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0.4-1.2 GHz HYBRID AL-CFRP OPEN-BOUNDARY QUAD-RIDGE HORN

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ABSTRACT

We present a 0.4-1.2 GHz open-boundary quad-ridge horn to be used as a wide-band probe at the DTU-ESA Spherical Near-Field Antenna Test Facility at the Technical University of Denmark (DTU). Due to adopted hybrid Al-CFRP fabrication technology, the weight of the probe is reduced by a factor of 2.3 as compared to the case of the same probe fabricated of solid aluminum. Measured characteristics of the probe as well as its performance with respect to the higher-order probe correction technique are presented and discussed.

1. INTRODUCTION

A number of the European Space Agency's (ESA) satellite missions planned for the current decade require metrology level accuracy for antenna measurements at relatively low frequencies. These include the BIOMASS radar (P-band: 435 MHz), the Galileo navigation service (L-band: E5: 1191.8 MHz; E6: 1278.8 MHz; L1: 1575.4 MHz), the Galileo search and rescue services (UHF band: 406 MHz; L-band: 1544.1 MHz), and the Meteosat data collection system (L-band: 1685 MHz). In response to ESA's needs, the DTU Electromagnetic Systems group, which operates the ESA external measurement facility, the DTU-ESA Spherical Near-Field Antenna Test Facility, is currently extending its operational capability for high-accuracy spherical near-field measurements in the 400 MHz - 3 GHz frequency range in general, and in the 430-440 MHz range in particular. Details for the project's first phase, which included development of a higher-order probe correction technique, were reported in [1]. Results for the second phase, which is focused on the design of a wideband scalable dual-polarized probe for 1-3 GHz frequency range, were recently presented at EuCAP 2011 in Rome [2]. The designed probe – an open-boundary quad-ridged horn – demonstrates excellent electrical performance in accordance with specifications.

The next phase, results of which are presented here, concerns the fabrication and measurements of the probe scaled down to 0.4-1.2 GHz. This, theoretically trivial, task meets however a serious challenge in practice – the weight. While the 1-3 GHz probe made of solid

aluminum weighs only 3.5 kg, its lower frequency counterpart scaled up in size by a factor of 2.5, would run up to unmanageable 52 kg, if fabricated by the same technology.

This contribution first outlines the electrical properties of the designed 0.4-1.2 GHz open-boundary quad-ridge horn dictated by the geometry of the anechoic chamber and its quiet zone. Then, a hybrid Aluminum - Carbon Fibre Reinforced Polymer (Al-CFRP) fabrication technology adopted to reduce the weight of the probe is described. Finally, measurement results are presented and discussed.

2. PROBE SPECIFICATIONS

In the entire frequency range 0.4-1.2 GHz, the probe shall exhibit stable electrical characteristics, including the main beam and the sidelobe level envelope. These are essentially dictated by the geometry of the anechoic chamber at the DTU-ESA Spherical Near-Field Antenna Test Facility [3]. First of all, it is important to have illumination of an antenna under test (AUT) with small amplitude taper and avoiding the probe pattern nulls, thus the maximum field variation within $\theta < \pm 30^\circ$ is limited to 10 dB. The reflectivity of the anechoic chamber absorbers increases towards the lower frequencies and it is thus desirable that the probe pattern contributes to the reduction of the wall reflectivity. Therefore, high suppression of the specular reflections from the chamber walls is also of high priority. Consequently, the normalized radiation pattern at angles towards the walls, that is $\theta \in \pm[50^\circ; 76^\circ]$, shall not exceed -10 dB. These two requirements together imply that the directivity of the probe should be around 10 to 14 dBi in the entire frequency range of interest.

Furthermore, to minimize the influence of the AUT tower during probe pattern calibration and influence of the probe tower during measurements, the probe radiation in the angular region $\theta \in \pm[120^\circ; 180^\circ]$ shall be less than -10 dB. These, as well as other important electrical specifications, such as probe polarization characteristics, port-to-port isolation, and return loss, 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 $\theta \in \pm[50^\circ; 76^\circ]$	< -10 dB
2.3	- front-to-back ratio within $\theta \in \pm[120^\circ; 180^\circ]$	> 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

3. OPEN-BOUNDARY QUAD-RIDGE HORN

Among various antenna types potentially able to meet the specifications in Table 1, an open-boundary quad-ridge horn has been selected as the most promising candidate. The electrical characteristics of the candidate antenna were optimized to meet the requirements and, at the same time, keep the overall dimensions small and paying attention to scalability and low manufacturing complexity. 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. As described in details in [2], the design prototype consists of a cylindrical excitation cavity, extended ground plane, and four ridges (Fig. 1).

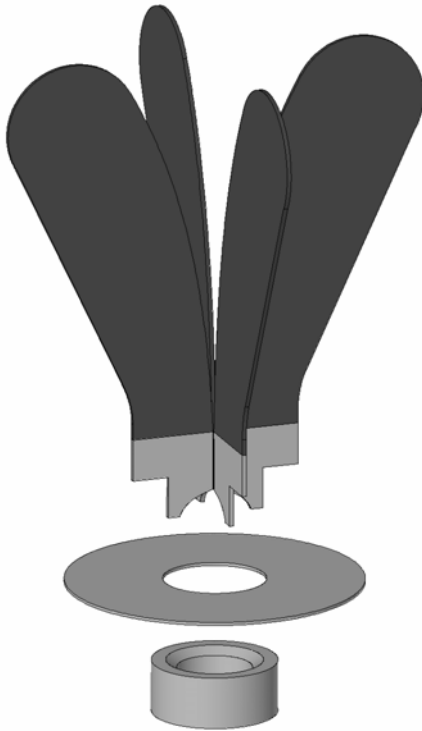


Figure 1. Parts of the designed open-boundary quad-ridge horn. Dark color marks parts made of CFRP.

Two orthogonal polarizations are excited by respective pins (one for each polarization) in the gaps between opposite ridges. The pins are made as extended central conductors of coaxial lines going through the ridges. A relatively high target directivity resulted after pattern optimization in the long and wide ridges, which would in turn result in an unacceptably heavy probe if it was made of solid aluminum. The estimated weight in this case was 52 kg.

To lighten the antenna, but at the same time maintain its electrical and mechanical stability, it has been decided to adopt a hybrid technology, where the heaviest, but less electrically critical parts of the antenna, are made of CFRP. As illustrated in Fig. 1 and Fig. 2, the major part of each ridge is fabricated of a CFRP sandwich, while the bottom excitation part is made of aluminum; subsequently the two parts are glued together. 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 excitation cavity, which requires high mechanical precision for achieving the desired electrical performance, as well as the ground plane, are made of aluminum. 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. 3 shows the assembled horn during radiation pattern measurements at the DTU-ESA Facility.



Figure 2. Horn ridge fabricated by the hybrid Al-CFRP technology.

4. MEASUREMENTS

Measurements have been performed at the DTU-ESA Spherical Near-Field Antenna Test Facility and the results are presented below.

4.1. S-parameters

The measured S-parameters of the manufactured quad-ridge horn are shown in Fig. 4. It is seen that the return loss do not exceed -12 dB not only in the target frequency band of 0.4-1.2 GHz, but also in a wider band of about 0.3-1.8 GHz. The port-to-port isolation generally stays below -40 dB, which is also well within the requirements.



Figure 3. Manufactured hybrid Al-CFRP quad-ridge horn during radiation measurements at the DTU-ESA Facility.

4.2. Radiation Pattern

The radiation characteristics of both probe ports were measured in the entire 0.3-1.8 GHz band at 30 frequency points. The radiation patterns at 3 selected frequencies, 0.4 GHz, 0.8 GHz, and 1.2 GHz, in the two main planes, are shown in Fig. 5.

It must be noted that an excellent agreement is observed between the measured and simulated patterns (the latter are not shown here). It is seen from Fig. 5 that the radiation pattern is symmetric in both planes and the patterns for both ports coincide with each other.

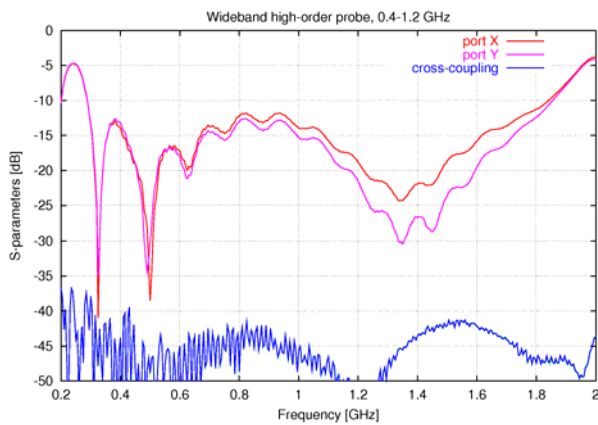


Figure 4. The measured S-parameters of the 0.4-1.2 GHz quad-ridge horn.

The measured pattern completely satisfies the requirements 2.1 and 2.3 indicated in Table 1. The requirement 2.2 is satisfied starting from 0.55 GHz and up, while between 0.4-0.5 GHz in a narrow angular range the pattern is slightly above the desired level. As it is seen in Fig. 5(a), at 0.4 GHz the normalized pattern level in the direction $\theta = 50^\circ$ is at the level of some -7 dB, but decreases fast and already at $\theta = 55^\circ$ it goes

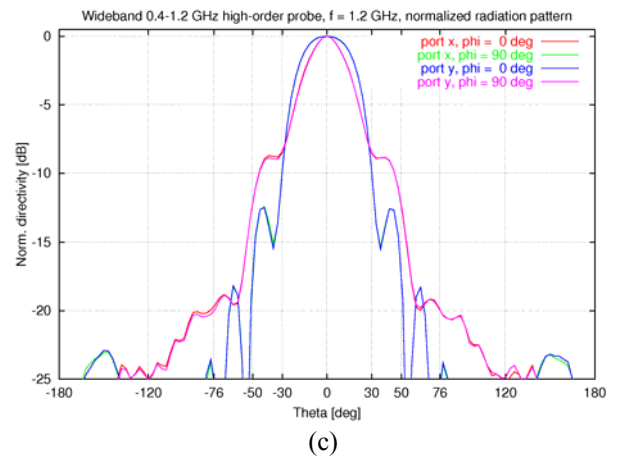
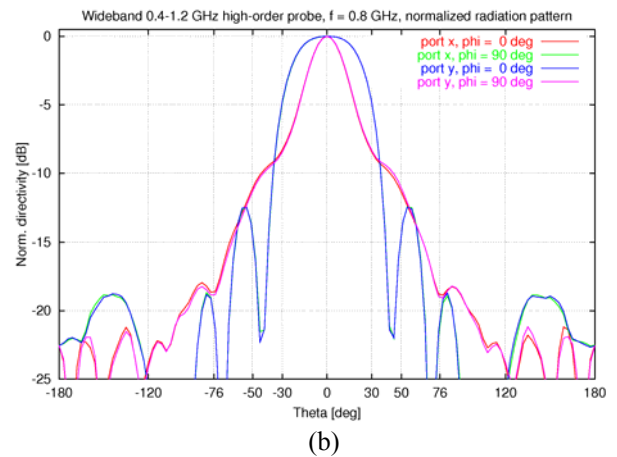
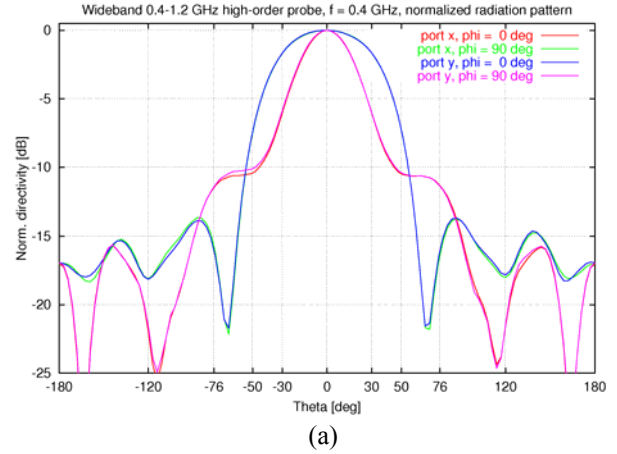


Figure 5. The measured radiation pattern of both ports of the quad-ridge horn at 0.4 GHz (a), 0.8 GHz (b), and 1.2 GHz (c).

below -10 dB. Similar behavior was predicted also from simulations.

The measured on-axis directivity versus frequency of the horn is shown in Fig. 6. It is seen that starting from about 0.7 GHz the peak directivity exhibits a slow growth typical for frequency-independent antennas. At the lower frequencies, some oscillations can be noted, which are mainly due to the presence of the enlarged ground plane employed to increase the front-to-back ratio.

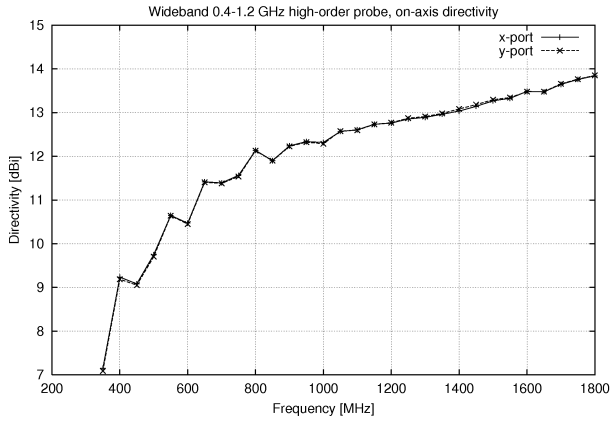


Figure 6. The measured on-axis directivity versus frequency of the quad-ridge horn.

The measured on-axis polarization axial ratio is above 45 dB and the two ports are indeed orthogonal with the polarization tilt angle for each port staying within $\pm 0.2^\circ$ over the frequency band. The amplitude-phase ratio (channel balance) between the two ports is excellent, with the amplitude difference not exceeding some 0.07 dB and the phase difference within 1° .

Finally, it can be said that the developed quad-ridge horn can also be used in a wider frequency band as compared to the design goal. Most of the characteristics remain stable up to 1.8 GHz, though the main beam of the pattern become narrower, while below 0.4 GHz, the main beam of the pattern becomes rather wide. In applications where such pattern is acceptable, this horn can be used in a relative frequency range of up to 1:6.

5. WIDEBAND PROBE FOR SPHERICAL NEAR-FIELD ANTENNA MEASUREMENTS

Traditional probe correction in spherical near-field antenna measurements requires a so-called first-order ($\mu = \pm 1$) probe, which means that the probe should possess only first-order azimuthal pattern variation [4]. The spectrum of the spherical mode coefficients of the quad-ridge horn was calculated from the measured pattern and this is presented in Fig. 7. It can be noted that even at the lowest frequency of 0.4 GHz, Fig. 7(a), the μ -mode spectrum contains significant power in the modes with indices $\mu = \pm 3$ and also $\mu = \pm 5$.

At the higher frequencies the μ -mode spectrum widens even further and thus the developed horn represents a high-order probe. In order to obtain correct results when it is used as probe in spherical near-field antenna measurements the corresponding high-order probe correction technique is required, for example the FFT/matrix inversion technique described in [1].

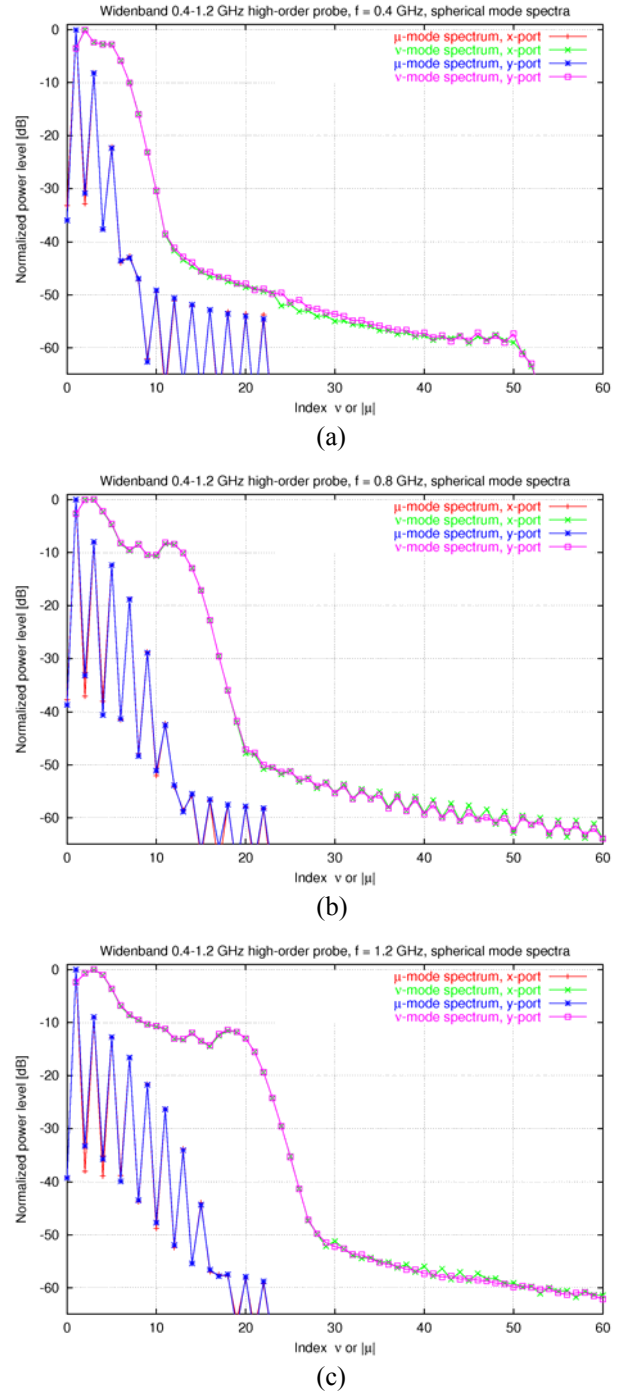


Figure 7. The spectra of the spherical mode coefficients calculated from the measured radiation pattern of the quad-ridge horn at 0.4 GHz (a), 0.8 GHz (b), and 1.2 GHz (c).

The experimental verification of the 0.4-1.2 GHz quad-ridge horn, when used as a probe in spherical near-field antenna measurements, is currently underway at the DTU-ESA Spherical Near-Field Antenna Test Facility. The verification of the probe correction technique itself was carried out earlier [1], and the planned measurements are aimed at gaining experience when measuring at the lower frequency limit of the anechoic chamber, where reflections become a major part of the uncertainty budget.

6. CONCLUSIONS

A 0.4-1.2 GHz open-boundary quad-ridge horn to be used as a wide-band probe in spherical near-field antenna measurements is presented. As a result of the adopted hybrid Al-CFRP fabrication technology, the weight of the horn is about 22 kg, which is a reduction by a factor of 2.3 as compared to the case of the same probe fabricated of solid aluminum. Measured characteristics of the horn show that all requirements are clearly satisfied, with little compromise at the lower frequencies on relative pattern level in a narrow angular region. The horn represents a higher-order antenna when described in terms of spherical wave expansion and it must be used with the corresponding high-order probe correction technique.

ACKNOWLEDGEMENT

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