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The SAR train concept: An along-track formation of SAR satellites for diluting the antenna area over N smaller satellites, while increasing performance by N

Jean Paul Aguttes*

CNES (Centre National d'Etudes Spatiales), 31401 Toulouse, France

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Abstract

This concept implements the coherent combination of N separate SAR flying along the same orbital arc as seen from ground. A particular case is when the N SAR are in visibility with a single one that transmits.

A "signal cleaning" class of trains keeps the antenna area requirement of each individual SAR unchanged and brings a factor N advantage that applies on SNR and ambiguity protection. The main formation flying constraint is the width of the tube containing the satellite trajectories. The multiplication by N of the total antenna area is the other counterpart to these advantages.

An "antenna dilution" class of train enables the distribution of an unchanged total antenna area into N smaller elementary antennas, together with multiplication by N of the SAR merit factor (swath over resolution ratio). With respect to the first class, the tube width constraint is increased and the space–time separation along the track has to be very accurate.

Use of appropriate spread spectrum waveforms instead of conventional pulse waveforms removes the major part of the extra orbit constraints introduced by the "antenna dilution" class.

A train of N SAR in visibility makes the concept more robust against loss of coherence and eases the metrology of the formation (DGPS). Moreover, the global energy efficiency is increased by N since with only a single transmit SAR the same performance is achieved. However, the along-track separation constraints for antenna dilution are made more stringent because of being restrained to the space domain, which reinforces the spread spectrum interest.

As part of its applications, the concept can circumvent the matter of huge antenna size for SAR mission in very low frequency (P band) or at high altitude (surveillance).

1. Introduction

It is well known that antenna area and power are the major design constraints of a spaceborne SAR. Both limit the swath-over-resolution ratio that is the key performance criteria and we call that here merit factor.

There is a particular SAR sizing called critical sizing [1] which maximises the achievable merit factor at a given antenna area. Moving to overcritical size causes great extra antenna area for small extra merit factor (+100% for +50%), whereas the merit factor

* Tel.: +33 5 61 27 41 28; fax: +33 5 61 27 43 59.
E-mail address: jean-paul.aguttes@cnes.fr.

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must be sacrificed well under the critical one to get a substantial antenna area saving (−75% for −30%). Merit factor at critical sizing is about 10 000 for a maximum incidence in the range 50°–60°. Compared to antenna area, the power sensitivity to the merit factor is more linear.

There are modes and designs [2] for circumventing these constraints although they cannot simultaneously relax antenna area and power constraints.

In the present study, we propose to evaluate the concept of collaboration of several SAR along the same track with two cumulative purposes:

- to dramatically push the practical limitation for power or antenna area by diluting them on several bodies,
- to remove the SAR merit factor barrier and to multiply the merit factor achievable under a given total antenna area.

The *N* SAR fly on the same orbital arc in an Earth frame, which means that the SARs are generally on different orbit planes because of the across orbit Earth rotation between successive passes. This time delay is supposed to be under the limits which cause the temporal decorrelation of the backscatter, the SAR are not necessarily in visibility although visibility provide a particular implementation case.

2. A train of *N* monostatic SAR

2.1. Basic advantage: energy addition

The *N* SAR provide *N* identical synthetic antennas (SA) focused on the processed point at different times. The addition of the *N* passes of the same (synthetic) antenna brings an improvement by *N* in energy budget and in SNR.

We will now look in more detail to improve the understanding and discover the other properties and advantages of such SAR trains.

2.2. Modelling as an N element antenna array

We use the representation of a synthetic antenna; that is to say the addition along the orbital arc of *S* identical signal samples received by the real antenna at *S* positions along the orbital arc and previously corrected (SAR processing) from the range variation to the processed pixel. This correction makes the orbital arc as it was circularly enrolled around the pixel. One can therefore consider the addition of the *N* synthetic antennas as a first addition of *N* samples coming from different SAR and previously corrected and then a second addition of the successive positions along the orbital arc of that composite *N* sample. The composite sample is equivalent to the sample issued from a single array antenna whose *N* elements are the antennas of the *N* SAR located at the *N* sampling points. Thanks to the processing correction, the array automatically matches a pattern steered towards the processed pixel. For this equivalence, we consider that each element receives only the contributions of its own transmit signal and nothing from the others or, in other words, that the array works only on transmit and at double frequency, which is already the assumption made for the long array representation of the synthetic antenna. The way the *N* samples are selected to form an array is indifferent, provided, by the end of the addition, we forget none of the *NS* samples and we do not count one several times.

We can consider the same array geometry flying all along SA in spite of edge effects (where some elements get out of SA) provided that WF is periodic (case of pulse waveform) and SA length, a multiple of the recurrence (*V* period). Indeed, each sorting element can be replaced by the same element when it was entering without changing the array response on the processed pixel or on any of the ambiguous pixels.

As shown in Fig. 1, the array pattern provides a coherent addition of the *N* useful energies from target, which also corresponds to an improvement by *N* of SNR if the antenna area is kept unchanged; while it reduces the ambiguous energy. As seen later, with efficient array geometries or/and waves forms (WF), the ambiguities are so reduced that they can be tolerated within the real antenna pattern for merit factor improvement and elementary antenna area reduction.

2.2.1. Random SAR separation and ambiguity reduction

We call the sampling interval of a given SAR section, p_0 and the sampling frequency PRF. The section length V/PRF is normally a bit smaller than the half