Antenna Pattern Effects in Wideband Polarimetric Imaging

G. Nesti, A. J. Sieber and M. Hohmann

Commission of the European Communities
Institute of Remote Sensing Applications
Joint Research Centre, 21020 Ispra - Italy

ABSTRACT

In this paper different techniques are considered for measuring the pattern characteristics of wideband antennae and applying suitable correction procedures to the acquired data for imaging purposes. Practical tests have been undertaken in the Interim Microwave Signature Laboratory at the JRC in Ispra with dual polarised quad-ridged antennae covering the 2 - 18 GHz frequency range. The measurements have been performed preserving the polarimetric content so that the distortions in phase and polarisation could be investigated. The one-way angular pattern has been measured using the standard method of rotating the antenna while the two-way pattern has been measured by means of test targets (metallic spheres and cylinders). In the latter case the spatial variability of the antenna response has been accurately investigated in the area around the calibration point. Correction schemes have been applied to the case of linear target motion. For the rotation case the errors induced by the irregularities of the antenna response have been quantified. These errors are important for the accurate measurement of the target scattering matrix but, in this particular experimental configuration, do not significantly influence the image quality.

INTRODUCTION

In laboratory experiments, when the target size is comparable or larger than the antenna beamwidth, the system calibration (which is normally performed at a single point along boresight) must be integrated with additional corrections to take into account the effects of the antenna pattern. The problem is even more complicated for wide bandwidth measurements because of the frequency dependence of the antenna pattern.

In some cases (e.g. a single measurement of the scattering matrix of a large object) there are no practical methods to correct “a posteriori” the measured data and only an estimation of the error can be done.
However, in imaging experiments, where the interaction “antenna pattern/target” changes depending on the target aspect angle, there are possibilities of introducing correction procedures in the imaging process itself.

The objectives of the experiment described here are the full characterisation of the antenna pattern for wideband antennae, the evaluation of the related errors in typical imaging measurement configurations, and finally the practical implementation of correction procedures. Although the measurements refer to a specific antenna type, the numerical results can be used as a realistic basis for deriving useful considerations which are valid in general for imaging experiments using wideband antennae. The measurements have been performed in the Interim Microwave Signature Laboratory at the JRC in Ispra with dual polarised, commercially available antennae, in the 2 - 18 GHz frequency range. The polarimetric information has been preserved so that the distortions in phase and polarisation could also be investigated.

1. ANTENNA PATTERN CHARACTERISATION

In principle the antenna pattern specifications could be supplied by the manufacturers, but usually only the power pattern for a limited number of frequencies is provided and the polarimetric aspect is completely neglected. Hence it has been decided to measure these characteristics by using the equipment available in the Interim Laboratory.

Fig. 1 shows the measurement configuration with the antenna alignment and the orientation of the polarisation planes. The transmit antenna was kept fixed and the receive antenna (under test) was rotated horizontally in steps of 1° in the range [-90°, 90°] around the vertical axis passing through the centre of the antenna aperture. This arrangement minimises the phase distortion introduced by

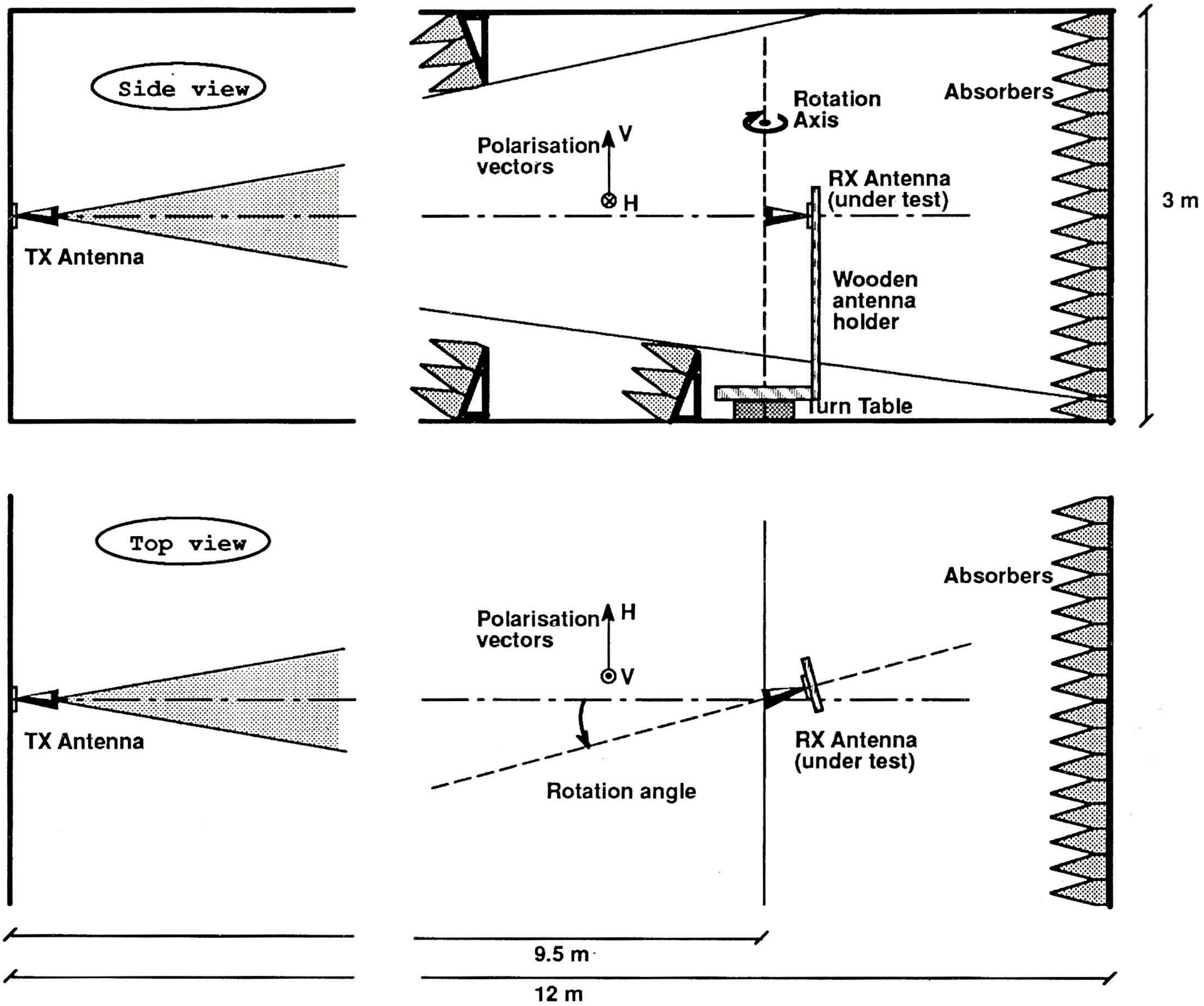


Fig. 1 - Experimental arrangement for the measurement of the antenna pattern.

the movement of the tested antenna itself. Data have been collected for the four possible combinations of transmit and receive polarisations at each horizontal angular step. The whole sequence was repeated after rotating the receiving antenna by 90° around the boresight. In this way both the copolar and crosspolar patterns of the antenna under test have been characterised along the E-plane and H-plane cuts (defined as shown in Fig. 2).

A sample of the measured data versus frequency and angle from boresight is reported in Figs. 3 and 4 in the form of colour-scaled two-dimensional images. For the purpose of comparison, a normalisation with the respect to the response at 0° has been introduced for the copolar response, while the crosspolar pattern has been normalised point-by-point (at a given frequency and at a given angle) with respect to the corresponding copolar response. A characterisation of the antenna pattern in terms of absolute gain is not necessary because this is taken into account by the end-to-end calibration as described for instance in (Nesti and Hohmann, 1990).

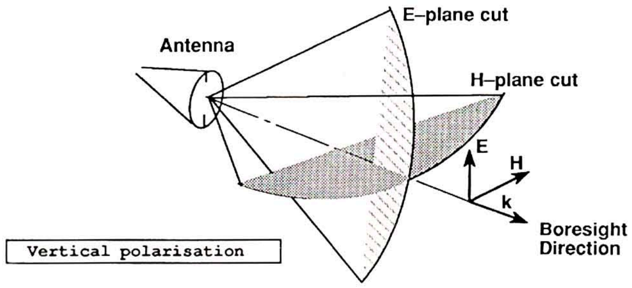


Fig. 2 - Nomenclature for the antenna pattern description.

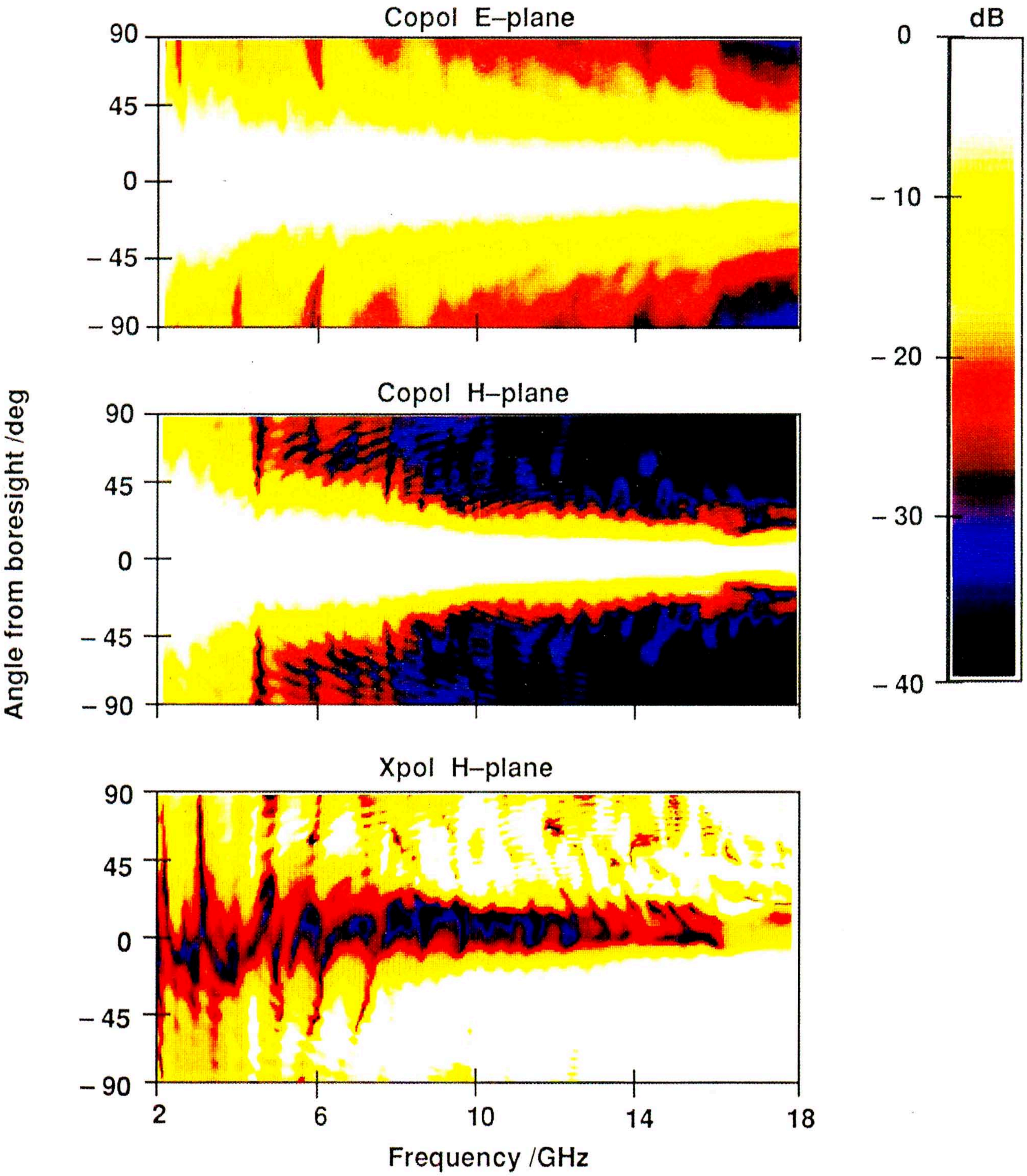


Fig. 3 - Measured power antenna pattern versus frequency and angle from boresight. The raw data have been normalised with respect to the boresight response for the copolar pattern and to the copolar response (point-by-point) for the crosspolar pattern.

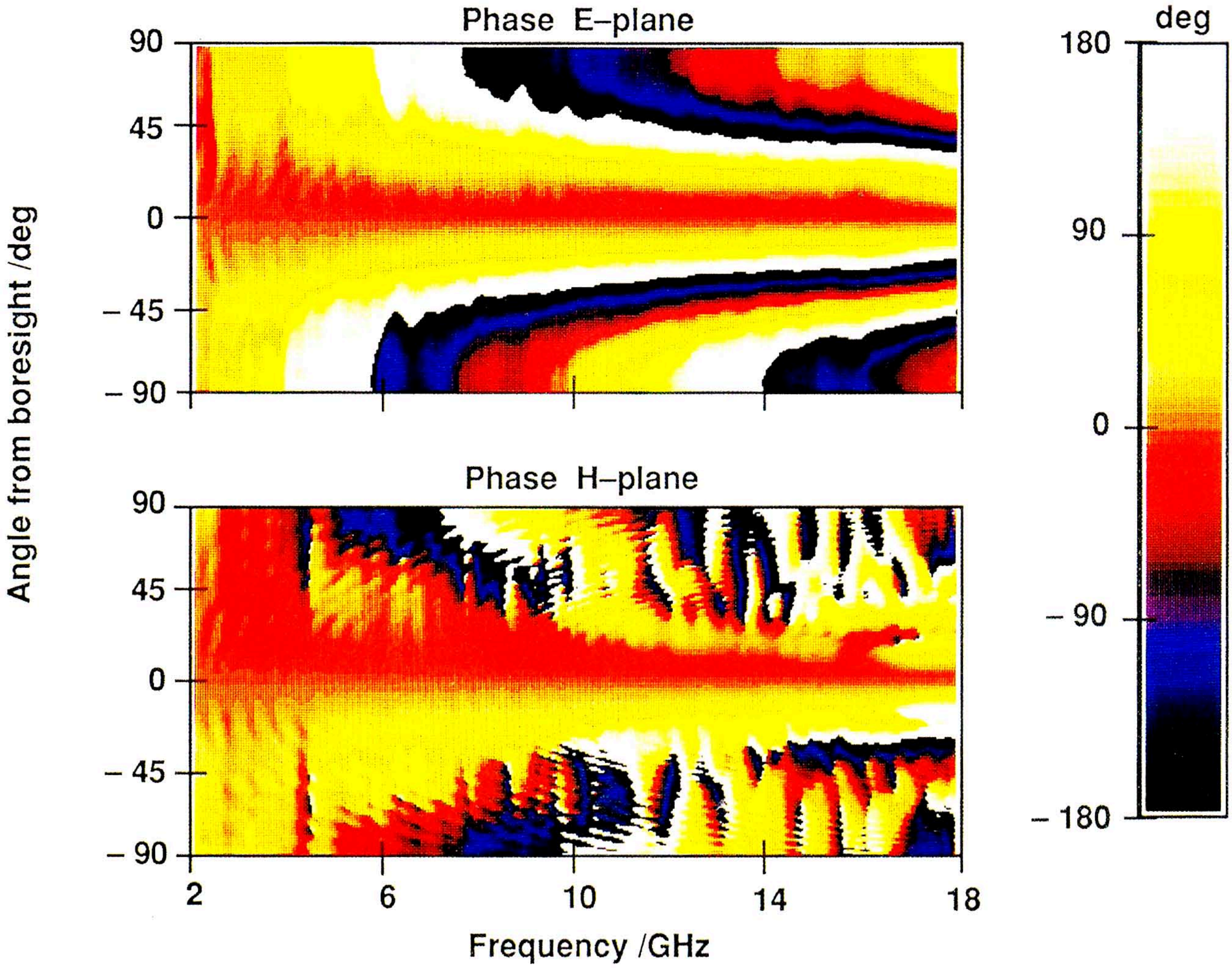


Fig. 4 - Measured copolar phase pattern versus frequency and angle from boresight. The raw data have been normalised with respect to the boresight response.

Fig. 3 shows the normalised power pattern for the copolar response (E and H planes) and for the crosspolar response (H plane). Fig. 4 shows the phase pattern for the copolar response (E and H planes). It can be noted that the behaviour for the copolar response is rather regular although the maximum is slightly shifted towards positive angles.

The crosspolar response is rather irregular and its level increases moving away from the boresight until it becomes comparable with the copolar response. Fortunately, this situation is significantly improved by the polarimetric calibration (Nesti and Hohmann, 1990) which corrects "a posteriori" the antenna response and permits the achievement of an effective polarisation purity) 40 dB along the boresight direction.

The most significant part of the copolar antenna pattern is shown in Fig. 5 for three representative frequencies. If the angular span around the boresight is limited to 10° (a typical situation for imaging experiments implying the target rotation) the variation in power is < 3 dB and the phase distortion is < 25° in the worst case (18 GHz). As it will be discussed in Section 3, these errors can be tolerated for imaging purposes and in most cases a specific correction procedure is not necessary. However, in experiments where a linear movement of the target is required, the angular span used is normally larger (30° - 40°). In these cases the antenna effects become so significant that a correction must be considered (see Section 3).

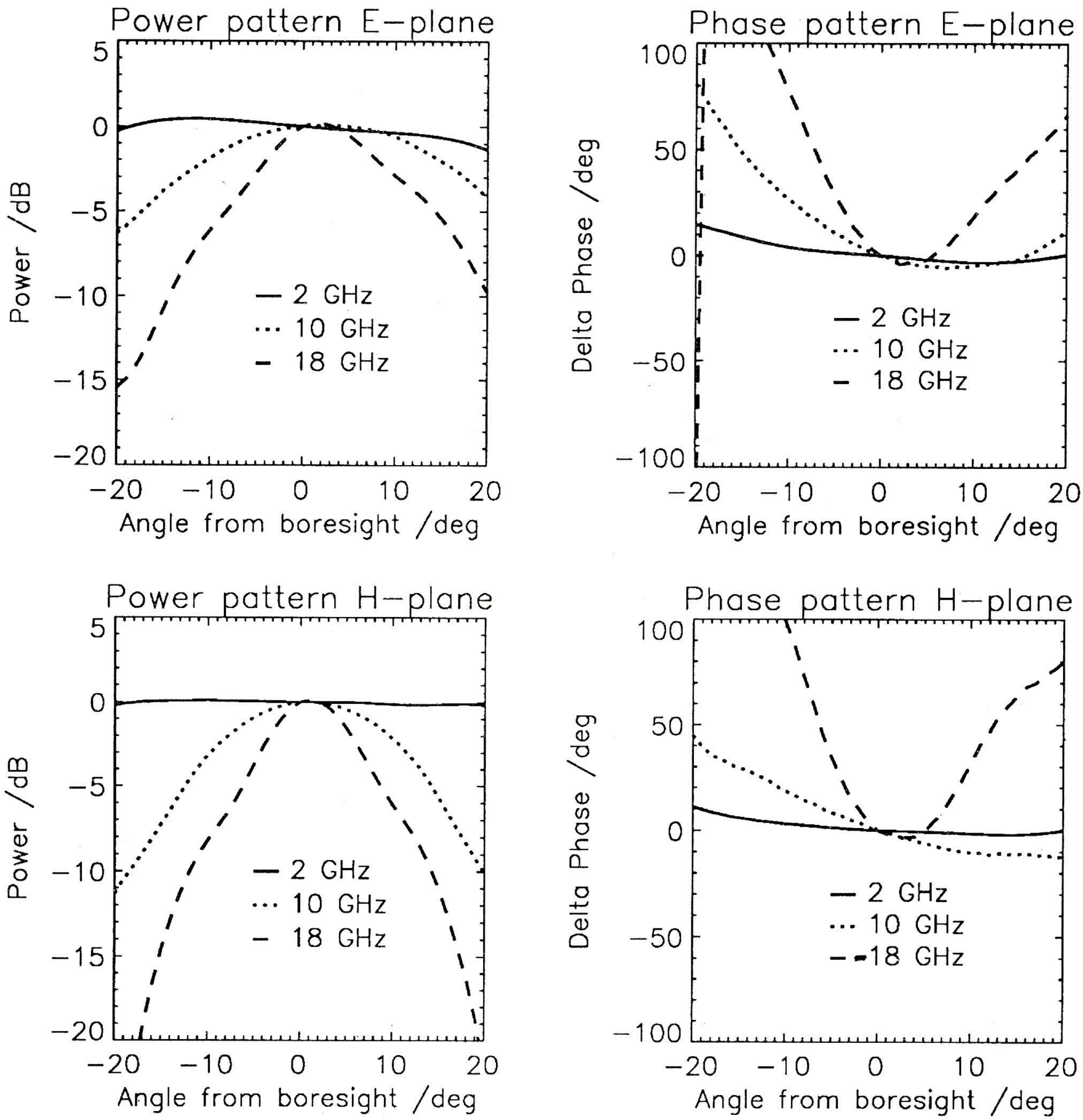


Fig. 5 - Measured antenna patterns for three frequencies (2, 10 and 18 GHz). The power patterns (left) and the phase patterns (right) are shown in E-plane (top) and H-plane (bottom).

2. SPATIAL VARIABILITY OF THE TWO-WAY ANTENNA RESPONSE

In principle there are an infinite number of ways of changing the target aspect angle to collect data for imaging purposes in laboratory experiments. In addition, wideband measurements normally require the use of two separate antennae for transmitting and receiving in order to achieve sufficient isolation over the entire frequency range. Obviously, the impact of the antenna pattern depends on the specific experimental configuration and in most cases it can not be simply derived from the characteristics of the single antenna.

This is particularly true when the polarimetric aspects must be taken into account. In the investigation discussed here two of the most popular measurement configurations have been considered:

1. Target rotation with respect to an axis perpendicular to the antenna boresight (that is the z-axis in Fig. 6).
2. Target linear displacement along a line perpendicular to the antenna boresight (that is the x-axis in Fig. 8).

2.1 Target rotation

In the first case the investigated region is a horizontal square (1.3x1.3 m^2) centred on the rotation axis. The two-way antenna response has been sampled using a vertical metallic cylinder (200 mm in length and 16 mm in diameter) as the probe, with the axis perpendicular to the boresight of the antennae. A limited set of probing positions has been used (Fig. 6) and then a spatial interpolation procedure (weighted mean of the four nearest measured values) has been used in order to reduce the number of single measurements necessary to cover the area of interest. The interpolation can be performed in the frequency or the time domain, in power or in complex amplitude, depending on the specific way the data are used by the imaging processing.

Fig. 7 shows an example of the variability in terms of power response over the area of interest for HH, VV and HV polarisations. These patterns have been obtained by performing the following steps:

1. Calibration in the frequency domain by using the calibration factors derived from measurements of reference targets located at the centre of the area.
2. Computation of the time domain response of the probe targets via Fourier Transform (frequency range 10 - 18 GHz) and evaluation of the peak level for each position (shown as a white dot in Fig. 7).
3. Spatial interpolation of the measured peak levels.

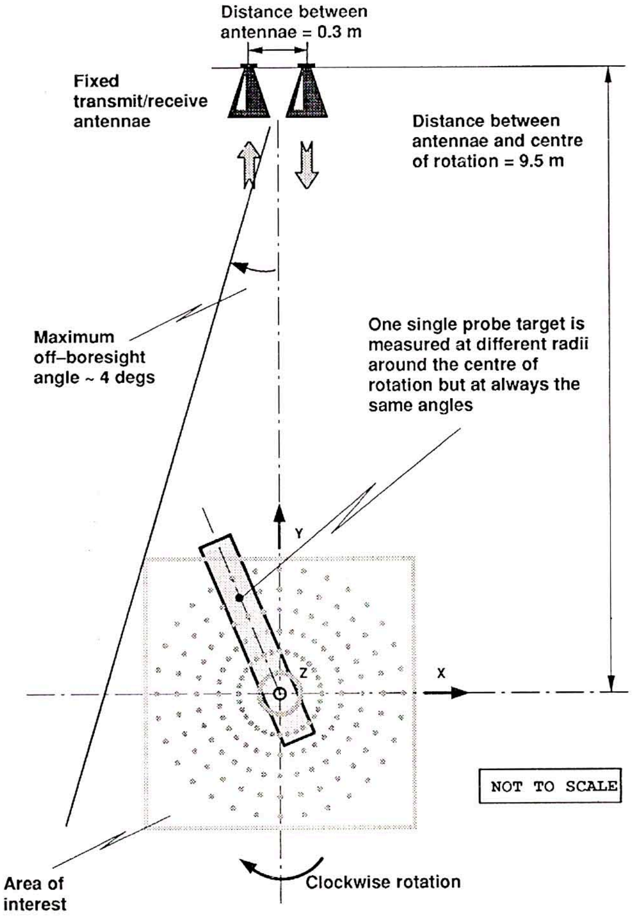
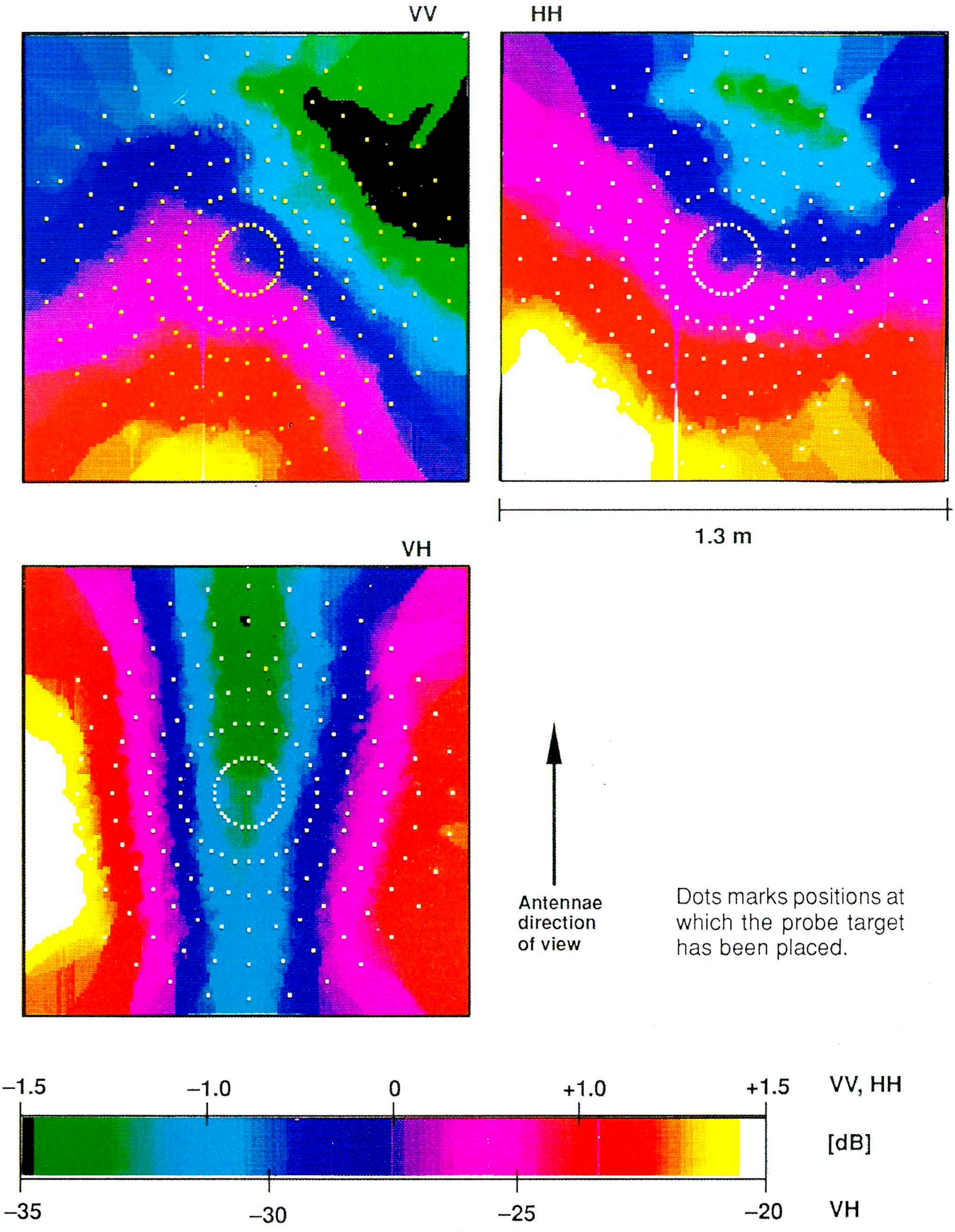


Fig. 6 - Measurement configuration for the investigation of the two-way antenna pattern variability in target area (target rotation).

4. Normalisation with respect to the copolar peak response at the calibration point.

No correction has been applied to the data to compensate for the range difference with respect to the calibration point.

The measured variability for the copolar channels is in the order of few dBs, as it was expected from the single antenna pattern measurements (Section 1), and it can be tolerated considering that the imaging process itself tends to spatially average the antenna response. More care must be used when the polarimetric aspects are of concern since only in one half of the area of interest can the polarisation purity be considered satisfactory (cross polarisation < -25 dB). However, once these variability patterns have been measured preserving the polarimetric content, different correction procedures can be implemented (Section 3) depending on the specific objectives of the experiments.



Antennae direction of view

Dots marks positions at which the probe target has been placed.

Fig. 7 - Spatial variability within the target area of the two-way antenna power pattern in HH, VV and HV polarisations. (Time domain response for 10 - 18 GHz frequency range).

2.2 Linear displacement

The linear displacement of the target presents more difficulties than the rotation considering the practical limitations of laboratory experiments.
The extension of the movement must be as large as possible in order to obtain a reasonable variation of the target aspect angle, but this necessarily implies the utilisation of those sectors of the antenna pattern where the characteristics are not optimum (low gain, high phase distortion, low polarisation purity).

In the linear case the investigation of the antenna pattern variability has been done by means of a single linear run of a metallic sphere (diameter 127 mm) over a range of 3.4 m in steps of 2 cm (Fig. 8). The measured data are shown in Fig. 9 in terms of time domain response of the probe target versus lateral displacement for VV and HV polarisation. In these images, the information which is used for the evaluation of the antenna pattern is the level of the peak value for each position (the brightest trace representing the

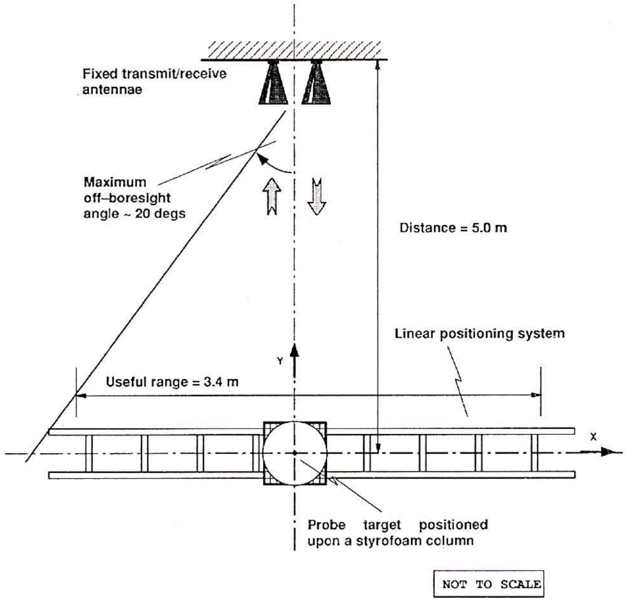


Fig. 8 - Measurement configuration for the investigation of the two-way antenna pattern variability (linear displacement).

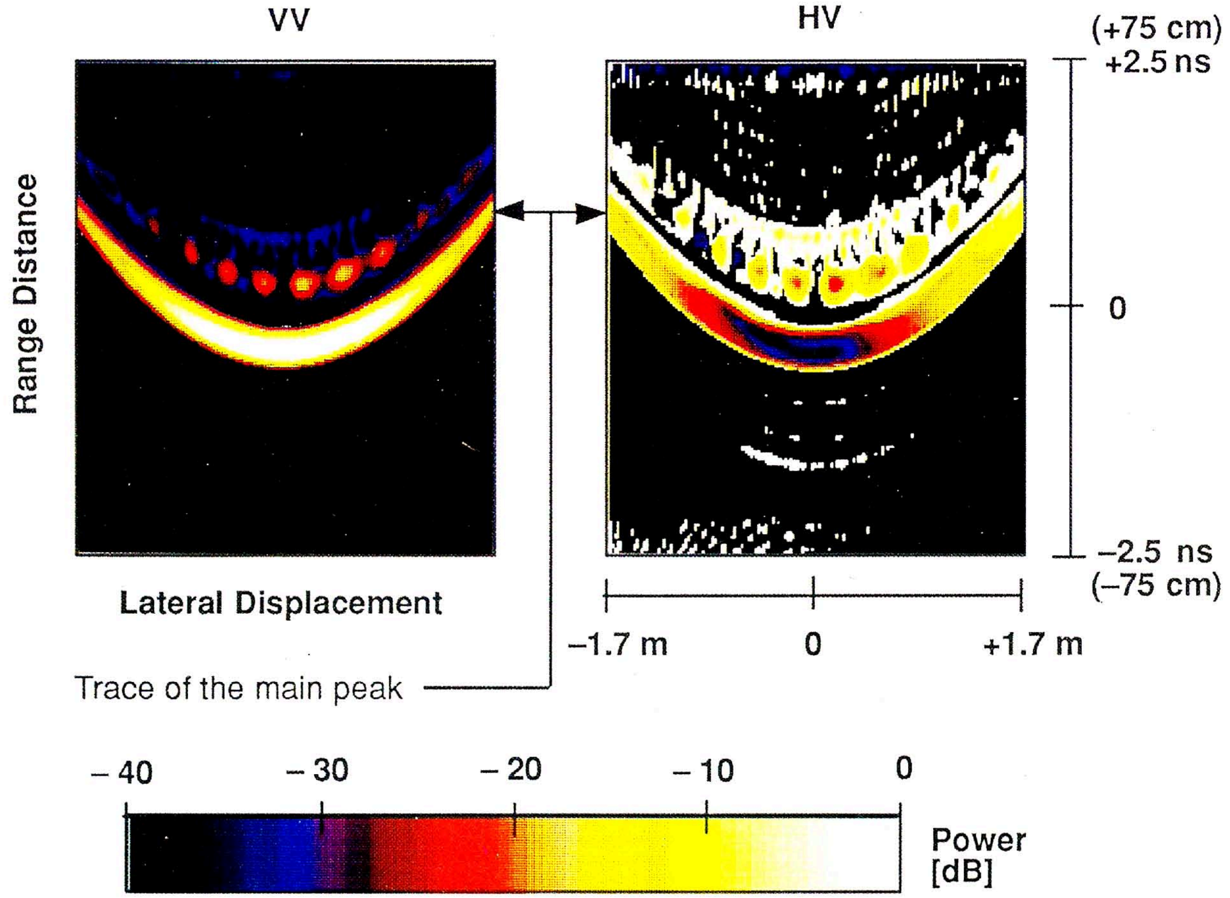


Fig. 9 - Time domain response of the probe target (metallic sphere) versus lateral displacement. VV (left) and HV (right) polarisations, 10 - 18 GHz frequency range. VV data are normalised with respect to the central position. HV data are normalised point-by-point with respect to VV data.

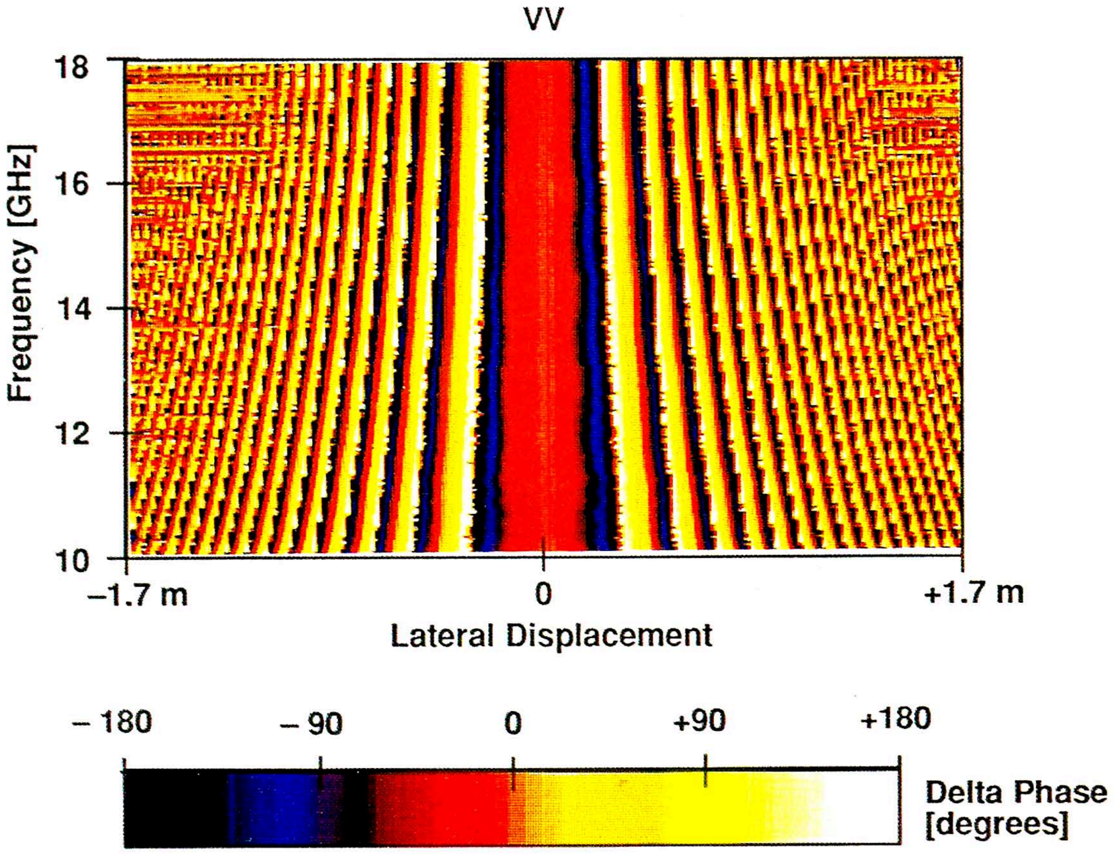


Fig. 10 - Phase pattern in the frequency domain versus lateral displacement. Data have been normalised with respect to the response of the probe target in the central position.

direct reflection of the sphere front edge). VV data have been normalised with respect to the central position which coincides with the calibration position. At the limits of the positioning range the response is reduced by about 20 dB. This is essentially due to the tapering of the antennae power pattern while the effect of range variation is relatively small (in the order of 0.5 dB).

HV data have been normalised point-by point with respect to the VV response and, because the sphere does not have any cross polarisation response, this represents directly the cross-polarisation purity of the antenna set (again the data which must be considered lie along the principal trace). It can be seen that near the limits of the linear range the cross-polarisation purity is very poor (< 5dB).

The measured phase variation with respect to the central position is shown in frequency domain for VV polarisation (Fig. 10). Here the key factor affecting the phase is the range distance while the phase pattern of the antennae introduces only an additional modulation. These two terms, if necessary, can be separated by using an accurate model of the geometrical configuration.

The above results clearly demonstrate the necessity of implementing correction procedures in order to utilise the available linear range especially if polarimetric information must be preserved. At the same time the regularity of the observed patterns gives confidence that simple analytical models can be constructed to interpolate in the entire area of interest the data obtained with a limited number of measurement runs.

3. CORRECTION PROCEDURES

The most general correction procedure must surely include an accurate absolute calibration, at least in one point of the region of interest.
In addition it should correct residual errors which may depend on position, frequency and polarisation. Assuming that a complete data set describing the antenna behaviour in the region of interest is available, different correction procedures can be applied.

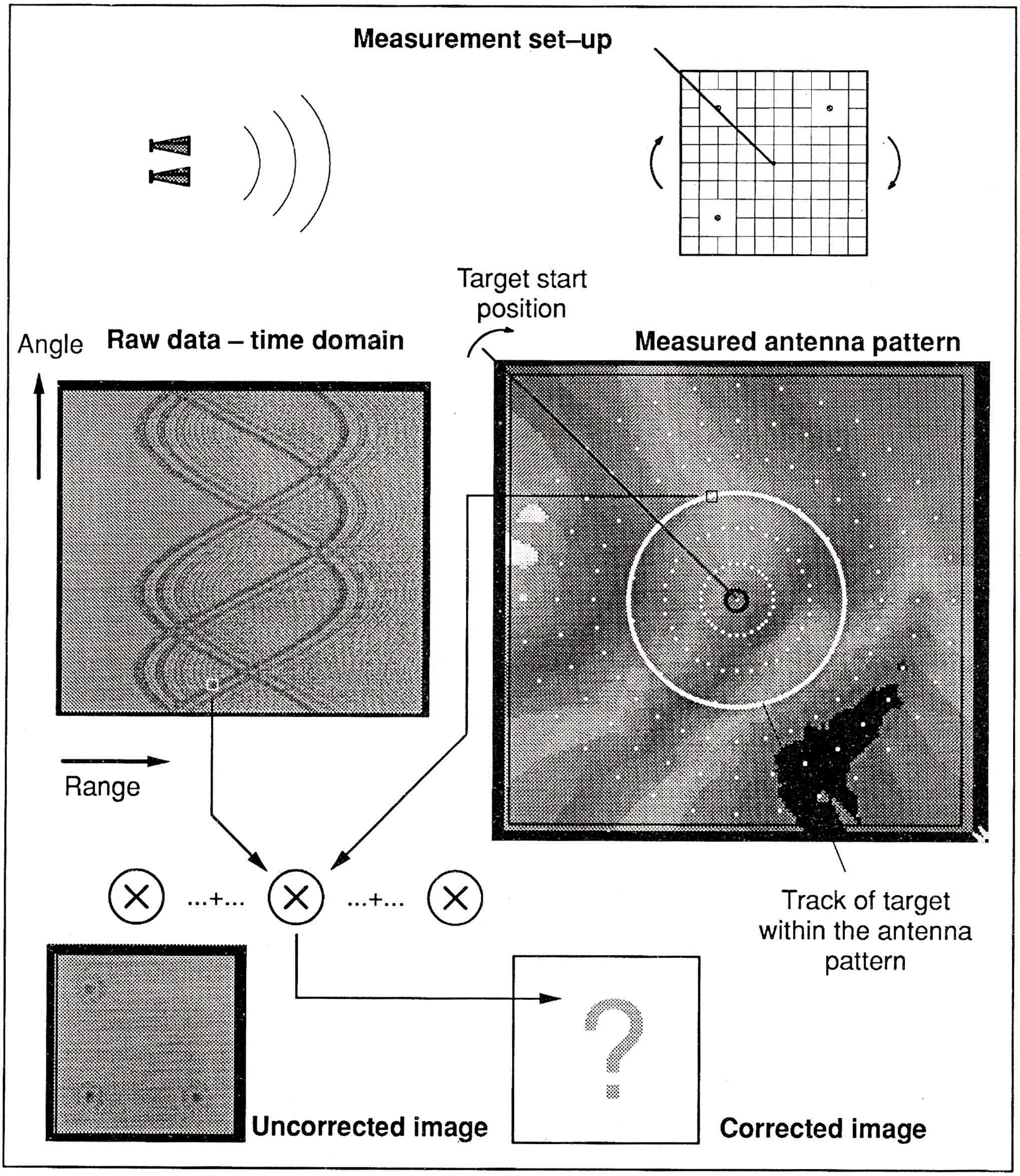


Fig. 11 - Schematic illustration of the general correction procedure for time domain imaging process.

Fig. 11 illustrates an approach which is appropriate for time domain processing (more information about the imaging method can be found in (Hohmann et al., 1991)). Each resolution cell in the final image is associated with a specific track in the raw time domain data (a sinusoid in Fig. 11) and with a specific track within the antenna pattern (a circle in Fig. 11). These tracks are uniquely determined by the geometry of the measurement and there is a point-by-point correspondence between them. Therefore, it is possible to multiply each term by the appropriate correction factor while the reconstruction algorithm adds up coherently the measured values along the track in the raw data domain.

The fact that the summation is performed coherently is essential for the quality of the correction. This is because each measured value in time domain is actually the summation of many terms coming from all the scatterers with identical time range and only the phase information permits the discrimination of the response of the selected resolution cell from the random contributions of the other cells.

3.1 Gain correction in time domain

A correction procedure to compensate for the antenna gain variation in case of linear displacement has been applied to a laboratory imaging experiment aimed at accurately reproducing the location of three vertical metallic cylinders (Hohmann et al., 1991). An antenna gain correction factor has been derived from the measured data of a sphere located at the centre of the imaged area (Section 2.2, Fig. 10) and applied to the raw data measured at each poisition used for the imaging measurements.

The original and the corrected images are compared in Fig. 12. The scale is linear in power. The position of the cylinders correspond to the three main peaks. An enlargement of the response for the top-right cylinder is shown in Fig. 13. The weak peaks which are present in the images are not related to antenna pattern effects and are discussed in (Hohmann et al., 1991). In spite of the fact that this correction is rather simple and straightforward, the impact on the image quality can be visually appreciated. It has been verified, by applying a standard method for image quality evaluation, that the resolution width in azimuth (x-direction in Figs. 12 and 13) is reduced by a factor 0.75 in the corrected image without a degradation of the peak response/background level ratio.

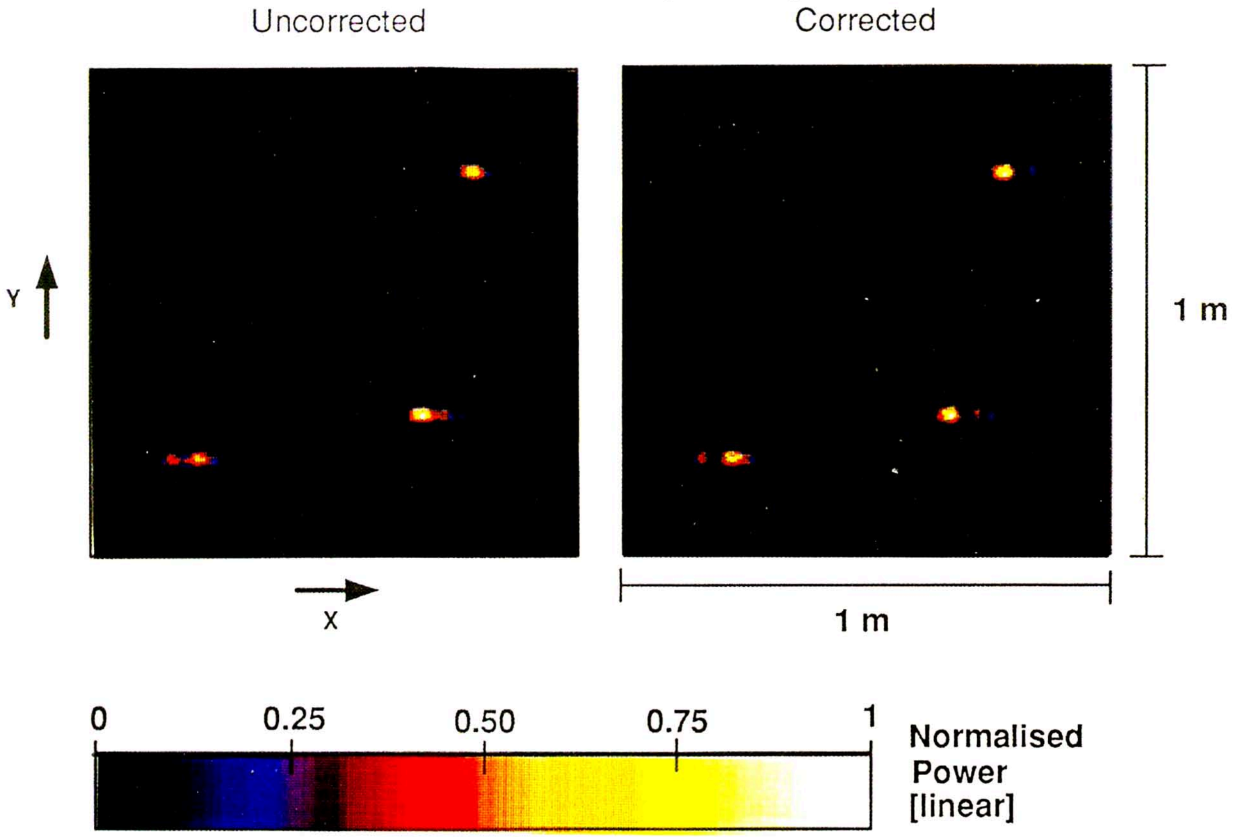


Fig. 12 - Two-dimensional images of three metallic cylinders with the axis perpendicular to the plane of the image. The colour scale is linear in power. On the left the original image and on the right the same after the introduction of an antenna gain correction factor. Displayed data are normalised with respect to the maximum value in each image.

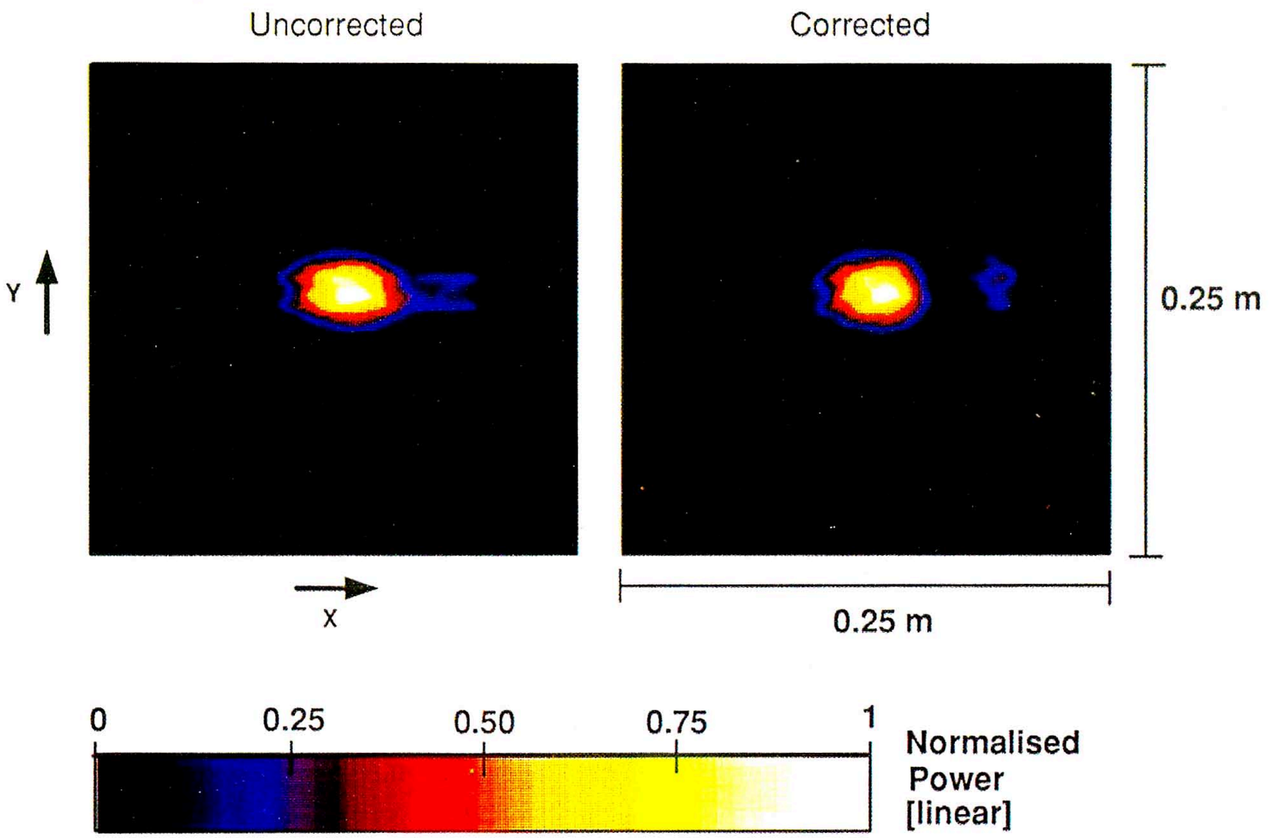


Fig. 13 - Enlargement of the response of the top-right cylinder in Fig. 12 for the uncorrected (left) and corrected (right) case. Displayed data are normalised with respect to the maximum value in each image.

CONCLUSION

The experimental investigation described in this paper has shown that the properties of the antenna pattern in laboratory measurements for application to microwave polarimetric imaging must be taken into account carefully. An accurate knowledge of the antenna characteristics versus target location, frequency and polarisation is necessary in order to quantify the errors and possibly correct the final image.

The investigation of these characteristics can be done using probe targets appropriate to the specific configuration of the experimental facility. Given the observed regularity of the measured antenna patterns, measured data for a set of well distributed probe positions can be interpolated in order to reduce the number of measurements.

The imaging approaches implying the rotation of the target are less sensitive to the antenna pattern effects than the approaches implying a linear displacement. In fact, in the first case, the area covered by the movement of the target can be limited to the sector of the antenna response where the characteristics are good and, in addition, the variations of the pattern tend to be averaged in the imaging process. Hence, in the case of target rotation, the impact on the final image in term of power response can be tolerated while correction procedures must be established when the polarimetric aspect of the final image is of primary concern. In the case of target linear displacement the variation in terms of power gain are also significant and must be corrected for.

It is possible to envisage different correction procedures which will depend strongly on the specific imaging approach (e.g. frequency or time domain processing). As an example, a correction for the antenna pattern gain tapering in the case of linear displacement has been applied in a time domain imaging process with encouraging results.

In the corrected image the resolution in azimuth is 25% better than in the original one.

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