Design of Low-Cost Active Reflectors for Advanced InSAR Applications: First Results

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***Abstract*—Differential SAR interferometry has been widely used in the last couple of decades to obtain accurate millimetric measurements of land displacements. Recently, to increase the number of measurement points and, hence, the accuracy of the attainable results, the deployment of active reflectors has been proposed. Whenever massive deployment of artificial reflectors is required availability of low-cost solutions is a key enabling factor. In this paper, after providing general guidelines for active reflectors design, a low-cost solution, based on the use of patch antenna arrays and a radio-frequency chain assembled using off-the-shelf components, is developed. Preliminary simulation results and laboratory measurements are presented.**

I. Introduction

Synthetic Aperture Radar interferometry (InSAR) has been widely used in the last decades as a tool to accurately monitor ground displacements from space over wide areas. In particular, in persistent scatterer (PS) InSAR the displacement measurements points are strong radar scatterers that keep coherence over sufficiently large SAR acquisition time series. PSs usually consist of opportunistic targets, i.e. man-made or natural structures that behave like trihedral or dihedral reflectors. Interestingly, PS InSAR demonstrated its effectiveness also for long-time monitoring of sensitive infrastructures, such as buildings, bridges, and motorways [1].

Focusing on motorway monitoring, PS formation is usually related to the man-made structures present at the side of the road, e.g. guardrails. However, appropriate orientation of the road along the sensor line of flight is required to obtain an adequate amount of PSs. Therefore, the use of ad-hoc artificial reflectors is often required to monitor sensitive sections of the road that are not appropriately oriented [1]. In particular, trihedral passive corner reflectors (PCRs) represent a low-cost solution to increase PS density in these areas. An advantage of the artificial corner reflectors is that the position of the measurement point can be much more controlled, since the geometry of the scatterer is perfectly known; conversely, opportunistic PSs can be only roughly localized. In order to obtain the prescribed levels of radar cross section (RCS) the size of PCRs must be increased for decreasing operating frequencies, so that increasingly larger structures must be used moving from X to C, and to L band [2]. Due to large sizes and problems in mechanical stability, the deployment of these structures might be not practical in actual situations.

An interesting alternative to PCRs is represented by transponders or active reflectors (AR), which amplify the received SAR signal thanks to an active radio-frequency (RF) chain. They represent a smaller and more manageable solution with respect to PCRs. ARs have been largely used for SAR system calibration and recently their use has been also advocated in support of InSAR applications [3], [4]. For these applications particular care must be devoted to AR phase stability, which may require appropriate control and/or compensation strategies to account for temperature variations over time [3]-[5]. Indeed, commercial ARs have been made recently available and their performance in deformation monitoring applications has been tested [5]. However, they still represent an expensive alternative to PCRs, especially in areas where multiple reflectors should be deployed. For this reason, recently low-cost AR solutions have been proposed [4].

In this paper we discuss the design guidelines of a low-cost AR to be used for C-band Sentinel-1 SAR sensors. The AR is based on the use of patch antenna arrays and a RF amplification chain assembled using off-the-shelf components. Here preliminary simulations and laboratory measurements are presented. The delicate issue of phase stability will be object of future work.

II. AR Design Guidelines

The working principle of the AR is illustrated in Fig. 1. The starting point for AR design is the evaluation of the overall required gain. In principle, the higher the AR return the smaller the error on phase and, hence, on the associated displacement measure. Indeed, the phase error φ_{er} can be related to the signal-to-clutter ratio (SCR), i.e., the ratio between the AR RCS and the clutter RCS, through the following equation [2]

$$\varphi_{er} = \frac{1}{\sqrt{2\mathrm{SCR}}}. \tag{1}$$

In turn, the displacement error d_{er} can be obtained as

$$d_{er} = \frac{\varphi_{er}\lambda}{4\pi}, \tag{2}$$

where λ is the wavelength.

In the AR synthesis, the starting point is to fix a maximum acceptable d_{er}. Then, inverting (1) and (2) it is possible to obtain the necessary SCR. Once a typical value of the clutter RCS is also fixed, it is possible to evaluate the required AR RCS from the SCR. Focusing our analysis on the Sentinel-1 system, which operates at a frequency of 5.405 GHz, and fixing d_{er} = 0.1 mm, i.e. a value largely sufficient for most InSAR applications, we obtain a SCR of about 30 dB. In order to work properly, the AR must be placed over a sufficiently low-backscattering area: hence, we can assume a clutter normalized RCS of −12 dB, in accordance with typical values provided by electromagnetic scattering models from bare soil [6]. This leads to a clutter RCS of about 10 dBm^2, considering the typical resolution parameters of Sentinel-1 (5 m in azimuth and about 8.7 m in ground range considering a look angle of 35°). Accordingly, an AR RCS of about 41 dBm^2 is necessary: this would require a triangular PCR with largest side equal to 1.75 m [2]. The AR RCS (RCS_{AR}) is related to the receiving and transmitting antenna gains, G_r and G_t, and to the RF circuit gain, G_{RF}, according to the following equation

$$RCS_{AR} = \frac{\lambda^2 G_r G_t G_{RF}}{4\pi}. \quad (3)$$

The design of the antennas should result from a trade-off between gain and size. Moreover, antenna beamwidth should be designed in order to not excessively hinder the pointing of the AR towards the sensor. Once antenna gains are available, it is possible to evaluate the required G_{RF} by simply inverting (3).

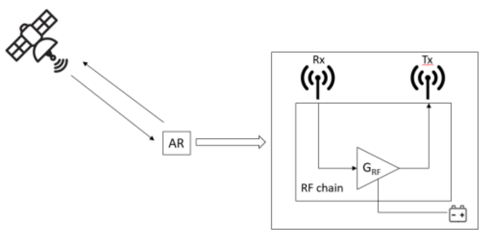

Figure 1. Working principle of the AR.

III. AR Development

A. Antennas

To obtain an appropriate trade-off between gain, size, and compactness a 4x4 patch antenna array has been designed and developed. The main performance parameters of the antenna, including half power beamwidth (HPBW), and side-lobe level (SLL) have been evaluated via numerical tools and are provided in Table I. A picture of one of the patch antenna arrays is reported in Fig. 2.

B. RF Chain

Inverting (3) using the antenna gains of Table I and the RCS_{AR} evaluated in Section II, we obtain that a G_{RF} of about 52.6 dB is required. The proposed RF chain is implemented using off-the-shelf components and its layout is shown in Fig. 3: it consists of a low-noise amplifier (LNA), followed by a band-pass filter (BPF) and by two medium-power amplifiers (MPA), separated by an isolator. The scattering matrix of the overall RF chain has been measured using a VNA Anritsu MS4623B: the gain in the range 5-6 GHz is shown in Fig. 3.

IV. Conclusion

A low-cost RF chain able to provide the desired gain has been set up and characterized. As future step the designed antennas should be characterized and the coupling between the antennas measured. It is important to define a proper arrangement of the antennas so that the coupling is lower than the gain realized by the RF chain.

TABLE I. AR Antenna Performance Parameters (Simulated)

Parameter	Value
Gain (realized)	12.1 dBi
Pointing (el, az)	(0, 0) deg
HPBW (el, az)	(25.9, 19.0) deg
SLL (el, az)	(-13.2, -9.9) dB

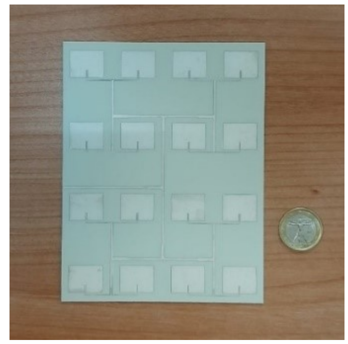

Figure 2. Patch antenna array.

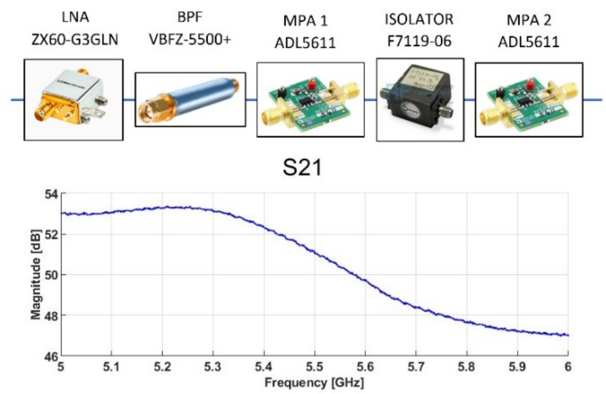

Figure 3. Block scheme of the RF chain, with indication of the used components (top); measured gain of the overall RF chain (bottom).

Acknowledgment

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