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Superdirective narrowband first-order probe versus wideband higher-order probe for spherical near-field antenna measurements at P-band

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SUPERDIRECTIVE NARROWBAND FIRST-ORDER PROBE VERSUS WIDEBAND HIGHER-ORDER PROBE FOR SPHERICAL NEAR-FIELD ANTENNA MEASUREMENTS AT P-BAND

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ABSTRACT

A comparative study of the wideband 400-1200 MHz higher-order probe and the narrowband 431 MHz first-order probe, in terms of their advantages and disadvantages for spherical near-field antenna measurements at P-band, is presented. The comparison is based on the experimental data and focused on pattern shape and other electrical characteristics, work efforts related to physical handling, probe calibrations, and post processing.

1. INTRODUCTION

For several on-going and future missions of the European Space Agency, accurate antenna measurements at frequencies extending from L-band to as low as 400 MHz are required. These include the BIOMASS radar, the Galileo navigation and search and rescue services, and the Meteosat data collection system. As the wavelength increases at these frequencies, several challenges need to be addressed, for example, probes become physically large and heavy and reflectivity level in the anechoic chamber increases.

As a combined solution to the above challenges, a dual-polarized wideband 400-1200 MHz probe for spherical near-field antenna measurements has recently been developed [1]. Its pattern has been optimized in the whole operation band to ensure suppression of the wall reflections by at least 10 dB and thus reducing the effect of the increased reflectivity. A composite design of the probe employing carbon fibre reinforced polymer has been implemented thus reducing its weight to manageable 22 kg, as compared to estimated 50 kg, if completely made of aluminum. The probe has the dimensions L x W x H = 1150 x 1000 x 1000 mm^3. Since the probe is wideband, its spherical mode spectrum contains higher order modes, thus requiring a higher-order probe pattern correction [2].

On the other hand, a light-weight, superdirective, but narrowband, first-order probe has recently been proposed [3]. This first-order probe represents a superdirective magnetic dipole array on a circular ground plane [3]. It has a narrow bandwidth, about 1 MHz at 431 MHz central frequency, but its weight is only about 2 kg, determined by the ground plane, since the magnetic dipoles are etched on a standard 1.5 mm thick dielectric substrate Rogers RO4003C. The dipole array is only 185 mm long and it is mounted on a circular ground plane of 720 mm in diameter.

In this paper, we present a comparative study of the wideband 400-1200 MHz higher-order probe and the narrowband 431 MHz first-order probe in terms of their advantages and disadvantages for spherical near-field antenna measurements at P-band. The comparison is based on the experimental data and focused on pattern shape and other electrical characteristics presented in Sections 2 and 3, respectively, work efforts related to probe calibrations, post processing, and physical handling discussed in Sections 4-6, with the overall conclusions shown in Section 7.

2. WIDEBAND 400-1200MHZ PROBE

The details of the generic scalable design of the dual-polarized wideband quad-ridge horn have been reported in [4] and its implemented version for the 400-1200 MHz band has been described in [1]. It is emphasized that the design has been focused on achieving specific pattern shape in a wide bandwidth and on scalability. The horn mounted to the probe tower at the DTU-ESA Facility is shown in Fig. 1.

Figure 1. The 400-1200 MHz horn mounted to the probe tower at the DTU-ESA Facility. The ground plane diameter is 700 mm and the length of the probe is 1150 mm

Focusing on the frequencies around 400 MHz, its main characteristics are as follows: return loss is better than 12 dB, peak directivity is around 9 dBi, cross-polarization and cross-coupling is below −45 dB, suppression of the wall specular reflections in the angular range θ = [50, 76]° is more than 7.5 dB, and radiation efficiency is larger than 90 %. The co-polar radiation pattern of the 400-1200 MHz horn for both ports at 400 MHz is shown in Fig. 2.

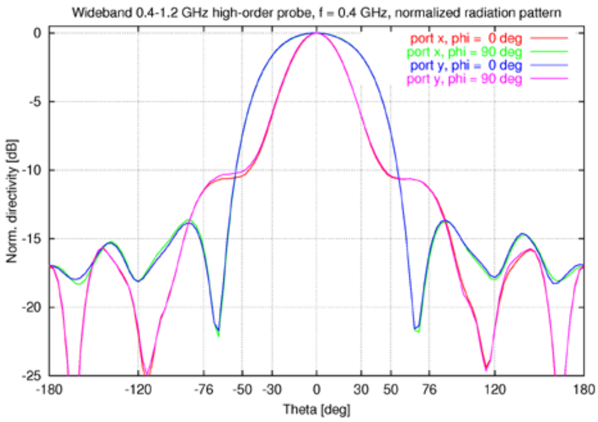

Figure 2. The measured co-polar radiation pattern of both ports of the quad-ridge horn at 400 MHz

Since this horn is used as a probe in spherical near-field antenna measurements, it spherical mode spectrum for the azimuthal μ-index has high importance; this is presented in Fig. 3 together with the spectrum for the polar ν-index. It is seen from Fig. 3 that in addition to the strongest excited modes with indices μ = ±1, the spectrum contains significant power in the modes with indices μ = ±3 and also μ = ±5. Also the power in the modes with indices μ = 0, ±2, and ±4 are non-negligible in some cases.

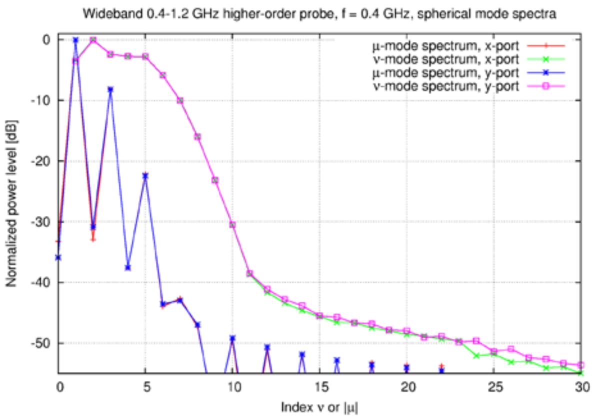

Figure 3. The spectra of the spherical mode coefficients calculated from the measured radiation pattern of the quad-ridge horn at 400 MHz

Thus, this probe is a so-called higher-order probe and its application with the spherical near-field antenna measurement technique requires corresponding higher-order probe pattern correction, for example, the one presented in [2].

3. SUPERDIRECTIVE FIRST-ORDER PROBE

The details of the theory as well as the results of simulations and measurements on the implemented version of the superdirective two-element array of magnetic dipole elements are presented in [3]. The manufactured two-element array on a circular ground plane is shown in Fig. 4.

Figure 4. The 431 MHz superdirective two-element array of magnetic dipoles on a circular ground plane. The ground plane diameter is 720 mm and the length of the array is 185mm

Summarizing its characteristics, the return loss is better than 30 dB at the resonance and the bandwidth at −10 dB level is about 1 MHz, peak directivity is around 9 dBi, cross-polarization is below −45 dB, suppression of the wall specular reflections in the angular range θ = [50, 76]° is more than 6 dB, and radiation efficiency is around 60 %. The measured co-polar radiation pattern of the two-element array at 431 MHz is shown in Fig. 5.

This antenna was designed to satisfy the μ = ±1 requirement for the probes in spherical near-field antenna measurements as explained in [3]. The spherical mode spectra for the azimuthal μ-index and for the polar ν-index calculated from the measured full-sphere data are presented in Fig. 6.

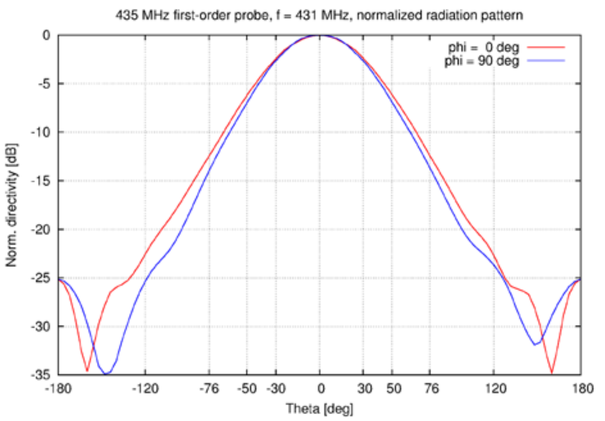

Figure 5. The measured co-polar radiation pattern of the superdirective two-element array at 431 MHz

It is seen from Fig. 6 that power in the modes with indices $\mu \neq \pm 1$ is about 40 dB down as compared to the $\mu = \pm 1$ modes, which agrees very well with the simulations and considered to be acceptably low.

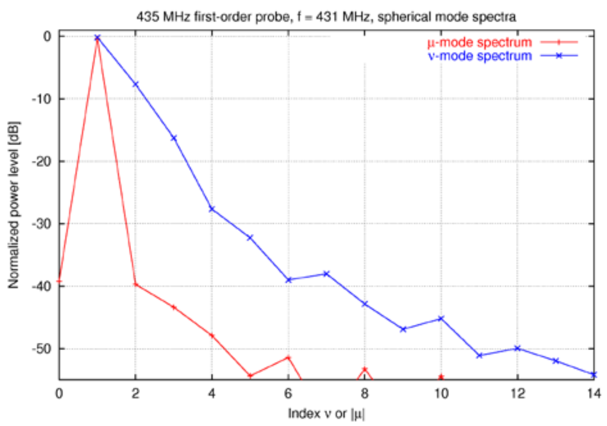

Figure 6. The spectra of the spherical mode coefficients calculated from the measured radiation pattern of the superdirective two-element array at 431 MHz

4. DIFFERENCE IN CALIBRATION

A standard calibration of a first-order probe for spherical near-field antenna measurements consists of two parts: measurement of the co-polar E-plane and co-polar H-plane patterns and on-axis polarization calibration [5]. In this way, all the calibration results are achieved with the highest accuracy. Even though this calibration procedure consists in total of 5 measurements (2 pattern measurements with orthogonal orientations of the auxiliary probe and 3-antenna polarization measurement), its implementation at the DTU-ESA Facility [6] takes about 2 hours. It is noted that the channel balance of the (dual-polarized) probe is determined from one of the polarization measurements, without need for an extra measurement.

A calibration of a higher-order probe consists of three parts: polarization calibration of an auxiliary probe, full-sphere pattern measurement of both ports of the higher-order probe using the calibrated auxiliary probe, and a channel balance measurement of the higher-order probe [7]. It consists in total of 6 measurements, and two of these, the full-sphere measurements, take about 1 hour each, thus the overall time for the higher-order probe calibration is about 4 hours.

5. DIFFERENCE IN APPLICATION

The designed first-order probe is single-polarized, thus measurement of an Antenna Under Test (AUT) must be carried out twice, with orthogonal orientations of the probe, thus twice increasing the AUT measurement time as compared to the measurement with a dual-polarized higher-order probe.

The narrow bandwidth of the designed first-order probe may represent a problem, if the AUT measurements are desired in a wider bandwidth. To this end, the development of an improved design of the first-order probe with wider bandwidth is on-going. Preliminary investigations show that it is possible to achieve about 15 MHz bandwidth at 435 MHz.

The post-processing of the AUT data measured with the first-order and the higher-order probes does not have much difference, but it must be emphasized that higher-order probe correction is necessary for the 400-1200 MHz horn through the whole operation band. Since the implemented higher-order probe correction has higher computation complexity as compared to the first-order probe correction, the processing time is longer for the former [7]. However, even for a physically large AUT, e.g. 3 m in diameter, at 400 MHz, it takes only few seconds to obtain the result, since the AUT electrical size, 4 wavelengths, is relatively small and the maximum polar index of the calculated spherical modes does not exceed N = 23 in this particular example.

6. DISCUSSION

Both probes have comparable electrical characteristics with some difference in suppression of the specular reflections (7.5 dB vs. 6 dB) and radiation efficiency (90 % vs. 60 %).

With respect to physical handling, the 22 kg weight of the 400-1200 MHz horn clearly represents a disadvantage, as compared to the 2 kg weight of the superdirective first-order probe. While the latter can easily be handled by one person, the former requires several persons for handling and a crane for mounting. Use of the heavier probe also requires much stronger support structure on the probe tower able to keep an accurate alignment under this load.

The work efforts for the calibration of both probes are rather comparable, though calibration of the higher-order probe takes noticeably longer time.

The narrow bandwidth and only single polarization of the designed superdirective first-order probe represent disadvantages, since it may result in significant increase of the AUT measurement time in a wider bandwidth, where, e.g. several narrowband probes have to be used. Development of the improved design of the first-order probe with bandwidth up to 15 MHz is on-going, while development of a dual-polarized version is planned.

7. CONCLUSIONS

Comparison of different application aspects of the wideband 400-1200 MHz higher-order probe and the narrowband 431 MHz first-order probe has shown that both probes have their advantages and disadvantages.

Handling much heavier wideband probe clearly represents its disadvantage, while on a good side, its wide bandwidth allows it to be calibrated once and then used at all desired frequencies, which reduces its handling time.

Narrow bandwidth of the first-order probe is a disadvantage when measurements are required in a wider bandwidth. However, several probes can be manufactured for the desired frequencies and their calibration carried out together, while their interchange does not represent any problem due to light weight.

Since for the projects related to characterization of the space antennas and payloads measurement time often represents main limiting factor, the narrow bandwidth and only single polarization of the designed first-order probe represent serious disadvantages. A wideband probe is the preferred choice in such cases.

On the other hand, in the development projects with more relaxed schedule, having lightweight probes, even though narrowband, may be considered as an advantage taking into account difficulties of handling a larger and heavier probe.

Development of more wideband and still lightweight first-order probe with bandwidth up to 15 MHz is currently on-going at DTU, while development of a dual-polarized version is planned. With such probes available, these will clearly be preferred in most of the situations.

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