apparent, the removal of the high Doppler frequency components by a low-pass filter leads to better performance in terms of noise equivalent sigma zero (NESZ) for the same quantization rate. However, if the transfer function of the filter is not flat in the processed bandwidth, an amplification of the quantization noise occurs, when compensating for the filter's transfer function in the processing.

## 1. INTRODUCTION

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 (PBW) is often desirable to comply with azimuth ambiguity requirements.

A novel strategy for data volume reduction in spaceborne SAR system has been proposed in [1], which consists of low-pass filtering and decimating the data prior to downlink. Criteria for the design of the low-pass filter have been presented, showing that a finite impulse response (FIR) filter with a relatively small number of taps suffices to completely suppress the additional ambiguous components and recover the original impulse response, provided that the filter's transfer function is compensated for in the processing. Furthermore, no scaling of the signal-to-noise ratio (SNR) is associated with the aforementioned data volume reduction strategy.

In a context of data volume reduction, however, the on-board Doppler filtering is likely to be followed by a quantization stage prior to downlink. The scope of this paper is to analyze the joint effects of on-board Doppler filtering and block adaptive quantization (BAQ) [2]. SAR raw data acquired by the German satellite TerraSAR-X are used for the analysis [3].

## 2. MUTUAL EFFECTS OF DOPPLER FILTERING AND QUANTIZATION

Block adaptive data quantization in spaceborne SAR systems allows a drastic reduction of the data volume at the cost of a usually acceptable image degradation. In particular, an increase of the quantization noise determines a degradation, among the others, of the noise equivalent sigma zero (NESZ), which is a measure of the system sensitivity and includes all error contributions induced by the system, such as antenna pattern, instrument thermal noise, and processing filters.

If data are low-pass filtered prior to quantization, i.e., if the Doppler frequency components outside the processed Doppler bandwidth are removed, an image degradation still occurs, but the resulting NESZ is better than for the non-filtered case. Indeed, the Doppler frequency components outside the processed bandwidth can be considered as a disturbance signal, as they are then cancelled out in the SAR processing. The removal of such a disturbance signal therefore allows reducing the energy of the signal to be quantized, leading to an absolute quantization error smaller than for the non-filtered (higher energy) signal for the same quantization rate.

So far an ideal low-pass filter has been intrinsically assumed. In practice, the Doppler low-pass filtering is performed on-board in time domain using a finite impulse response (FIR) filter with a relatively small number of taps. In particular, two filters for data volume reduction are considered in [1], namely the Wiener filter, characterized by a higher number of taps and by a flat response in the pass band, and a filter based on the minimum variance distortionless response (MVDR) or Capon beamformer, which is characterized by a lower number of taps and by an attenuation at the edges of the pass band, which can be compensated for in the SAR processing (on ground). The transfer functions of the two aforementioned filters and the ideal filter are shown in Fig. 1.

When compensating for the transfer function of the filter in the SAR processing, however, the quantization noise is amplified as well. Filter characterized by a flat response in processed Doppler bandwidth, such as the Wiener filter, are expected to be robust to this problem, while for other filters, such as the MVDR filter, a degradation of the NESZ is expected.

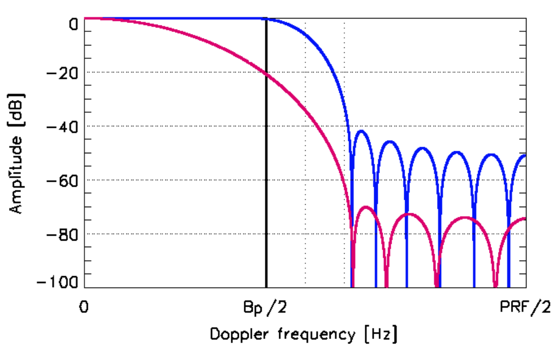


Fig. 1 Transfer functions of the 25-tap Wiener filter (blue) and the 9-tap MVDR filter (purple). The transfer function of the ideal low-pass filter is shown in black.

## 3. EXPERIMENTS WITH REAL DATA

SAR raw data acquired by the German satellite TerraSAR-X over the Amazon rainforest are used for the analysis. The calibrated radar brightness (beta nought) for the test scene is represented in Fig. 2. The PRF for the considered acquisition is 3785 Hz, and the processed Doppler bandwidth has been set to 1514 Hz, resulting in a ratio PRF/PBW equal to 2.5.

The original raw data set, output of an 8-bit analog-to-digital converter (ADC), has been quantized using a compression rate of 2 bit/sample. Furthermore, the original (8-bit) raw data have been also filtered using each of the two aforementioned filters (Wiener and MVDR), decimated by a factor of 2, upsampled by a factor of 2 by means of zero-padding of the fast Fourier transform (FFT) and finally quantized using a compression rate of 2 bit/sample.

For each of the six available data set (8-bit not-filtered, 2-bit not-filtered, 8-bit Wiener-filtered, 2-bit Wiener-filtered, 8-bit MVDR-filtered, and 2-bit MVDR-filtered) SAR processing has been performed, the transfer function of the filter (where applied) has been compensated for and the NESZ has been evaluated.

The procedure for the evaluation of the NESZ is sketched in Fig. 3 and consists of identifying water areas, characterized by a backscatter lower than a given threshold, and evaluating the NESZ as a function of incident angle on these areas using a median filter.

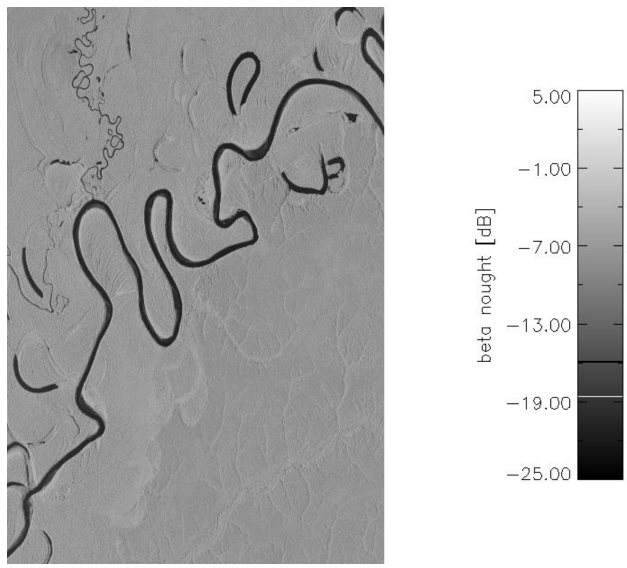


Fig. 2 Beta nought [dB] for the test scene, located in the Amazon rainforest.

The NESZ as a function of the incident angle is displayed for the six data sets in Fig. 4. The 8-bit and 2-bit data sets are represented with dashed and solid lines, respectively. A NESZ degradation of approximately 2 dB is observed for the data sets with reduced quantization rate. While there is no appreciable difference between the three 8-bit data sets (the three curves overlap almost perfectly), the issues pointed out in the previous section are apparent for the 2-bit data sets. A slight improvement of the NESZ (0.3 dB with respect to the 2-bit not-filtered case) is achieved, if the Wiener filter is employed prior to quantization. This improvement can be also seen as a possibility to achieve the same performance with a reduced quantization rate. In this case, a 2.2 bit/sample quantization is needed in the not-filtered case to achieve the same performance as the 2-bit Wiener-filtered case, assuming that azimuth-switched quantization (ASQ) is used [4].

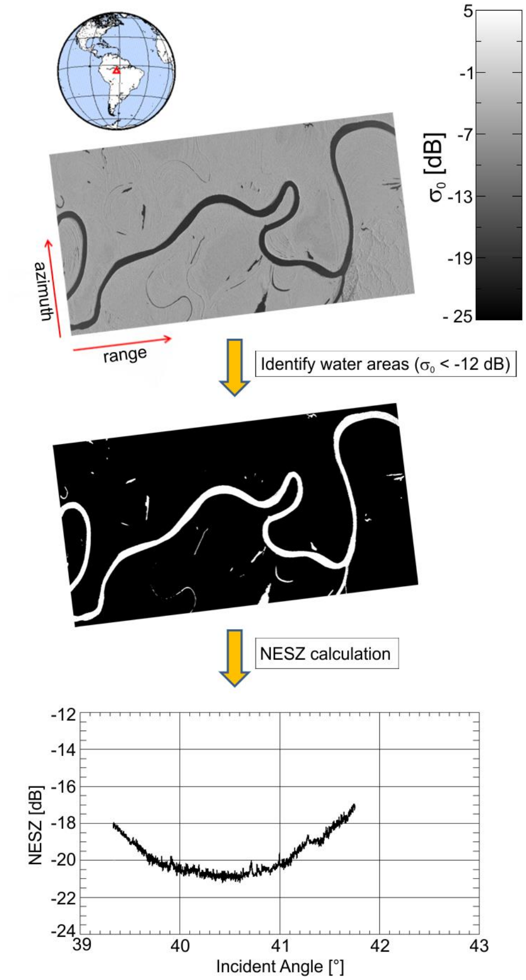


Fig. 3 Procedure for the evaluation of the NESZ.

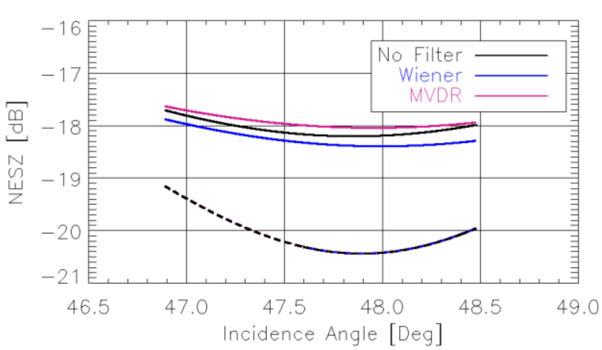


Fig. 4 NESZ for each of the six available data set. The three 8-bit data sets are represented with dashed lines, which overlap almost perfectly. The three 2-bit data sets are represented with solid lines.

In Fig. 4, it can be also noticed that for the MVDR filter the amplification of the quantization noise leads to a NESZ worse than the not-filtered case. The degradation is however only slight and could be accepted, if the on-board computational capacity only allows using a filter with a smaller number of taps.

## 4. CONCLUSION

The joint effects of on-board Doppler filtering and block-adaptive quantization (BAQ) in spaceborne synthetic aperture radar (SAR) systems have been analyzed, using SAR raw data acquired by the German satellite TerraSAR-X. As is apparent, the use of a low-pass Wiener filter leads to better performance in terms of noise equivalent sigma zero (NESZ) for the same quantization rate. As far as the MVDR filter is concerned, a slight amplification of the quantization noise occurs, when compensating for the filter's transfer function in the processing.

## ACKNOWLEDGMENT


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