Requirements and Calibration of L-band and C-band Compact SAR

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Background

Compact & Hybrid: An adaptation of the Dual Circular Polarization RR-RL to Linearly (H-V) polarized antenna

- Transmitted polarization: CP (Compact or Hybrid)
- Received polarization: H and V

Firstly introduced in the 60th: Lang (1965), P.E. Green (1968)


Large promotion of Compact Applications (K. Raney, J.C. Souyris, P. Dubois-Fernandes, F. Charbonneau et al., …)

Compact Missions:


Are we READY for COMPACT CALIBRATION??!!
Compact (Hybrid) SAR
Lang and Green 1967

- Transmit CP using H-V antenna
  - Receive linear (H & V)
    - RCP=> RH-RV (Compact)
    - LCP=> LH-LV (Compact)
- Convenient way for implementation of Dual-CP using H-V antenna

Alert:
- Transmitted CP Not Circular
  - Elliptical polarization with ellipticity varying with incidence angle

Generation of CP from an H-V Antenna (Stutzman1984)
OUTLINE

- **Variations** of the Transmitted polarization parameters (orientation and helicity) with **incidence angle**

- **Quantification** of the **impact** of **Not CP** transmitted wave on Compact **information**
  - Radiometry, DoP, and Received polarization synthesis

- Requirements on the calibration of the Compact

- Calibration & Validation of the RCM Compact SAR

- Simulated data from C-Radarsat2 and L-band ALOS
RCM Transmitted “Circular” Polarization Axial Ratio

- Transmit CP Receive linear (H & V)
  - RCP=> RH-RV
  - LCP=> LH-LV

- Transmitted (R&L)CP **Not Circular**
  - $|R| = \frac{\text{major axis length}}{\text{minor axis length}} \Rightarrow R_{dB}$
  - Polarization angles ($\psi, \chi$)

- Varies with incidence angle (50km to 350km)
  - RCM: $R_{dB} = 1.4 \text{ dB to 3.0 dB}$
  - RISAT: $R_{dB} = 3\text{ dB}$ (Raney PolinSAR13)
  - ALOS2 ?? Swath 50 km (Experimental)
5° to 10° error in the ellipticity as a function of the Beam Scan Angle (0° to 17.5° from 50km to 350km)

⇒ Radiometric Error: 2-3 dB error in RH and RV
Ice Classification: Radiometric Error (RS 2)

- Up to 3 dB error (Wide ScanSAR) in RH and RV
- Error varies with incidence angle (0.7dB to 3dB)

m-δ decomposition

Graphs showing intensity [dB] for RH and RV zones.

Zones: Z1 to Z7
Zones: Z1 to Z7

Intensity [dB]: -21 to -14 for RH, -25 to -15 for RV

Graphs for RH and RV with three lines for different cases.
Ship Detection
Polarimetry & Compact DoP Excursion & RH-RV

$\Delta p$

SEALINK PUSHER (30m)
Ship Detection using RCP

Ship-Ocean Contrast (dB)

RR better than RH and RV

Synthesis of RR & RL => Calibrated RH, RV & $\phi_{RH-RV}$
Ship Received & Scattered Wave Polarization Signatures

RR: -7.4 dB => -6.3 dB
DoP: 0.52 => 0.69

Received wave Polarization Signature

χ_{error} = 10º
Ψ_{error} = 10º

DoP signature

SEA LiNK PUSHER (30m)

R. Touzi, ASAR2013, St-Hub
Radiometric Error ($RV$): 1 to 3 dB

$$RV = -35^\circ, \psi = 10^\circ$$

Min($Rap, 1/Rap$)
Received Wave Polarization Signature:

Urban Area

Error: Radiometry 1 dB  DoP: 11 dB

Original
LCP

Not-CP
RCP
Received Wave Polarization Signature:

**Forest**

*Error: Radiometry 1 dB DoP: 2.5 dB*

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**Original**

- **LCP**
- **RCP**

**Not-CP**

- **LCP**
- **RCP**
ALOS / PALSAR
OTTAWA - CANADA AREA
CHANNELS: HH, HV, VV (R G B)
Ottawa (ALOS October 2008)
Radiometric Error RV and RH
Received Wave Polarization Signature

Forest

Error: Radiometry 1 dB  DoP: 7 dB

Original

LCP

RCP

Not-CP

R. Touzi, ASAR2013, St-Hubert, 15-18 Sep. 2013
Received Wave Polarization Signature
Urban Area

LCP

RCP

R. Touzi, ASAR2013, St-Hubert, 15-18 Sep. 2013
Transmitted Polarization Not Circular

Compact SAR Calibration Model NOT Valid ??!!

Freeman Model (Freeman08, Quegan11)

\[
\begin{bmatrix}
M_{RH} \\
M_{RV}
\end{bmatrix}
= A(r, \theta) e^{j\varphi} \cdot \frac{1}{\sqrt{2}} \begin{bmatrix}
1 & \delta_2 \\
\delta_1 & f
\end{bmatrix} \cdot \begin{bmatrix}
\cos\Omega & \sin\Omega \\
-\sin\Omega & \cos\Omega
\end{bmatrix}
\cdot \begin{bmatrix}
S_{HH} & S_{HV} \\
S_{VH} & S_{VV}
\end{bmatrix}
\cdot \begin{bmatrix}
e^{-j\Omega} + \delta_c e^{j\Omega} \\
-j(e^{-j\Omega} - \delta_c e^{j\Omega})
\end{bmatrix}
+ \begin{bmatrix}
N_1 \\
N_2
\end{bmatrix}
\]

\(\delta_c\): RCP-LCP X-talk  \(\delta_1\) and \(\delta_2\): Receiving channel X-talks

Problems:

- Transmitted (R or L)-CP assumed to be perfectly circular
- Not realistic: Actual technology does not permit the generation of perfect CP (RCM, ALOS2, RISAT)

R. Touzi, ASAR2013, St-Hubert, 15-18 Sep. 2013
New calibration activity in collaboration with CSA and MDA

Objective: Calibration of the RCM Compact Modes using transponder and Amazonian Forest measurements

- **New Calibration Model**
- Transponder will be used for high precision measurements of the Compact calibration parameters
- Amazonian forests will be used for convenient calibration of Wide swath modes
- Validation using simulated RCM from Polarimetric Radarsat2
Calibration Requirements

• RH and RV:
  – within 0.5 dB in radiometry
  – Phase difference: within 10 degree

RCM X-talk requirements improved: from -20 to -30 dB


➢ Radarsat2 X-talks independent of incidence angles

➢ High precision X-talk measurements using transponder

Requirement on Antenna Cross-Polarization Isolation for the Operational Use of C-Band SAR Constellations in Maritime Surveillance

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Abstract—The issue of antenna cross-polarization isolation has been previously discussed for the design of fully polarimetric synthetic aperture radar (SAR) systems. Dual-polarized antennas with cross-polarization isolation that is better than -30 dB are desirable for more convenient polarimetric data calibration since measurements of antenna crosspolarization ratios and phase differences at incidence angles are not required. For an antenna with significant cross-polarization, it is difficult to retrieve pure backscatter measurements of HH, HV, VH, and VV provided that the four corresponding received voltages are measured. However, it is not possible to recover from cross-polarization contamination for single- or dual-polarization measurements. Therefore, it is important to set a minimum requirement on cross-polarized antenna isolation in single- and dual-polarization applications, in order to avoid any disturbance of the cross-polarization channel. As a result, this requirement is necessary for future SAR constellations in maritime surveillance. A requirement for a minimum isolation of -30 dB at 10° incidence angle is sufficient to prevent any significant cross-polarization contamination at HH, HV, VH, and VV bands. It is noted that a requirement of -35 dB is desirable for reliable exploitation of the HH channel at lower incidence angles.

I. INTRODUCTION

The Environmental Satellite (ENVISAT) Advanced Synthetic Aperture Radar (ASAR) was the first space-based synthetic aperture radar (SAR) to use a dual-polarized antenna for measurements of target backscatter at single (i.e., HH, VV, or HV) and dual (i.e., HH+HV or VV+VH) polarization. ASAR operates with a dual-polarized antenna with an original isolation requirement of -25 dB [1]. Fortunately, actual ASAR isolation performance has proven to be much better (about -35 dB) [2], [3], and this permits the acquisition of pure "true" data (i.e., suitable for ship detection at steep incidence angles (14° to 22°) for the single mode) [4], [5].

Since the launch of ASAR, several more satellite SARs with dual-polarized antennas have been launched. In 2006, the Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) [6] was launched with an antenna isolation that is better than -35 dB [7] (the original requirement on antenna isolation was -25 dB [6]). In 2007, RADARSAT-2's C-band SAR was launched with an antenna isolation that is better than -32 dB [8] (the original requirement on antenna isolation was -20 dB). Also, in 2007, TerraSAR-X was launched with an antenna isolation requirement of -25 dB [9].

In 2012, a new era in the operational use of dual-polarized C-band SARs will start with the launch of two constellations of SAR satellites: the European Sentinel-1 [10] and the Canadian RADARSAT Constellation Mission (RCM) [11]-[13]. The Sentinel-1 antenna is being built with a requirement on cross-polarization isolation of -30 dB [14]. Based on the current design, it is expected that the actual cross-polarization isolation will be on the order of -35 dB [14]. RCM is being conceived with a requirement on antenna isolation of -30 dB [11]-[13]. However, it is noted that the antenna isolation will be better than -28 dB. These missions should satisfy the requirement of -35 dB minimum antenna isolation that was established during the 2005 Committee on Earth Observation Satellite Working Group on Calibration and Validation [15].

One of the key applications of these future C-band constellation missions is maritime surveillance. The use of ASAR and RADARSAT-2 single-polarization HV imagery in SeasAR mode or dual-polarization HV+VV or VH+VH in standard mode is providing very promising ship-detection results [4], [5]. It is now accepted that HV performs much better than HH or VV for ship detection at incidence angles in the 20°–45° range [5], [16]. Furthermore, Vachon and Wolfe [17], [18] have shown, by using RADARSAT-2 Fine Quad (FQ) data, that it is possible to make an accurate measurement of ocean wind speed that is independent of wind direction and SAR illumination angle. Both ship detection and wind-speed measurement require the use of "pure" HV polarization data. Therefore, there is an immediate need for the determination of the minimum requirement on antenna cross-polarization isolation to support these and related maritime surveillance applications, particularly for smaller incidence angles for which the copolarization backscatter (main source of the HV contamination) can become quite large.

High-Precision Assessment and Calibration of Polarimetric RADARSAT-2 SAR Using Transponder Measurements
Roula Touzi, R. K. Hawkins, and Stephane Côté

Abstract—Independent assessment and calibration of polarimetric RADARSAT-2 (RS2) synthetic aperture radar (SAR) are conducted using “encalibrated” data collected at various incidence angles (from 20° to 40°). Analysis of the response of a transponder deployed at HV and VH configurations permits high-precision measurement of RS2 antenna crosstalk. It is shown that the RS2 antenna is highly isolated (better than −32 dB) with crosstalk stable with incidence angle. A new calibration method based on transponder measurements is introduced. It is shown that the transponder calibration method removes almost completely the low antenna crosstalk with a residual crosstalk lower than −40 dB. Only one transmitter–receiver distortion matrix measured at a given incidence angle is required for accurate calibration of the 26-polarimetric modes of the RS2 SAR from 20° to 40°. Uncalibrated RS2 single-look complex (SLC) data with real and imaginary parts provided in 32-bit floating point are required for an effective application of the transponder calibration method. RS2 “calibrated” data are also considered for the assessment of the actual RS2 polarimetric calibration. It is shown that RS2 calibration meets comfortably the CEOS Cal-Val requirements with a residual crosstalk lower than −32 dB. The RS2 calibration accuracy does depend on the mode (i.e., incidence angle) with residual crosstalk that varies between −32 and −43 dB. To assess the impact of the residual crosstalk on polarimetric applications, the RS2 data are recalibrated using transponder measurements. Each data set was processed four times with a different lookup table (LUT) to reconstruct the 32-bit floating-point data prior to the application of the transponder calibration method. It is shown that the recalibration may not be required for natural targets of relatively high HV backscattering (higher than −36 dB). For forests, data recalibration improves significantly the accuracy of targets of low HV backscattering measurements, whereas polarization HHH and VV does not seem to be affected by the residual antenna crosstalk (∼32 dB). Urban targets that manifest significant helicity scattering may have their helicity polarization affected and require data recalibration. However, RS2 data recalibration requires the deployment of a transponder at HV and VH polarizations for each mode (i.e., incidence angle). Data symmetrization is introduced as a more convenient way to improve polarimetric RS2 data quality without the need to deploy transponders. It is shown that the symmetrization of the modes with the highest residual crosstalk significantly improves the calibration accuracy with a residual crosstalk lower than −37 dB. The latter is negligible as the RS2 noise floor is below −30 and −34 dB.

I. INTRODUCTION
The Canadian satellite RADARSAT-2 (RS2) was launched in December 2007. It is the first free-flying satellite equipped with a SAR that permits the acquisition at C-band of fully PolSAR measurements at multiple incidence angles and resolutions of 9 m (fine mode) and 24 m (standard mode) [1]. Initially, RS2 was operating with 20 modes covering incidence angles of 20° to 40°. Recently, RS2 has been upgraded with ten additional modes to cover up to 50° incidence angle. Several studies [2], [3] have been published on RS2 data quality. It was shown that RS2 antenna is highly isolated with an HV isolation better than −32 dB [3]. After calibration, the residual crosstalk is lower than −40 dB [3]. These results are very encouraging when we know that the RS2 antenna was supposed to be conceived with an isolation requirement of −20 dB [3].

Our experience with the calibration of Convair 580 PolSAR [4] permitted influencing the design of the RS2 antenna. A formal report [5] was sent in 1998 to MacDonnell Dettwiler and Associates (MDA) to justify the need for an antenna of isolation better than −30 dB. Thanks to the support of Dr. A.P. Laszowcz, who was the head of RS2 technical team at that time, our concerns about the antenna isolation were given full consideration, and RS2 antenna was finalized with a better isolation of −30 dB.

However, and even if the results presented in [3] are comforting, there is a need for an independent assessment of the polarimetric RS2 antenna and evaluation of the RS2 calibration accuracy. In addition, RS2 has been assessed and calibrated using only Amazonian forests [6], and no reference target points were used as in the case with RADARSAT-1 (RS1) [7], [8], Erosion [9], and ALOS [10], [11]. This study will investigate the use of a transponder as a suitable tool for the measurement of low RS2 antenna crosstalk (better than −30 dB). It will be shown that the transponder’s ability to provide high-precision measurements of antenna crosstalk will permit the improvement of RS2 calibration accuracy.

Several calibration methods have been developed for the assessment and correction of polarimetric antenna crosstalks.