Electronic target for bistatic/monostatic SAR systems

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Abstract

This paper presents an electronic target designed for bistatic/monostatic synthetic aperture radar systems. The electronic target features two distinct antennas, so it can have different directions for transmitting and receiving. The electronic target basically receives a signal, down-converts it to baseband, applies a controllable time delay on the complex envelope, up-converts the delayed signal and transmits it towards the receiver of the bistatic/monostatic system. Since the delay is controllable, it can be used as artificial target with adjustable range. Even if the electronic target is placed in a cluttered area, its radar reflection can be moved away from its physical position.

1 Introduction

Ground based synthetic aperture radar (GB-SAR) is used in the fields of infrastructure elements monitoring [1] [2], terrain deformation (landslide [3] and avalanche) detection, early warning systems, and for detection of structural changes in buildings. GB-SAR can be used both in monostatic and bistatic configurations. The bistatic layout is composed of a SAR satellite transmitter or ground based transmitter and one or more ground antennas for receiving the two needed microwave signals: one directly from the transmitter and another from the imaged scene.

The described instrument is used for accurate displacement measurement of remote targets. In the present background, an electronic target (or transponder, as named in [4]) is useful for testing and calibrating SAR interferometric systems. Electronic targets have also been successfully used in the past as control points [5] for height determination, named polarimetric active radar calibrators.

The electronic target (transmitter-responder) presented in this paper practically emulates a target at a configurable range (using a controlled delay) in the same azimuth position as its physical location.

The procedure helps at separating the echo provided by the electronic target from clutter (echoes from real targets arriving from the same direction). Therefore, the emulated target can be placed in a clutter-free area, by adjusting the delay.

Unlike other instruments of similar purpose, the proposed electronic target downconverts the radio-frequency signal from the receive antenna and memorizes the baseband samples. It applies a programmable time delay, than upconverts the signal and transmits it using another antenna. The input stage amplification, output power of the transmitted signal is also configurable, as well as the carrier frequency. Other electronic targets are known to produce a fixed delay without any frequency mixing.

The electronic target described in this paper features two antennas, which can be oriented in any direction independently, allowing for a higher degree of flexibility, suitable for bistatic SAR geometry.

2 Electronic Target Description

2.1. System block diagram

The platform offers a broad range of TX/RX frequency domain for using the electronic target, as well as a large instantaneous bandwidth (160MHz). The USRP (Universal Software Radio Peripheral) offers a favourable platform for hardware description language design, along with rapid and versatile prototyping.

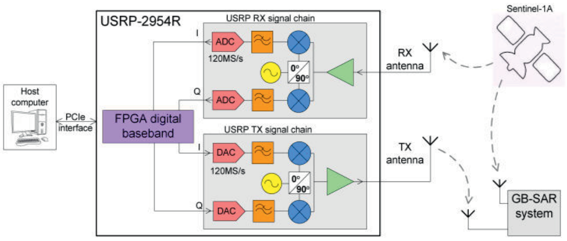

Figure 1: Block diagram of electronic target system

Figure 1 shows the block diagram of the entire system. It is composed of the USRP platform which is controlled by the host computer using the PCIe interface. The TX and RX antennas are connected the USRP RF connectors, which interface with the corresponding signal chains. Both blocks contain homodyne architecture, with in phase/quadrature mixing directly to or from baseband. The I and Q signals are fed to the ADC in the receive signal chain or are generated by the DAC in the transmit signal chain.

The present approach was mostly used due to the simplicity of the implementation. Another advantage of the platform is the broad ranges of carrier transmit and receive frequencies, allowing for the usage of this platform anywhere between 30MHz and 6GHz. The present electronic target works at a carrier frequency of 5.755GHz.

The USRP accommodates two RF daughterboards, both with TX and RX signal chains. In order to minimize leakage, the used transmit and receive modules are located on different daughterboards. For precise timing purposes, it is specified that the local oscillators contained by each daughterboard are phase-locked to the same clock reference.

Commercial electronic target product as referenced in [6] (as electronic corner reflector) features a fixed delay, operates in the C band (5.4GHz) , has a single block form factor equipped with 4 incorporated fixed antennas and works only for monostatic radar systems. On the contrast, the proposed electronic target features an adjustable delay, two independent antennas and has an adjustable central frequency. The “ECR-C” does not require an external data connection for operation. The proposed electronic target needs a PCIe or an Ethernet connection for proper operation. Some key elements of these two electronic targets are presented comparatively in **Table 1**.

Parameter	*ECR-C*	*This work*
Electrical delay (ns)	7ns	adjustable
Carrier frequency	5.4GHz	Adjustable, between 30MHz…6GHz
Bandwidth (MHz)	100	160

Table 1: Comparison between “ECR-C” electronic target and this work’s electronic target.

2.2 Baseband implementation

In this section, we present the design and functioning of the digital baseband section.

The baseband section of the proposed electronic target practically consists of a memory and a counter which increments the address field in the memory. The counter continuously outputs a number, which is used as the address field for the write section of the memory. Data is read at the next address than the one at which the writing operation currently takes place. The counter uses the data sampling clock as clock input, therefore incrementing one address unit every sampling clock period. The total delay introduced by this electronic target equals the length of the memory times the sampling period.

Additional unwanted delays add up to the configured value, due to the analog front-ends sections of the transmitter and receiver group delays. The delays were estimated at a total value around 0.7µs.

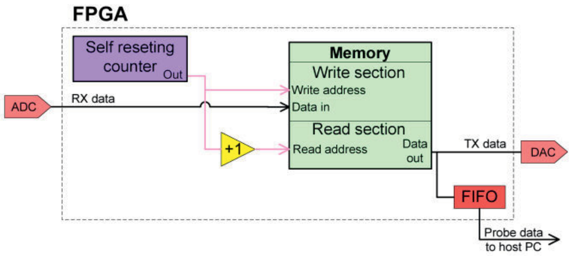

Figure 2: Block diagram for the baseband implementation of the electronic target.

A possible approach for implementing digital delays in FPGA is by using standard flip-flops [7]. Practically, the delay formed is proportional to the number of cascaded flip-flops and the period of the clock signal.

A calibration procedure was developed, in order to decrease carrier power level. It was implemented using baseband ADC values correction with fixed coefficients on the RX data. The coefficients are summed or subtracted with/from the received ADC values. The correction takes place before writing the values to the circular memory.

The correction coefficients were chosen empirically in order to obtain a rejection of the carrier level of at least 40dB.

3 Electronic target focusing

3.1 Electronic target in the background of bistatic radar

We consider that the electronic target is used with a ground-based bistatic system composed of a transmitter that can move on rail to form an azimuth aperture and a fixed receiver. The ground based transmitter generates a chirp signal written as:

$$s_{TX}(t) = \exp\left[j\left(2\pi f_0 t + \frac{\alpha t^2}{2} + \varphi_0 \right) \right] \qquad (1)$$

where α is the chirp angular rate, f_o is the carrier frequency and φ_0 is the initial phase.

The received signal on the electronic target side is a delayed version of the transmitted signal, delayed by t_{r1}, which is proportional to the transmitter-electronic target distance (2):

$$s_{\text{RX-el\_target}} = s_{TX}\left(t - t_{r1}\right) \tag{2}$$

The electronic target downconverts the signal to baseband using homodyne architecture. It uses a local oscillator which generates a carrier and it's nominally 90° phase shifted version. The LO suffers from a random frequency shift Δf_{LO} and a certain initial phase shift φ_{LO_RX} (3).

$$s_{LO\_RX}(t) = \exp\left[j\left(2\pi f_0 t + 2\pi\Delta f_{LO} t + \varphi_{LO\,RX}\right)\right] \tag{3}$$

These signals are mixed with the received signal, and the baseband signal (4) is formed.

$$\begin{aligned} s_{BB}(t) &= s_{RX-el\_target}(t) \cdot s_{LO\_RX}{}^{*}(t) = \\ &= \exp\left[j\left(-2\pi\Delta f_{LO} t + \frac{\alpha(t - t_{r1})^2}{2} + \varphi_0\right)\right] \cdot \\ &\cdot \exp\left[j\left(-\varphi_{LO\_RX} - 2\pi f_0 t_{r1}\right)\right] \end{aligned} \tag{4}$$

Afterwards, the baseband signal is delayed with a predefined time t_{del} using the structure presented in the previous paragraph.

$$\begin{aligned} s_{BB\_del}(t) &= \exp\left[j(-2\pi\Delta f_{LO}(t - t_{del})\right] \cdot \\ &\cdot \exp\left[j\left(\frac{\alpha\left(t - t_{r1} - t_{del}\right)^2}{2} + \varphi_0 - \varphi_{LO\_RX} - 2\pi f_0 t_{r1}\right)\right] \end{aligned} \tag{5}$$

The delayed signal is denoted $s_{\text{BB-del}}(t)$, which is up-converted using the transmit LO signal on the transmit side of the electronic target. It was experimentally observed that a phase shift exists between the transmit path LO and the receive path LO. Therefore, the phases will be accounted separately, as φ_{LO_RX} and φ_{LO_TX}. The signal is then radiated using the TX antenna.

$$\begin{aligned} s_{TX-xponder}(t) &= s_{BB\_del}(t) \cdot s_{LO\_TX}(t) = \\ &= \exp\left[j(2\pi f_0(t - t_{r1}) + \frac{\alpha(t - t_{r1} - t_{del})^2}{2}\right] \cdot \\ &\cdot \exp[j(2\pi\Delta f_{LO} t_{del} + \varphi_0 - \varphi_{LO\_RX} + \varphi_{LO\_TX})] \end{aligned} \tag{6}$$

The transmitted signal (6) is received by the ground radar receiver with a supplementary delay t_{r2}, proportional to the electronic target-receiver range.

$$\begin{aligned} s_{RX\_radar}(t) &= \exp[\,j(2\pi f_0(t - t_{r1} - t_{r2})] \cdot \\ &\cdot \exp\left[j\left(\frac{\alpha(t - t_{r1} - t_{del} - t_{r2})^2}{2} + \varphi_0\right)\right] \cdot \\ &\cdot \exp[\,j(2\pi\Delta f_{LO} t_{del} - \varphi_{LO\_RX} + \varphi_{LO\_TX})] \end{aligned} \tag{7}$$

Assuming that both the transmitter and the receiver of the ground-based bistatic system are GPS disciplined, the received signal is down converted to baseband with the same carrier frequency. It can be shown [8] that if the range compression is performed using a delayed version of the transmitted signal (which is received directly by the receiver on a separate direct path), the range compressed signal in baseband is:

$$\begin{aligned} s_{rc\_bb}(t) &= psf[t - (t_{r1} + t_{r2} - t_0 + t_{del})] \cdot \\ &\cdot \exp[-j2\pi f_0(t_{r1} + t_{r2} - t_0)] \cdot \exp[j2\pi\Delta f_{LO} t_{del}] \\ &\cdot \exp[j\left(-\varphi_{LO\_RX} + \varphi_{LO\_TX}\right)] \end{aligned} \tag{8}$$

where *psf()* is the range point spread function (the autocorrelation function of the complex envelope *s(t)*) and t_0 is the propagation delay on the direct path between transmitter and receiver.

The range compressed signal of the electronic target (8) contains 4 important terms: the point spread function, the phase history (carrier) term and two phase offsets: one corresponding with the electronic target's frequency shift and another one determined by the phase difference between the local oscillators used for transmit and receive. Note that the psf() function that corresponds to the signal's envelope has a different delay than the phase history due to the artificial delay of the electronic target, which is applied in baseband and does not contribute to the phase term.

In order to perform an azimuth focusing of the electronic target, in the focusing algorithm the phase history of the azimuth matched filter (that is not influenced by t_{del}) has to be artificially shifted to the position of the *psf()* in the range profile. Otherwise, since the target's artificial delay is comparable or larger than the physical delays (corresponding to the distances between the transmitter/receiver and the target), the artificial target can be highly defocused.

The final term yields a spurious constant phase component which is proportional to Δf_{LO}. A numerical estimation of the displacement δr caused by a Δf_{LO} shift is approximately 100μm per 29KHz frequency shift at 5.755GHz carrier frequency and 133ns electronic target delay. The main drawback of this component is that it degrades the SNR. Therefore, the Δf_{LO} shift must be below tens of kilohertz from one acquisition to another in order to use the electronic target for interferometric purposes.

3.2 Bistatic radar image focusing

The signal transmitted by the electronic target is regarded as an echo from the target scene. The signal at the receive antenna of the radar system contains echoes from the scene's targets, alongside the echo generated by the electronic target.

Image focusing from raw data signals is obtained using the backprojection algorithm. The phase history of the first term is used as phase history term for the backprojection focusing algorithm, but does not contain the t_{del} value introduced by the electronic target. The t_{del} value appears in the baseband chirp component. Since both components are used for focusing, they must be time aligned.

When used in bistatic configuration with the satellite as a transmitter, t_{r1} is considerably larger than t_{del} and no additional correction must be done. In ground-based scenarios, t_{del} is on the same order of magnitude with t_{r1}, and a t_{del} delay must be added to the first term so that the focusing algorithm works correctly.

4 In-field Results

A ground based radar system was used for initial testing of the electronic target. It operates in the C band, at a frequency of 5.755GHz. The transmitted chirp bandwidth is 50MHz and lasts for 50µs. The radar transmitter is moving on a 2m length linear rail and transmits an impulse every 1cm. Therefore, there are 200 impulses available for focusing. The radar system is placed on the rooftop of a building, while the electronic target's antennas are placed on the facade of another building, at a line-of-sight distance of approximately 680m.

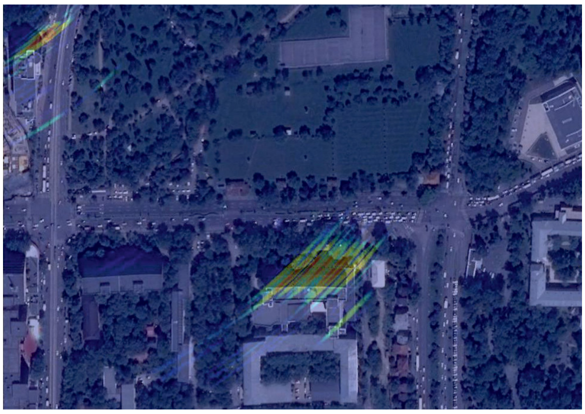

Figure 3: Backprojection image focusing: without phase history correction, overlayed on optical sattelite image provided by „Google Earth“

The images from **Figure 3 and 4** are presented comparatively, since they are the result of the focusing on the same scene. The difference is the correction of the distance for the phase history of the electronic target. **Figure 3** shows the focusing without the phase correction operation required for the electronic target. Practically, the tallest building in the scene is present as a highly reflective target.

The phase history correction procedure involves shifting the distance of the target from the artificial distance to its real distance, where the phase history required for focusing is correct.

Figure 4: Backprojection image focusing: with phase history correction, overlayed on optical sattelite image provided by „Google Earth“

A delay of 60µs was implemented in hardware and an additional delay of 0.7µs is introduced by the analog signal chains. Therefore, the distance for the phase correction was chosen at 18210m, corresponding to the previously mentioned time delay. This way, **Figure 4** shows only the reflection of the electronic target. By using phase history correction, the focused image shows only the target of interest, therefore removing the nearby clutter.

5 Conclusions

The versatility and the adjustable parameters of the electronic target make it suitable for a broad range of applications and SAR systems.

The developed electronic target is suitable for monitoring a target of interest in a cluttered area. It can be used to shift the target position out of the area and to remove other targets from the focused image using phase history correction. It can also be used for the calibration and validation of SAR systems.

6 Acknowledgement

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References

[1] Anghel, A., Vasile, G., Cacoveanu, R., et al.: *Short-Range Wideband FMCW Radar for Millimetric Displacement Measurements*, IEEE Trans. on Geoscience and Remote Sensing, 2014, **52**, (9), pp. 5633-5642

[2] Cunlong, L., Weimin C., Gang L., *et al.: A Noncontact FMCW Radar Sensor for Displacement Measurement in Structural Health Monitoring*, Sensors, 2015, **15**, (4), pp. 7412-7433

[3] Monserrat, O., Crosetto M., Luzzi G.: *A review of ground-based SAR interferometry for deformation measurement, ISPRS Journal of Photogrammetry and Remote Sensing*, 2014, **93**, pp. 40-48

[4] Dumper, K., Buck, C., Day S.R., King, D., Gomm, P.E. : *Design and Performance of the Prototype Advanced SAR Calibration Transponder*, CEOS_SAR 2004.

[5] Duque, S., Lopez-Dekker, P., Merlano, J.C., Mallorqui, J.J., *Bistatic SAR Tomography: Processing and Experimental Results*, IGARSS 2010

[6] Electronic Corner Reflector ECR-R, “Metasensing”, https://www.metasensing-group.com/ecr-c

[7] Chin-Yuan Chu, Tzon-Huei Chien, Kun-Shan Chen, *A FPGA Based Range Delay Active Radar Calibrator*, Commuincation System Research Center & Center for Space and Remote Sensing

[8] A. Anghel, R. Cacoveanu, A. S. Moldovan, A. A. Popescu, M. Datcu, and F. Serban, “Simplified bistatic SAR imaging with a fixed receiver and TerraSAR-X as transmitter of opportunity - First results,” in IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Beijing, China, Jul. 2016, pp. 2094–2097