A Low Cost Active Corner Reflector to assist Snow Monitoring through Sentinel-1 images

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Abstract—The use of Sentinel-1 SAR images for snow behavior monitoring and its parameters estimation is one of the most studied applications, but due to the high temporal and spatial heterogeneity of this media, is quite challenging. The presence of reference targets in the observed areas is of main concern both for amplitude and interferometric based techniques, but in a typical scenario as snow covered slopes or glaciers there is a lack of stable natural targets; this can demand the installation of Corner Reflectors. In this study, the design and the first test of an active corner reflector (ACR) operating at 5.405 GHz ± 50 MHz band, designed to be used in support to ESA Sentinel-1 spaceborne SAR images analysis and processing, is reported. The system here described was designed aiming at a tradeoff among low cost, simple functioning, easy and rugged hardware, to be deployed also in sites, as snow covered areas and glaciers. Using off-the-shelf components, one of the most challenging issue is to obtain a device with an adequate phase stability over long temporal interval.

Index Terms—SAR, backscattering, Interferometry.

I. INTRODUCTION

It is well known that SAR imagery from space allows the study of the cryosphere and land surfaces with negligible effects of the meteorological status, and not affected by illumination conditions. The retrieval through amplitude and phase (interferometric techniques) of imaged areas to map snow cover extent (SCE) and characteristics in mountain areas, can be challenging due to topography, atmospheric screen, vegetation, and other environmental and geometrical factors [1][2]. Within this context, a significant support can be obtained by the presence of benchmarks in the radar images, which usually consist in strong reflectors, with accurate localization. These good targets allow a better image interpretation, radiometric calibration, and to check phase stability for interferometric applications. While in urban and densely populated areas buildings and infrastructures are available as “natural” reflectors, in mountain regions there is the need to install artificial reflectors, usually consisting in passive corner reflectors (PCR). A PCR is passive target with a simple geometrical shape, designed to perform a high radar reflectivity. Such objects are usually constructed with metal plates, with a size large with respect to wavelength, and with faces oriented to maximize the energy reflected towards the radar. Several kinds PCR can be realized the best famous are the Triangular Trihedral (TT) [3]. PCRs are usually cumbersome, heavy and suffer from heavy weather conditions, as sever rainfall, strong winds and snowfall; in addition, the installation of a PCR can be difficult due to a hard accessibility, as in the case of glaciers or snow-covered areas. An alternative approach is represented by the installation of active corner reflectors (ACR), which are smaller, lighter, the main drawback being the need a power source, usually a battery and/or a solar panel. An ACR basically consists in specific RF device, in the case here reported, powered by a battery, able to provide a radar response seen as a bright pixel in the image and, possibly with a stable phase response. Historically the use of transponders linked to spaceborn SAR started contemporary to the first SAR space missions, and they were mainly urged by the need of radiometric calibration, but also as tagging technique to identify and locate particular targets when the surrounding area can make it difficult.

Recently, some ACR have been manufactured by companies [4][5], but their cost is too high to allow a wide use of these devices for a massive use. For this reason, the development of ACR with simpler installation procedures, handy, and low cost (approx. < 1000 euros), low power consuming, in spite of reducing some performances for an operational use, has started within a project funded by an innovation action of H2020 framework [6]. In this document we mainly describe the first phase of the realization of a Radio Frequency front end, designed and implemented by Centre Tecnològic de Telecomunicacions de Catalunya CTTC, to be used as ACR during SENTINEL1 SAR passages.

II. THE DESIGN

A. The rationale

Main goals of the use of the prototype described in this paper can be summarized in supporting the interferometric use of the satellite data with a low cost, portable and reliable device, and an employ also for amplitude image
interpretation, including a rough radiometric calibration, for backscattering coefficient estimate. This ACR was specifically designed for the SENTINEL-1 SAR sensor. The principle of working is shown in fig. 1 through a simple scheme. The basic version of an ARC consists of a receiving antenna, an amplifying section operating on the signal received from the Satellite, and a second antenna, retransmitting the amplified signal towards the same satellite.

To assure an adequate visibility of the target, its equivalent radar cross section (RCS) must be higher than a value, related to the radar brightness of the background. A stable phase target is useful when the point target is visible in the SAR image above the background backscattering level, or clutter, and this visibility is usually estimated through the Signal-to-Clutter [3]. Considering the high variability of the background of a natural surface, an estimate can be empirically obtained considering the RCS of PCR installed in previous campaigns; for example, in [3] (Table 1 at pag.6), considering a clutter of -10 dB, a pixel RCS = 10.4 dBm², the required RCS is 40.4 dBm², which corresponds to that of a Triangular Slant Trihedral CR Size = 1.7 m.

III. THE DESIGN

A. Design choice and expected performances

To calculate the equivalent RCS of the ACR, which depends on the gain of the two antennas, the gain of the amplifying section, and on the wavelength, the following simple formula can be used [7]:

\[ RCS = \frac{G_{\text{loop}} G_t G_r}{4\pi} \]  

(1)

Where \( G_{\text{loop}} \) is the gain of the RF amplifying section, \( G_t \) and \( G_r \) the transmitting and receiving antenna gain. Considering a required RCS>40dBsm, a tradeoff can be reached with the gain of the two implemented antennas greater than 15 dB (see following section). On these bases, we can invert the eq. 1 and determine the value of the required \( G_{\text{loop}} \) see fig. 2, which must be not greater than the coupling between the two antennas, to avoid an auto feed of the ACR due to leakage. Considering a position of the two antennas not closer than 30 cm, to reduce the encumbrance of the device, this value can be calculated through a simulation, also confirmed by a measurement. In our case the maximum acceptable \( G_{\text{loop}} \) is evaluated in 50 dB. The second parameter to know for the design of the ACR is the gain of the two antennas.

B. The antennas

A specific antenna patch array has been developed for this system. It consists in a 4 x 4 linear patch array, designed to provide a value greater than 15 dB, and hence reducing the necessary \( G_{\text{loop}} \). For the ACR best performances, also a good SWR is mandatory to reduce losses and reflections which can make the system more unstable in its phase response, when the temperature of the system, passive and active components, is fluctuating. In fig. 3 a comparison between the simulated and measured s11 parameter of the designed and implemented antenna array is shown. The result is satisfactory, considering also that a maximum gain of 17 dB was measured, close to the expected 18 dB of the simulation. The radiation patterns, simulated and measured in the two planes, horizontal and vertical, are shown in fig. 4 and fig. 5 respectively.

![Figure 1. Simple scheme of the functioning principle of an ACR.](image)

![Figure 2. Relationship among the three parameters involved in ACR design: required loop gain vs antennas gain with a fixed value of RCS = 40 dBsm.](image)

![Figure 3. Axial ratio of the patch array simulated, and measured, in the required bandwidth.](image)
The main requirements in the ACR implementation was to arrange an amplifying section with components off-the-shelf. Observing fig. 2, now knowing the antennas gain, 17 dB, we can estimate the required $G_{\text{loop}}$: it must be not lower than 42 dB. The RF chain must also include a bandpass filter to reduce interferences coming from external sources, as wireless or mobile network. In fig. 6 the schematic of the RF section is shown. The chain includes: a low noise amplifier (LNA) followed by a bandpass filter (5150 MHz - 5990 MHz), and three Medium Power Amplifiers (MPA). Attenuators and isolators are added to reduce the saturation and optimize the line. At the moment the implemented prototypes have been based on the evaluation boards of commercial low cost components; the final version will be integrated in a single board.

C. The amplifying section

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IV. THE TEST OF THE PROTOTYPE

Till now, different prototypes have been mounted and tried out, with the purpose to test different amplifiers and design schemes. In fig. 7, it is shown a result of the gain measurement of one of these prototypes, excluding the antennas. To estimate the $G_{\text{loop}}$ the measurement consists in sending a RF signal, generated by the signal Generator Agilent E8257D, a continuous step frequency signal, with initial frequency $f_{\text{min}}=5.2$ GHz, and stop frequency, $f_{\text{Max}}=5.6$ GHz, number of frequency points=201; the output is displayed through a Spectrum Analyzer (SA). Agilent E4445A in the range 5.0 GHz - 6.0 GHz. The value obtained with the ACR, $-9$ dBm @ 5.4 GHz, is compared to that obtained at the same frequency simply connecting the two instruments through a cable. The measured @ 5.4 GHz is 43 dB, a value compliant with the requirement. In fig. 6 a picture of the RF section of the ACR is shown. Further
design solutions have been implemented aiming at a minimum costs’ rationale. The ACR was also installed in a agricultural field for a first test aimed at checking its visibility during the satellite passages. Fig. 9 shows a picture of the set up in the field. Finally, as a preliminary qualitative result, we show in fig. 10 two images obtained from the Sentinel Hub browser managed by ESA [8] corresponding to the area where the ACR was installed, in the UPC campus, close to the CTTC plant. The figure shows the bright pixels appearing in the date when the ACR was installed with respect to the previous satellite passage without the ACR: first image Sentinel-1 A SLC IW mode acquired on May 20th, second image, same mode, but acquired on May 26th.

V. CONCLUSIONS

In this paper the development and implementation of an Active Corner Reflector operating at the Sentinel-1 SAR sensor frequency has been described. The manufactured device demonstrated to satisfy the requirements in terms of amplitude response, as confirmed by the acquisition of satellite images. Next step will be the test of its phase stability performances, and the implementation of an engineered system.

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