Linking Reference Target Properties to Its Perceived RCS in SAR Images

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Abstract

A synthetic aperture radar (SAR) system is a measurement instrument which maps radar reflectivity. Prior to scientific and commercial use, the SAR system is typically calibrated, and here the focus shall be on radiometric calibration. Reference point targets like active transponders or passive corner reflectors provide a reference reflectivity against which the instrument offset can be determined. Up to now, no direct link between the reference point target properties (like its frequency response) and its perceived backscattering was available. In this paper it is proposed to close this gap using a point target SAR simulator, which links the target properties to the derived absolute calibration factor. This allows to derive correction factors which result in a normalization of calibration results over SAR mode settings and target properties.

1 Absolute Radiometric Calibration

In science and for commercial applications, reproducible and compatible measurement results are of crucial importance. In the case of synthetic aperture radar (SAR) systems, one of the measurands is the terrain reflectivity. Relative and absolute radiometric calibration is required in order to compensate for system drifts and systematic offsets.

The absolute radiometric calibration usually involves point targets like active transponders or passive corner reflectors [1, 2]. Once an image containing the reference target has been acquired, absolute radiometric calibration is accomplished by comparing the reflectivity of each image pixel with the *perceived* radar cross section (RCS) of the known target.

In the past, the reference target properties have been assumed to be ideal (no frequency dependence). It is now proposed to include a signal processing step, in which the effects of measurable target properties on its perceived RCS are included. By this, the target uncertainty can be further reduced and more accurately calibrated SAR systems can be achieved. The proposed signal processing step is realized as a point target SAR simulator, which mimics the complete absolute radiometric calibration process. The output of this target simulator is a SAR mode and target dependent target correction factor, which should subsequently be included in the derived absolute calibration factor.

1.1 Perceived Radar Cross Section

The term *perceived RCS* needs some further explanation. The radar cross section σ of any body is defined as the scaled ratio of the scattered to the incident power, as in

$$\sigma = \lim_{R\to\infty} 4\pi R^2 \frac{|\mathbf{E}_s|^2}{|\mathbf{E}_i|^2} \tag{1}$$

where R is the target/observer distance, and $\mathbf{E}_s$ and $\mathbf{E}_i$ are the scattered and incident electrical fields (see e. g. [3]). The RCS is frequency dependent for corner reflectors and transponders. Also, the RCS is a scalar, which only depends on amplitudes; the phase response has no influence on the target RCS. Since the target RCS is only derived after processing, the perceived RCS or pixel brightness is nevertheless affected by the target phase response. An imperfect (i. e. non-linear) phase response results, for instance, in a broadening of the impulse response while reducing the amplitude of the peak. The RCS of the target according to Eq. (1) would be unaltered, the *perceived* RCS would be different though. With the proposed point target simulator, differences in the perceived RCS can be quantified.

2 Point Target SAR Simulator

The point target SAR simulator models the complete absolute radiometric calibration process: A non-ideal point target is placed within an artificial scene, the raw data as seen by a specific SAR system is simulated, the data is focused, and finally a point target analysis is conducted. By performing a set of simulations with varying input parameters, the relative effect of these parameters on the derived perceived target RCS can be computed.

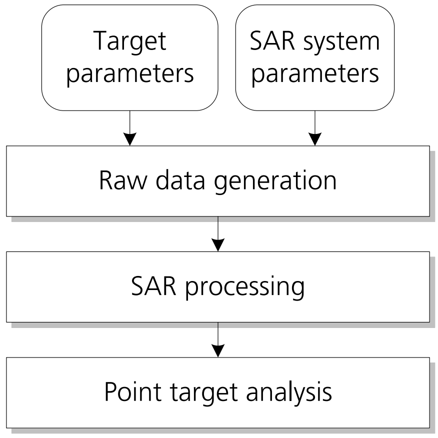

Figure 1: Principal structure and data flow of the point target SAR simulator.

The program structure, as shown in **Figure 1**, is organized as follows:

1. Raw data generation, incorporating reference target deficiencies (e. g. frequency-dependent transfer function) and SAR system specific settings (e. g. chirp settings).

2. SAR data processing, which focuses the generated raw data.

3. Point-target analysis, which extracts point target parameters like its perceived RCS from the focused image. Both of the extraction methods (peak, integral) as described in [4] are implemented.

Many processing steps which are found in an operational SAR processor have been deliberately left out. Therefore, range cell migration, instrument antenna pattern compensation, pointing correction, motion compensation, etc. have been excluded. Instead, the raw data is generated in such a way that these effects do not need to be reversed during processing, resulting in a processor which does not introduce any additional perceived RCS deviation not caused by the target under consideration.
The following point target properties are incorporated in the raw data generation step:

- A set of chained complex transfer functions

- Noise introduced by the transponder (defined by the signal-to-noise ratio)

- Interference signals (e. g. due to imperfect LO-RF isolation of mixers)

- Different internal calibration strategies

The raw data is generated range line by range line. For reasons of efficiency, a distinction is being made between azimuth time dependent contributions (noise) and constant contributions (transfer functions).

3 Exemplary Simulations

As an exemplary application of the point target simulator, an imperfect active target (transponder) shall be compared to an ideal target. The frequency response of the imperfect target is modeled by chaining four bandpass filters (a simplified model of the transponder under development at DLR [5], for which precise measurements are not yet available). The ideal target, which is needed for the comparison, is assumed to have a flat amplitude response and a linear phase response. The amplitudes of both transfer functions are normalized so that their amplitudes are equal at the center frequency (a commonly used transponder internal calibration strategy). The simulation is performed for a TerraSAR-X like stripmap mode with the notable difference of a 600 MHz bandwidth range chirp (instead of 150 MHz).

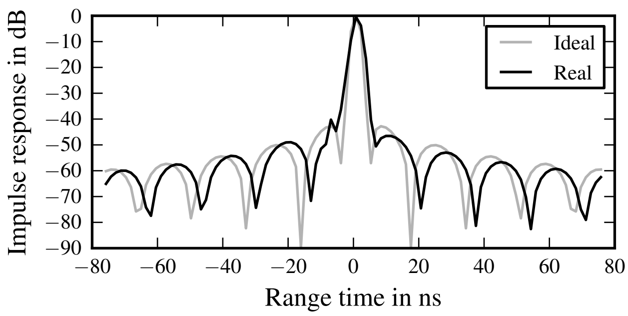

Figure 2: Comparison of an ideal impulse response and the response of an actual target. Both plots are normalized to the peak of the ideal signal and time-centered around their peaks.

A comparison of the impulse responses of the real and ideal targets is shown in **Figure 2**. The derived difference in the perceived target RCS for those two targets is 0.092 dB for the integral method and even 0.28 dB for the peak method. Had this contrived target been used for absolute SAR calibration, the derived absolute calibration factor would be off by nearly 0.1 dB even if the usually advantageous integral method was used. Considering that upcoming SAR systems like Sentinel-1 aim for a radiometric standard uncertainty of 0.3 dB [6], it becomes apparent that 0.1 dB is quite significant.

4 Conclusion

In this paper a point target SAR simulator was presented. It allows to link reference point target properties like its frequency response to the actually measured radar reflectivity, the perceived RCS. This link is important for two main fields:

1. During reference target development, an engineer now has a tool to assess, for instance, the effects of filter and amplifier gain flatness and group delays, temperature drifts, and others on the derived

perceived RCS.

2. During calibration campaigns, reference targets with differing frequency responses can be used interchangeably since correction coefficients can be computed. Also, calibration data takes which have been performed with differing SAR mode settings (e. g. bandwidth or center frequency) but the same target can now be normalized, leading to truly compatible SAR systems and SAR data products.

References

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