POLARIMETRIC ANALYSIS FROM COMPACT-POL MEASUREMENTS: POTENTIAL AND LIMITATION

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1. INTRODUCTION

Compact polarimetry has been shown to be an interesting alternative mode to full polarimetry when global coverage and revisit time are key issues. It consists on transmitting a single polarization, while receiving on two. Several critical points have been identified, one being the Faraday rotation correction and the other the calibration. When a low frequency electromagnetic wave travels through the ionosphere, it undergoes a rotation of the polarization plane about the radar line of sight for a linearly polarized wave, and a simple phase shift for a circularly polarized wave. In a low frequency radar, the only possible choice of the transmit polarization is the circular one, in order to guaranty that the scattering element on the ground is illuminated with a constant polarization independently of the ionosphere state. This will allow meaningful time series analysis, interferometry as long as the Faraday rotation effect is corrected for the return path. In full-polarimetric (FP) mode, two techniques allow to estimate the FR: Freeman method using linearly polarized data [1], and Bickel and Bates theory based on the transformation of the measured scattering matrix to a circular basis [2]. In CP mode, an alternate procedure is presented which relies on the bare surface scattering properties. These bare surfaces are selected by the conformity coefficient, invariant with FR. This coefficient is compared to other published classifications to show its potential in distinguishing three different scattering types: surface, double-bounce and volume. The performances of the bare surfaces selection and FR estimation are evaluated on PALSAR and airborne data. Once the bare surfaces are selected and Faraday angle estimated over them, the correction can be applied over the whole scene. The algorithm is benchmarked against both FP techniques. In the last part of the paper, we study how to calibrate the CP system and correct for both cross-talk and Faraday effects.

2. SELECTING BARE SURFACES

The selection of bare surfaces from CP data can be achieved based on the conformity coefficient which has been shown to be invariant with Faraday rotation. This coefficient, used in CP mode (μ_{CP}) as well as FP mode (μ_{FP}), allows discriminating the three main scattering types (surface, double-bounce and volume scattering) and is expressed as:

$$\mu_{CP} = \frac{2\,\mathrm{Im}\left\langle M_{RH} M_{RV}^{*} \right\rangle}{\left\langle M_{RH} M_{RH}^{*} \right\rangle + \left\langle M_{RV} M_{RV}^{*} \right\rangle}$$
$$\mu_{FP} = \frac{\mathrm{Re}(S_{HH} S_{VV}^{*}) - \left|S_{HV}\right|^{2}}{\left(\left|S_{HH}\right|^{2} + 2\left|S_{HV}\right|^{2} + \left|S_{VV}\right|^{2}\right)} \tag{1}$$

where M_{RH} and M_{RV} are the measured scattering elements, considering a right circular transmission and two linear receptions (H & V).

When $t_1<\mu<1$ the scattering element is identified as a surface, $t_2< \mu<t_1$ identified a volume and $-1< \mu<t_2$ describes a double-bounce scattering.

This scattering characterization is then compared to the output of the Freeman-Durden, van Zyl and Cloude-Pottier classifications over RAMSES, AIRSAR and PALSAR data.

3. FARADAY ROTATION ESTIMATES

To estimate the Faraday rotation, we rely on two assumptions based on natural surfaces properties. The first assumption is the reflexion symmetry, valid over surfaces presenting symmetry with respect to the vertical plane containing the line of sight. In that case, it can be shown that the averaged cross products between the co- and cross-pol channels are equal to zero:

$$\langle S_{HH} S_{HV}^{*} \rangle \approx \langle S_{VV} S_{HV}^{*} \rangle \approx 0 \quad (2)$$

The second hypothesis assumes that the phase between the co-pol channels is close to zero for bare surfaces:

$$Arg\langle S_{HH} S_{VV}^{*} \rangle \approx 0 \quad (3)$$

Providing these two assumptions, we can then estimate the Faraday rotation angle with one of these following equations:

$$\Omega = \frac{1}{2} Arg\langle M_{RR} M_{RL}^{*} \rangle \pm \frac{\pi}{2} \quad (4)$$

Or

$$\Omega = \frac{1}{2} Arc\tan\left(2 \frac{\mathrm{Re}(M_{RH} M_{RV}^{*})}{(\langle M_{RV} M_{RV}^{*} \rangle - \langle M_{RH} M_{RH}^{*} \rangle)} \right) \pm \frac{\pi}{4} \quad (5)$$

The estimations of the Faraday rotation associated with these two equations are compared to the Faraday angle estimation provided by Bickel and Bates in one part and by Freeman in another part.

4. COMPACT-POL CALIBRATION

Two of the main issues of the CP calibration are the cross-talk and Faraday effects.
The distortion model is written as followed:

$$\begin{aligned} \vec{K} &= AR_{\Omega} \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_r \end{pmatrix} S \begin{pmatrix} 1 & \delta_3 \\ \delta_3 & f_t \end{pmatrix} \begin{pmatrix} 1 \\ -j \end{pmatrix} \\ \vec{K} &= BR_{\Omega} D_t S(\vec{J}_{RC} + \beta \vec{J}_{LC}) \end{aligned} \quad (6)$$

where $\vec{K}$ is the measurement vector, $\overrightarrow{J_{RC}}$ and $\overrightarrow{J_{LC}}$ are the Jones vector of the right circular and left circular and β is the apparent cross talk on transmit. In FP mode, once the distortion matrices are estimated, they can be corrected for. This is not the case with the CP mode as only one polarization is transmitted. As a result, the imperfection in the transmit channel cannot be corrected for. There is a strong requirement on the polarization purity for the transmit wave which can be translated in a requirement on the system:

$$\beta \approx \frac{1 - f_t}{1 + f_t} - j\delta_3 \quad (7)$$

The f_t parameter: it has to be of unit 1, and of phase close to 0°.

On the receive channel, cross talk and FR will have similar effects. The question of uncoupling them remains unanswered and we will address this issue in the paper.

5. CONCLUSION

In presence of FR, the choice of the transmit polarization is important. Indeed, we have seen that at low frequency, circularly polarised wave in transmission is the only solution to overcome FR effect, as the EM wave seen by the scattering element has a constant polarization whatever the FR.

On receive, the Faraday rotation can be corrected for if known. An estimation technique is presented based on the bare surface properties. The selection of the bare surfaces can be done using the conformity coefficient, itself FR invariant.
In order to provide a meaningful polarimetric information, the polarization of the transmit wave has to be perfect as it is not possible to correct for any distortion afterwards as one polarization is transmitted. On receive, we propose a procedure to correct for the cross talk and channel imbalance.

6. REFERENCES

[1] A. Freeman, and S. Saatchi, “On the Detection of Faraday Rotation in Linearly Polarized L-Band SAR Backscatter Signatures,” Trans. On Geoscience and Remote Sensing, vol. 42, No. 8, pp. 1607–1616, 2004.

[2] S. H. Bickel and R. H. T. Bates, “Effects of magneto-ionic propagation on the polarization scattering matrix,” Proc. IRE, vol. 53, pp. 1089–1091, 1965.