AN INNOVATIVE SPACEBORNE RADAR CONCEPT FOR GLOBAL MARITIME SURVEILLANCE: DESCRIPTION AND PERFORMANCE DEMONSTRATION

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1. Introduction

The surveillance of economic ocean zones and adjacent waters is growing in interest. On the sensor side, a mixture of active and passive sensors, and cooperative and non-cooperative techniques provide new opportunities for maritime surveillance.

The radar, which is an all-weather, day and night, and non-cooperative technique, appears as a key contributor for future maritime surveillance systems.

Ship detection with satellite based SAR was first demonstrated by the experimental Seasat in 1978. With later first-generation satellites such as ERS-1, JERS-1, ERS-2 and Radarsat-1, the field has reached some maturity. The second generation of radar satellites, ENVISAT (2002), Radarsat-2 (2005), ALOS (2004), have steerable beams, some polarization flexibility, and many imaging modes, several of which have some potential for operational ship detection. Radarsat-2 is best suited for wide-area (300 km) ship detection. ENVISAT has a significant capability in more narrow swaths (<100 km). The third generation satellites TerraSAR-X (2006), Cosmo-SkyMed (2006), SAR-Lupe (2005) are somewhat different, as the design is more heavily influenced by the requirement for high-resolution imagery on land. This introduces some limitations regarding maritime use, especially concerning the swath width, which is rather limited. The main elements affecting the ship detection capability of SAR instruments are: swath width, incidence angle, spatial resolution, number of looks, polarization, instrument noise floor and sea clutter level.

However, conventional SAR instruments are not actually well adapted to maritime surveillance (i.e. ship detection) over wide areas. Their detection performances are by principle modest because of the speckled behaviour of radar targets and sea clutter that can not be sufficiently reduced with the low number of independent looks offered by this technique. The use of the ScanSAR technique for increasing the swath width further degrades the number of looks and consequently the detection performances in this mode. In addition, such instruments present a limited operation time over their orbit (20 minutes for best satellites i.e. 20% of the orbit) because of their very high power consumption and dissipation (several kilowatts).

An innovative radar concept (called LPRF radar or Low Pulse Repetition Frequency radar) has been proposed by Thales Alenia Space that mitigates the SAR technique limitations.

The concept is specifically oriented for ship detection, and not for land or sea imaging. It allows wide swath coverage (as high as 1000 km). It exhibits high detection performances of small ships even in adverse sea states conditions. Its power consumption is reduced allowing a permanent operation all along the orbit. At least, it uses already developed and low cost technologies.

2. Innovative LPRF Radar Concept

The concept starts from the Side Looking Aperture Radar (SLAR) principle with real azimuth antenna aperture. Wide Swath Width (SW) leads to a low Pulse Repetition Frequency (PRF) according the following formula:

$$PRF_{\max} = \frac{c}{2.k_4.SW.\sin(i)}$$

where "*c*" is the light propagation celerity, "*k4*" is a margin factor slightly above 1 and "*i*" is the incidence angle.

For example, for a swath width (*SW*) of 1000 km close to the horizon ($i \approx 90°$), a PRF less than 120 Hz is necessary.

This PRF is much smaller than the Doppler bandwidth of received echoes (1500Hz for a 10 m antenna length and for a satellite at a typical observation altitude). With such a low PRF, azimuth synthetic aperture processing is not allowed because of azimuth ambiguities than would result. Thus, the azimuth resolution of a low PRF and real aperture radar is given by the antenna aperture in the azimuth direction, according to the formula:

$$R_{azimut} = \theta_{ant\ az} \cdot D = \frac{\lambda \cdot D}{L_{ant}}$$

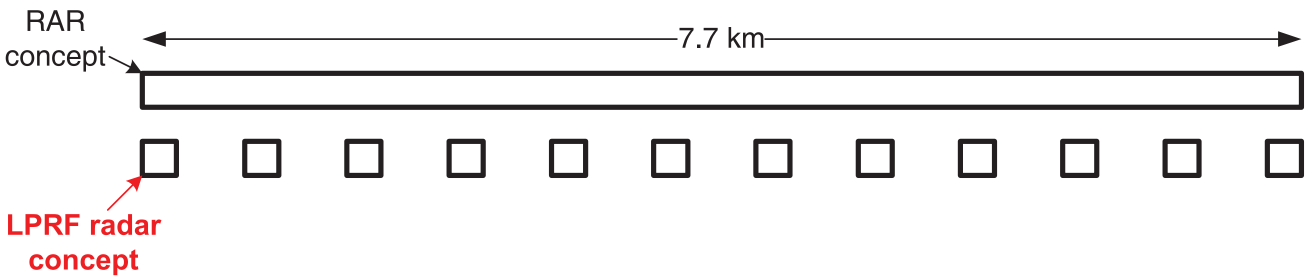
For example, for an altitude *H* of 500 km (*D* = 2480 km), an incidence *i* around 90°, an antenna length L_{ant} of 10 m and X-band (9.65 GHz), the real aperture radar has an azimuth resolution $R_{azimuth}$ of 7.7 km. Such a spatial resolution explains that this type of instrument can work only at very low grazing angles for which sea clutter backscattering is known to be low. The detection performances of such a radar are maximized by incoherent post-integration over the observation time of the target (time for a target to cross the antenna footprint).

The presented innovative LPRF radar concept includes two improvements with report to this standard real aperture radar instrument:

- A coherent integration is implemented (despite the low PRF with report to the Doppler bandwidth),
- The « Scan-On-Receive » technique is implemented.

The coherent integration allows to reduce the azimuth resolution. But, because the PRF is less than the Doppler bandwidth, the LPRF radar gets ambiguities in azimuth. For an imaging radar, these ambiguities would be absolutely not acceptable. For the present application (ship detection over seas) we want to do only detection (and not a conventional image) and these ambiguities are actually acceptable. The number of ambiguities is 2Vsat/Lant/PRF i.e. 13 ambiguities for our example with an antenna length *Lant* of 10 m and a *PRF* of 120 Hz.

The following figure shows the pixel of the standard real aperture radar (RAR concept) and the pixel of the proposed LPRF radar concept.



From this figure, we understand that the surface of the clutter is reduced giving a better contrast between the useful target (ship) and the sea clutter. The coherent integration time can not last all the observation time of the ship because the detection performances would be bad due to the speckle behavior of the ship and of the clutter. Instead, the observation time has to be split in a number of intervals. Over each interval, a coherent integration is done then a radar frequency agility is done between two intervals to get independent observations of the target. The signals obtained for each interval are detected then post-integrated. Of course the post-integration gain is less for the LPRF radar concept than for the RAR concept. However, the global gain on the target/clutter contrast plus the post-integration is higher for the proposed LPRF concept by a few dB's giving high interest in this concept.

The interest of the Scan-On-Rx technique is already well known. It allows the improvement of the link budget and of the range ambiguities ratio. The implementation of this technique is of particular interest for the present concept and application. The antenna of our reference configuration has a 1.2 m height, a 4.7° Tx aperture to cover the 1000km swath width and a shaped Tx beam to favor the gain towards the horizon. The implementation of a narrow beam for echoes reception provides a 4.5 dB gain on the link budget, which is quite significant. This allows to reduce the power consumption of the LPRF instrument compared to known SAR instruments and the possibility to operate the instrument all along the orbit to perform global coverage of the oceans.

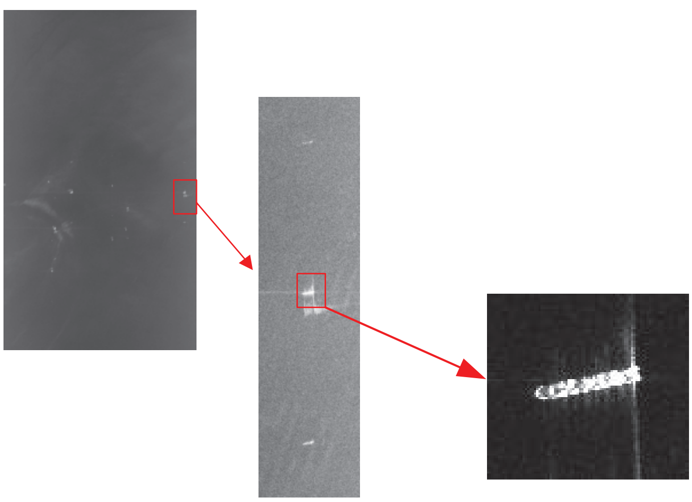
3. LPRF radar concept definition status

Several studies have been conducted by Thales Alenia Space for CNES (French Space Agency) for defining the LPRF radar concept and assessing its performances. These studies used ship and sea clutter models available in the literature with extrapolations more or less valid when necessary.

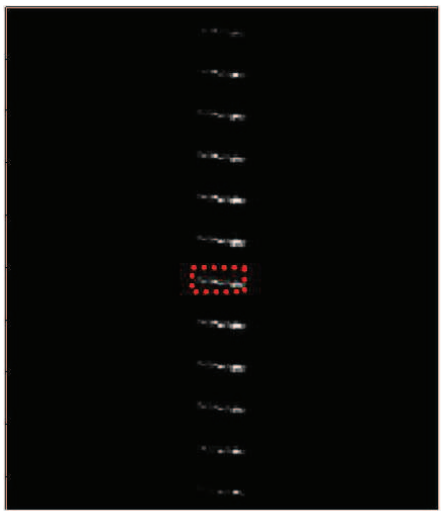
Thus, it appeared necessary to get more reliable and adapted ship and clutter data to allow a more accurate assessment of the performances of the LPRF radar concept. So, ONERA has recently conducted for CNES the airborne campaign MENAS to build a suitable data base of (small) ship and clutter model. This campaign and its main outcome are described in [3].

A new study conducted by Thales Alenia Space and ONERA for CNES has started in September 2009 and will end in May 2010. This study aims at assessing and demonstrating the detection performances of the innovative LPRF radar concept by developing a performance simulator of the concept and running this simulator on the ship and clutter data acquired during the campaign MENAS and at comparing the performances of this LPRF radar concept with that of the conventional SAR concept.

The following figure shows a first output of the LPRF radar demonstrator fed with TerraSAR-X images.



TerraSAR-X image of a cargo



LPRF radar image of the same cargo showing the expected azimuth ambiguities but also the reduction of the clutter level given by the post-integration

4. Content of the paper proposed to IGARSS 2010

The paper that is proposed to IGARSS 2010 shall include the following topics:

- remind the innovative concept proposed for Global Maritime Surveillance,
- description of the LPRF radar concept software demonstrator,
- results of the LPRF radar concept performances assessment using the ship and clutter data acquired by the airborne campaign MENAS,
- comparison of the performances of the LPRF radar concept to the performances of a SAR instrument.

5. Bibliography

[1] A new concept of Spaceborne Maritime Surveillance Radar, Jacques Richard, IGARSS 2009, Cape Town, 13-17 July 2009

[2] L'avant-projet "sécurité maritime" du CNES : quelle contribution des systèmes spatiaux ?, Serge Potteck, Jean-Paul Abadie, Valérie Foix, Les 7èmes journées scientifiques et techniques du CETMEF, Paris, 8-10 December 2008

[3] Ship detection using airborne SAR data acquired at X-band, Sébastien Angelliaume, Ph. Martineau, J. Peyret, H. Oriot, V. Foix, Ph. Durand, J.C. Souyris, submitted to EUSAR 2010, Aaren, June 2010

[4] Constellation of AIS + RADAR sensors for global maritime surveillance, Sophie Ramongassié, T. Calmettes, P. Pavia, V. Foix, submitted to IGARSS 2010, Honolulu, 25-30 July 2010