Passive calibration targets with large, stable and controllable radar cross section for spaceborne SAR

PASSIVE CALIBRATION TARGETS WITH LARGE, STABLE AND CONTROLLABLE RADAR CROSS SECTION FOR SPACEBORNE SAR

A.I. Zakharov(1), P.A. Zherdev(2), M.M. Borisov(2), A.B. Sokolov(2), C.G.M van 't Klooster(3)

(1) Institute of Radioengineering and Electronics of Russian Academy of Sciences
Vvedensky sq., 1, Fryazino, 141120 Russia,
Email: aizakhar@ire.rssi.ru

(2) Special Design Bureau of Moscow Power Engineering Institute (OKB MEI)
Krasnokazarmennaya 14, Moscow, 111250 Russia,
Email: jerdev@okbmei.msk.su

(3) ESA ESTEC
Keplerlaan 1, P.O.Box 299, 2200 AG Noordwijk, Netherlands,
Email: kvtkloos@estec.esa.nl

ABSTRACT

The series of calibration experiments with ERS-1/2 SAR were conducted in 1995 and 1999-2000 at the Bear Lakes calibration site near Moscow. Since very beginning a number of calibration scenarios with new passive calibration targets based on parabolic antennas was exploited. Some results of a study of the scatterers stability and ideas about a way to broaden scatterer pattern were reported earlier.
Experiments of the year 1999-2000 were conducted under AO3-343 project and devoted to the continuation of the study of the temporal stability of parabolic antennas scattering, antenna pattern shape and a way to control their polarization properties and radar cross section. Three parabolic antennas, used in the experiment, were located at the corners of the rectangular triangle with 50 m legs. Two antennas were used as a reference, and another one was a calibration target with polarization grid in focal area. The use of the polarization grid allowed us to modify scattering matrix of the antenna. As a result, changing the angle θ between the SAR polarization plane and the grid polarization plane, we were able to change the target's RCS for a single polarization system, like as ERS SAR.
The SLCI data obtained under AO3-343 project were used usually for the measurements of the scatterers RCS. The measurements show, that reference antennas have very stable and very large ~ 55 dBm^2 radar cross-section. The cross-section of the antenna could be controlled by the orientation of the polarization grid with respect to ERS-2 polarization plane. The results are in good agreement with theoretical predictions and laboratory measurements except for the orthogonal orientation, where instead of 20 dBm^2 decrease of RCS we observe 16 dBm^2 decrease only. The reason is an interfering backscatter from the antenna structure and a layer of polarization grid.
The study conducted with a use of ERS SAR data confirms high stability of the parabolic antennas and the possibility to control the polarization plane (and, respectively, RCS for a single polarization SAR system) of the backscattered signal.

INTRODUCTION

SAR radiometric calibration is a very important stage, supposing and providing highly accurate measurements of the backscattering properties of the Earth covers. For a single channel the calibration problem is restricted to the relation of the intensity information with normalized radar cross-section of the scattering surface. Today's achievements in the area of calibration techniques and active/passive instruments provide the absolute accuracy of the measurements of about one dB, what become now to be a standard requirement.
Most accurately radiometric calibration is being made with a use of artificial targets – active or passive calibrators, allowing to create an echo with a level sufficient for measurements of all the details of SAR impulse response function. Among the most common are active devices, allowing the creation of large radar cross-section (RCS). The passive ones, the corner reflectors can not be used as a targets with similar RCS because of mechanical and cost problems.
The new technique of the creation the passive targets with large RCS is based on a use of parabolic reflector antennas with large mirror modified by an insertion of the scattering body into a focal area. For the first time the technique was tested in experiments with ERS SAR in 1995 [1] and continued in 1999-2000 under AO3-343 project "Research and

development of highly efficient calibration techniques for spaceborne SAR systems on the base of ground based reflector antennas".

AN EXPERIENCE OBTAINED FROM CALIBRATION CAMPAIGN OF 1995 AT BEAR LAKES TEST SITE

The OKB MEI calibration site is located at the distance of 10 km to the East from Moscow city border (55°51′45″N, 37°57′42″E). From a very beginning of the calibration activities at OKB MEI in early 1990[s] a very complex calibration scenario was established on a base of passive targets. It consisted of 10 parabolic antennas and corner reflectors of various size with dominating distance between targets of 50 m. Original calibration scenario, mentioned in [1], included 3 parabolic antennas with 2.5 m diameter, 3 parabolic antennas 4.8 m in diameter and 4 triangular corner reflectors with 0.55-1.5 m legs (see Fig. 1).

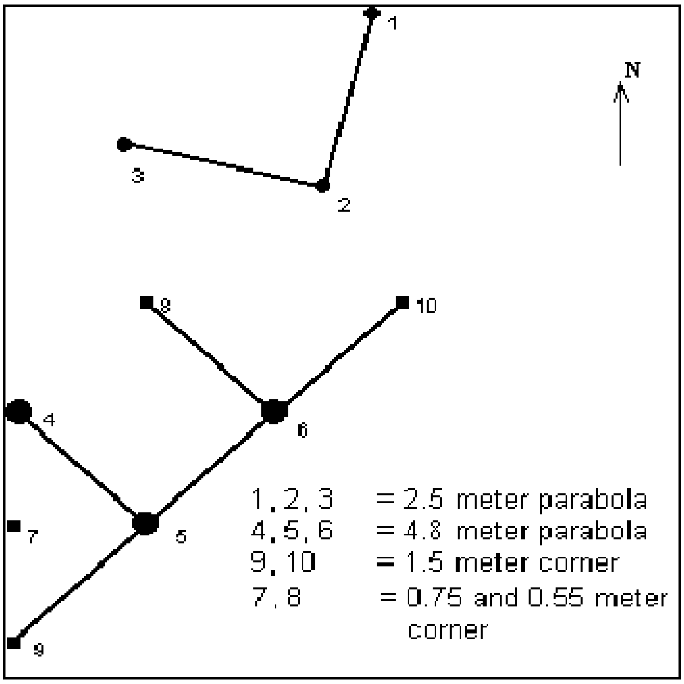

Fig. 1. Calibration scenario at Bear Lakes calibration site.

During the experiment of 1995 among the main task was study of scattering properties of the antennas of various type. For that reason the construction of focal area of large parabolic antennas was modified - one of them, N6, had conducting sphere in focal area, another one, N5, - had a logoperiodic structure. The RCS values measured on PRI images are presented in Table 1.
According to [1], two main reasons might explain so serious deviations of the RCS values obtained from theoretical value of 54 dBm^2. First of all, it is a high sensitivity to the pointing accuracy of the antenna with such a narrow antenna pattern. An estimations show, that 0.15^0 depointing of the antenna leads to 0.5 dB decrease in RCS. Another significant factor is that a peak value method have been used to derive RCS values from the ERS data.

Table 1. The observation results of calibration campaign of the year 1995

Date of observation	Target No	RCS(dBm^2)
19950206	6	50.94
19950211	6	49.88
19950303	6	46.04
19950206	5	47.08
19950226	5	47.50

The main achievement of the calibration activity was experimental study of the scattering properties of various passive targets and generation of the targets with large ~50 dBm^2 cross section in C-band on the base of parabolic reflectors 4.8 m in diameter.

CALIBRATION SCENARIO IN THE EXPERIMENTS OF 1999-2000

The calibration scenarios at the Bear Lakes test site in 1999-2000 were based on a use of 3 passive calibration targets - large parabolic antennas of 4.8 m in diameter, located at the corners of the rectangular triangle with 50 m legs. The target N5 was an antenna with a conducting disc 0.5 m in diameter, located in the focal area. The target N4 was antenna adapted for a use by ERS ground station, being under testing at Bear Lakes test site in 1998-1999. The target N6, shown on a Fig. 2, was an antenna usually equipped with polarization grid in focal area.

Fig. 2. Large antenna with polarization grid in focal area

The polarization grid consisted of dielectric layer covered with a grid of metal wires with 0.5 mm diameter and 5 mm spacing between the wires. The construction allows for the control of the orientation of polarization grid with respect to polarization plane of the ERS-2 signal.

The target N5 equipped with conducting disc was used typically as a reference target with a stable level of backscatter. Preliminary estimations predicted the width of the pattern to be about 10^0, what made the measurements to be practically insensitive to the pointing errors. The antenna was pointed in every ERS calibration session during 1999-2000. Target N4 existed in the calibration scenario in the case of test acquisitions of SAR data at the Bear Lakes ERS ground station. It was shown in [2], that the receiving antennas of ground stations may also represent stable calibration targets for SAR systems.

DATA DESCRIPTION

Since the AO3 project start in 1999 more than 20 ERS-2 SAR observations of Bear Lakes calibration site were made. Radar images in SLCI format, synthesized in UK-PAF and I-PAF, were used for measurements of RCS of calibration targets. The 16 bits complex numbers were converted to RCS values according to [3,4]:

$$\sigma = \frac{\left(\mathrm{Re}^2+\mathrm{Im}^2\right)}{K} * \frac{\sin(\alpha)}{\sin\left(\alpha_{ref}\right)} * \frac{r^3}{r_{ref}} * \frac{\alpha_{az} * \alpha_r}{g(\beta)}, \tag{1}$$

where K- calibration constant, α and α_{ref} – incidence angle and its reference value, r and r_{ref} – slant range and its reference value, $g(\beta)$ – antenna pattern, α_{az} and α_r – pixel spacing in azimuth and range. An example of SLCI image of the calibration scenario on March 30, 1999 is presented on Fig. 3. Bright target in the center of the image is an antenna N5. The antenna of ERS ground station is in the lower right direction.

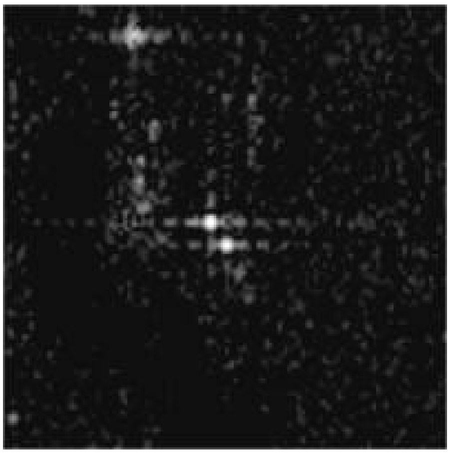

Fig. 3. ERS-2 SAR image of Bear Lakes calibration site on March 30, 1999

As the distance between targets was short for a given SAR resolution, the intensity integration was conducted in a small window, in the area of main lobe. The background intensity was estimated outside the impulse response function and subtracted from signal power. The results of RCS measurements for all the 3 targets from observations made in 1999 are presented in Table 2. Last column shows the orientation angle θ – the orientation of the polarization grid with respect to polarization plane of the ERS-2 signal.

Table 2. RCS (dBm^2) for calibration targets at the test site in 1999

N	Date	Target 5	Target 4	Target 6	θ
1	990330	55.4			
2	992305	54.8			
3	990806	55.4	52.3		
4	990627	54.7	52.0		
5	990713	56.0	53.3		
6	990801	54.3			
7	990817	54.7		55.1	0^0
8	990905	54.9			
9	990921	55.3	52.3	39.9	90^0
10	991010	53.6		47.9	45^0
11	991114	52.4		51.0	22.5^0
12	991130	55.2	52.3	38.56	67.5^0
13	991219	54.7		49.1	-45^0

AN ANALYSIS OF THE MEASUREMENTS MADE IN 1999-2000

The stability of the RCS of Parabolic Antenna

An analysis of the numbers presented allows us to make some conclusions about the stability of the ERS SAR plus

influence of the state of propagation media, as well as scattering properties and stability of the passive targets at the test site. According to the entire set of RCS measurements for target N5, mean value for antenna with a disc in focal area is 54.7 dBm^2, standard deviation 0.87, peak to peak error 3.0 dBm^2. If we reject the observations on 991010 and 991114, which were made in a heavy snowfall conditions, than mean RCS will be 55.05 dBm^2 with standard deviation 0.45 and peak to peak error 1.67 dBm^2. According to [3], the overall stability is twice lower, than that obtained for ERS-2 with ESA transponders. The numbers are comparable with those obtained in ERS-2 observations of Kiruna and Neustrelitz ground stations in [2].
We can subdivide the errors introduced by ground segment, as we have sessions with targets N5 and N4 observed simultaneously. For the observations 3,4,5,9 and 12 we can calculate the RCS_{N5} and RCS_{N4} and estimate the mean difference to be 2.9 dBm^2 with standard deviation as 0.16 dBm^2. The last number may characterize the passive targets relative stability, which is obviously higher, than the estimations derived from observations of each standalone target. Most of the instability here may be explained by onboard instrument properties as well as propagation media.

Control of the Antenna Scattering Properties

Another topic investigated in the series of calibration measurements of the year 1999 was scattering properties of the antenna with polarization grid in focal area. An insertion of the scatterer into the focal area modifies scattering matrix of the antenna. In the case of a disc it will be proportional to that of sphere. Antenna with polarization grid acts as a dipole, so the cross-section at co-polarized mode *xx* will be:

$$\sigma_{xx} = \sigma_{\max} \cos^4 \theta, \qquad (2)$$

and at cross-polarized mode *xy:*

$$\sigma_{xy} = \sigma_{\max} \cos^2 \theta \sin^2 \theta, \qquad (3)$$

where θ – angle between the grid orientation and signal polarization plane.
Prior to the experiments the polarization properties of the polarization grid were tested in laboratory. The attenuation of the signal with linear polarization travelling from receiver to transmitter via the grid was measured at different orientation of the grid. The plot presented on Fig. 4a shows ~20 dB variations of the signal attenuation as a function of the orientation angle θ in the laboratory conditions.
In order to compensate possible instability of ERS-2 SAR and propagating media, the scattering properties of the antenna with a grid are presented in the Table 3 related to the target N5.

Table 3. Relative scattering properties of target 3, dBm^2.

N	Date	RCS_{N6}-RCS_{N5}	$\cos^4(\theta)$	θ
7	990817	0.4	0	0^0
9	990921	-16.4	-∞	90^0
10	991010	-5.7	-6	45^0
11	991114	-1.4	-1.38	22.5^0
12	991130	-16.7	-16.7	67.5^0
13	991219	-5.7	-6	-45^0

The graphical representation of the numbers is presented on Fig. 4b, where solid line is a prediction and stars represent the measurements. Comparing the measured values of RCS decrease with theoretical model in a form of $\cos^4(\theta)$, we can see good agreement of the values with theory except for the orthogonal case, when instead of –20 dB decrease predicted in literature and confirmed in ground measurements, we have only –16.7 dB.
We can assume 0.4 dBm^2 excess of the measurements over the model because of higher RCS_{max} of the target N3 compared to target N1. The idea about background signal for orthogonal orientation because of "scattering from feed and/or sub-reflector support structure and multiple interactions" was supposed earlier in [1]. From experiments of 20000227, 20000314, 20000402 we got the unwanted level of the backscatter at orthogonal orientation to be as high as –10 ÷ –14 dB depending also on the media type in the grid layer. The experiments with various types of polarization grid with a goal to decrease an unwanted backscatter at orthogonal orientation are planned as final ones under the AO3-343.

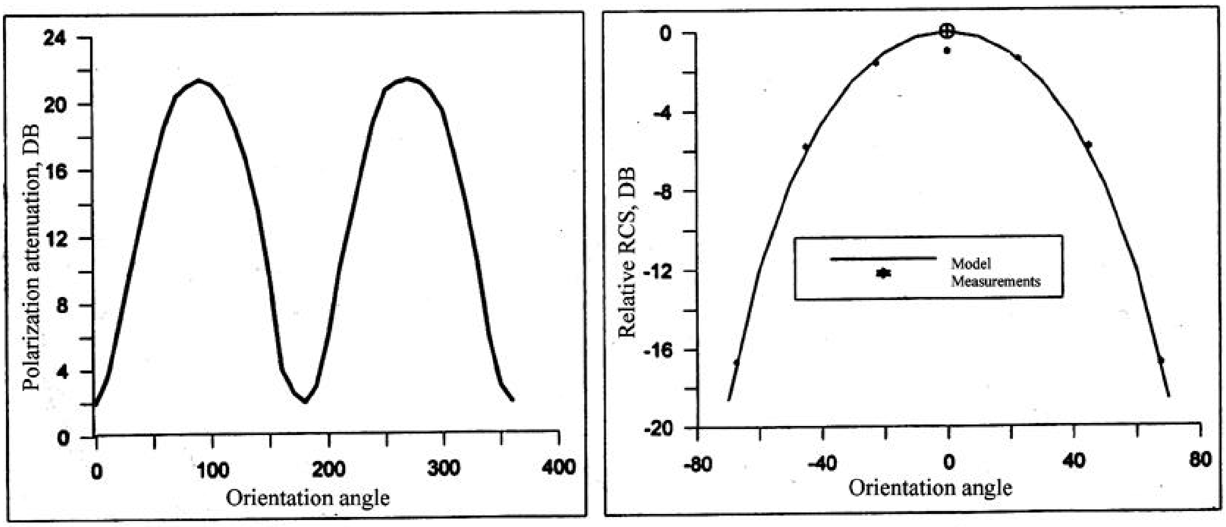

Fig. 4. On the right: polarization attenuation in ground tests, on the left: RCS measurements and model values.

Study of the Width of the Antenna Pattern

Study of the width of the antenna pattern was conducted during this year on the dates mentioned in the Table 4. Antennas N5 and N6 were equipped with similar conducting discs. Three upper rows in the table correspond to the observations with the same pointing conditions made in order to check the relative stability of the scatterers. The last one, 20000716, is the case, when antenna N5 had depointing $\gamma=5^0$ in elevation angle. We can see, that mean difference in RCS of antennas with the same conducting disc in focal area and the same pointing conditions is 0.177 dBm^2, the relative stability is 0.09 dBm^2.
The depointing of the antenna at 5^0 led to 1.84 dBm^2 decrease in RCS. Comparing the measurement with theoretical estimations of the pattern for 4.8 m antenna with 0.48 m disc in focal area, presented on Fig. 5, we can see, that an increase of the pattern width takes place. The experiment is to be continued for various values of the depointing angle during the rest of observations under AO3-343.

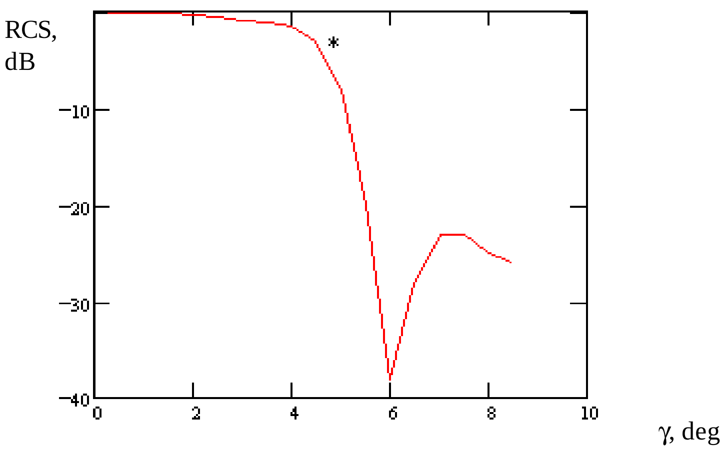

Fig. 5. Modeling results of the antenna pattern with a disc in focal area (solid line) and a measurement (star).

During the experiment on 20000627 the insensibility of the antenna RCS to the moisture conditions was checked also. Few minutes before the ERS overflight the mirror of antenna N6 was watered by a fresh water. There is no serious deviation in the RCS of antenna N6 according to the numbers in the third row of the Table 4.

Table 4. RCS measurements in dBm^2 for observations during the year 2000.

Date of observation	RCS_{N5}	RCS_{N6}	RCS_{N5}- RCS_{N6}
20000507	53.54	53.45	0.09
20000523	55.25	55.11	0.14
20000627	55.35	55.05	0.3
20000716	51.83	53.67	-1.84

Experiment on Geometric Calibration and Estimation of ERS Resolution

For geometric calibration purposes and estimation of the ERS spatial resolution we used fragments of SLCI image FFT interpolated in azimuth and range. The 16 times interpolation is being made in spectral domain by adding zeroes at higher frequencies. Hamming weighting was applied in order to decrease Gibbs effect after the interpolation of truncated series. An example of interpolated array of the data from ERS-2 observation made on 19990330 is presented on Fig. 6.
The range and azimuth resolution was estimated via the width of the main lobe of impulse response function at half power level. For the example on Fig. 6 it is about 11 m in slant range (28 m in ground range) and 6.7 m in azimuth.
For the relative geometric calibration we used the location of the maximums of the signals of the point targets on the FFT interpolated images. Compared with real distance 50 m, the measured distance between antennas N5 and N6 is 50.3 m on the image from 19990920 and 49.98 m - on the image from 19991010. For a pair N4 and N5 with a distance of 70.7 m we have measured values 72.4 m and 72.73 m respectively.

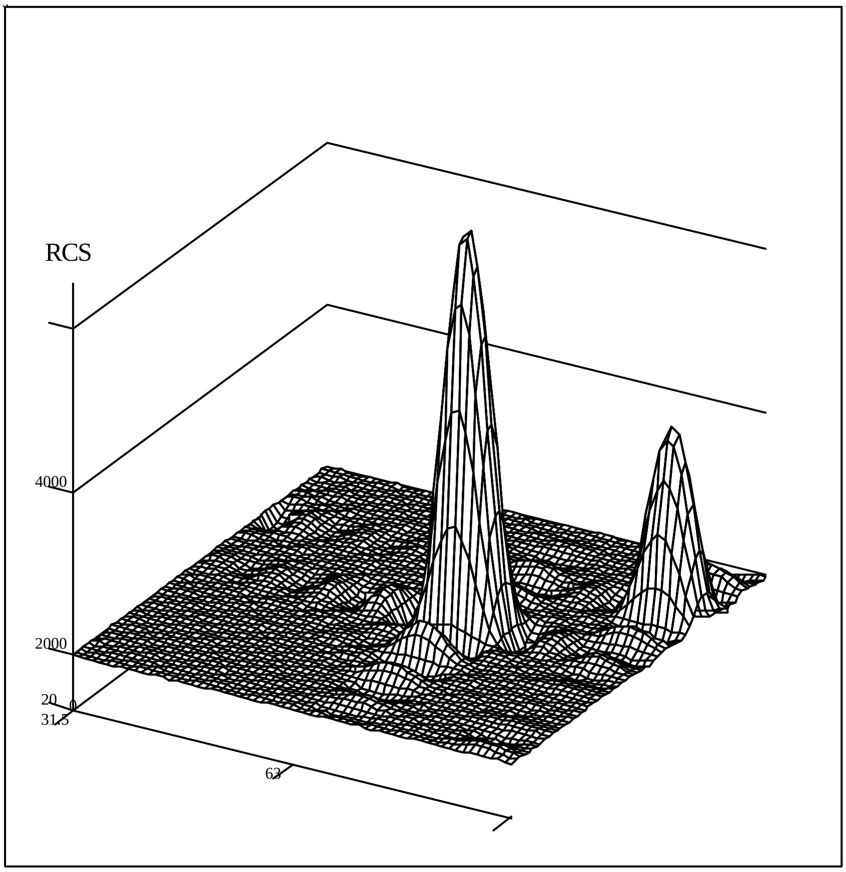

Fig. 6. FFT interpolated image of the point scatterers from 19990330.

CONCLUSION

The proposed passive calibration targets on the base of parabolic antennas with 4.8 m mirror were shown to have large ~55 dBm^2 and stable ~0.16 dBm^2 radar cross section. Both the antennas with a disc in focal area and regular antenna of the receiving station may be used as stable calibration targets. An insertion of a conducting disc increases the width of the antenna pattern. An insertion of the polarization grid in the antenna focal area allows to control the RCS level for a single polarization SAR and to obtain new polarization properties of the entire scatterer, which may be of high interest for the polarimetric calibration of prospective SAR systems.

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