Cross-pol long-cable transponder for bistatic ground-based synthetic aperture radar

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A transponder consisting of two antennas and an amplifier allows a ground-based synthetic aperture radar to operate as a bistatic system. In such a way, it is able to detect two displacement components of targets in its field of view. An enhanced transponder is proposed. Its special features are (i) cross-polarised antennas and (ii) antennas separated by a long RF cable (35 m). This transponder is able to provide 82 dB gain without triggering auto-oscillations. Monostatic and bistatic images have been obtained in an urban scenario.

Introduction: Ground-based synthetic aperture radar (GBSAR) systems are commonly used for detecting the ground changes of landslides [1], glaciers [2], and open pits [3] as well as for detecting small displacements of large structures as bridges [4] and dams [5]. Recently, the authors of this Letter proposed in a Letter [6] a novel mono/bistatic GBSAR configuration for retrieving the displacement vector using a transponder. Michelini and Coppi [7] studied other configurations of bistatic GBSAR. A critical issue using a transponder is its gain, that ideally should be greater than the path loss. Unfortunately, the gain is limited by the isolation between the two antennas. In this Letter, we demonstrate the operability of GBSAR with a transponder with antennas cross-polarised and separated by a long RF cable in such a way to provide a very high gain without triggering oscillations.

Working principle of monostatic/bistatic GBSAR with a cross-pol long-cable transponder: The working principle of a GBSAR able to acquire monostatic and bistatic images using the transponder proposed in this Letter is shown in Fig. 1. A linear GBSAR acquires a (monostatic) image of the targets in its own field of view. Using the third antenna, it acquires a second image of the same targets exploiting the signal passing through the transponder. The two antennas of the transponder are cross-polarised, as well as the second receiver (RX) antenna of the radar head is cross-polarised with respect to the transmitter (TX) antenna. An RF cable of 35 m separates the two antennas of the transponder. The transponder has two amplifiers A_1 and A_2 at the two ends of the cable. The gain of A_1 is 84 dB and the gain of A_2 is 28 dB. The loss of the RF cable is −30 dB. Therefore, the effective transponder gain is 82 dB.

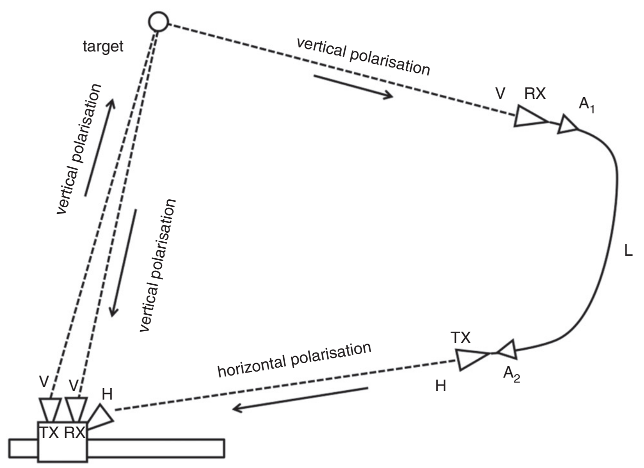

Fig. 1 *Working principle of monostatic/bistatic GBSAR using cross-polarised long-cable transponder*

In-field test: Fig. 2 shows the aerial picture of the test site, where we tested the radar equipment. The radar was facing a seven-storey building at 140 m distance. The TX antenna of the transponder was at the right-hand side of the radar at 53 m distance. The RX antenna of the transponder was at 31 m distance from the TX antenna. The radar operated in the band 9.915–10.075 GHz. The number of frequencies was 801. The length of the mechanical scan (orthogonal to the view direction) was 1.82 m. The number of steps along the scan was 180. The transmit power was 19 dBm.

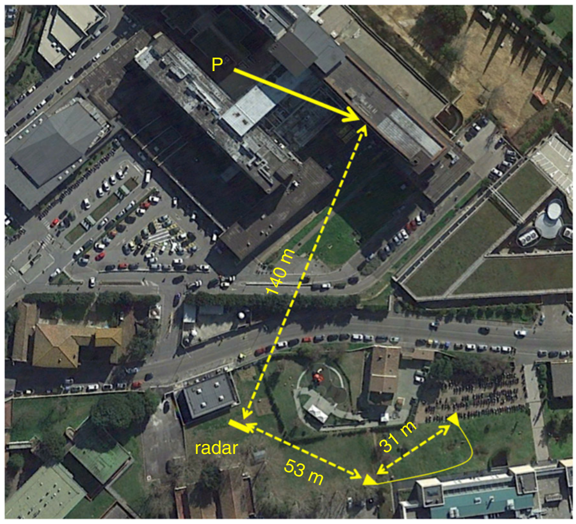

Fig. 2 *Aerial picture of test site*

Fig. 3 shows the obtained monostatic image. The edges of the building are well-evident. The bistatic image is shown in Fig. 4. The arrow indicates the same point P in the aerial picture, the monostatic image, and the bistatic image.

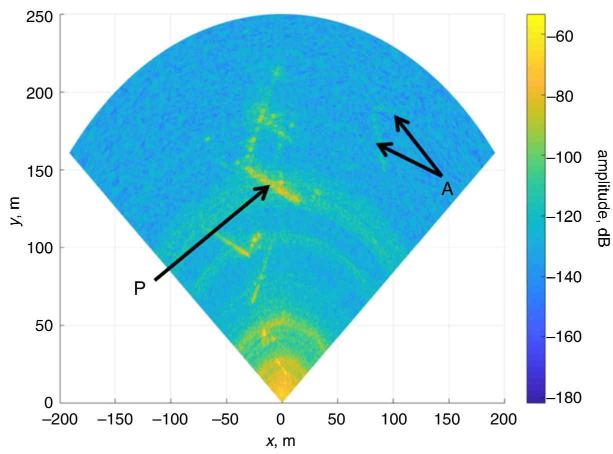

Fig. 3 *Monostatic radar image of test site*

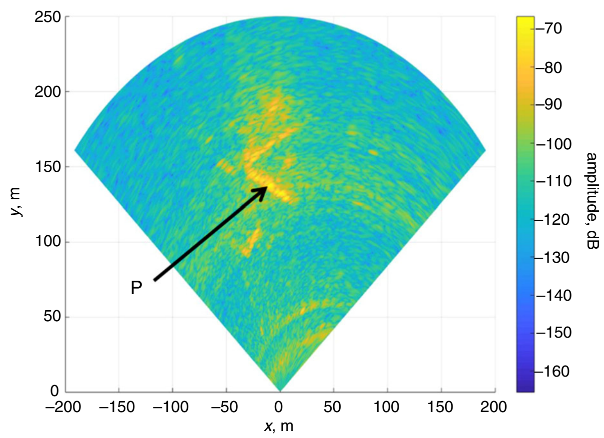

Fig. 4 *Bistatic radar image of test site*

The TX antenna of the transponder and the monostatic RX antenna of the radar are cross-polarised, so their coupling should be low. Nevertheless, the transponder (with 82 dB gain) is active even when the radar operates in monostatic modality. Therefore, we cannot exclude that a week signal passes through the transponder producing a sort of 'ghost' image. To verify it, we focused the bistatic signal with the monostatic algorithm. The obtained image is shown in Fig. 5. We can argue that the feature marked with A in the monostatic image (Fig. 3) is the 'ghost' image of the building. Its amplitude is low (40 dB lower than the highest signal), but it must not be mistaken for a true target.

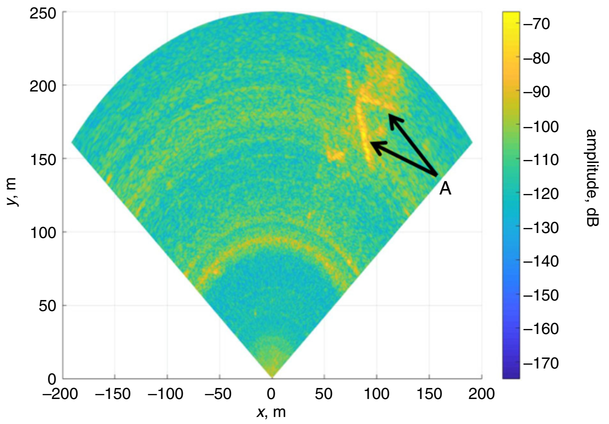

Fig. 5 *Bistatic signal focused with monostatic algorithm*

To test the phase stability of the equipment, we acquired 12 images (monostatic and bistatic) in 8 h and we calculated the interferograms between any image and its subsequent image. As an example, Fig. 6 shows one monostatic interferogram. The pixels relative to the building appear rather stable in phase.

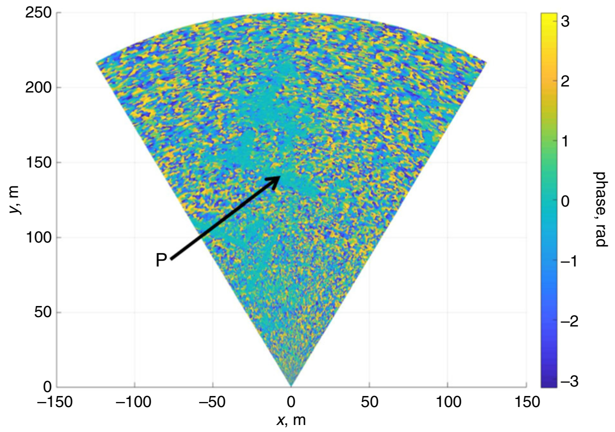

Fig. 6 *Example of monostatic interferogram*

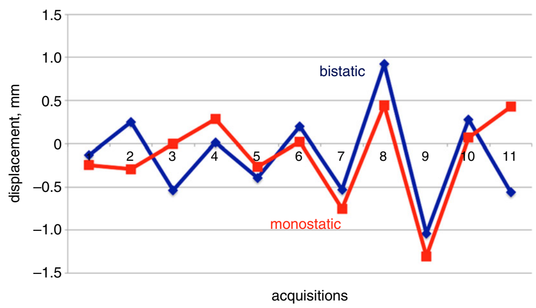

Fig. 7 *Displacement of point A as detected by 11 monostatic and bistatic interferograms*

To quantify this phase stability, we selected the point marked with *P* and we detected the 'apparent' displacement (ΔR) calculated as

$$\Delta R = \frac{\lambda}{4\pi}\Delta\phi \tag{1}$$

where λ is the wavelength at the central frequency and ($\Delta\phi$) is the detected phase in the interferogram. As the point marked with *P* is presumably a stable point, any displacement fluctuation is due to the radar system, atmospheric fluctuation, and environmental temperature changes. Fig. 7 shows the plots of these displacements for monostatic and bistatic configurations. These statistical fluctuations are in good agreement with other measurement campaigns with similar equipment [4, 8].

Conclusion: In this Letter, we designed and tested a high gain (82 dB) transponder for operating a GBSAR in bistatic modality. This high gain is obtained by decoupling the TX and RX channels by cross-polarisation and by separating the two antennas of the transponder with a long RF cable. Furthermore, as it is not always easy to find a single point where to see both the radar and the target, the long cable gives great flexibility in the deployment of the equipment.

When we tested in-field this solution, we found that though the TX antenna of the transponder and the monostatic RX antenna of the radar are cross-polarised, a residual weak bistatic signal is mixed to the monostatic signal producing a sort of 'ghost' image that could be mistaken for a true target. For avoiding it, the transponder should be switched off during the bistatic operation.

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One or more of the Figures in this Letter are available in colour online.

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