EXAMINATION OF SPATIAL INTEGRATION METHOD FOR EXTRACTING THE RCS OF A CALIBRATION TARGET FROM SAR IMAGES

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ABSTRACT ... This paper presents an examination of the spatial integration method for extracting the RCS of a trihedral corner reflector from SAR images for SAR external calibration. An exact external radiometric calibration technique is required for extracting an exact calibration constant. Therefore, we examine the accuracy of the spatial integration method, which is commonly used for the SAR external radiometric calibration. At first, an SAR image for a trihedral corner reflector is simulated with a high-resolution SAR impulse response with a known theoretical RCS of the reflector, and a background clutter image for the high resolution SAR system is also generated. Then, a SAR image in a high resolution is generated for a trihedral corner reflector located on a background clutter by superposition of the two SAR images. The radar cross section of a trihedral corner reflector in the SAR image is retrieved by integrating the radar signals of the pixels adjacent to the reflector for various size of the integration area. By comparison of the measured RCS by the integration method and the theoretical RCS of the reflector, the effect of the size of the integration area on the extraction of the calibration constant is examined.

KEY WORDS: SAR image, external calibration, calibration target, trihedral corner reflector

1. INTRODUCTION

Synthetic Aperture Radar (SAR) images are used to remotely sense the characteristics of wide areas and applied to a variety of areas, such as sensing forest resources, topographical and geographic surveys, harvest prospects, artificial structure search, sensing sea pollution, survey and sensing of typhoons, forest fires, or floods, water resources exploration, sea state and weather forecasts, polar region exploration, and so forth (Ulaby et al, 1986). To increase the efficiency of SAR images, the SAR system must be accurately calibrated to enhance the image quality. The calibration of the SAR system is largely divided into 'geometric calibration' and 'radiometric calibration'; the latter is subdivided into internal and external calibrations. While internal calibration, using 'calibration loop', measures the system variables, which in turn reveals relative gain variations, external calibration involves 'calibration target' which is set up on the ground, calculates the RCS (radar cross section) of the target and then a calibration coefficient. This calibration coefficient is used to find an accurate 'backward scattering coefficient' of SAR images (Freeman, 1992). Only when this external calibration is accurately carried out can other SAR system image be compared and can research for quantitatively finding out the physical state of the earth's surface.

This study summarizes conventional theories on the external calibration of the SAR system. Also, after a 'trihedral corner reflector' with the known RCS is installed in areas with relatively little backward scattering to get SAR images, research for finding calibration coefficients from the images will be done. The SAR system when calibration technologies had just been come to life had very low resolution, but the recent or future version of it to be loaded on to satellites has substantially high resolution, which calls for research into how many pixels have to be integrated to find an accurate calibration coefficient.

Therefore, in this study, a high-resolution SAR image of reflector (Mahafza, 2005; Mahafza et al, 2004) is simulated, and a virtual SAR image is created by overlapping the original SAR image on the background image, in order to find a calibration coefficient (Gray et al, 1990; Lukowski et al, 1993). During the process, pixels near the reflector are integrated, and the coefficient is found according to the size of the integrated area, in order to ultimately examine the accuracy of this technology.

2. SAR SYSTEM EXTERNAL CALIBRATION TECHNOLOGY

The SAR system is characterized as a microwave sensor which measures a scattering coefficient with high resolution. A scattering coefficient (or RSC per area) is defined as follows:

$$\sigma_{pq}^{0} = \frac{\left\langle \sigma_{pq}^{(n)} \right\rangle}{A} \qquad (1)$$

Here <⋯> refers to an average; $\sigma_{pq}^{(n)}$ indicates the nth RCS estimate of q-polarized transmission and p-polarized reception; A is the area of radio-wave reflection of the earth's surface. In case of the unit pixel of SAR images, area A is found as follows:

$$A = \frac{p_a p_r}{\sin\theta_i} \qquad (2)$$

where p_a and p_r refer to the azimuth and range resolutions, θ_i indicates the angle of incidence; $p_r/\sin\theta_i$ becomes p_g, the ground resolution.

The RCS of the target has the following relationship with the scattering matrix for a pq-polarized wave.

$$\sigma_{pq} = 4\pi \left|S_{pq}\right|^2 , \qquad (3)$$

with the scattering matrix defined as

$$\begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \frac{e^{jkR}}{R} \begin{bmatrix} S_{hh} & S_{vh} \\ S_{hv} & S_{vv} \end{bmatrix} \begin{bmatrix} E_h^i \\ E_v^i \end{bmatrix} , \qquad (4)$$

where R is the distance between the radar antenna and a scattering object; upper suffixes i and s indicate the electric fields of incident and scattering waves respectively; lower suffixes h and v respectively horizontal and vertical polarized waves.

Since the signal processing of SAR images is not perfect, noises occur, and the measured voltage of SAR images can be expressed as follows (Freeman, 1992):

$$V(x,y) = \sqrt{K_S}\, e^{j\phi_s} S_{pq}(x,y) \otimes h(x,y) + \sqrt{K_n}\, n(x,y) , \qquad (5)$$

where x and y refer to the position of images; h is an impulse response function (or image blurring function); ⊗ means convolution; n indicates the noise that occurs during the estimation of backward scattering; K_s and K_n are the gain constant of the signal and noise respectively, and the former is particularly called calibration constant because of gains from a radar transmitter-receiver and a SAR correlator. Provided that there is no relationship between the noise and the signal, the average intensity sensed by radar is as follows:

$$\langle P(x,y) \rangle = K_S\, \sigma_{pq}(x,y) \otimes h'(x,y) + K_n\, \sigma_n(x,y) , \qquad (6)$$

where σ_n is the noise intensity of images. Since the radar backward scattering RCS of the target can be expressed,

$$\sigma_{pq}(x,y) = \sigma_{pq}^T\, \delta(x)\delta(y) \qquad (7)$$

The above formula becomes as follows;

$$\langle P(x,y) \rangle = K_S\, \sigma_{pq}^T h'(x,y) + K_n\, \sigma_n(x,y) , \qquad (8)$$

And if area A is integrated again, then it becomes as follows:

$$\int_A \langle P(x,y) \rangle dxdy \cong K_S\, \sigma_{pq}^T + \int_A K_n\, \sigma_n(x,y) dxdy . \qquad (9)$$

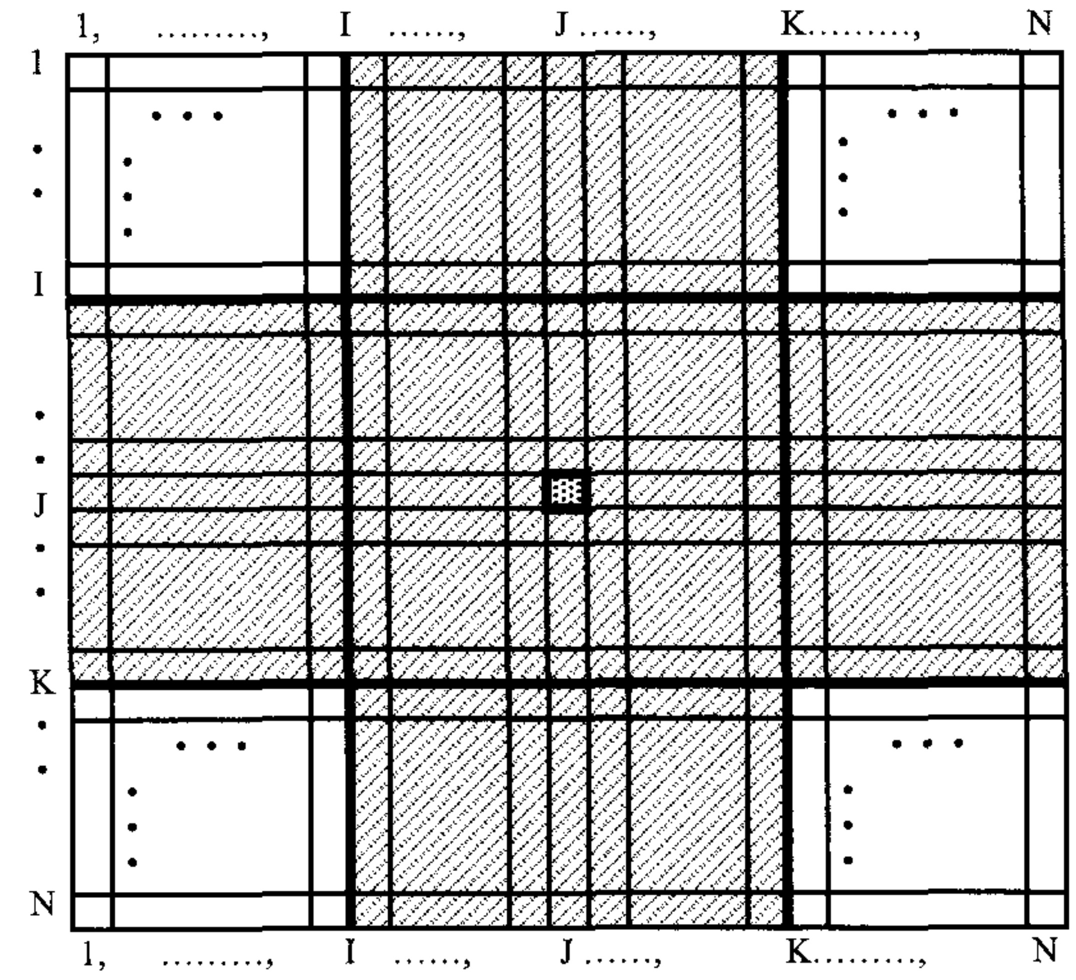
Providing that the integrated area is large enough, it can also be assumed as follows:

$$\int_A h'(x,y)\, dxdy \cong 1 . \qquad (10)$$

Thus, calibration constant Ks can be found by using the integrated values of the background noise (clutter) and of the area including trihedral corner reflector, and the theoretical RCS value. Figure 1, a SAR image when a reflector is installed in the center of an area with a consistent and low scattering coefficient, shows the integrated area very well. The shaded region indicates an area for a radio-wave reflector signal to be integrated; the white part for a clutter to be integrated.

3. CREATION OF SAR IMAGES INVOLVING RADIO-WAVE REFLECTOR

Although high-resolution (1m x 1m) satellite SAR system TerraSAR-X was successfully launched, since it is still on probation, a high-resolution SAR image has been simulated. At first, with the numerical formula and programs in (Mahafza et al, 2004; Mahafza, 2005), SAR images for the reflectors with the RCS values of 20 and 30 dBsm have been generated. Figure 2 shows a high-resolution image of the reflector with 20-dBsm RCS in 1m x 1m resolution.



: Corner Reflector

: Corner Reflector + Background

: Background

Figure 1. SAR image pixels adjacent to a calibration target.

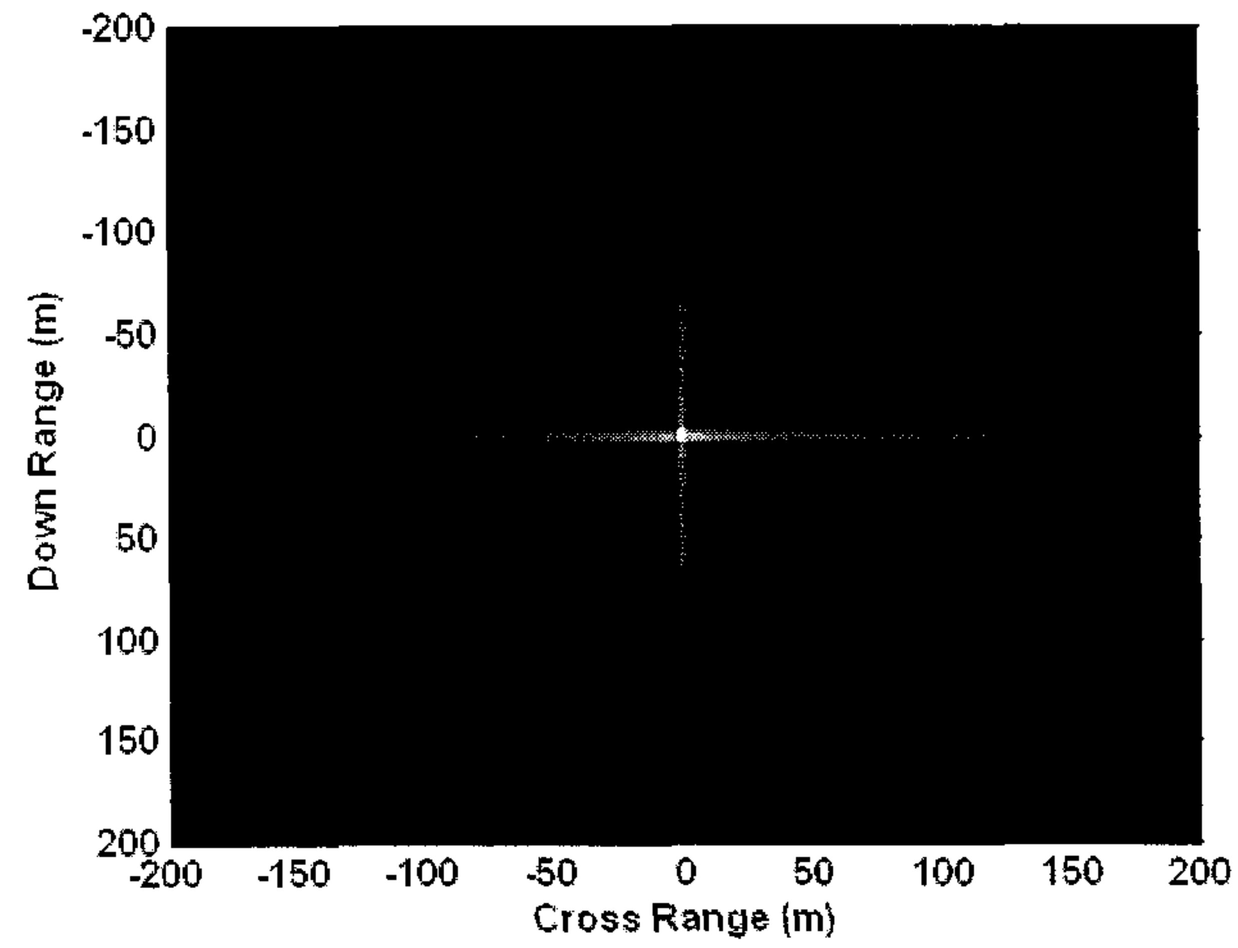


Figure 2. A SAR Image of a reflector

The images gained from a JPL AirSAR image for a rice field and a randomly generated data are used as background clutter. Both images have average -10dB of RCS. Despite of originally different resolution, it was assumed for the sake of convenience that 1m x 1m resolution was used. Figure 3 overlaps a background clutter image with a reflector image, displaying a SAR image similar to the actual SAR image.

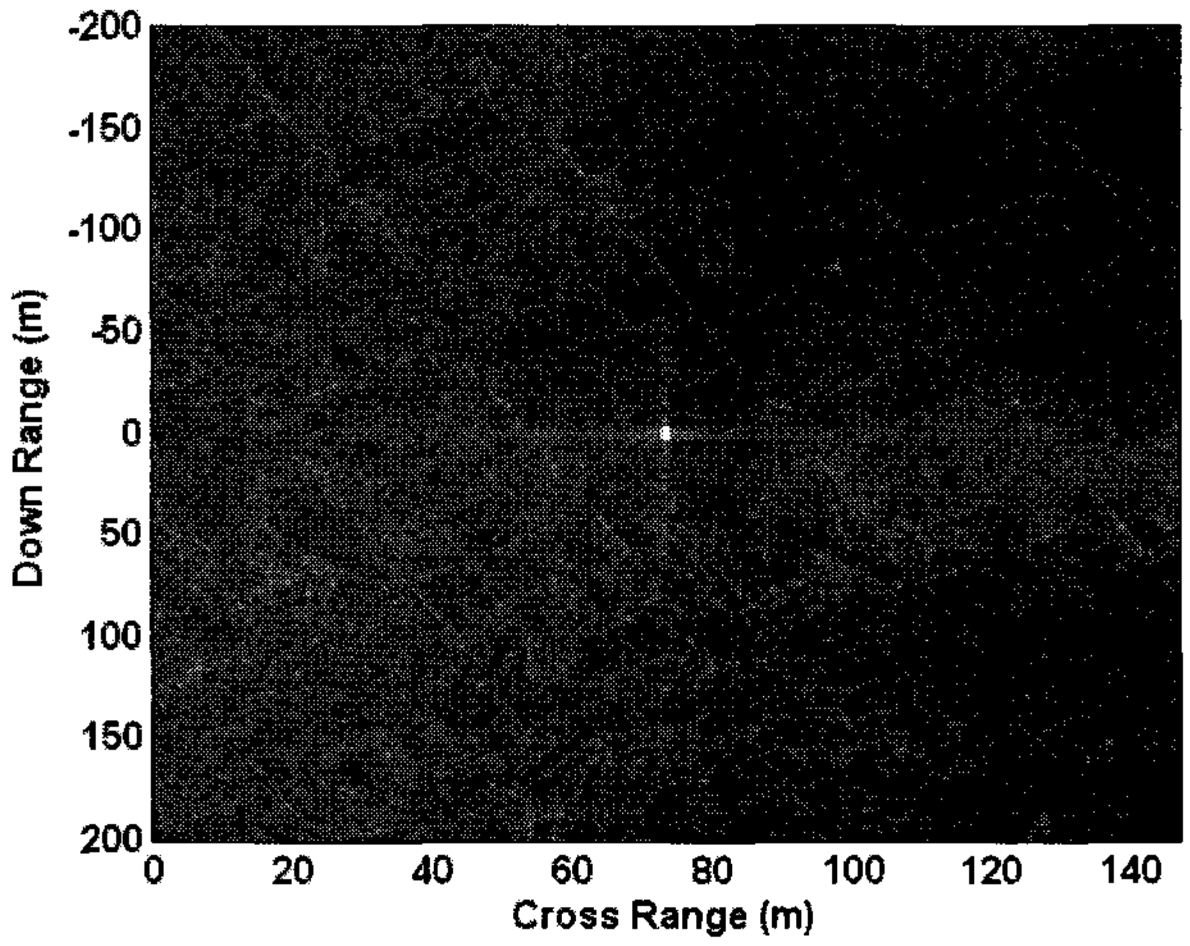


Figure 3. A SAR image created by overlapping background clutter and reflector images.

4. CALCULATION OF THE CALIBRATION CONSTANT THROUGH INTEGRATION

Generally, a SAR image is saved in digital numbers per pixel, so an integral value of (9) can be found through simple summation. Also, if variations in the distant, angle, and antenna gains are ignored because the reflector and the background clutter are in the same position, a calibration constant can be found simply as follows:

$$K_S = \frac{\sigma^E}{\sigma^T}, \quad (11)$$

where σ^T is a theoretical RCS value of the reflector; σ^E is the RCS of the reflector found through integration, which is calculated as follows:

$$\sigma^E = \left(\sum_{N_A}^{(area\,A)} a_{ij}^2 - \frac{N_A}{N_C} \sum_{N_C}^{(area\,C)} a_{ij}^2 \right) p_a p_g \quad (12)$$

Here, area A represents the entire area to be integrated; area C is the background clutter area; N_A and N_C refers to the number of pixels in the entire area and background clutter area respectively; a_{ij} is a digital number of the ijth pixel and its square, which therefore becomes an unit of intensity. In Fig. 1, area C is the white part and area A the entire area which is part of a square that includes central pixels in Figure 3.

At Figure 4, the area of this square was expanded starting from 1 x 1 pixels up to 100 x 100 pixels of the full image in 1m x 1m resolution. Figure 4 shows the RCS of the reflector found through integration, the more have integrated zone, the more closed to the basis of a theoretical RCS value, 20 dBsm and 30dBsm. In this case, the background clutter area used a rice field with JPL AirSAR.

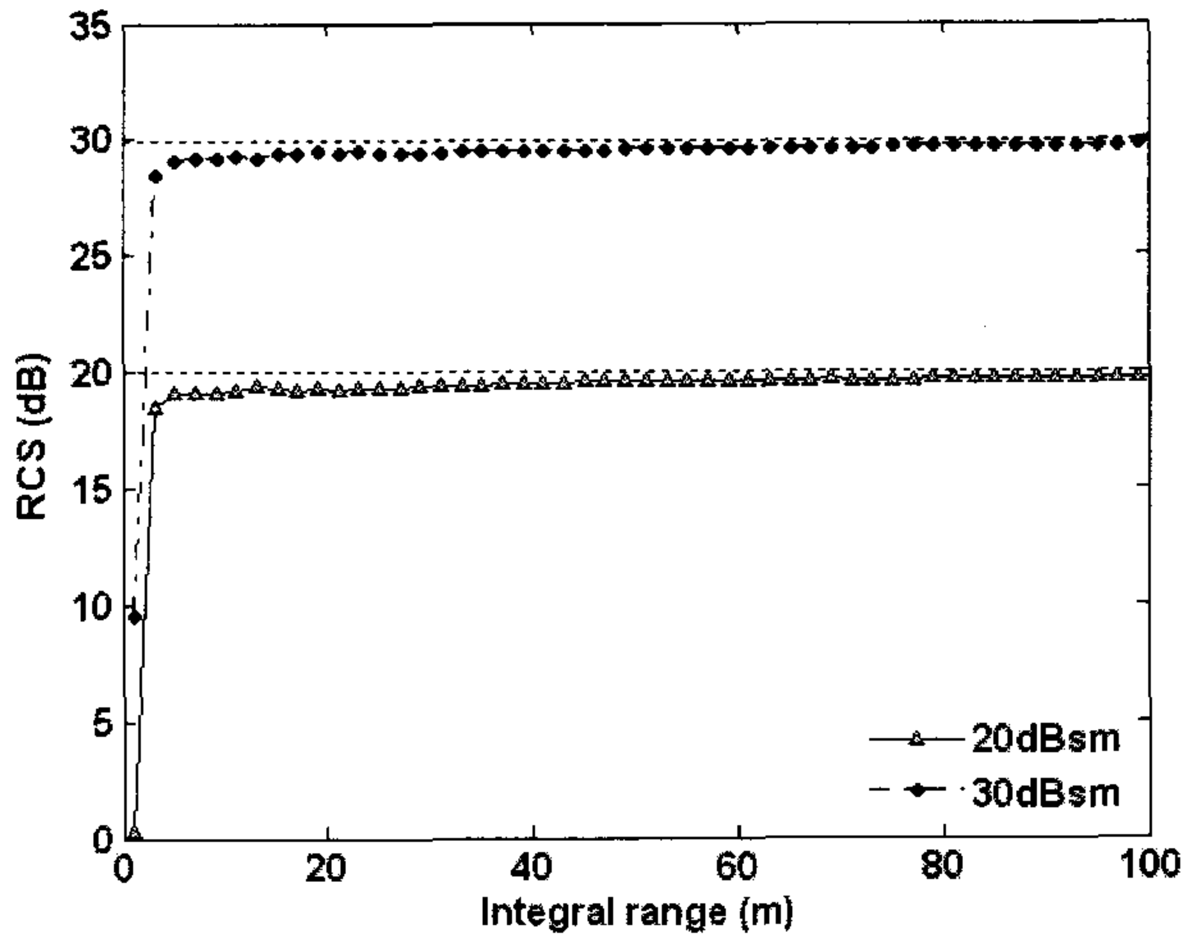


Figure 4. The RCS of the reflector found from a SAR image through integration.

Figure 5 shows the calibration constants with the same results of Figure 4 If pixels over 40m x 40m are integrated, there is an error roughly within the rage of 0.5dB. In this case, the resolution was 1m x 1m and the background clutter area was used a rice field with JPL AirSAR.

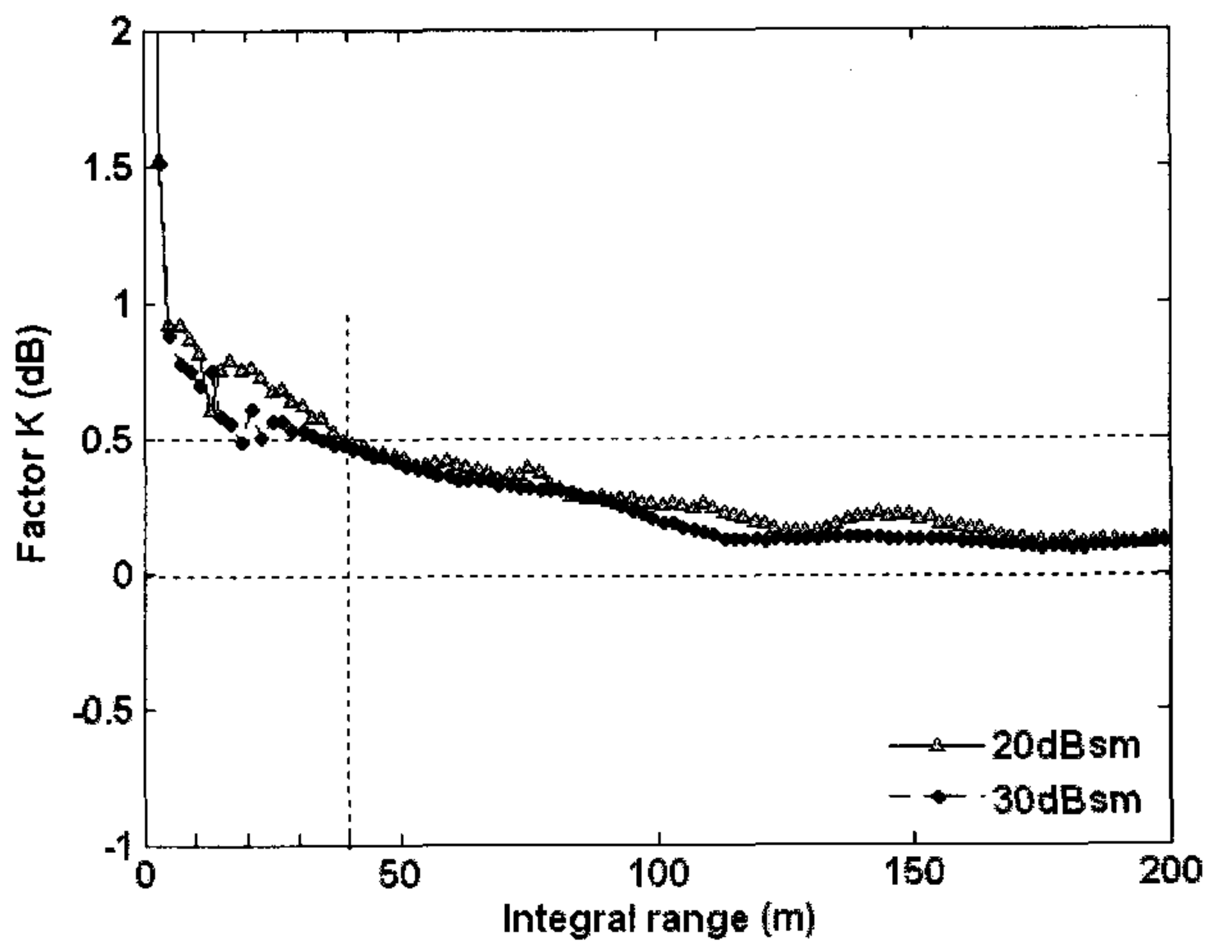


Figure 5. The change in the calibration coefficient extracted according to the change in the integrated area.

In the same case, after only background was changed with average -10dB background data which was random generation, the very similar results with the Figures 4 and 5 were obtained, except that the calibration constants were quite stable at large integration area.

Next, the resolution was changed with 3m x 3m. In result, Figure 6 shows the RCS was closed to the basis of a theoretical RCS value, 20 dBsm or 30dBsm. In this case, the background clutter area was used a rice field with JPL AirSAR. Figure 7 shows calibration constants of each integrated zone in 3m x 3m resolution. If pixels over 12m x 12m are integrated, there is an error roughly within the range of 0.5dB.

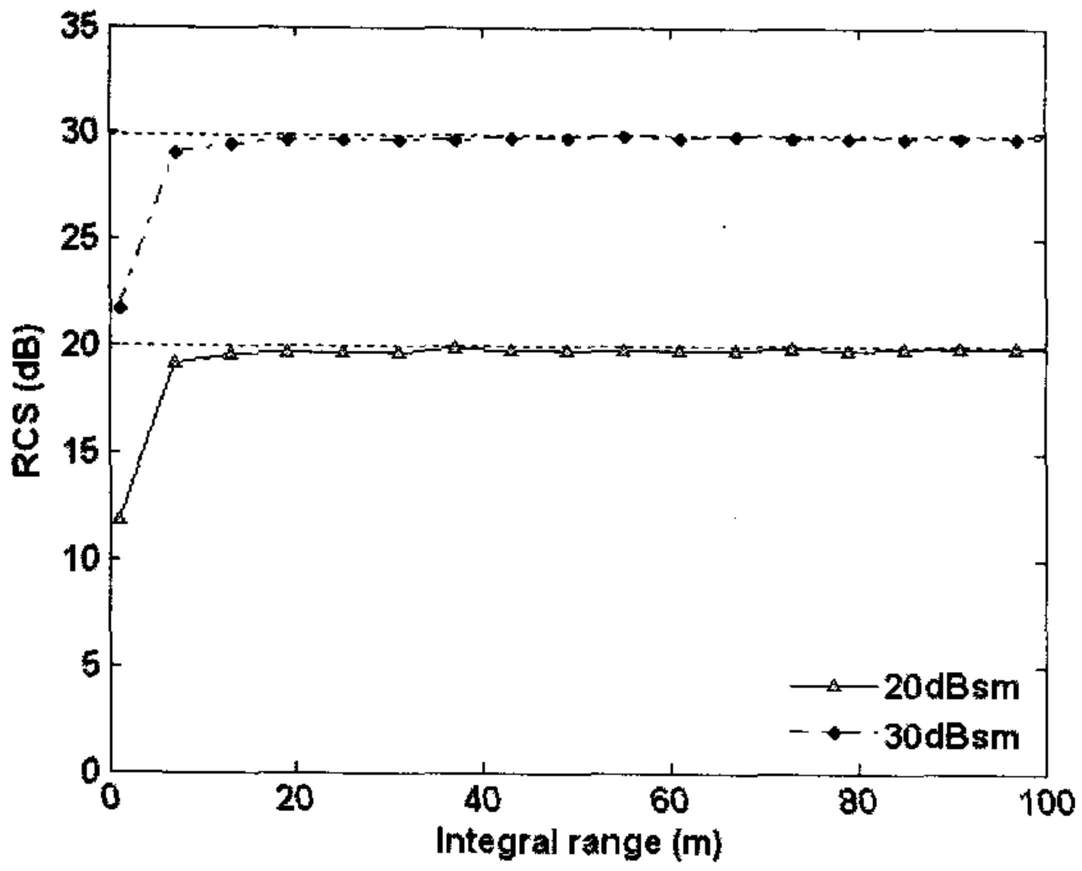


Figure 6. RCS of the reflector found from a SAR image through integration (resolution: 3m x 3m, background: a rice field).

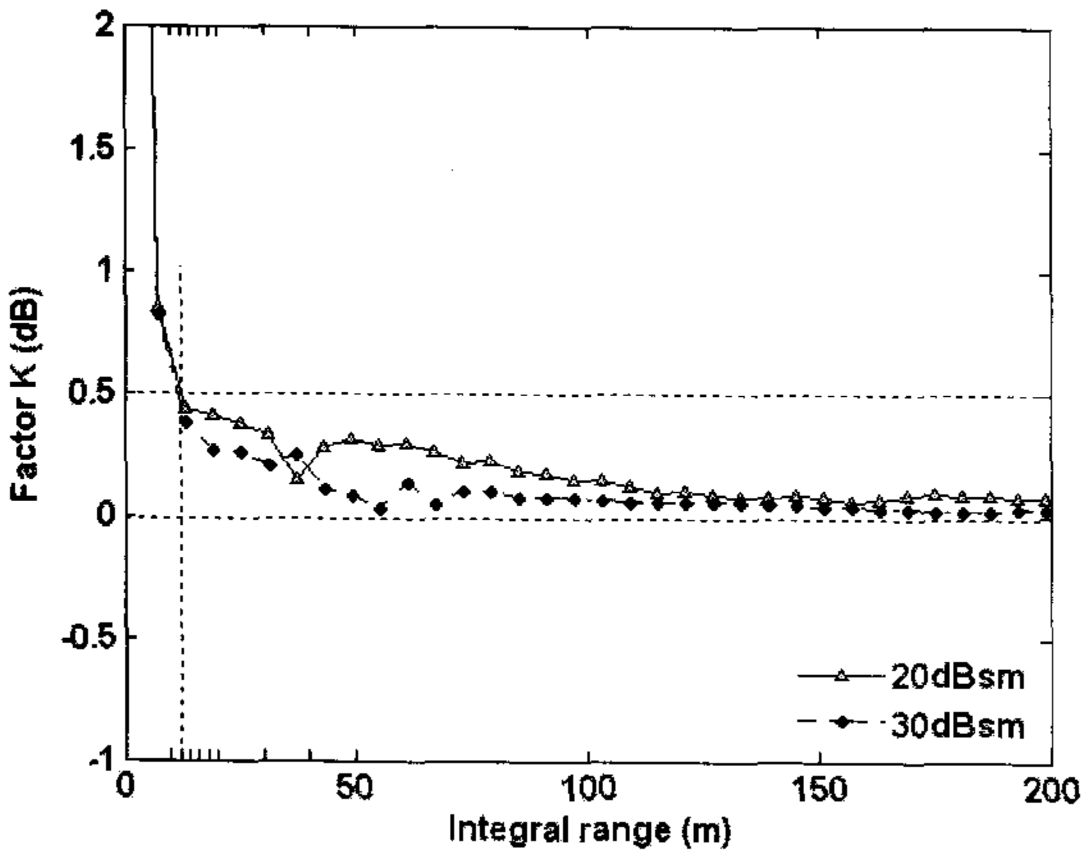


Figure 7. Change in the calibration constant extracted according to the change in the integrated area (resolution: 3m x 3m, background: a rice field).

In the same case, after only background was changed with average -10dB background data which was random generation, Figure 8 shows calibration coenstant was the more have integrated zone, the more closed to zero point.

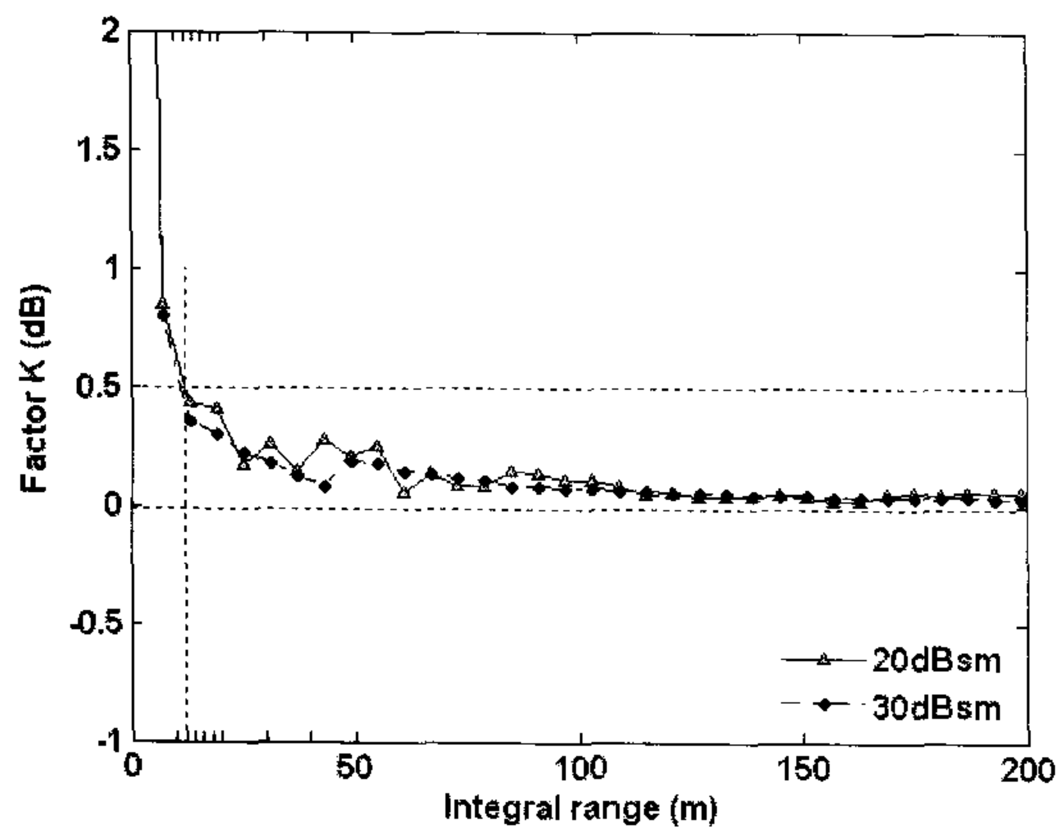


Figure 8. Change in the calibration constant extracted according to the change in the integrated area (resolution: 3m x 3m, background: random generation).

5. CONCLUDING REMARKS

The study has summarized the numerical formula for the microwave backscattering external calibration of the satellite SAR system using a trihedral corner reflector, leading to the calculation of the calibration constant through integration. As well, a SAR image of the reflector was created and overlapped with a background clutter image, to simulate a high-resolution SAR image. Then, with the simulated SAR image, the RCS of the reflector was extracted through integration. Ultimately, the calibration constant was found by comparing with the theoretical RCS value. Additionally, the study demonstrated that even a high-resolution SAR image of 1m x 1m can produce a pretty accurate calibration coefficient, as long as pixels more than 40m x 40m can be integrated and a high-resolution SAR image of 3m x 3m can produce a pretty accurate calibration coefficient, as long as pixels more than 12m x 12m can be integrated. Calibration errors would not be eliminated even after expanding the area when the calibration target is smeared and the background clutter is not perfectly random.

In closing, the study suggests that the future research should prove the finding of this study by using a high-resolution SAR image of TerraSAR-X.

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