Design and performance verification of a wideband scalable dual-polarized probe for spherical near-field antenna measurements

Pivnenko, Sergey; Kim, Oleksiy S.; Nielsen, Jeppe Majlund; Breinbjerg, Olav

Published in:
Proceedings of the 34th Annual Symposium of the Antenna Measurement Techniques Association

Publication date:
2012

Citation (APA):
Pivnenko, S., Kim, O. S., Nielsen, J. M., & Breinbjerg, O. (2012). Design and performance verification of a wideband scalable dual-polarized probe for spherical near-field antenna measurements. In *Proceedings of the 34th Annual Symposium of the Antenna Measurement Techniques Association*

DESIGN AND PERFORMANCE VERIFICATION OF A WIDEBAND SCALABLE DUAL-POLARIZED PROBE FOR SPHERICAL NEAR-FIELD ANTENNA MEASUREMENTS

S. Pivnenko, O. S. Kim, J. M. Nielsen, and O. Breinbjerg
Dept. of Electrical Engineering, Technical University of Denmark
Ørsteds Plads, 348, DK-2800, Kgs. Lyngby, Denmark
Email: sp@elektro.dtu.dk

L. Salghetti Drioli
ESA-ESTEC, Keplerlaan 1, 2200 AG Noordwijk, the Netherlands
Email: luca.salghetti.drioli@esa.int

ABSTRACT

A wideband scalable dual-polarized probe designed by the Electromagnetic Systems group at the Technical University of Denmark is presented. The design was scaled and two probes were manufactured for the frequency bands 1-3 GHz and 0.4-1.2 GHz. The results of the acceptance tests of the 0.4-1.2 GHz probe are briefly discussed. Since these probes represent so-called higher-order antennas, applicability of the recently developed higher-order probe correction technique [3] for these probes was investigated. Extensive tests were carried out for two representative antennas under test using the manufactured probes; the results of these tests are presented and discussed in details.

Keywords: Dual-Polarized Probe, Wideband Probe, Spherical Near-Field Measurements, Uncertainties

1. Introduction

A number of European Space Agency's (ESA) initiatives planned for the current decade require metrology level accuracy antenna measurements at frequencies extending from L-band to as low as 400 MHz. These include the BIOMASS radar, the Galileo navigation and search and rescue services, and the Meteosat data collection system. Within the project "Higher-Order Near-Field Probes" supported by ESA, a wideband scalable dual-polarized probe was designed by the Electromagnetic Systems group at the Technical University of Denmark (DTU). The design was subsequently scaled and two probes were manufactured for the frequency bands 1-3 GHz and 0.4-1.2 GHz. These probes have undergone extensive tests in order to verify the compliance of their characteristics to the requirements. Some first results of the verification tests for these probes were presented in [1] and [2]. Since these probes represent so-called higher-order antennas, when their radiation pattern is represented in terms of the spherical wave expansion, applicability of the recently developed higher-order probe correction technique [3] for these probes was also investigated. In addition to the standard phi-scanning scheme required for the technique [3], another, new scanning scheme called double phi-step theta-scanning proposed in [4] was also verified by measurements with the new probes at the DTU-ESA Spherical Near-Field Antenna Test Facility.

This paper briefly presents the details of the design of the scalable probe and its two implemented versions and then focuses on the results of their verification tests.

2. Probe Specifications

A set of requirements to the wideband near-field probe was specified [1] considering the geometry of the anechoic chamber at the DTU-ESA Spherical Near-Field Antenna Test Facility [5] (see Fig. 1). In particular, the probe pattern variation within $\theta < \pm 30^\circ$ covering the AUT minimum sphere shall not exceed 10 dB; the pattern level towards the chamber walls, that is $\theta \in \pm[50^\circ;76^\circ]$, shall not exceed -10 dB and the backward radiation in the angular region $\theta \in \pm[120^\circ;180^\circ]$ shall be less than -10 dB relative to the pattern peak.

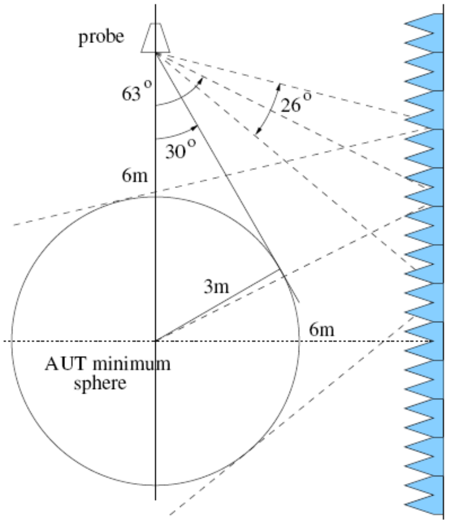

Figure 1 - Location of the AUT and probe with respect to a chamber wall.

The electrical specifications are summarized in Table 1.

Table 1. Specifications for a wideband scalable probe

	Characteristic	**Requirement**
1	Bandwidth	1:3
2	Radiation pattern:	
2.1	- variation within $\theta < \pm 30^\circ$	< 10 dB
2.2	- normalized level within $\theta \in \pm[50°;76°]$	<−10 dB
2.3	- front-to-back ratio within $\theta \in \pm[120°;180°]$	> 10 dB
3	Ports orthogonality (polarization axial ratio at $\theta = 0^\circ$)	> 35 dB
4	Port-to-port isolation	> 35 dB
5	Return loss	<−10 dB

The other considered requirements were the scalability, high mechanical and electrical stability, size and weight.

3. Wideband Scalable Probe Design

After preliminary selection of possible candidate antennas, an open-boundary quad-ridge horn was chosen and its electrical characteristics were optimized to meet all the requirements [1]. The final design represents a compromise between the increasing size and thus weight of the horn on one hand and acceptable performance at the lower frequencies on the other hand.

The designed open-boundary quad-ridged horn scaled for the frequency range 1-3 GHz was manufactured at the DTU mechanical workshop [1]. For this horn, no weight reduction technique was applied; the final weight of the horn is 3.5 kg.

However, the horn scaled to the frequency range 0.4-1.2 GHz would have the weight of about 50 kg, if it was made of solid aluminum. To lighten the antenna, but at the same time maintain its electrical and mechanical stability, it has been decided to adopt a hybrid manufacturing technology, where the major part of each ridge is fabricated of carbon-fiber reinforced polymer (CFRP), while the bottom excitation part is made of aluminum; subsequently the two parts are glued together [2]. To ensure a proper surface conductivity, the CFRP part of the ridges is then covered by a conductive paint and a thin protective layer of a transparent lacquer. The resulting weight of the manufactured hybrid Al-CFRP horn is 22.5 kg, which represent a reduction of weight by a factor of about 2.3 as compared to an entire aluminum antenna. Fig. 2 shows both manufactured 1-3 GHz and 0.4-1.2 GHz dual polarized probes.

4. Radiation Tests

The measured S-parameters of the manufactured 0.4-1.2 GHz probe are shown in Fig. 3. It is seen that the return loss does not exceed –12 dB in frequency band of about 0.3-1.8 GHz thus exceeding the requirement. The port-to-port isolation is generally below –40 dB, which is also well within the requirements.

Figure 2 - The manufactured 1-3 GHz and 0.4-1.2 GHz dual-polarized probes.

The radiation characteristics of both probe ports were also measured in the extended 0.3-1.8 GHz band at 30 frequency points. The radiation patterns at two selected frequencies, 0.4 GHz and 1.2 GHz, in the two main planes, are shown in Fig. 4.

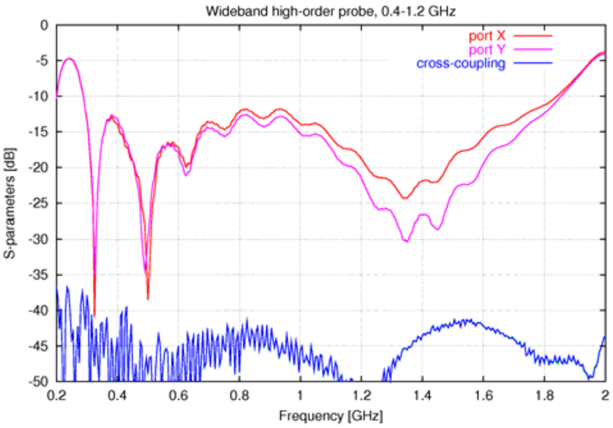

Figure 3 - The measured S-parameters of the 0.4-1.2 GHz probe.

It is seen from Fig. 4 that the radiation pattern is symmetric in both planes and the patterns for both ports coincide with each other.

At the lower part of the frequency band, 0.4-0.5 GHz, the pattern suppression around θ = 50° does not reach the desired −10 dB, but achieved level of <–7.5 dB was found acceptable.

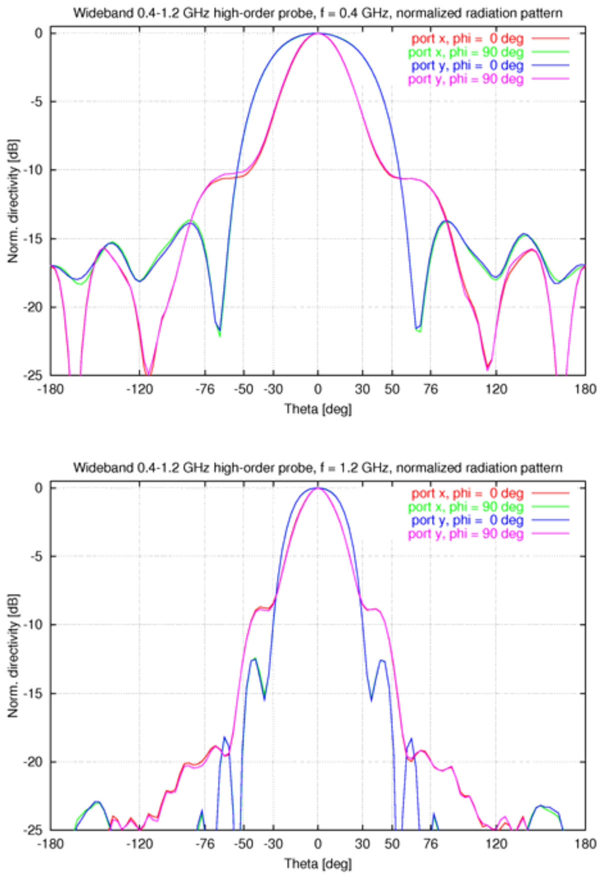

Figure 4 - The measured radiation pattern of both ports of the probe at 0.4 GHz (top) and 1.2 GHz (bottom).

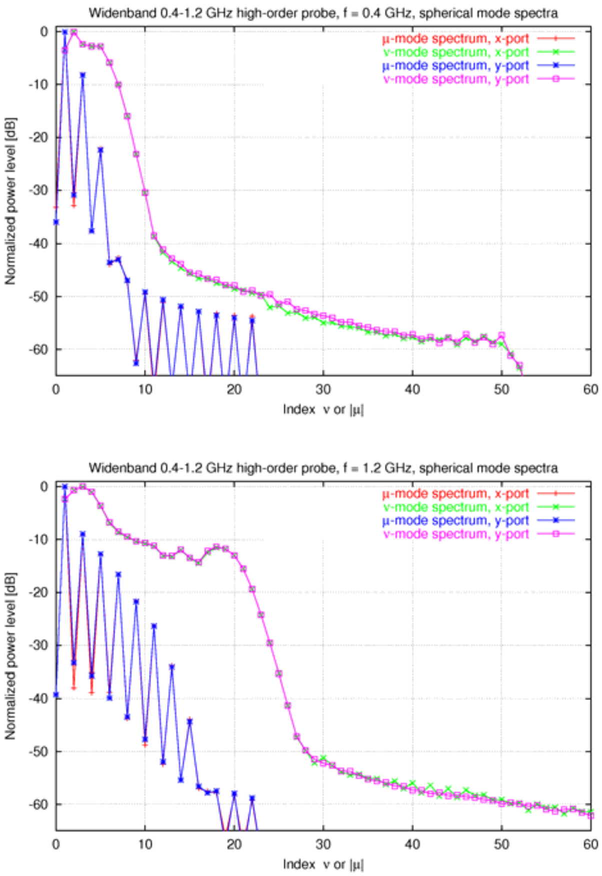

Figure 5 - The spectra of the spherical mode coefficients calculated from the measured radiation pattern at 0.4 GHz (top) and 1.2 GHz (bottom).

The spectra of the spherical mode coefficients of the 0.4-1.2 GHz probe were calculated from the measured pattern and these are shown in Fig. 5. It can be seen that even at the lowest frequency of 0.4 GHz, Fig. 7 (top), the μ-mode spectrum contains significant power in the modes with indices $\mu = \pm 3$ and also $\mu = \pm 5$. At the highest frequency of 1.2 GHz the mode spectra contain significant power in the modes with indices up to $\mu = \pm 13$. Therefore, these probes represent higher-order antennas and the corresponding higher-order probe correction must be used when processing of the near-field data received by these probes.

5. Verification of Antenna Measurement Procedure

The verification measurements were carried out for two representative antennas: an offset-mounted (AUT1) and a center-mounted (AUT2) standard gain horns, see Fig. 6. The former antenna represents a challenging test case, since, due to the offset, it has properties of an electrically large antenna for which the effect of appropriate probe correction is very important.

For these two antennas accurate reference patterns were obtained at 1.1 GHz and 1.2 GHz with the 1-3 GHz probe (verified earlier) and at 430 MHz and 431 MHz with the first-order probe specially designed for this purpose [6]. The reference results were obtained using the ϕ-scanning scheme.

The measurements of both AUTs were then repeated using the 0.4-1.2 GHz probe. For the AUT1 the measurement was carried out using the ϕ-scanning scheme, while for the AUT2 the measurement was carried out two times: using the ϕ-scanning scheme and using the double ϕ-step θ-scanning scheme. The measured near-field data were then processed using the higher-order probe correction software developed at DTU [3-4].

The obtained AUT1 and AUT2 far-field patterns from measurements with the 0.4-1.2 GHz probe were compared to the reference AUT1 and AUT2 far-field patterns. The plots with examples of pattern comparisons at 431 MHz and at 1.2 GHz are shown in Figs. 7-10. It is seen that both the co-polar and cross-polar patterns agree very well in all cases.

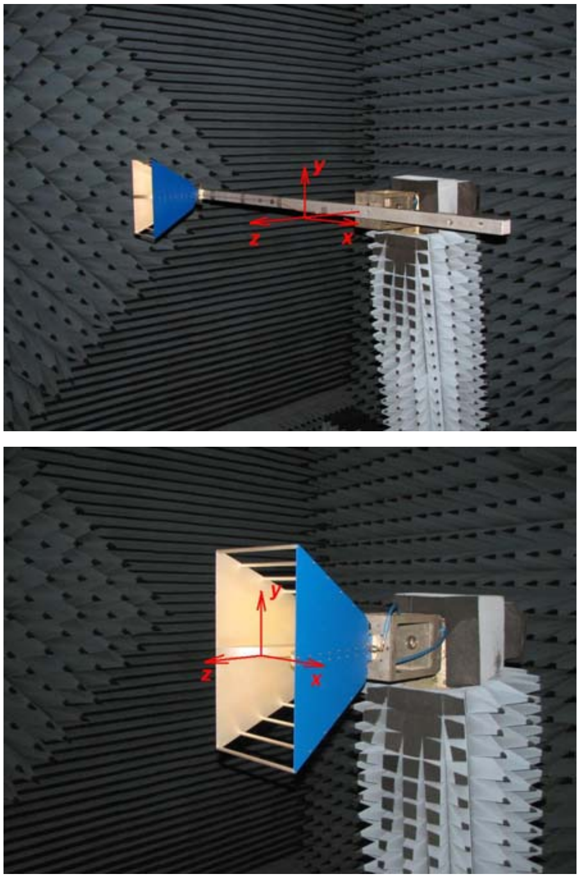

Figure 6 – Offset-mounted (top) and center-mounted (bottom) SH400 horn used as the test objects.

The statistics for the difference in dB between the co-polar patterns was calculated in the main beam region (3dB beamwidth) within θ = [0, 30°] at 430-431 MHz and within θ = [0, 20°] at 1.1-1.2 GHz. The standard deviation for the difference is shown in Table 2. It is seen that for the AUT1 the standard deviation is about 0.09 dB at 430-431 MHz, which might be caused by stronger influence of scattering and reflections for this challenging AUT at these low frequencies. At 1.1-1.2 GHz the standard deviation for the AUT1 decreases to some 0.06-0.07 dB.

Table 2. Standard deviation for the difference in dB between the co-polar patterns in the main beam region

Freq. MHz	AUT1 ϕ-scan	AUT2 ϕ-scan	AUT2 2ϕ θ-scan	AUT2 ϕ-scan vs. 2ϕ θ-scan
430	0.089	0.025	0.032	0.051
431	0.091	0.019	0.040	0.051
1100	0.069	0.042	0.039	0.008
1200	0.061	0.014	0.014	0.010

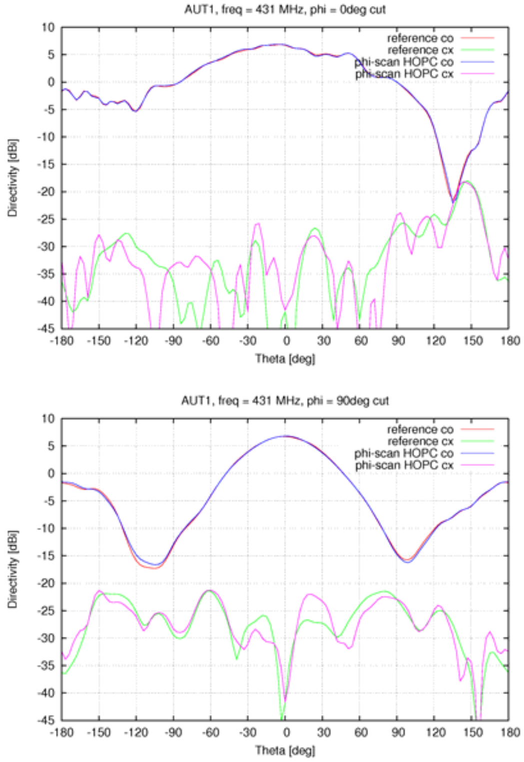

Figure 7 – Far-field pattern comparison for AUT1 at 431 MHz: ϕ-scan with 0.4-1.2 GHz probe.

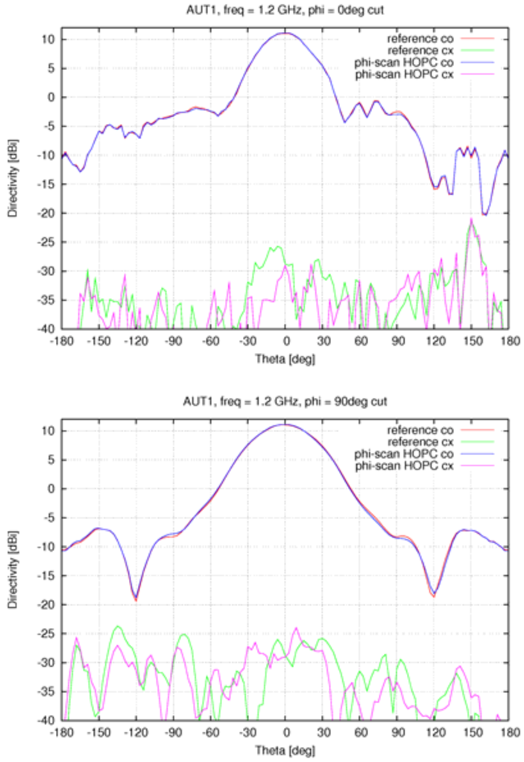

Figure 8 – Far-field pattern comparison for AUT1 at 1.2 GHz: ϕ-scan with 0.4-1.2 GHz probe.

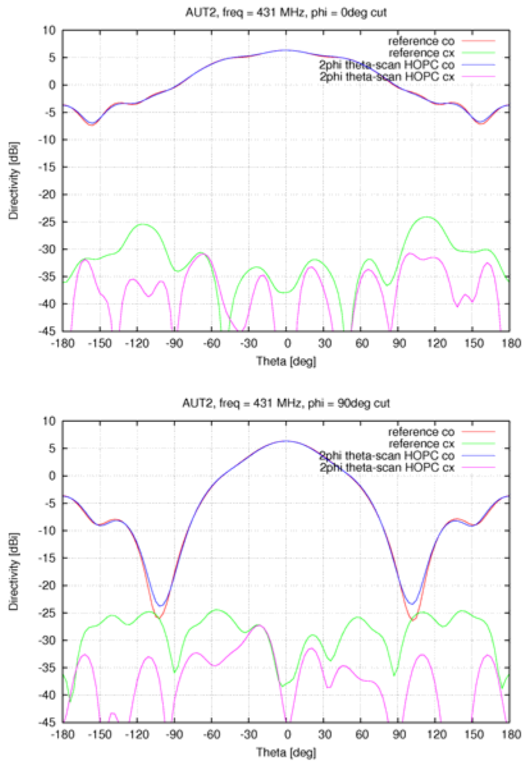

Figure 9 – Far-field pattern comparison for AUT2 at 431 MHz: 2ϕ θ-scan with 0.4-1.2 GHz probe.

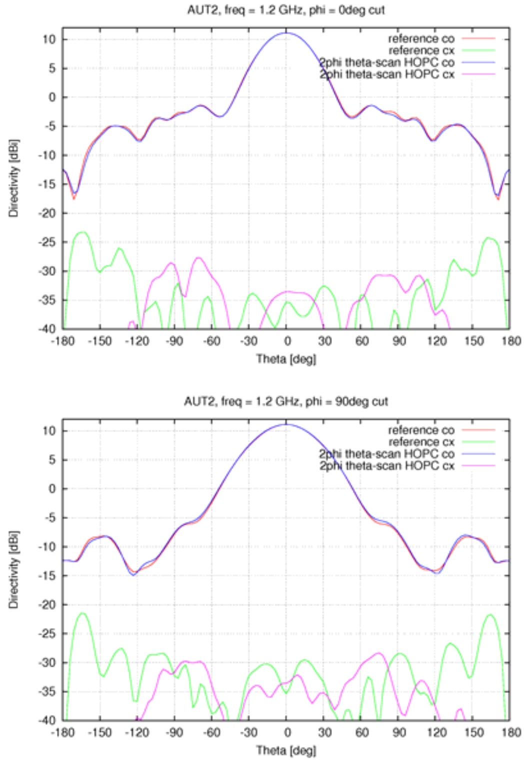

Figure 10 – Far-field pattern comparison for AUT2 at 1.2 GHz: 2ϕ θ-scan with 0.4-1.2 GHz probe.

Assuming that the uncertainty of each result in this comparison is about the same, each of these uncertainties can be estimated as being about √2 = 1.4 times smaller than the values in Table 2, thus in the worst case it does not exceed 0.06 dB (AUT1 at 430-431 MHz). For the AUT2 the standard deviation does not exceed 0.05 dB for all comparisons.

It was also observed that the cross-polar pattern obtained with the double ϕ-step θ-scanning scheme has noticeably lower level for the data at 430-431 MHz, see Fig. 9. For the data at 1.1-1.2 GHz, in Fig. 10, the cross-polar pattern obtained with the double ϕ-step θ-scanning scheme has similar level, but different shape, as compared to the reference data. At the moment, there is no clear explanation to this difference. More experience is necessary for this new scanning scheme applied to different types of antennas in order to understand its advantages and possible drawbacks.

6. Conclusions

A wideband scalable dual-polarized probe design for spherical near-field antenna measurements is presented. The design was scaled and two probes were manufactured for the frequency bands 1-3 GHz and 0.4-1.2 GHz. The weight of the 1-3 GHz probe is about 3.5 kg. For the 0.4-1.2 GHz probe, a hybrid Al-CFRP fabrication technology allowed reducing the weight of the horn to about 22 kg, which is a reduction by a factor of 2.3 as compared to the case, if the same probe was fabricated of solid aluminum.

The results of the acceptance tests for both probes show that all requirements are satisfied. The probes are higher-order antennas when described in terms of spherical wave expansion and must be used with the corresponding high-order probe correction technique.

Extensive measurements of two representative AUTs were carried out using the manufactured probes. The obtained near-field data were processed using the recently developed higher-order probe correction technique [3-4]. Comparison of the obtained far-field data for these antennas with the reference patterns have shown that the uncertainty in the main beam region does not exceed 0.05 dB above 1 GHz and about 0.06 dB at 430 MHz.

7. References

[1] O.S. Kim, S. Pivnenko, and O. Breinbjerg: Wideband scalable probe for spherical near-field antenna measurements. Proc. of the 5th European Conference on Antennas and Propagation, Rome, Italy, 2011.

[2] O.S. Kim, S. Pivnenko, and O. Breinbjerg: 0.4-1.2 GHz hybrid Al-CFRP open-boundary quad-ridge horn. Proc. 33rd ESA Antenna Workshop on Challenges for Space Antenna Systems, Noordwijk, the Netherlands, Oct. 18-21, 2011.

[3] T. Laitinen, S. Pivnenko, J.M. Nielsen, and O. Breinbjerg, "Theory and practice of the FFT/matrix inversion technique for probe-corrected spherical near-field antenna measurements with high-order probes", *IEEE Trans. Antennas Propagat.*, 2010, vol. 58, no. 8. pp. 2623-2631.

[4] T. A. Laitinen, "Double phi-step theta-scanning technique for spherical near-field antenna measurements," *IEEE Trans Antennas Propagat.*, vol. 56, no. 6, pp. 1633-1639, June 2008.

[5] DTU-ESA Spherical Near-Field Antenna Test Facility: http://www.dtu.dk/centre/ems/English/research/dtu_esa_facility.aspx

[6] O.S. Kim, S. Pivnenko, and O. Breinbjerg: "Superdirective Magnetic Dipole Array as a First-Order Probe for Spherical Near-Field Antenna Measurements", *IEEE Trans. Antennas Propagat.*, vol. 60, no. 10, 2012.

8. Acknowledgements

This work was supported by European Space Agency under the contract No. 22812/09/NL/JD/al "Higher-order near-field probes".