Introducing Equivalent Radar Cross Section – A First Step Toward new Radiometric Requirement Definitions

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Abstract

Stringent radiometric SAR system requirements often significantly shape the design and cost of modern SAR systems. Yet the wording in current requirement documents is ambiguous, and a diligent conformance assessment at the end of project phases currently questionable. In order to improve the situation for future SAR missions, a review of the requirements is proposed. As a first step toward this end, a new radiometric measurement quantity (equivalent radar cross section) is proposed, which resolves the problem of frequency and angular dependent, complex backscatter of measured targets. A numerical example for an important special case, a calibration corner reflector, is given to stress the need.

1 Introduction

Requirements are the driving force during the planning and realization of any SAR project. The requirements document gives guidance and focus, and its contents constantly influence the necessary next steps taken within the project. At the end of project phases, the conformance to the requirements is assessed by different parties.
At the moment though, the definitions of a subset of these requirements, the *radiometric requirements*, are not formulated in a way which allow diligent conformance assessments. With radiometric requirements we mean the three requirements (a) radiometric stability, (b) radiometric accuracy, and (c) relative radiometric accuracy which are similarly defined for different SAR missions [6, 4], and which are likely to be used in the definition of future SAR mission requirements. The two main points of critique are:

- The wording of the requirements allows room for interpretation, the terminology (e. g. *accuracy*) does not follow standards in metrology [7, 8], and they cannot be directly checked for conformance (partial effects like atmosphere excluded).
- Radar cross section (RCS) is used as the relevant measurement quantity for reference point targets, although it is not defined how the always existing frequency and aspect-angle dependent RCS of these targets shall be handled during calibration and conformance assessment.

This paper specifically addresses the second concern, i. e., the definition of the radiometric measurement quantity for SAR images. Finding a solution and coming to an agreement about the radiometric measurement quantity will allow to rethink the formulation of radiometric requirements. Eventually, the unambiguous and unquestionable assessment of conformance with radiometric requirements will become possible.

The layout of the paper is as follows: Section 2 addresses the two major problems with the current radiometric measurement quantity (radar cross section, RCS). The following Sec. 3 introduces equivalent radar cross section (ERCS) as the new quantity. In Sec. 4 a numerical example for an important special case, a calibration corner reflector, will be given to highlight the difference between RCS and ERCS.

2 Problems with RCS as the Measurement Quantity

Radiometric calibration of SAR images is achieved by placing a known point target like a corner reflector with a known backscatter in an imaged area. Exploiting the linearity of the imaging process, the backscatter of any unknown target can then be computed through proportionality [3]. At the moment, the backscatter of the reference target is quantified by stating its radar cross section (RCS), so that the backscatter of all unknown (point) targets can also be expressed in RCS.
The radar cross section (RCS, symbol σ) of any target is defined as the scaled ratio of the scattered power (seen at distance R away from the target) 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 $\mathbf{E}_s$ and $\mathbf{E}_i$ are the scattered and incident electrical fields [5]. The RCS is a body property. For a given scatterer, it depends on the shape, material, wavelength, incidence direction, observed/scattering direction, and the polarization of transmitter and receiver.
The problem is that a SAR system does not measure RCS. The pixel intensity does not (only) depend on RCS. A SAR system measures a different quantity, which results from a filtering operation and the recording of complex amplitudes. That is, the complex pixels $V(x, y)$ of a fo-

cused SAR image are formed by the filtering operation

$$V(x,y) = KS(x,y) \otimes h(x,y), \quad (2)$$

where K is a system-dependent complex calibration constant, $S(x,y)$ is the complex target scattering, $\otimes$ denotes two-dimensional convolution, and $h(x,y)$ is the SAR system's impulse response. This fact results in two problems, which make RCS untenable as the radiometric measurement quantity.

First, the RCS is defined as a ratio of powers, see Eq. (1). A SAR system, on the other hand, necessarily measures complex amplitudes. Two targets with an identical RCS can appear differently bright in a processed SAR image, simply due to their (frequency and angular-dependent) phase response. This effect is certainly not expected of a radiometrically calibrated image.

Second, a high-resolution SAR image is formed by exploiting the information gained by using a certain range pulse bandwidth and a certain azimuth angular range. Consequentially, the target will scatter back the SAR pulses depending on the signal's instantaneous frequency and incidence direction. The pixel intensity in the resulting image stems from a weighted average over frequency and angular range according to Eq. (2), where the weights are determined by the SAR system impulse response (i. e., mostly the apodization functions which are included for an increased side-lobe suppression). The link between RCS and the pixel intensity is broken because it is unclear *which* RCS within the frequency and angular ranges shall actually be reported.

Previously, the frequency and angular-dependent target backscatter could be and was neglected. This simplified target model is reasonable especially for low resolution, low radiometric accuracy SAR systems. Now that relative bandwidths are not necessarily below 1 % any more but go up to 10 % or even exceed 100 %, and now that the range of incidence angles increased from a tenth of a degree to sometimes full 360° (circular SAR), this simplified target model just does not reflect reality any longer. Traceable radiometric SAR calibration and unambiguous requirement conformity assessments depend on a definition of how the frequency and angular-dependent target RCS shall be handled in the future.

3 Equivalent Radar Cross Section

It was argued that a SAR system does not measure radar cross section, but rather another quantity which results from taking the weighted average of the target's complex backscatter. Instead of referring to RCS, it is proposed to call the radiometric measurement quantity for point targets *equivalent radar cross section*.

> The equivalent radar cross section σ_e shall be equal to the radar cross section of a perfectly conducting sphere which would result in an equivalent pixel intensity if the sphere were to replace the measured target.

The definition exploits the crucial frequency and angular independence of the monostatic RCS of a sphere with radius a

$$\sigma_{\text{sphere}} = \pi a^2, \quad (3)$$

which is valid as long as the sphere circumference is much (say, at least more than ten times) larger than the wavelength [5].

Replacing RCS by *equivalent RCS* pays tribute to the two general points of critique. Now,

- the filtering of *complex* signals according to Eq. (2) is correctly distinguished from the definition of RCS, which only takes signal magnitudes into consideration, and
- cases for which the target frequency or angular dependence is significant are covered.

One could say that the terminology of *equivalent RCS* allows to distinguish between the target's body property RCS (Eq. (1)) and the target's pixel intensity as seen through the eyes of the SAR processing filter (Eq. (2)). The proposed terminology allows to describe target backscatters with an arbitrary frequency or angular dependence. Depending on the target, the measurement uncertainty can appear greatly reduced due to the more accurate measurement model, which especially benefits high resolution, high accuracy systems.

The transition from the present to the proposed terminology is smooth. For instance, the measurement unit for RCS and equivalent RCS is the same: square meter. Also, it is straightforward to transform the backscatter coefficient σ^0 and other derived quantities to equivalent quantities, i. e., to an *equivalent* backscatter coefficient σ_e^0, etc. Furthermore, describing the measurement quantity in terms of an equivalent physical object (a sphere) allows one to form a simple mental model of what this quantity means.

4 Numerical Example: Trihedral Corner Reflectors

Trihedral corner reflectors and transponders are the two most often used calibration standards for the absolute radiometric calibration of SAR systems. Understanding their frequency and angular dependent backscatter is therefore especially important because any error made during calibration measurements will consequentially influence all subsequent measurement results.

In this section, the frequency-dependent RCS of two trihedral corner reflectors with triangular faces shall be studied. A corner size (inner leg length) of 1.5 m and 3.0 m is assumed, which represents the corners that are most often used by DLR during radiometric calibration campaigns. Their RCS was computed with a commercial method-of-moments (MoM) solver, and the results are shown in Fig. 1.

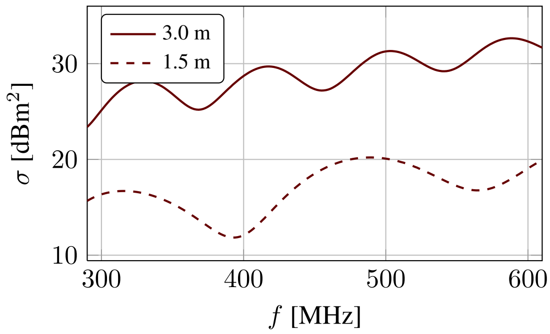

Figure 1: Frequency-dependent RCS σ of two trihedral corner reflectors at P-band in broadside direction, simulated with FEKO.

The visible strong RCS undulation of several decibels is mostly a result of edge effects, which are not covered by the well-known physical optics approximation formula

$$\sigma_{\triangle} = \frac{4\pi l^4}{3\lambda^2}, \tag{4}$$

where l is the corner's inner leg length and λ is the wavelength [5]. The current density shown in Fig. 2 confirms the explanation for this corner which is despite of its large absolute dimensions still comparably small with respect to the wavelength (3.0 m equals 6λ at 600 MHz).

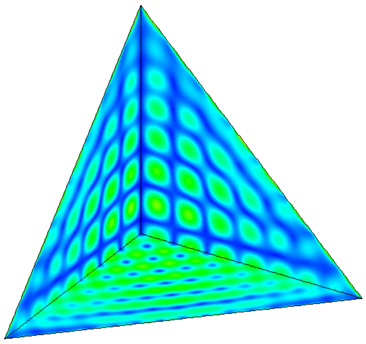

Figure 2: Current distribution on a 3.0 m corner for broadside illumination at 600 MHz. Mainly edge effects result in the frequency-dependent RCS shown in Fig. 1.

The question now is: What is the ERCS ($\sim$ SAR pixel intensity) seen by a SAR instrument? To answer this, a P-band system with a bandwidth of 100 MHz is assumed. This bandwidth resembles DLR's airborne F-SAR system, which operates at a center frequency of 350 MHz. If the center frequency of this SAR system is changed in a thought experiment, the perceived pixel intensity will thus vary considerably. In order to quantify the variation, a point-target simulator was used which takes a target's frequency and angular-dependent RCS into consideration when computing pixel intensities [1]. The results of the point-target simulations for a range of center frequencies f_0 is shown in Fig. 3.

The ERCS variation of more than 2 dB is clearly a result of the averaging process within the assumed bandwidth of 100 MHz. The variation alone easily exceeds the total radiometric accuracy requirement of most systems, which is often in the order of 1 dB [6]. Therefore, the frequency dependent RCS of a corner reflector, which is used for absolute radiometric calibration, needs to be compensated during calibration. A possible approach based on an additional correction term, along with further numerical examples demonstrating the need for ERCS, is given in [2].

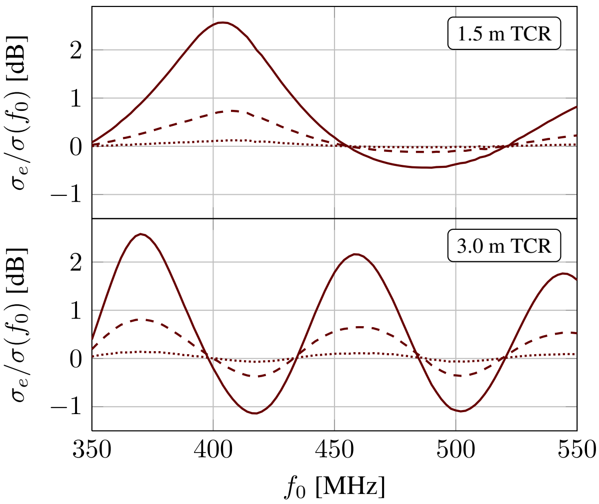

Figure 3: Comparison of the ERCS σ_e ($\sim$ SAR pixel intensity) of the corners from Fig. 1 and their RCS at the range pulse center frequency $\sigma(f_0)$, computed with a point-target SAR simulator at three bandwidths: 20 MHz (········), 50 MHz(- - -), and 100 MHz (——).

5 Conclusions

It was argued that future SAR missions should use an improved set of radiometric requirement definitions as the basis for an unambiguous and unquestionable assessment of conformance. To this end, it was proposed to replace the current radiometric measurement quantity *radar cross section* (RCS) with the new quantity *equivalent radar cross section* (ERCS). The new definition allows to distinguish between the body property RCS on the one hand, and the quantity that is actually measured by a SAR system on the other hand, ERCS. Numerical simulations of an important special case, a corner reflector used for calibration, clearly showed the need, as the difference between the RCS and the ERCS can exceed 2 dB.

Any new definition is only useful if a community agrees on it. We hope that we could at least initiate and contribute to a necessary discussion toward this end.

References

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