Polarimetric Calibration Monitoring by Permanent Scatterers

Paolo Biancardi1, Davide D’Aria1, Alessandro Ferretti2, Davide Giudici1, Lorenzo Iannini1, Andrea Monti Guarnieri1, Betlem Rosich3, Paul Snoeij4, Stefano Tebaldini1

1ARESYS srl, Via Bistolfi, 49, 20134 Milano - Italy
2Tele-Rilevamento Europa (TRE), Via V. Colonna 7, 20149 Milano, Italy
3Politecnico di Milano, DEI, Piazza Leonardo da Vinci, 32, 20133 Milano, Italy, e-mail: monti@elet.polimi.it
4European Space Agency (ESA)

ABSTRACT

The PS calibration combines external devices, like corner reflectors, transponders and the stable targets to provide continuous monitoring of the radiometric quality of a SAR instrument. The aim is to provide, on the bases of image blocks (say 10 x 10 km), the precise geolocation and the polarimetric signature of each scatterer. The scheme thus requires (1) the identification of the stable targets, and (2) the characterization of their Polarimetric scattering matrix by external references. In that way, it would be possible to calibrate even a dual polarimetric system.

I. INTRODUCTION

Radiometric calibration is a fundamental issue in Sentinel-1 SAR modern Synthetic Aperture RADAR: its achievement allows the proper exploitation of the backscatter coefficient in many applications [1]. The objective is to estimate the overall system gain, including the transmitter, the receiver, the propagation and the processor. Such a goal is usually achieved by exploiting an internal calibration scheme that monitors the acquisition system, by using calibrated targets in the scene, like corner reflectors and transponders, and by acquiring in full-pol mode [2]. The manufacturing and deployment of such devices are quite expensive, and so it is their maintenance throughout the whole mission. The purpose of the present paper is to provide a scheme for SAR calibration that integrates information coming from these external devices, maintained only for a short time, and those of the targets in the scene that are intrinsically stable, the PS [3]. The PS phase stability has been exploited ever since for interferometric applications, however the interest in this paper is to exploit the PS amplitude stability to monitor the slightest change in the systematic gain. Thus, each PS behaves like a stable calibrator with unknown scattering matrix, and with a quality that can be estimated by the repeated observations.

The accuracy of the technique follows after averaging many independent measures, where typical PS densities in urban areas can be as high as 500 per square km [3] in C-band and for a medium resolution (5 m), up to 9000 in X band at resolution of one meter [4].

The typical scenario for a Space Borne SAR system is the exploitation of the commissioning phase, when several external calibration sites are available. This information will be used to monitor and calibrate the PS series. We notice that it is not strictly necessary to have simultaneous acquisitions on the reference calibrators and the PSs, provided that the system ensures a good radiometric stability in short time, that is usually expected at the beginning of life. The ubiquity of the PSs will then allow to construct a wide set of calibration sites (say in rocky areas, towns etc) distributed all over the earth, that does not demand for committing special acquisitions that would interfere with the operations.

II. THE SYSTEM AND THE PS POLARIMETRIC MODEL

The geometry of a typical SAR acquisition system by repeated observations is shown in Fig. 1. The figure refers to
the Space Borne (SB) case, where the sensor repeats a set of \( N_t \) observations by the same geometry. In particular we assume that the variation in the look and squint angles by which each target is observed, is small enough to neglect changes in the target’s polarimetric signature, at least for those targets of interest. The goal of this PS-based analysis is to identify and exploit the largest number of stable targets of interest. The technique is made by two major steps: a PS-based polarimetric normalization of the stack of data, shown in the shaded block of the figure and discussed here, and the absolute calibration of the stack, aided by external targets. We then assume a stack leading to the simple case: 

where only one additional complex parameter, the unbalance \( f_i \), needs to be estimated for each of the \( N_t \) images.

Let us rephrase the model in a compact matrix formulation:

\( y = x + w \)

(7)

where \( x \) is a column vector of size \([4N_tN_p,1]\), defined as:

\[ x = (B \otimes a) \cdot \phi \]

(8)

\[ B = \begin{bmatrix} b_1(p) & \ldots & b_{4N_tN_p}(p) \end{bmatrix} \]

(9)

\[ a = [a_1, \ldots, a_{N_t}] \]

(10)

the symbols \( \otimes \) and \( \cdot \) in (8) standing respectively for the Kronecker and the Hadamard dot products. The vector \( B \) is
defined by stacking all the vectors $b_p$, likewise for the vector $w_a$ and $\Phi_1$, in which all the terms $\exp(j\phi_{i,p,k})$ are conveniently ordered.

### III. Maximum Likelihood Estimate

The log-likelihood of the complex observations can be expressed as follows:

\[
L(y|x, C) = -(y - x)^T C^{-1} (y - x) - \log|C|
\]

\[
= 2 \text{Re}\{y^T C^{-1} y - y^T C^{-1} x - x^T C^{-1} x - \log|C|\}
\]

having omitted a constant that is irrelevant for the maximization. Eventually, by taking advantage of the non-correlation of noise, $C$ being diagonal, we get the following expression:

\[
L = 2Y - \sum_{i=1}^{N_i} \sum_{p=1}^{N_p} y_p(i,p,k) - N_i \sum_{i=1}^{N_i} \sum_{p=1}^{N_p} \left( b_p(i,p,k)^2 + \log|v(i,p,k)| \right)
\]

\[
= -8N_x \sum_{i=1}^{N_i} \sum_{p=1}^{N_p} \log|a(i)|
\]

where $Y = \text{Re}\left\{ \sum_{i=1}^{N_i} \sum_{p=1}^{N_p} a^*(i,p,k) y^* (i,p,k) \exp(j\phi_{i,p,k}) \right\}$.

The maximization of $L$ has been solved by trivially extending the same iterative approach in [5] [6], in the block diagram of Fig. 2. The convergence is provided by the accuracy of the initial solution, that is achieved by the internal calibration capabilities of the system, typically better than 1 dB, at least in their initial life [7].

### IV. Experimental Results

Experimental results have been achieved by both processing single-polarization datasets (ERS-2) and fully polarimetric datasets, from ESA AgriSAR 2009 and SOAR campaigns. In the present version we show the results achieved by processing ERS-2 data. A total of 40 + 46 images have been exploited in the area of Flevoland and Milano. A summary of the acquisitions is in Tab. 1, whereas the location of PS and ESA transponders is in Fig. 3. The results of the PS calibration are shown in Fig. 4, for both Flevoland and Milano, and compared with transponders series.

It is remarkable how both two series (Flevoland and Milano), were able to predict the ERS-2 power decay, and the gains estimated by images acquired in slightly different time, but very different location and orbit, matches tightly. In order...
to provide a better evaluation, the sequence of the PS and the ESA transponders have been superposed after detrending for the ERS power decay in the plot of Fig. 4 (below). In the plot, there were a few cases when one of the three transponders in the same image gave measures much different from the other two, and this happens for each one of the transponder, even if it is much more frequent for TR2. A sensible dispersion of the estimated system gain by both the PS and the transponders is found close to the end of the series, in 2000. The reason is to be found in the solar activity that has a maximum at that age. For a draft comparison, Fig. 5 plots the sunspots numbers (courtesy of SWO-NOAA) measured for each month superposed with the absolute value of the PSCal gain in both Flevoland and Milano. We observe that, when the solar activity is close to its minimum, in 1997, the estimated gains are dispersed in less than 0.1 dB, whereas the dispersion increases when moving at periods of higher solar activity, and there is a noticeable correlation between the most dispersed gains and the peaks in the sunspots.

For a better comparison, we analyzed the series where the three transponders in Flevoland gave consensus, when measures were dispersed in less than say half of a dB. There were only seven of such images from the original 46, and they are represented in Fig. 6. The standard deviation of the PS measures with respect to the average of the three transponders is \(\sim 0.017\) dB, that should again be interpreted as the result of the two errors (the 66000 PS and three transponders). Notice that such value is not close to the performances expected by a transponder, according to [8], and it would be really hard to find a more accurate reference.

V. CONCLUSION

The extension of the PS calibration to the polarimetric case has been shown. Experimental results here reported the ERS datasets, with accuracy achievable in the order of 0.02 dB when compared with ESA transponders. Results from fully polarimetric data from AgriSAR and SOAR campaigns are expected to be available for EUSAR symposium.

ACKNOWLEDGMENT

The work has been carried out in the framework of ESA AgriSAR 2009 and SOAR campaign. We thank ESA for the availability of those datasets, as well as for ERS datasets.

REFERENCES