PLANAR NEAR FIELD TESTING OF THE ENVISAT ASAR ACTIVE PHASED ARRAY ANTENNA

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ABSTRACT

The ASAR antenna has dimensions 10m x 1.3m and utilises an array of 320 active transmit/receive modules. The antenna weighs approximately 750kg and is a deployed structure designed for a zero-g environment. The antenna generates relatively high peak transmit powers with low duty cycle, while the sensitive receivers have limited power handling capability. Testing such an array therefore poses challenges for the measurement facilities that are not encountered in typical applications. This paper gives a brief overview of the ASAR antenna and the Planar Near Field Test facility and provides a review of some of the difficulties encountered. Patterns were measured in transmit, receive, vertical and horizontal polarizations at several frequencies. Cross-polar measurements were also made on selected beams. The various methods of test and data analysis are outlined, and finally a set of typical test results are presented in comparison with theoretical predictions, which demonstrate excellent agreement.

1. INTRODUCTION

ASAR is an earth resources imaging synthetic aperture RADAR (SAR) developed for the European Space Agency (ESA). It will operate along with various other instruments on board the first polar platform mission - the environmental satellite ENVISAT which is scheduled for launch on Ariane 5 in October 2001. ASAR will succeed the highly successful ERS1 & 2 satellites made by Astrium Ltd., as part of the new generation of space-borne SAR instruments. Operating at C-band with dual polarization and beam steering capability ASAR will provide increased diversity in both image product and ground coverage utilising different modes of operation. This enhanced capability is in the main due to the antenna architecture.

Principal requirements for the antenna are to provide dual polarization and beam steering in elevation. SAR system requirements also demand high levels of beam stability and low side-lobes. The physical size of the antenna is determined by key SAR performance parameters and in general this leads to a relatively large aperture with high aspect ratio. In this case a height of 1.3m (elevation) and width of 10m (azimuth). No steering is required in azimuth so the concept can be considered a relatively simple linear array. However, an antenna of such size ultimately needs to be stowed for launch, and deployed in orbit. In addition to practical reasons this leads to an arrangement that forms discrete phase centres in azimuth.

The antenna is configured as five azimuth panels (one fixed, four deployed) each with a grid of four identical tiles. Each tile comprises sixteen transmit/receive modules feeding individual radiating subarrays to form an overall antenna aperture of 32 (elevation) by 10 (azimuth), or 320 phase centres. In addition to the stability of the electrical functions the mechanical structure has to ensure a high degree of flatness and stability to avoid degrading the pattern and hence SAR performance. A particular problem facing the measurement of such a complex, heavy and delicate structure (designed for zero gravity), is the provision of good mechanical support for on-ground testing.

In addition to standard pattern measurements there were certain alignment and characterisation measurements required. The first of these was to align all the tile phase centres to form a uniform phase plane. Since the tiles are manufactured and tested in isolation their insertion phase was expected to vary to a certain degree. The planar scanner is ideally suited to this as use of the probe can be made to take near-field measurements at each phase centre. The next characterisation test was to acquire the embedded pattern of each antenna row to allow more accurate simulation of the full antenna patterns. However, both these tests imposed requirements on the range measurement system which are not usually considered in detail: specifically the absolute alignment and position of each phase centre in the first case, and then maintaining an accurate phase reference between successive antenna acquisitions in the second.

Full beamforming tests were required for eight pre-defined beams with each measured in both transmit and receive, and for both vertical and horizontal

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polarizations. Cross-polar information was also required in some cases. Being a pulsed RADAR system the measurements were carried out in pulse continuous wave (CW) mode.

2. TEST RANGE FACILITY

2.1 Overview

To support the antenna test campaign the construction of a new, general purpose planar near field test facility [1] was started at Astrium ltd., Portsmouth in 1995 and completed a year later. The facility was built into an existing structure which already housed a clean room area. As part of the specific antenna test facility a deployment test room was also constructed with a purpose laid epoxy floor to exacting flatness requirements, as needed to support the deployment air bearings. A plan view of these AIT (Assembly Integration & Test) areas is provided in Fig. 1 and Table 1 provides a summary of the range capabilites.

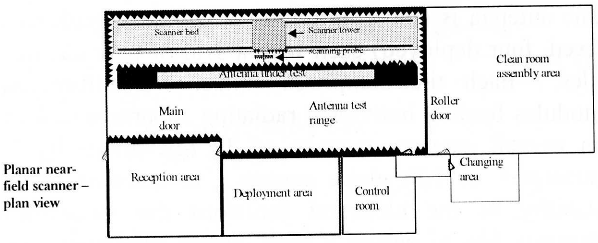

Fig. 1. Test Facility Layout

Radiation measurements of large planar arrays, SARs, medium to high gain comms. antennas
Chamber 27m x 12m x12m, main access door 8 m wide x 5 m high
Class 3 clean room environment, with class 4 reception facility and access to class 3 assembly area
Scan plane 22m x 8m
Laser calibrated encoders for enhanced Z axis precision. ±0.05mm with laser, ±0.3mm without
Secure control room for acquisition control and post processing
Pulse mode capability for RADAR testing
In range antenna alignment measurement capability
Dedicated near to far field processing software suite with probe correction capability
Aperture diagnostics capability
1 to 40GHz frequency range
RF Isolation >70dB
Reflectivity < -50dB at 1.5 GHz improving to < -80dB above 12 GHz
RF Stability ±0.05dB and 0.5° over 8 hours
Crane rated to 5 tonnes
CCTV monitoring and intercom

Table 1 Planar Near Field Scanner Range Capabilities

The mass and complexity of the ASAR antenna, combined with the considerable quantities of accompanying electrical and mechanical ground support equipment (EGSE and MGSE) precluded movement of the antenna during the measurement process. This coupled with the physical size of the antenna led to the particular choice of a planar near field scanning method. A photograph of the full flight model antenna under test in the planar range is provided in Fig. 2.

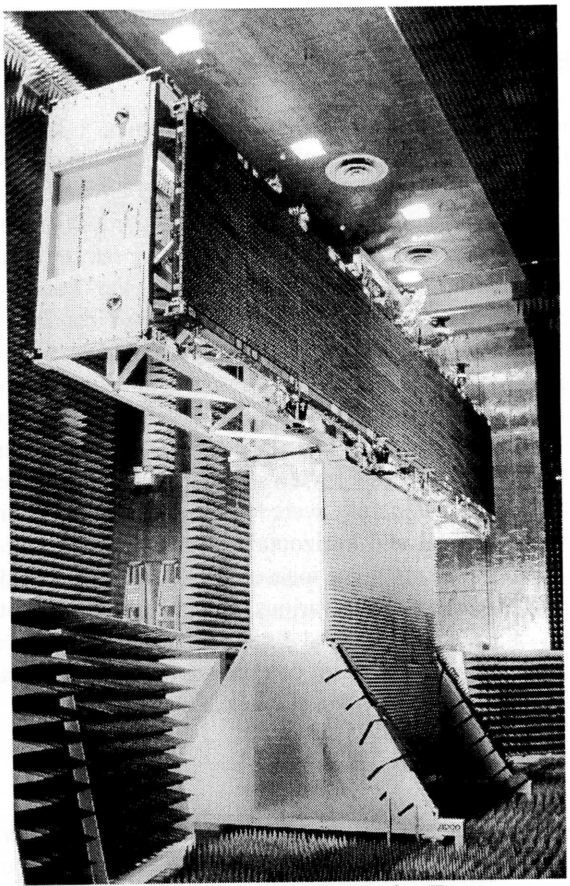

Fig. 2. ASAR Antenna under Test

Use of a conventional planar facility means that only a portion of the forward propagating energy is sampled. Therefore a correct specification for the dimensions of the acquisition plane is necessary for the far field antenna patterns to be reliable. The size of the measurement plane was principally governed by the following considerations:

a. The dimensions of the effective radiating area of the antenna (10m by 1.3m)
b. A requirement to minimise the effect of truncation and to provide far field data to an angle of ±70° from boresight.

c. A requirement to achieve an uncertainty of better than 2dB at 40dB below peak.
d. The requirement to minimise the coupling between the AUT and the scanning probe.

Minimisation of coupling is particularly important since it is neglected in the prevailing theory of near field measurements, and could in extreme cases create a disturbance of the array excitations. An AUT-to-probe separation of 1m was selected as this provided a good compromise between minimising truncation and coupling errors while maintaining a reasonably sized measurement plane. A specific scan plane of approximately 12m wide by 7m high was derived according to these requirements permitting the production of far-field data over an angular range of ±4° in azimuth and ±70° in elevation.

2.2 RF Instrumentation

Being a pulsed radar system the measurements were carried out in pulse continuous wave (CW) mode. Hence the signal levels in the measurement system had to be carefully set up to maintain adequate signal-to-noise ratio while ensuring no saturation of either the range receiver or the antenna receive circuits. In practise this was relatively simple for the transmit measurements but in receive, where the antenna peak input power has to be limited, the mean output power is low and had to be boosted by a low noise amplifier. Linearity and noise checks were carried out as part of this exercise.

The RF measurement subsystem comprises an adapted Hewlett Packard pulsed HP85301B. The principle modifications were concerned with the use of low loss Gortex Type 7 cables and distributed local oscillator (LO) drive amplification to maintain the required drive levels at the LO mixer.

Use of an ortho-mode transducer (OMT) to simultaneously sample two orthogonal tangential electric field components was initially considered, but discouraged by a limitation imposed from within the RF and control subsystems. The difference in the observed level between the pulsed signals from each field component was considerable due to high cross-polar discrimination. With the limited receiver dynamic range this would have resulted in the smaller signal suffering significant errors. A possible solution existed within the transformation software since it has the ability to rigorously process data acquired using a probe with an arbitrary but known orientation. This would have enabled measurements to be made with the probe at angles of, say 45° and 135° which would have ensured the measurements would be of comparable levels. Unfortunately however, limits within the control software precluded the use of this technique and hence separate tie-scanned acquisitions for each field component were made. This doubled the test time for those beams requiring cross-polar measurements.

2.3 Test Requirements

Because of accommodation and potential radiation hazard all antenna electrical tests were carried out in the planar range. Noise figure, gain and individual TRM path gain and phase are examples of parameters verified in this way using a purpose built test equipment assembly, and utilising a specific signal port designed into the antenna..

The radiating test campaign required to be carried out in three main stages:

The first stage was to align all the phase centres, since the tiles are manufactured and tested in isolation variation in absolute insertion phase was a distinct possibility. The planar scanner is ideally suited to this and the first results were achieved by making near field measurements at a fixed point relative to each phase centre. Correction factors were applied in the set-up data for each tile as necessary to achieve uniform behaviour.

The next stage required characterisation of each antenna row as these provide the embedded subarray patterns, which allow more accurate simulation of expected full antenna patterns. However, both these tests impose requirements on the range measurement system, which are not usually considered in detail, *e.g.* alignment and position of each phase centre, and maintaining an accurate phase reference between successive antenna acquisitions.

Finally, full beamforming tests were required for eight beams in both transmit and receive, and vertical and horizontal polarization. Cross-polar information was also required in some cases. The requirements on these tests were not only to demonstrate the performance obtained, but also to provide an accurate characterisation of the antenna beam patterns for in-orbit performance optimisation of the overall SAR system.

In order that these requirements could be met, the transformation software had to be deployed in a way that deviated from the conventional. Traditionally the AUT is orientated in the range so that its mechanical interface is aligned carefully to the axes of the range.

However due to the considerable size and mass of the ASAR instrument and its associated MGSE it was quite impossible to perform this alignment operation with the degree of precision required. Instead the orientation of the AUT with respect to the range was determined with the use of a precision mechanical contacting probe. The transformation software was then used to correct the processed aperture-plane and far field data [2][3].

Since the ASAR antenna has a narrow azimuth beam-width the far field data needed to be tabulated on an angular grid, or cut, with a fine abscissa. The near field to far field transformation was accomplished by using a factored two dimensional discrete Fourier transform (DFT). This was chosen in preference to the ubiquitous fast Fourier transform (FFT), as it could yield the required density of data over the angular region of interest without recourse to additional interpolation. Such interpolation is typically used to present data on a regular angular co-ordinate system, however it tends either to be approximate or, when rigorously employed, computationally intensive.

3. MEASUREMENTS

3.1 Antenna Physical Alignment

The acquisition of antenna-to-range alignment data was based upon the existence of eight reference points that were easily accessible to a precision contacting probe in order that the Cartesian co-ordinates of each point could be determined in terms of the range co-ordinate system.[3]

3.2 Phase Centre Alignment

Before any true antenna measurements could be made the function and performance of each phase centre needed to be checked and adjusted if necessary. The adopted technique used the range scanning probe and required the position of each phase centre to be known in scanner co-ordinates. The range probe was positioned directly above each phase centre as it was activated with a reference gain/phase setting in isolation from all the others. The response was measured before moving on to the next, and repeating for all 320 elements. This was carried out in both polarizations for transmit and receive. Since tiles had been accurately set up by the supplier the response of the associated 16 elements was averaged in each case to determine any adjustments necessary to electrically align all 20 tiles.

3.3 Embedded Element Patterns

The first real antenna measurements consisted of determining the far field pattern for each of the 32 individually excited embedded rows. These data were required to improve the theoretical predictions for the entire antenna. An embedded row effectively constitutes a 10m wide by 0.015m high antenna. Clearly, the resulting pattern possesses a broad pattern in elevation and a high directivity pattern in azimuth. This required data to be taken over a large area in order to minimise Gibbs's ripple in the far-field potentially caused by truncating the aperture in elevation.

Embedded element pattern results were processed to derive the far-field and aperture plane profiles. The far-field data is represented for each of the 32 rows in Fig. 3 for amplitude and in Fig. 4 for phase.

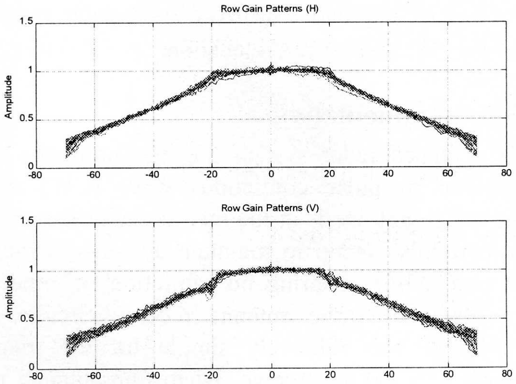

Fig. 3. Plot of embedded element amplitude patterns for 32 rows

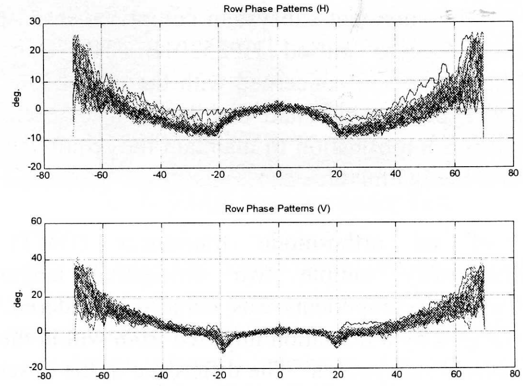

Fig. 4. Plot of embedded element phase patterns for 32 rows

The gain patterns measured were readily comparable from row to row as could be expected, however the phase patterns revealed differences between the phase functions on certain rows, not conforming to the general trend. These issues required further post processing of the data to derive the correct performance and they arose due to loss of an absolute phase reference between successive acquisitions. Such mis-registration occurred in all three scan axes and was generally due to software re-setting of the scan plane at certain times between successive row acquisitions. It should be noted that this is not normally a problem since single antennas are acquired in one scan, and throughout the scan the system is stable. It is only when trying to maintain an absolute reference for comparing effectively 32 antennas that it becomes an issue.

Additionally, the phase profile with scan-angle suffered a slope that appeared to be dependent on the acquisition frequency. This occurred since the measurements at each frequency were taken sequentially as the scanner moved, effectively resulting in acquiring each frequency on a regular rectangular Cartesian grid with each 'frequency' grid being displaced with respect to one another. Once these features were identified it was a relatively straightforward matter to correct the test data to achieve the results presented in Fig. 4.

3.4 Aperture Diagnostics

At the start of the full pattern measurement campaign the results from a uniform aperture illumination configuration were analysed as a diagnostic check. The technique of microwave holographic metrology (MHM) was employed to recover the aperture plane of the AUT and facilitate the diagnosis of various anomalies, which became clearly visible. The application of alignment data was found to be crucial in this process as it ensured the recovered aperture illumination function remained clearly "focused" and free of phase tapers. The procedure was carried out for transmit and receive in both polarisations to establish the aperture function in each case. A typical pattern is provided in Fig. 5 illustrating the reconstructed amplitude for transmit horizontal.

Fig. 5 clearly shows the 'active' area of the antenna and demonstrates the utility of this 'back-transform' process in identifying anomalies within the aperture. The light region observed within the aperture corresponds to a single phase centre comprising a radiating subarray and T/R module. The anomaly represents a failed device within the module. The affected tile has since been repaired and a failed SSPA identified as the cause within the T/R module.

In other instances the high resolution of this technique has also revealed individual annular slot radiator failures (24 within a subarray) but since these are few and have negligible effect on overall performance they have been accepted. Also noticeable in Fig. 5 are the field disturbances caused by the mechanisms and deployment motors around the radiating aperture.

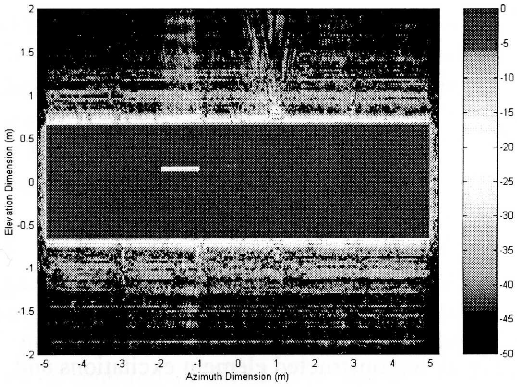

Fig. 5. Reconstructed aperture plane power showing failed TR module

Ultimately the use of this technique was found to be more reliable in determining differences in the average gain and phase betrween tiles than the probing checks done for phase centre alignment. The results were used to fine tune the removal of phase offsets between tiles.

3.5 Pattern Measurements

After the initial diagnostic tests were completed the antenna was set up for each of the performance beams and the acquisitions taken. The reconstructed aperture plane and far field patterns were generated and could then easily be compared against the requirements and the theoretical predictions. Alignment issues were again shown to be of importance as the antenna was found to have a small electrical mis-pointing that would otherwise have been confused with the mechanical pointing of the antenna in the range.

The aperture illumination derived using MHM techniques has been carried out for each beam and by averaging over all azimuth contributions the elevation gain and phase functions can be derived. Fig. 6 contains plots of these reconstructed elemental excitations plotted against the commanded excitation for one of the ASAR beams. There is close agreement found between the commanded and reconstructed excitations.

The gain of the ASAR antenna, for each measured beam was determined by performing a substitution with a calibrated gain standard [4] this was appropriate since, by design the AUT-probe interaction was negligible. A typical example of a gain corrected far-field pattern is shown in Fig. 7.

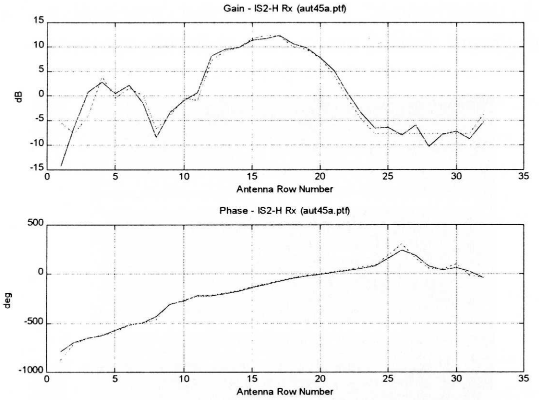

Fig. 6. Reconstructed element excitations and commanded excitations (dashed line).

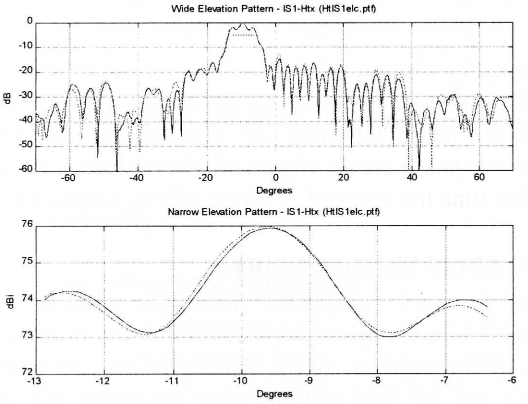

Fig. 7 Typical far-field elevation gain pattern vs theoretical pattern comparison

The solid line represents the measurement and the dotted line represents the theoretical pattern derived using the embedded element patterns. Once again there is a excellent correlation between the two curves. Gain is referred to the active feed antenna input so includes electronic gain from the TRM and feed losses.

A typical azimuth pattern is shown in Fig. 8 for close-in and far-out angles. Clearly this approaches very well the expected sinc function response.

4. CONCLUSIONS

The test and measurement campaign for a large active SAR antenna has been successfully completed using a purpose built large accurate planar near field facility. The presented results have shown the high level of agreement attained between theoretical prediction and measured data in both the near and far fields.

Use of a planar scanning approach has therefore proven to be very successful. Limitations on far-out angle coverage have not been a concern for this application, where ease of mounting the antenna and maintaining structural integrity with accurate alignment have been major positive benefits from this approach. In addition the ability to probe individual subarrays for diagnostic and set-up purpose has been useful.

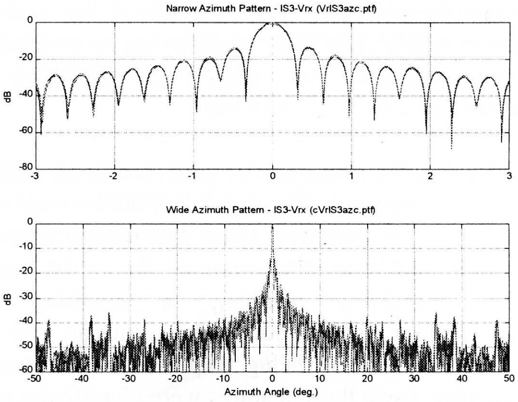

Fig. 8 Far-field azimuth pattern vs theoretical pattern

Development and use of holographic metrology for aperture diagnostics has provided invaluable information to allow understanding of each active element behaviour, and hence details contributing to the achieved patterns.

The range facility and software, co-located AIT support areas and the experience gained on ASAR now places Astrium Ltd. in a lead position regarding test of space antennas, large and small.

5. REFERENCES

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