

A New Measurement Principle for Determining the Polarization Direction of Calibration Transponder Antennas

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Abstract

Polarimetric synthetic aperture radar (SAR) systems require verification and calibration of their polarimetric performance after launch. Dual-antenna calibration transponders with freely rotatable, linearly-polarized antennas are one of the most common calibration targets for this task. Because the transponders are used as a measurement standard, any misorientation of the polarization direction of the transponder antennas leads to characterization errors for the SAR instrument. In this paper, we present a novel calibration approach with which the polarization direction of linearly polarized antennas can be accurately determined; no additional reference antenna with a previously known polarization is required. The novel approach will reduce polarimetric transponder calibration errors in the future and will lead to a higher accuracy in calibrated, fully polarimetric SAR systems.

1 Introduction

Transponders are one of two typically used calibration point targets for the calibration of synthetic aperture radar (SAR) systems. In comparison to trihedral corner reflectors, the other common calibration target, a transponder has a distinctive advantage: Its polarimetric backscattering matrix can be freely adapted. In practice this is achieved by using separate, rotatable receive and transmit antennas as implemented for instance in DLR's *Kalibri* transponder, shown in Fig. 1 [2, 5].



Figure 1: DLR's C-band *Kalibri* transponder, featuring one transmit and one receive antenna, both with an automated rotation mechanism.

Such a transponder offers the ideal polarization agility with respect to the calibration of fully polarimetric SAR systems. Existing calibration approaches such as [7] are based on a fundamental assumption though, namely that the polarization of the linearly polarized antennas is precisely known. It is assumed, for instance, that the E -field vector of a horizontally (H) polarized antenna is exactly leveled with the local horizon because any slight orien-

tation errors would deteriorate later calibration measurements.

A simple method of determining the polarization direction of a horn antenna is to measure the alignment of the waveguide feed with a precision level [7]. This measurement is purely mechanical, and deviations of the electromagnetic polarization direction from the mechanical alignment cannot be discovered. The approach is therefore insufficient for high-accuracy transponders, also because there is no clear approach of how the measurement uncertainty can be derived.

Other existing measurement approaches can be divided into two categories: polarization transfer (or comparison) methods and absolute methods [1]. Realizations from the first category are problematic if low measurement uncertainties are sought because it is not clear how the polarization direction of the required reference antenna can be established. Known realizations of the second approach based on three unknown antennas require six magnitude and phase measurements [6]. While magnitude and phase measurements ultimately provide the complete polarization characteristics for elliptically polarized antennas, a simpler approach for the special case of linearly polarized antennas is advantageous in the case of calibration transponders.

Here such a simpler approach is introduced for accurately measuring the polarization direction of any three or more linearly-polarized antennas without *a priori* knowledge. The approach is called the Three-Linearly-Polarized-Antenna Method, or 3LPAM. Similar in spirit to the three-antenna [4] and three-transponder methods [3], three antenna measurements with a pair of two antennas each are sufficient to determine the polarization direction of all of the three antennas. No phase measurements are required which simplifies the measurement setup.

The novel approach should find its application whenever an accurate determination of the polarization direction of

a linearly polarized antenna is required. This especially includes the determination of the polarization direction of antennas which are installed in calibration transponders as described above, so that this approach contributes to the calibration accuracy of polarimetric SAR systems.

2 Problem Description

Three linearly-polarized antennas A , B , and C with unknown polarization direction but known main-beam direction shall be given. The respective main beam direction shall be denoted by the unit vectors \mathbf{z}_A , \mathbf{z}_B , and \mathbf{z}_C . Each antenna shall be equipped with an arbitrary but fixed mechanical reference plane which allows to determine the mechanical antenna rotation around the main beam direction \mathbf{z}_X (where X stands for any of the antennas A , B , or C) after installation.

The problem is to determine the polarization directions α , β , and γ , which are defined as delta angles with respect to the mechanical reference direction.¹ See Fig. 2 for an example.

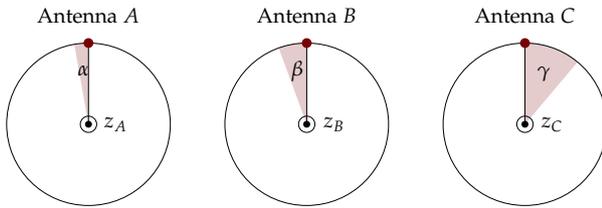


Figure 2: Antenna apertures showing the definition of local coordinate systems and exemplary angles α , β , and γ which denote the offset of the polarization direction from a mechanical reference direction (marked with a dot in vertical direction). In this example, the angles α and β are positive, γ is negative.

3 Measurement Setup

In total, three antenna measurements are required, and each measurement is performed with two antennas. The antennas shall be installed in the typical fashion, i. e., facing each other so that the main beam directions are collinear but inverse.

A possible set of antenna combinations is AB , AC , and BC . Due to reciprocity, it does not matter which antenna is used for transmitting and which for receiving, but the antennas should be set up in the far-field distance of each other, i. e., the distance d should exceed

$$d = \frac{2D^2}{\lambda}, \quad (1)$$

where D is the maximal aperture diameter of the largest antenna, and λ is the wavelength. A signal generator shall be connected to the transmitting antenna, and it should

emit a stable continuous wave signal at the frequency of interest. A stable receiver (power meter) shall be connected to the receiving antenna.

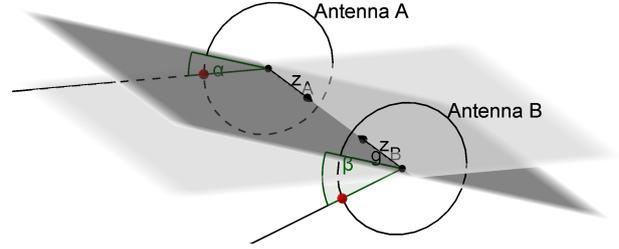


Figure 3: Measurement setup. The two antennas are facing each other. The red points indicate the mechanical reference direction. Angles counting from this point denote the respective antenna's polarization direction, which are brought to coincide by an antenna measurement.

A mechanical reference plane shall be defined which is fixed with respect to the measurement setup. One simple choice is the horizontal plane which in practice can be easily established with a level. The main beam directions of the two antennas shall then fall into this horizontal plane, see Fig. 3.

For each antenna pair AB , AC , and BC , the following steps shall be conducted:

1. Mount the first antenna so that the horizontal plane and the antenna reference plane coincide (see antenna A in Fig. 3). Connect the antenna to the signal generator.
2. Mount the second antenna so that the horizontal plane and the antenna reference plane coincide. Connect the antenna to the power meter.
3. Rotate the second antenna until the indicated receive power is maximal, and note the rotation angle δ_{XY} . At this rotation, the antennas' polarization directions are collinear (see Fig. 3).

4 Derive Absolute Polarization Directions

The measurement results are the three angles δ_{AB} , δ_{AC} , and δ_{BC} or

$$\boldsymbol{\delta} = (\delta_{AB}, \delta_{AC}, \delta_{BC})^T.$$

Each of these angles results from a difference of the wanted absolute antenna polarization directions, which results from geometric considerations, so that

$$\begin{pmatrix} \delta_{AB} \\ \delta_{AC} \\ \delta_{BC} \end{pmatrix} = \begin{pmatrix} -\alpha - \beta \\ -\alpha - \gamma \\ -\beta - \gamma \end{pmatrix}, \quad (2)$$

¹ For a horn antenna with a rectangular waveguide, this reference direction could be defined by one of the walls of the waveguide, and the antenna rotation could then be measured after installation by mounting an inclinometer on this surface, provided that the main beam direction is collinear with the horizontal plane.

or

$$-\begin{pmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{pmatrix} \begin{pmatrix} \alpha \\ \beta \\ \gamma \end{pmatrix} = \begin{pmatrix} \delta_{AB} \\ \delta_{AC} \\ \delta_{BC} \end{pmatrix} = \mathbf{Ax} = \boldsymbol{\delta}. \quad (3)$$

This system of equations is solved by inverting \mathbf{A} . One yields

$$\begin{pmatrix} \alpha \\ \beta \\ \gamma \end{pmatrix} = -\frac{1}{2} \begin{pmatrix} 1 & 1 & -1 \\ 1 & -1 & 1 \\ -1 & 1 & 1 \end{pmatrix} \begin{pmatrix} \delta_{AB} \\ \delta_{AC} \\ \delta_{BC} \end{pmatrix}. \quad (4)$$

The last Eq. (4) summarizes how one can compute the absolute antenna polarization direction for three antennas with unknown polarization.

5 Conclusion

A new and simple method was introduced which allows to absolutely determine the polarization direction of three unknown linearly polarized antennas, requiring only three measurements. In comparison to a (relative) polarization transfer method, no additional measurement standard is required so an additional source of measurement uncertainty is avoided. However, the method is only applicable to linearly polarized antennas. If one wants to determine the axial ratio, polarization direction, and sense of polarization of elliptically polarized antennas, the more involved procedure introduced by Newell [6] should be used. Nevertheless, the method is well applicable in cases of linearly polarized antennas, for instance in the accurate polarimetric characterization of SAR calibration transponders. Employing this accurate calibration approach for existing and future calibration transponders, and therefore the polarimetric measurement standard, will allow to further increase the performance of fully polarimetric SAR systems.

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