

SDR SAR Target: Corner Reflector and Communication

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Abstract

This paper presents a novel target, based on software-defined radio (SDR) technology, that allows the support of remote sensing processes and enables a transparent communication link in synthetic aperture radar (SAR) systems. Nowadays the integration of communication services in technologies that are not developed for this purpose can be an interesting solution for the increasing communication demand. The novel target acts in two different ways for SAR systems: as software-defined corner reflector (SDCR) for localization and calibration support, but also as SAR target to integrate a transparent communication link for target identification and tracking.

1 Introduction

Nowadays the importance of remote sensing is growing constantly due to the variety of airborne and spaceborne applications where it is involved. One of the most important techniques is Synthetic Aperture Radar (SAR), where the radar movement enables a large synthetic antenna aperture for high-resolution images acquisition of earth surface independently of weather and daylight [1].

The research community is always oriented to the satellite approach. Besides remote sensing satellites as COSMO-SkyMed and ESA Sentinel constellations, in smart cities perspective new services supported by satellites are becoming popular, in particular for new communications standards as 5G and 6G with massive IoT applications.

Backscattering is the common point between radar and SAR, and it is constantly linked to wireless communications and sensor-based systems because it allows the use of passive devices for low-power applications as ambient backscattering [2] and radio frequency identification (RFID) [3].

Nowadays there is a growing interest in communication services implementation, even into technologies that are not supposed for this purpose, like radar and SAR. Moreover, targets have an important role in the validation of the results of acquisition processes made by the SAR satellite; in general, they are used to support satellites in calibration processes and also for geopositioning and localization in remote sensing applications. Corner reflector (CR) is a device

frequently used for these purposes.

In this paper is presented a novel target for a generic SAR system already on air, referring to satellite SAR systems without loss of generality; through software-defined radio (SDR) flexibility, it can act in two different manners, as software-defined corner reflector (SDCR) but also as modulator for transparent communication link integration. The transparency reduces the interference of the communication link in the classic imaging processing, and the communication can be extracted in the received SAR signals to implement services like identification and tracking.

2 Radar and communication

The use of shared resources is the real challenge for the research community, in particular bandwidth due to the increasing spectrum demand in wireless communications but also radar technology; hence, the joint approach of wireless communication and radar can be an optimal solution.

This joint approach is long-standing, and today these activities are classified in several manners; a first classification is indicated as communication and radar spectrum sharing (CRSS) where they share the same resource and are classified in primary and secondary service [4].

Dual-function radar-communication (DFRC) can be considered as a sub-group of CRSS applications with a deeper

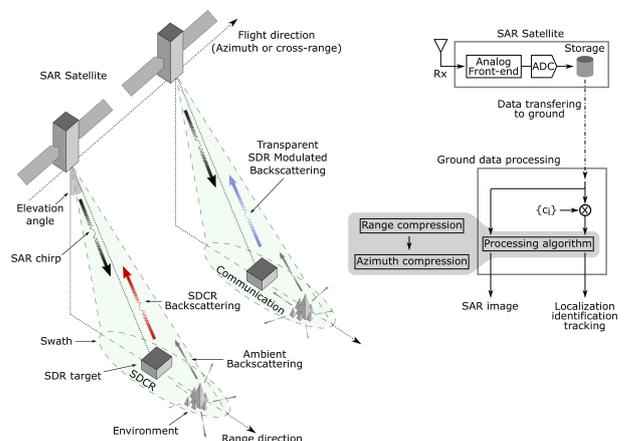


Figure 1. Simplified schematic representation of the proposed SDR target with both functionalities.

level of combination where the coexistence is extended toward some common features to operate simultaneously without interference, as described in [5].

Finally, in joint radar and communication (JRC) is designed a joint service that can operate both as radar and communication at the same time, without any distinction between primary and secondary service, as indicated in [6].

This dual approach is also extended to SAR remote sensing applications as in [7], where the communication is integrated into a planar SAR system through an antenna backscattering approach based on spreading techniques as for UWB RFID systems [8][9].

Targets play a fundamental role for satellite approach in SAR systems, due to the support for geopositioning and calibration but also for new communication services implementation as in [10], and CR are an optimal solution.

3 Corner reflectors

CR is an object that supports satellite SAR for calibration but also for image quality purposes and geolocalization. Usually a CR is located in places without natural reflectors so that it can backscatter the SAR signal with a certain gain to have a high radar cross-section (RCS).

In general CRs are classified between passive and active CRs; passive CRs are big and cheap since are made by metal plates with sides up to meters. Several shapes have been studied and the most used are the triangular CR, the rectangular CR and also the circular CR, as shown in [11]. The great advantage is the absence of power supply so that they can be located everywhere independently of weather conditions, but the main drawback is the size and weight.

Active CR is powered with power supply, battery or solar panels; differently from passive CR, active CR is smaller and compact, and it executes amplification, filtering and then transmits the signal back to the SAR satellite with better performance [12]. The main disadvantage is the power source that limits the possibility to locate it everywhere.

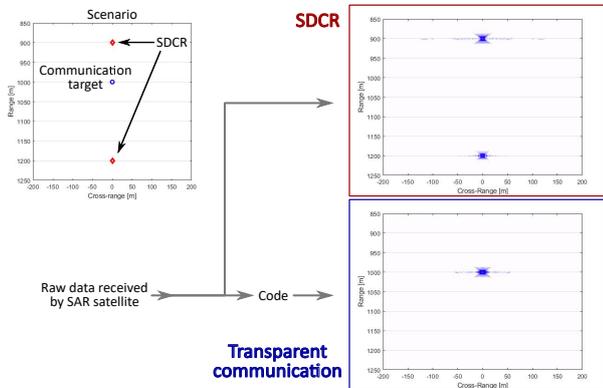


Figure 2. Simulation of both functionalities in a reference scenario with two red targets as SDCR and the blue one that implements the transparent communication.

4 SDR SAR target

As previously introduced, in this paper is presented a novel target that can execute two different functionalities for support a generic satellite SAR system but also to integrate a transparent communication link without interference in the classic imaging process; these two approaches are illustrated in figure 1 with a simplified representation.

The first functionality is the software-defined corner reflector (SDCR) that takes advantage of SDR technology jointly with the advantages of active and passive CRs. The SDCR transmits back the signal received by the satellite SAR as a classic CR, but the SDR choice enables a set of additive features: it can operate at different carrier frequencies to operate with several satellite constellations, and it enables the gain management.

The advantages of SDCR compared to passive CR are the compact design that allows its positioning even in high-complexity environments, and the higher gain due to amplifiers and antennas. Differently from active CR, SDCR enables interference mitigation, satellite signals monitoring and digitalization through the SDR FPGA, which allows also the real-time processing of the received signal.

Nevertheless, digitalization is also a drawback since is responsible for an additive latency that will be investigated in the following section; another drawback is the power source requirement, but they have low power consumption, thus some trade-offs must be considered.

The second functionality is the transparent communication link integration into a generic satellite SAR system already on air. This approach is focused on transparency, such that the contribution of the proposed communication target must be negligible. The idea is to operate in a way similar to SDCR with the integration of a transparent communication link. Due to the reduced time window, identification is the first strategy and it is implemented through a modulation of the signals received and backscattered to the satellite SAR with a specific code similar to CDMA or DSSS techniques. The signals received by the SAR satellite can be processed as usual to obtain the final image without interference due to the transparency; otherwise, applying the same code the contribution of the environment is reduced and the one of the target is highlighted, enabling the identification through code matching, target localization and also tracking with multiple localization images. An example is shown in figure 2 with a simple scenario.

The real challenge for the transparency is the choice of the code; the main requirements are the zero mean and the balancing property during the time window in which the SAR is receiving the modulated replicas of the transmitted signal, expressed as $\sum_{i=1}^N c_i = 0$ where $c_i \in \{-1, +1\}$ is the code of length N . Since π is the phase shift resulting from the code bits, in the processing algorithms for the final image the contribution of the code can be neglected; moreover, to preserve transparency, the balancing property must be valid in a short time window due to the SAR movement. It must be highlighted that the two functionalities are implemented in the same object which can perform them to-

gether in real-time or separately switching between them, since these execute conceptually the same task.

5 Analysis and critical issues

In this section are described the issues related to the proposed SDR target development for both SDCR and communication integration functionalities. Since this activity is in its early stage, the purpose is to present them with the description of their behaviors and all the advantages and drawbacks related to the classic technologies supported by simulations and analysis in a controlled environment.

The first issue to deal with is the delay introduced by the SDR platform used for the target prototype, which is related to both functionalities since it depends on the level of design inside the SDR device. The test has been conducted with several SDR platforms, but for conciseness purpose just NI USRP 2954R has been reported in this paper; the USRP has been programmed through LabVIEW and LabVIEW FPGA. Both functionalities have been developed in hardware domain to reduce the delay introduced by the device; it must be considered that the SDR platform introduces a minimum constant delay based on the analog front-end and analog-digital conversion blocks (ADC and DAC) involved in the receiver-transmitter chain, and this assumption is valid for both functionalities since it depends on the SDR device itself.

To analyze the delay effect, two different approaches have been studied; in the first approach, a test has been conducted in a controlled environment to quantify the amount of delay introduced by the system. Since SAR is based on radar technology, the test has been conducted through another USRP which acts as a radar that transmits a chirp waveform similar to real SAR satellites, and acquire it back in two channels, the first as a direct path and the second as the reflected path with additive 60m cables and the devices under test. The higher distance of the reflected path allows to distinguish the delayed path since the SDR sample rate could not be enough; the block scheme of the scenario under test is shown in figure 3.

The minimum delay introduced by the SDR device is equal to 550ns but it must be taken into account that any further processing inside the FPGA has a deterministic delay that can be computed as multiple clock cycles depending on the operations to implement. In figure 4 are shown the results of the test, where the direct and reflected paths have been correlated through a matched filter and the correlation has been coherently summed in the entire signal acquisition to reduce the contribution of the noise.

While the first approach has quantified the minimum delay of the proposed target, the second approach allows to understand the effect of this delay in the final SAR image; hence, a simulation has been conducted through MATLAB software and its Phased Array System Toolbox in the same scenario of figure 2, where the three targets reflect the satellite SAR signal with three different delays: the first with no delay, the second with 550ns which is the same quantity measured with the previous test and the third with a higher

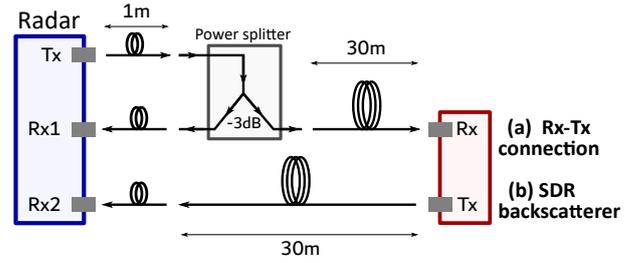


Figure 3. Block scheme of the scenario under test and the two paths with 60m cables (a) in addition to the SDR delay (b).

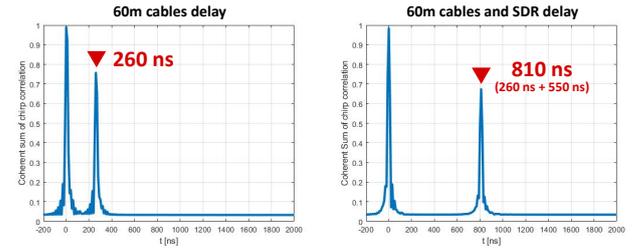


Figure 4. Coherent sum of signal correlation, with only the 60m cables to the left and with the addition of the SDR platform to the right.

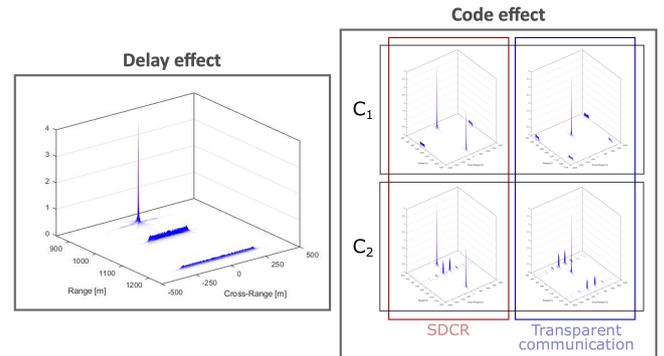


Figure 5. Simulation of the scenario presented in figure 2 to analyze the effects of delay independently of the functionality implemented, and the effects of the code for the transparency communication; two codes has been tested, c_1 with the commutation between +1 and -1 every one chirp signal, and c_2 with the commutation every eight chirps.

delay of 1200ns. In this case, as shown in figure 5, the delay introduced by the SDR platform corresponds to a spreading effect of the target contribution in the cross-range direction of the satellite that increases with higher delays. At the writing step of this paper, this spreading effect of the delay is under investigation to find a proper solution.

The second main issue of this proposal is the effect of the code used to implement the communication process. Since the time window in which the target is illuminated by the satellite is short, the first assumption is that a code, required for the identification process, must be transmitted in a single time window. Moreover, it is assumed that each code bit corresponds to a single chirp waveform; with these as-

sumptions, transparency is guaranteed if the code has zero mean and is balanced during the observation time window. In this case, the integration of communication link has been simulated in the same way as for the delay analysis; two different codes has been used based on the switching between $+1$ and -1 , c_1 with the commutation of the code bit at every chirp and c_2 with the commutation at every 8 chirp, as shown in figure 5. The simulation results show in figure 5 that the effect of the code is a filtering operation that leads to unwanted replicas in the cross-range direction that are limited in amplitude but can interfere in the final image. Also this issue is currently under investigation, and a solution can be the use of different codes like the bipolar or alternate mark inversion, but different assumptions regarding the code bit mapping are required.

6 Conclusions

Nowadays the importance of satellite systems is constantly increasing for remote sensing applications but also for communication purposes due to the increasing demand for connectivity; the trend of communication integration in technologies that are not designed for this purpose is becoming popular, in particular in radar and SAR systems. In this background, SAR targets are one of the most important solutions to integrate communication services and also to support satellite SAR systems in calibration and remote sensing operations.

In this paper has been proposed a novel target based on the versatility of SDR technology that implements two different functionalities, the SDCR for target localization and to support SAR technology and the processes that it has to implement, but also the integration of a transparent communication link that enables services like identification and tracking; these two functionalities are implemented in the same target and it can perform them together in real-time or separately. It has been shown that both functionalities have drawbacks in the target design, like the additive delay introduced by the SDR platform or the choice of the code and its properties to guarantee the transparency to avoid interference in the imaging process. These issues have been described and analyzed through software simulations and tests in a controlled environment.

The further analysis of this work will be focused on prototype tests in a real environment with real SAR satellites like the ESA Sentinel-1 constellation, with all the complexities that will be included.

7 Acknowledgements

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