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FIRST ANALYSIS OF C-BAND ECR TRANSPONDERS FOR INSAR GEODESY

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ABSTRACT

Well-identifiable reference benchmarks are important in SAR interferometry to enable linking between different measurement techniques, or to enable datum connection between the local InSAR datum and Terrestrial Reference Systems. As corner reflectors for C-band are rather large, weather sensitive, and difficult to maintain over time frames of several years, active electronic transponders are an alternative. However, low cost transponders have not been on the market until recently. Here we report results from field tests of a new type of transponder. We show that the phase precision is in the order of an equivalent displacement of 0.5 mm, and that the RCS of the transponder is equivalent to a trihedral corner reflector with a leg length of 1.03 m.

Index Terms— SAR, InSAR, radar transponder, corner reflector

1. INTRODUCTION

The inherently relative character of the InSAR technique, for estimating displacements of geo-objects, limits the unambiguous interpretation of InSAR results. The reported displacement of a point in the SAR image is, in fact, completely uninterpretable as long as it is not known relative to which reference (or geodetic datum) it is estimated. Whether this datum is defined as a single reference point, or e.g. the mean of a group of points, is irrelevant: without external knowledge of the dynamic behavior of the datum the results cannot be compared to other geodetic results, or with other non-overlapping datasets. The datum definition problem relates to both space and time.

A second problem typical of InSAR is the inhomogeneous spatial distribution of the coherent measurement points. If a particular phenomenon or geo-object needs to be surveyed, it may be required to add or install a dedicated scatterer at a particular location. Examples are remote areas such as volcanoes where a reliable scatterer is needed, or an area suffering from significant temporal decorrelation.

For these cases, the standard ground control points for InSAR are mechanical corner reflectors. Even though they have clear advantages in terms of cost and low-complexity, corner reflectors are difficult to maintain for longer multi-year time intervals due to their sensitivity to the environment: weather,

and human interference.

Radar transponders are an interesting alternative. Traditional transponders used for the amplitude calibration of satellite SAR sensors are generally too bulky and expensive, since their aim is to provide very precise amplitude stability, down to the 0.1 dB level. In contrast, for InSAR applications, the main requirements are dictated by phase stability, minimum power level and cost. Phase stability, between consecutive acquisitions and over time intervals up to several years, is important so not to confuse instrumental phase drift with the (geo)physical signals of interest. Moreover, the group and phase delay should be stable over time. The minimum power level is important to ensure that the transponder signal is still observable over the clutter at the site. Furthermore, the cost of the device should be low, to make it feasible to operate them economically in networks in remote areas with an acceptable risk of losing a device. Nevertheless, the most important requirement is that the devices should be available commercial off-the-shelf (COTS).

Following earlier studies, [1, 2, 3], in this study, we investigate whether a new prototype radar transponders, here referred to as an Electronic Corner Reflector (ECR), developed by MetaSensing, is a feasible alternative to mechanical corner reflectors for InSAR geodesy, and whether it satisfies the most important criteria. This is performed in a controlled field test.

2. TRANSPONDER DEVICES

The prototype ECR from MetaSensing has a footprint of about 67×36 cm. Its outer housing consists of a metal baseplate and PVC radome. The metal baseplate has two grips for carrying the device and six holes for attaching the device to a carrier or underground. The PVC radome is attached by 28 bolts to the metal ground plate, making a watertight connection, see Fig. 1a. The two external interfaces are a weatherproof USB connector and the solar panel cable, as well as a pressure equalizing vent in the PVC enclosure.

Internally the ECR device consists of one receive and one transmit antenna for C-band, a C-band RF chain with amplifier and filters, a microcontroller responsible for switching the RF chain on during a satellite overpass, a GPS receiver for time synchronization, and a rechargeable solar battery with 5V power equalizer. The tested prototype is uni-directional,

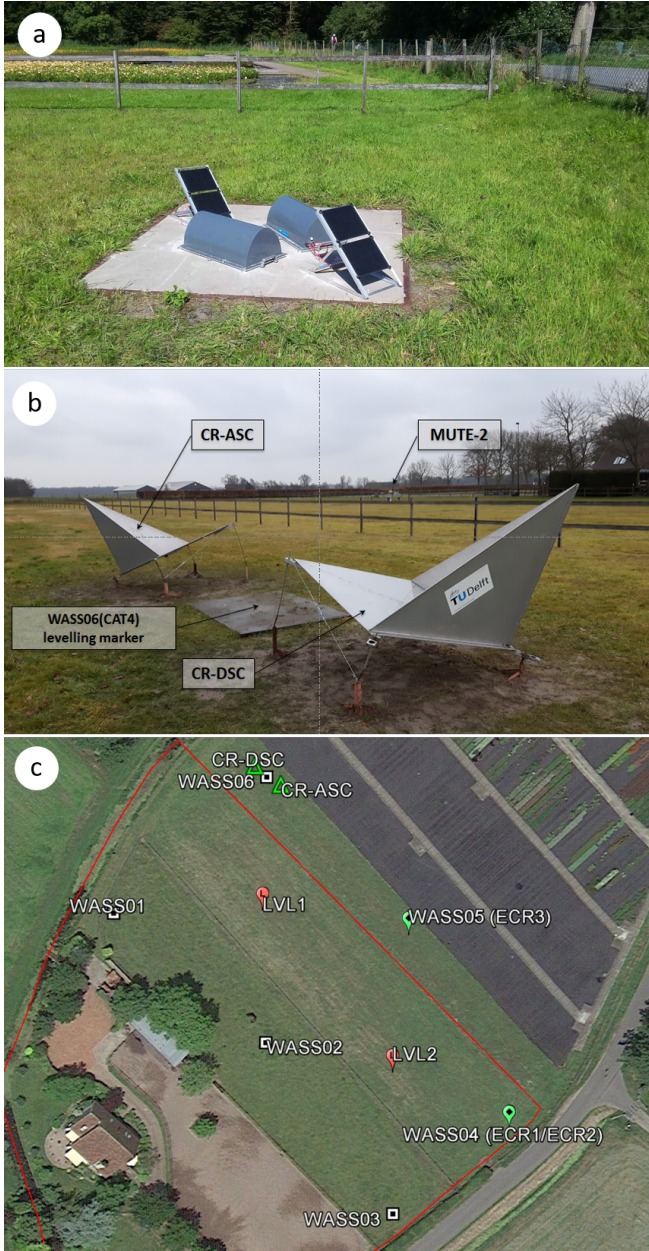


Fig. 1. (a) ECR1 and ECR2 on slab WASS04 aimed towards the descending and ascending orbits of Sentinel-1. (b) Reference corner reflectors CR-ASC (left) and CR-DSC (right), next to slab WASS06. (c) Location of the TU Delft reflector test site. The location holds sets of stable concrete slabs on which reflectors and transponders can be placed. The three transponders ECR1 (dsc), ECR2 (asc) and ECR3 (asc) are at the concrete slabs WASS04 and WASS05, and the location of the reference Corner Reflectors CR-DSC for descending tracks and CR-ASC for ascending tracks near concrete slab WASS06. The other concrete slabs WASS01, WASS02, and WASS03 have been used for testing other equipment during the test period. LVL1 and LVL2 are the locations from where regular levelling is carried out.

and needs to be aimed at either the ascending or the descending pass. The boresight angle of the antenna is optimized for the Sentinel-1 acquisitions from neighboring tracks and for the location within the beam. The times of activation of the device (alarm times) are uploaded via a csv-file, also indicating the duration of activation.

3. FIELD EXPERIMENT SETUP

The TU Delft reflector/transponder test site in Wassenaar, the Netherlands, is used since 2013 for testing transponders. The ECRs are installed on concrete slabs, see Fig. 1a, on stable sand bodies. The concrete slabs have markers for levelling. Two corner reflectors on site act as reference for the ECRs. One corner reflector is used for the ascending tracks, the other is used for the descending tracks, see Fig. 1b.

An overview of the test site is shown in Fig. 1c. Three ECRs were installed in August 2017, one aimed at descending Sentinel-1 tracks 110 and 037, and two aimed at ascending tracks 161 and 088.

The incidence and off-boresight angles are given in Table 1. The corner reflectors are aluminum square-based triangular corner reflectors with a leg length of 1.425 m. The corner reflectors are mounted on a square metal frame of iron, with square 30×30 cm flat plates attached to each corner, that is buried 25 cm in the ground.

To monitor the stability of the measurement test setup, local levelling surveys are carried out every one or two months. The levelling instrument is a Leica DNA-03 digital primary levelling instrument with a calibrated invar bar-code rod. The levelling instrument is placed at the LVL1 or the LVL2 location, see Fig. 1c. At these locations the distances to the nearby levelling markers are roughly equal (between 29 and 33 meter), which is important to eliminate collimation errors inside the instrument. The heights are measured in two double circuits. Each circuit has a clockwise (forward) and counter-clockwise (backward) loop designed to compensate for the setting of the levelling instrument. The average readings of the clock- and counter-clock wise look are taken. After the first double circuit, observer and rod-holder change position, and the procedure is repeated. The relative accuracy of these measurements is 0.2 mm.

4. RADAR DATA PROCESSING

The Sentinel-1 data is processed by the DORIS interferometric software in a single master stack configuration. At least three burst before and after the Wassenaar test site are processed, to optimize coregistration using enhanced spectral diversity. Based on the orbit data, timing parameters and ITRF2008 (WGS84) coordinates of the transponders and corner reflectors (CRs), the radar coordinates of these devices are calculated per stack. Moreover, also the radar coordinates of the mid-point between the three devices are calculated.

Table 1. Incidence and off boresight angles for various Sentinel-1 tracks (antenna boresight angle is 38 degrees.)

| | | Incidence angle | Off boresight | Mean RCS | Std RCS | Std DD phase |
|------|------------------------|-----------------|---------------|---------------------|---------------------|--------------|
| | | [deg] | [deg] | [dBm ²] | [dBm ²] | mm |
| ECR1 | dsc t110 swath2 burst4 | 36.68 | -1.32 | 34.5 | 1.74 | 0.84 |
| | dsc t037 swath3 burst3 | 44.64 | 6.64 | 29.6 | 2.05 | 0.91 |
| ECR2 | asc t161 swath3 burst3 | 41.77 | 3.77 | 32.0 | 0.39 | 0.73 |
| | asc t088 swath1 burst3 | 33.23 | -4.77 | 32.6 | 0.59 | 1.15 |
| ECR3 | asc t161 swath3 burst3 | 41.77 | 3.77 | 29.8 | 0.50 | 0.58 |
| | asc t088 swath1 burst3 | 33.23 | -4.77 | 32.1 | 0.49 | 0.48 |

Based on the radar coordinates of the mid-point of the three devices, a square window of 200 m is extracted from the data stacks for each co-registered image. The extracted data windows are oversampled to (i) get a better estimate of the peak value of the transponder/CR signal, and (ii) to get approximately square pixels (in azimuth and slant range direction). For Sentinel-1, an oversampling factor of 96 in azimuth and 16 in slant range direction is used. (This corresponds with a ground resolution of approximately 20 cm).

Based on the co-registered data stack, the mean amplitude of the data stack is computed. This mean amplitude image is used to detect the maximum peak location of the signal of the transponders and CRs. A search window is defined for each device around the calculated radar coordinates. When the maximum amplitude value is found on the edge of the search window, the window was apparently too small, and the window is iteratively enlarged in azimuth or range direction, until an actual maximum within the window is found. Hereby, a visual check is applied to ensure that not mistakenly the peak of another device is found. Once the radar image location of the maximum mean peak is determined, complex values (I, Q) at this location are extracted for each individual SLC image. These complex values are used to calculate the RCS and phase values.

Once the complex values are extracted for each image in the stack, the Radar Cross Section [dBm²] is calculated in multiple steps. First, beta naught (β^0) is calculated in linear scale via the Digital Number (DN) and the radiometric calibration factor k . This calibration factor is annotated in the annotation files of the S1 products. For Sentinel-1 data, the calibrated β^0 is calculated by

$$\beta^0 = \frac{1}{k_{S1}^2} \cdot |DN|^2, \quad (1)$$

where $DN = \sqrt{I^2 + Q^2}$. The radar cross section RCS is obtained by

$$RCS = 10 \cdot \log_{10} (\beta^0 \cdot \Delta_a \cdot \Delta_r), \quad (2)$$

where Δ_a and Δ_r are the azimuth and slant range resolution, respectively.

The RCS of the transponders is analyzed, as well as the the RCS of the corner reflectors, for which we have the theo-

retical RCS values. The complex values (I, Q) of the single-master interferograms are extracted at the mean peak location of the transponders and CRs, to derive the phase values.

The phases are evaluated differentially: the phase differences between the transponders, or between a transponder and the CR are analyzed. The stability of the phases is assessed based on the deviation from the mean, or optionally based on the residuals of a 2nd or 1st degree polynomial estimated based on the time series, together with the estimation of possible jumps in the time series. The phase is first analyzed in the line of sight for each individual stack. For this the phase is converted from degrees to displacements in the line of sight in mm.

Table 2. Double-difference deformations derived from levelling, in mm, relative to first epoch, and relative to the mean of concrete slabs WASS05 and WASS06. WASS06 is in between the two reference reflectors. WASS05 supports ECR3. Relative motions remain less than 0.2 mm.

| | 21/9/16 | 27/12/16 | 7/3/17 | 11/4/17 | 14/5/17 |
|--------|---------|----------|--------|---------|---------|
| # days | 0 | 97 | 167 | 202 | 235 |
| | [mm] | [mm] | [mm] | [mm] | [mm] |
| CR-DSC | | | 0.00 | 0.01 | 0.09 |
| WASS06 | 0.00 | -0.01 | 0.02 | 0.02 | -0.08 |
| CR-ASC | | | 0.00 | 0.22 | 0.00 |
| WASS05 | 0.00 | 0.01 | -0.02 | -0.02 | 0.08 |

5. RESULTS

The results of the levelling campaigns in the period of September 2016 until June 2017 are given in Table 2, as height changes with respect to the first epoch. The accuracy of these measurements is 0.2 mm. The levelling markers on the concrete slabs WASS04 and WASS05, which were installed on July 23, 2013, are used as reference for the levelling campaigns. These provide a very stable reference.

Table 1 lists the main results of the ECR analysis. The average RCS of the ECR was found to be 31.8 dBm². This is comparable to a triangular trihedral corner reflector with a leg length of 1.03 m. Although this is quite small for C-band this is sufficient for areas with moderate clutter. The standard

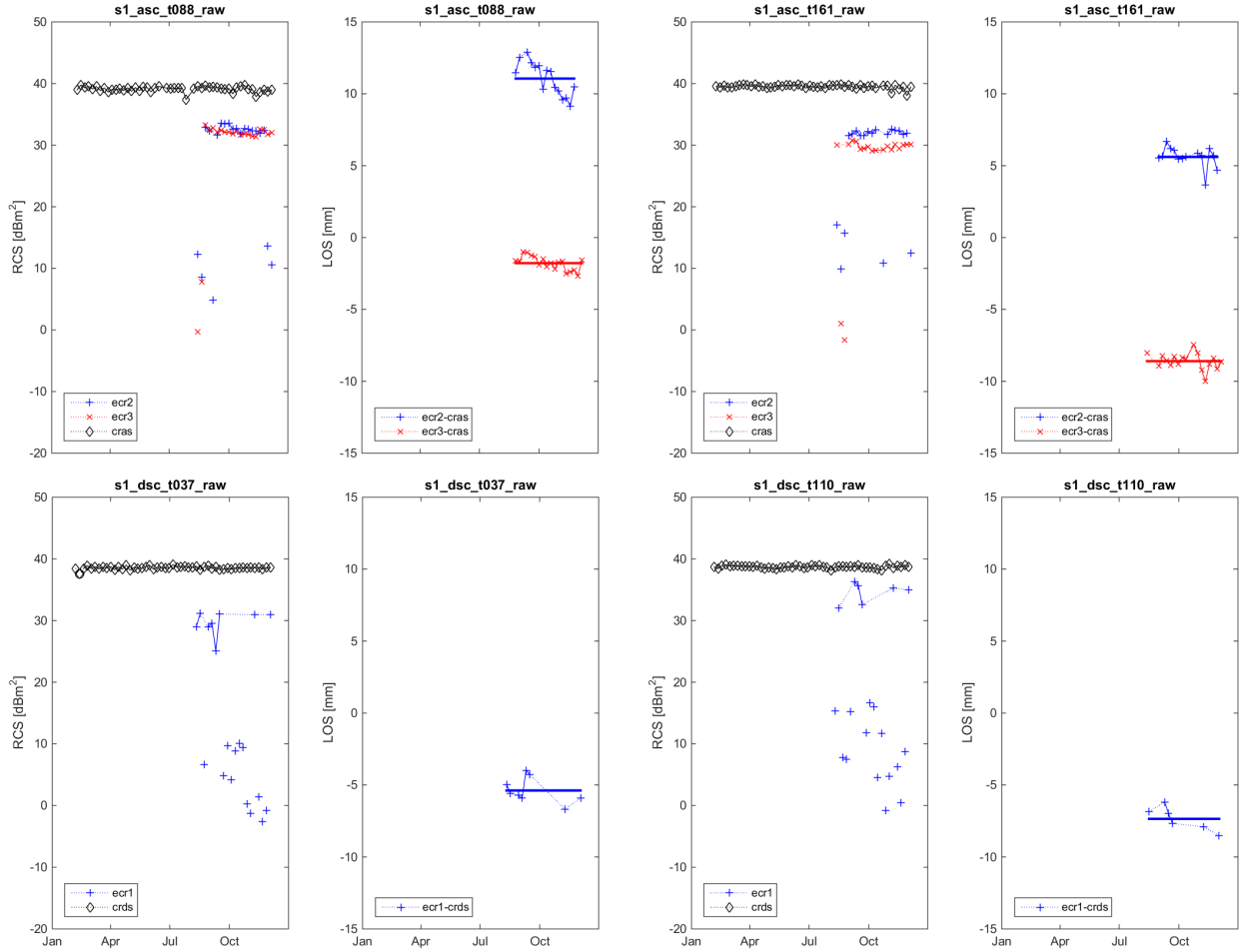


Fig. 2. ECR results. (top) ascending orbits (bottom) descending orbits. RCS time series are shown for the corner reflectors and each ECR, including times when the device was switched off. Phase time series are expressed in line of sight (LOS) in equivalent displacements [mm].

deviation of the double-difference phase is 0.8 mm in line of sight, over a period of 4 months. Fig. 2 shows the RCS and phase time series for the two ascending (top) and descending (bottom) orbits. The RCS plots show the reference CRs and the ECRs, including the times when the ECRs were switched off. The phase time series, expressed in mm LoS position show a steady behavior over time.

6. DISCUSSION AND CONCLUSIONS

The first experimental analysis of ECRs shows that it is feasible to obtain valuable geodetic time series from new COTS transponders. With slight boresight misalignment, they can serve two adjacent Sentinel-1 tracks, equivalent to a 1.03 m corner reflector. An average double-difference phase stability of 0.8 mm is obtained, which also includes the (limited) dynamic behavior of the corner reflector and ECR platforms. A one-sigma displacement precision of 0.5 mm of the ECR is

therefore a reasonable estimate.

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