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ERS-1 IN-ORBIT ANTENNA PERFORMANCES

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Abstract

ERS-1, the European Remote Sensing satellite, carries an Active Microwave Instrument (AMI), which can operate in a Synthetic Aperture Radar (SAR) mode and in a wind-scatterometer mode. It has specific antennas as instrument sensors. The antennas for the SAR and the wind-scatterometer have been accurately measured in isolation on the ground before launch. Both SAR and wind-scatterometer instrument have been calibrated in-orbit during the commissioning of ERS-1. Data have been deduced from different sources in order to arrive at information about the antenna behaviour. This paper describes these antenna related aspects.

Introduction

Microwave remote sensing requires the use of specific antennas as instrument sensors. The AMI on-board the ERS-1 satellite provides a wind-scatterometer and a SAR function. The antennas for the AMI have seen an intriguing development program and an extensive, accurate pre-launch RF verification for various antenna parameters. In this paper, data are discussed related to in-orbit performances of the antennas and compared with on-ground measured data.

For the SAR antenna, the deployment and the subsequently realised planarity is of interest, for the wind-scatterometer, the precision in the realised pattern is of interest.

The SAR antenna is stowed during launch as a package consisting of 5 mechanical panels stacked on top of each other. After deployment a 10 by 1 meter aperture is realised.
Two wind-scatterometer antennas or 'side' antennas are folded along the ERS-1 payload during launch. The third scatterometer antenna is rigidly mounted on top of the payload. Fig.1 shows the ERS-1 payload during the integration at Fokker.

The deployment of a large antenna in orbit is a critical operation. Any failure can lead to a total loss of the instrument or radio-link for which the particular deployable antenna is used. This has been observed in other programs (eg. Anik, Galileo, JERS), where deployment activities were either 'nerve demanding' or even without success.

The deployment of the ERS-1 antennas considered here has been realised successfully during the early phase of ERS-1.

Information has become availabe during the operation of ERS-1 from a number of sources. The latter sources included data obtained with specialised (active) transponders, as well as processed instrument responses from distributed targets with specific backscatter properties (Brazilian rain-forest).

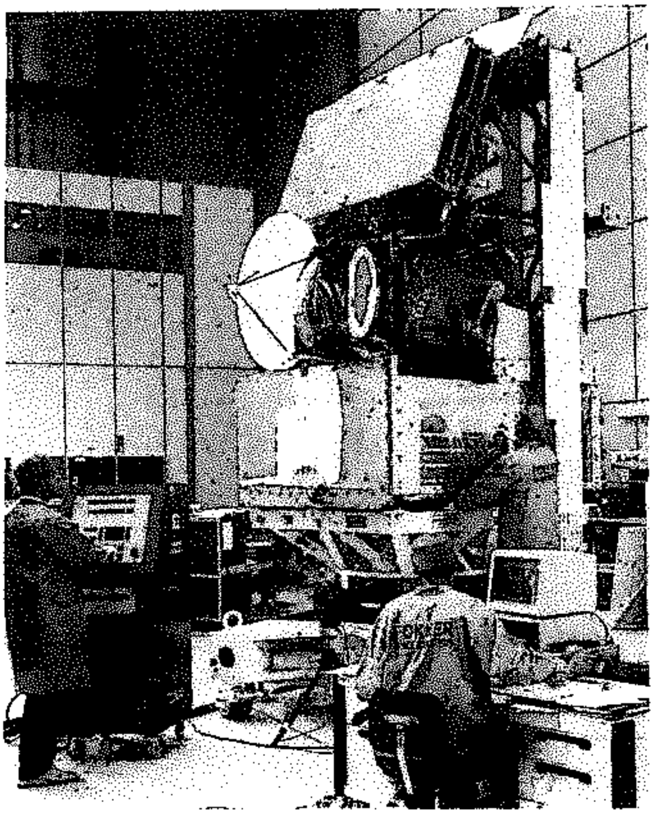

Figure 1: **ERS-1** Payload during integration at Fokker.

A number of highly accurate transponders has been designed and built at Estec (XRI) for the calibration of the AMI. The transponder uses antennas, which, for an as clean as possible response, have to fulfill severe requirements concerning pointing, sidelobe level and beamshape. However, the latter antennas have a small aperture in terms of λ [1]. Fig.2 shows the antennas, which are used for the transmit and for the receive function in above mentioned transponders.

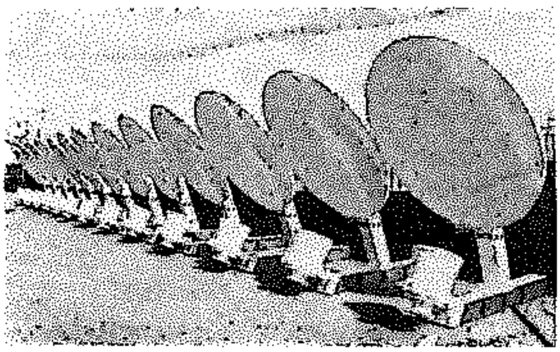

Figure 2: Offset (low sidelobe) antennas [1] for transponders.

SAR Antenna and On-Ground Verification

Carbon fibre reinforced plastic material is used as basic construction material in the 10 by 1 meter deployable slotted waveguide SAR antenna (also for the metallised slotted waveguides). The overall antenna mass is below 85 kilogram. A further description of the antenna is found elsewhere [2].

The SAR antenna has been characterised accurately before launch with the ESA Ericsson planar near-field facility [3]. Near-field data have been obtained to derive the complete field description or the complex (amplitude and phase) co- and cross-polarisation patterns. Gain has been measured with a direct method. The ohmic loss in the complete antenna is below 1.5 dB.

The SAR antenna on-board ERS-1 is linearly polarised (vertical, both on transmit and receive - or VV), with a high degree of purity. The crosspolarisation level is around -40 dB. The required residual phase deviations in the antenna pattern are small, both over the frequency band and in the angular domain for the coverage region. Consequently, it seems indicative, that the correction for the antenna elevation pattern in the SAR-processing can be based on a scalar real pattern. The elevation pattern shows a very small change in width as a function of frequency over the operational band.

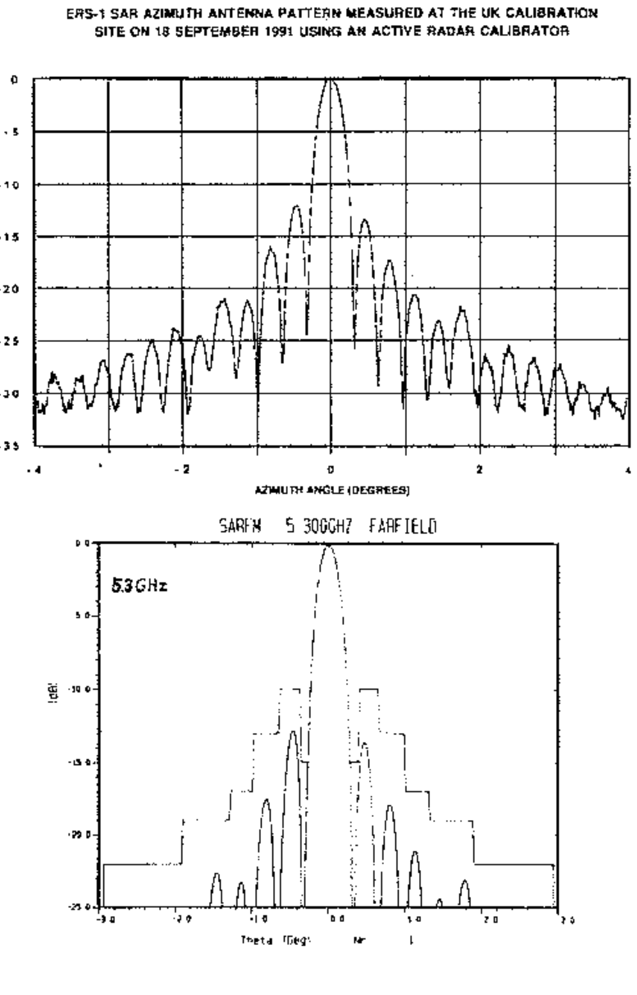

Figure 3: Azimuthal pattern derived from RAE transponder (top) and from pre-launch near-field measurements.

ERS-1 SAR Antenna in Orbit

The ERS-1 SAR has been calibrated in orbit with active transponders. The received power at a transponder location was also recorded during an overflight over an transponder, made by Rutherford Appleton Laboratory (RAE). The latter data are interesting from antenna point of view, because information is provided about the SAR antenna for the 'along-track' direction (azimuthal pattern related to the 10 meter dimension). Comparison of this pattern with the pattern measured before launch provides very indicative information for the success of the deployment and the realised planarity in orbit. Fig.3 shows the two patterns.

An error,if any, in the excitation of an electrical sub-panel would show up as well in the azimuth pattern.
The measurement before launch was carried out at 5 frequencies within the operational frequency band. Such a near-field measurement leads to a far-field pattern as shown in fig.4, where a relative accuracy in the pattern is better than circa ± 0.1 dB.

Effort has been done at Estec (XRI) to derive the antenna elevation pattern for the coverage area from the instrument response itself, using well-behaved scattering of distributed targets (rainforest). It was found at Estec, that the elevation pattern obtained in this way is about 0.3° broader. This is under further investigation. The pre-launch measurements do not give such pattern beamwidth.

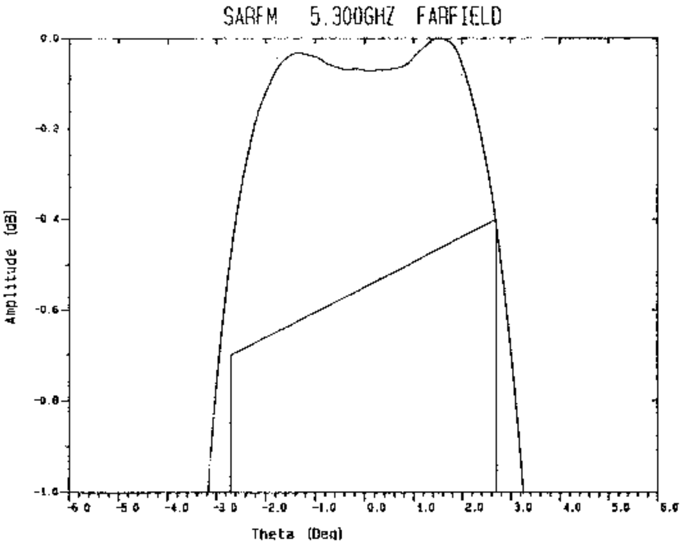

Figure 4: Elevation pattern (main-beam), courtesy Ericsson

Wind-scatterometer Antennas and On-Ground Verification

The antennas are made out of aluminium slotted waveguides, supported by an aluminium backing structure. Each antenna consists of two electrical sub-panels, fed from a waveguide feed network [4]. Extensive effort has been carried to realise an accurate thermal modelling. The impact of temperature changes during the orbiting has been translated as if the antenna would be operating at a different frequency. Measurements were carried out at such related frequencies.

The antennas have been measured in isolation on a spherical near-field range at Ericsson. The aperture of each antenna is rather elongated. The resulting pattern shape is basically a 'fanned-beam', with the strong shaping in the pattern in the plane perpendicular to the long dimension (elevation).

The gain has been derived from a comparison with a transformed near-field measurement of a standard gain horn, calibrated at ESA-TUD. Fig.5 shows one of the 'side' antennas, together with a standard gain horn, both mounted on the polar positioner in the spherical near-field facility. The realised ohmic loss of each of the windscatterometer antennas is only a fraction of a decibel.

A set of pattern data (complex, full polarisation in principle) has been derived for each antenna at 5 different frequencies, equivalent to certain temperatures as mentioned above, over a bandwidth wider than the signal bandwidth.

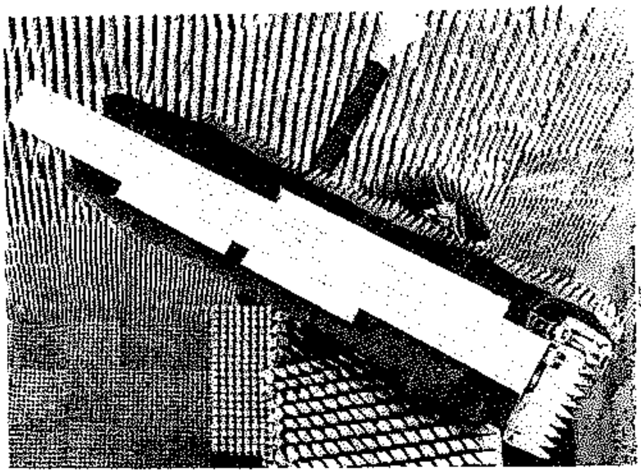

Figure 5: Wind scatterometer antenna ('side') on test range.

Wind-scatterometer Antennas In-Orbit

The wind scatterometer has been calibrated as instrument during the commissioning phase of ERS-1 by analysing echo data, both from 3 (Estec) transponders (point targets), positioned for this purpose in the south of Spain and from the Brazilian rain forest (well-behaving distributed target). The transponders re-transmit the received pulses according to an accurately measured radar cross section (RCS), while the assumption is made, that the rain forest has a RCS proportional to the cosine of the incidence angle as measured from nadir.

Azimuthal pattern

The power $P_r(t)$ received by the transponders is found as a function of time, for which we have:

$$P_r(t) = k * \frac{G_{az}(t) * G_{el}(t)}{R(t)^2}, \qquad (1)$$

in which the azimuth pattern $G_{az}(t)$ and elevation pattern $G_{el}(t)$ of a scatterometer antenna are written as a function of antenna angles as a function of time. The range distance $R(t)$ also varies during the pass over the transponder (different for each antenna). Furthermore, k is assumed to be constant during the pass. The basic assumption is, that the three dimensional pattern can be written as a product of $G_{az}(t)$ and $G_{el}(t)$. The azimuth and elevation angles found by the orbit propagator are transformed into the antenna frames, using the rotation matrices measured on ground.

The azimuthal pattern can be deduced for the given transponder configuration. The azimuth and elevation angle as well as the slantrange follow from an orbit prediction program. The accurate knowledge of $P_r(t)$ and the other configuration parameters provide an estimate for the normalised azimuthal pattern with an accuracy of about 0.2 dB. A small error is made due to the assumption, that a pattern decomposition can be applied. About 0.2 dB error at the top of the beam gives an error level of about 0.8 dB at the level of the first sidelobe.

Fig.6 shows the azimuth pattern as measured on the ground for the Mid antenna, as well as the response derived from the transponder data.

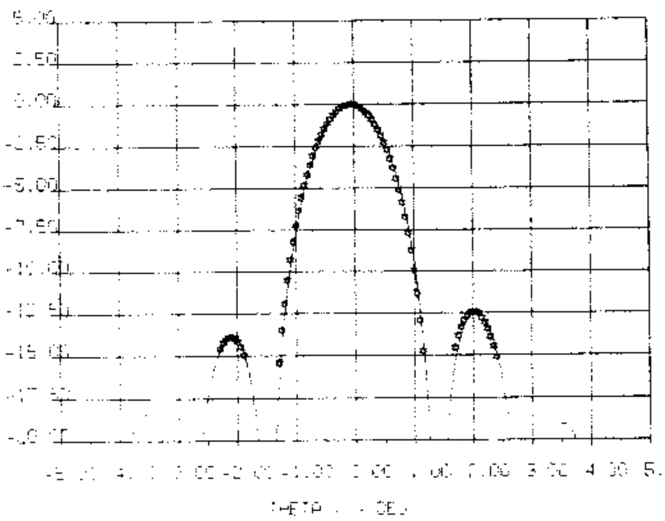

Figure 6: Azimuthal pattern (solid line = prelaunch)

A small phase unbalance between the two electrical sub-panels in the Mid antenna leads to an un-balance in the levels for the first sidelobe on each side of the mainbeam. The latter effect has been reconfirmed from the transponder data, as noticed in fig.6.

Elevation pattern

The rain forest in Brazilia has been used as an (assumed) well-behaved scatterer, with a RCS proportional to the cosine of the incidence angle, measured from nadir. The response measured from the rain forest (in range and orbit time) is converted to σ_o, by processing this data according to a *S*catterometer *S*ystem *S*imulator (SSS), which has the antenna patterns as input (as well as other parameters). During the commissioning phase, the antenna patterns which were input to the 'SSS', were iteratively updated, so, that the across-track response of $\sigma_o/cos(\theta i)$ varied as little as possible (ca ± 0.2 dB *two-way*). The difference between the measured patterns (before launch) and the patterns input to the 'SSS' accomodate deviations between the on-ground measured antenna patterns and the actual realised antenna patterns in orbit together with all other effects (among which diffraction effects due to near-in structures on the spacecraft, especially for the Mid-antenna).

Fig.7 shows the realised elevation pattern for the Mid antenna as measured on-ground. The coverage zone extends from $\theta = -10°$ to $+14°$. It is noticed, that the pattern level in the directions for larger θ is relatively high. Fig.8 shows the main-beam as derived from spherical near-field measurements (dotted) and the expected response as derived by iteration from the rain-forest data. The difference curve is given around the '0'- dB line.
About $\pm 0.35 dB$ is observed. Such a fast ripple was not found in similar comparisons for the side antennas, as indicated in fig.9. A small diffracted signal due to the presence of the SAR antenna edge close to the Mid antenna is suspected to be the reason for this. A simulation by measurement was carried out using the ERS-2 Mid antenna with a simulated SAR-antenna edge. It was found (by spherical NF measurement), that the presence of such edge caused a small error of a few tenth's of a dB. This is being investigated further. The observed effect is important, because the additional few tenth's of a dB is slightly more than the variation in the pattern of the antenna in isolation, over the frequency band as related to temperature changes. This implies, that the correction for changes in the temperature cannot be applied. (changes due to degradation of the thermal hardware might be expected towards the end-of-life)

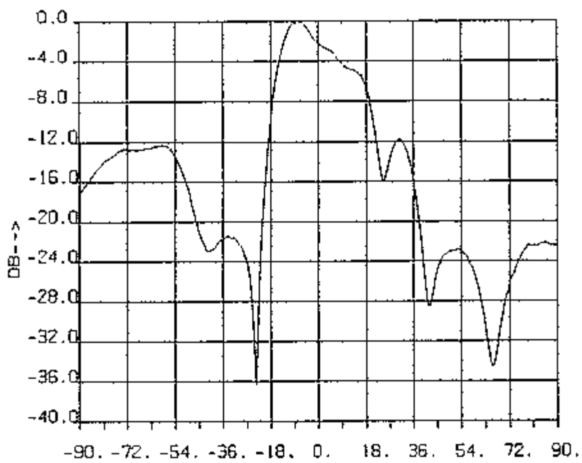

Figure 7: Elevation pattern Wind scatterometer Mid antenna

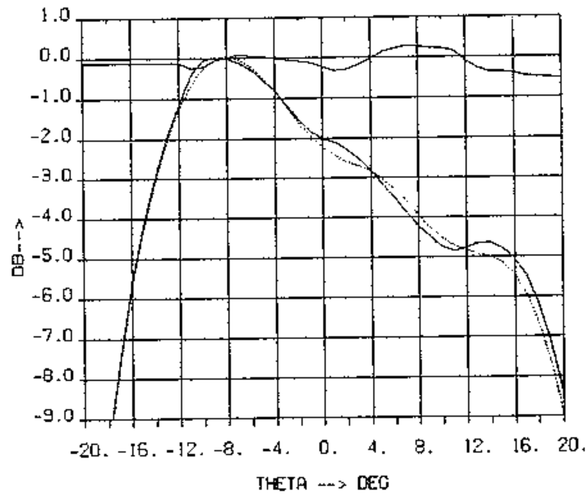

Figure 8: Comparison Mid antenna elevation pattern, see text

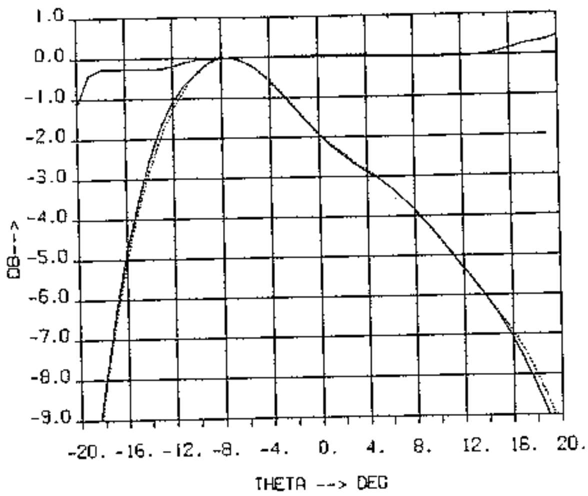

Figure 9. Comparison Fore antenna elevation pattern, see text

Conclusion

Data related to in-orbit performances of the SAR antenna were discussed. The good agreement between the azimuthal patterns (measured before launch and derived from transponder data) indicates not only successful deployment, but also a good planarity of the SAR antenna. The elevation pattern of the SAR antenna is observed to be slightly wider than expected from the pre-launch tests. an effect, which needs to be investigated further.
The azimuthal patterns of the wind-scatterometer antennas are according to expectation. The Mid antenna elevation pattern is slightly influenced by a diffracted signal coming from the edge of the SAR antenna. The fore antenna doesnot show such influence. The methods for data acquisition were outlined, both for azimuth and elevation.

Acknowledgement

RAE is acknowledged for making the azimuthal pattern of the SAR antenna available to Estec.

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