

Recent Advances in Antenna Measurement Techniques at the DTU-ESA Spherical Near-Field Antenna Test Facility

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Abstract

This paper reports recent antenna measurement projects and research at the DTU-ESA Spherical Near-Field Antenna Test Facility at the Technical University of Denmark. High-accuracy measurement projects for the SMOS, SENTINEL-1, and BIOMASS missions of the European Space Agency were driven by uncertainty requirements of a few hundredths of dB for the directivity and correspondingly strong requirements for gain and/or phase. Research and development of 1:3 bandwidth range probes, and the near-field to far-field transformation algorithm accounting for the higher-order azimuthal modes in the spherical wave expansion of such probes, are also reported. Also, a metamaterial-inspired super-directive first-order probe enabling small-sized probes at low frequencies, such as P-band, is reviewed.

1. Introduction

Spherical near-field measurements in radio anechoic chambers constitute the most accurate experimental technique for antenna radiation pattern characterization. Due to the shielding and absorbers of the radio anechoic chamber the interference from extraneous and scattered fields is suppressed, the closed spherical scanning surface captures the radiation in all directions from the antenna under test (AUT), and the truncated spherical wave expansion (SWE) of the radiated field serves as a filter to reduce unwanted noise and signals [1].

The DTU-ESA Spherical Near-Field Antenna Test Facility [2] is operated by the Technical University of Denmark (DTU) as an external reference laboratory for the European Space Agency (ESA). It is also in charge of antenna test range validation with the DTU-ESA 12GHz Validation Standard antenna [3] and the host of the Advanced Spherical Near-Field Antenna Measurement Techniques Ph.D. course of the European School of Antennas [4]. High-accuracy antenna calibrations and measurements are conducted for ESA, for Danish and European academia and industry, and for DTU's research and education. The anechoic chamber measures 15m x 12m x 12m between absorbers and is equipped with a roll-over-azimuth antenna positioner and a static range probe tower at 6m distance. The RF system comprises a MI-3103 signal source and a MI-1797 receiver which, together with the data acquisition system, are controlled from a MI-3000 workstation. The near-field to far-field transformation and general data processing is based on software developed by DTU and TICRA.

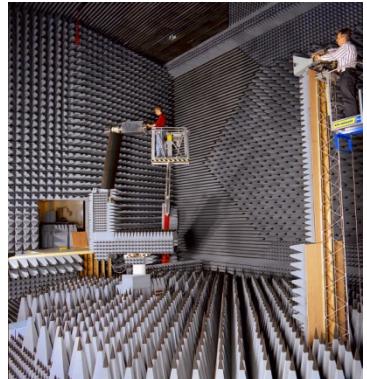


Figure 1: DTU-ESA Spherical Near-Field Antenna Test Facility.

Here we present recent progress in theory and practice of spherical near-field antenna measurements at the DTU-ESA Facility to form an overview of several previously reported measurement and research projects [5-12,14,16-17].

2. High-Accuracy Antenna Measurements for ESA Satellite Missions

Several satellite missions of the European Space Agency, in particular those of the Earth Observation Programme, comprise radar or radiometer systems with science data accuracy requirements that lead to very stringent requirements

for the radiation pattern accuracy of the on-ground antenna testing. The DTU-ESA Facility has recently been involved in the on-ground calibration of the flight-hardware antenna system for the SMOS mission, in the calibration of the planar near-field probe for on-ground characterization of the flight-hardware antenna for the SENTINEL-1 mission, and the phase-A antenna testing methodology development of the BIOMASS mission; the individual antenna systems and the accuracy requirements are summarized in Table 1.

Table 1: ESA satellite missions requiring high-accuracy antenna measurements

Mission	Antenna system	Accuracy requirements
SMOS	69 L-band dual-port cavity-backed patch antennas with integrated receivers; antennas are positioned in an 8m diameter Y-shaped support structure.	0.05dB magnitude and 0.33deg. phase (1σ) for top 3dB of radiation pattern (70deg. x 70deg.)
SENTINEL-1	C-band open-ended rectangular waveguide probe with integrated absorber plate.	0.03dB directivity and 0.1dB gain (3σ) for top 3dB of radiation pattern (70deg. x 120deg.)
BIOMASS	P-band 17m offset reflector with 2x2 element patch array feed.	0.15dB gain (1σ).

For the SMOS measurement the main challenges were to suppress the multiple reflections, between the antenna under test and the range probe, and taking into account the interaction of the measured antenna with the neighbouring antennas and support structure; these challenges necessitated an extensive series of investigatory measurements and development of several software and hardware measures [5-6]. For the SENTINEL-1 measurement the influence of multiple reflections and receiver non-linearity on the radiation pattern were suppressed through averaging of 4 separate measurements with different measurements distances and power levels, while gain accuracy was ensured through the use of both a near-field and a finite-distance techniques [7-8]. For BIOMASS the large deployable reflector prevents a direct measurement of the entire antenna system and a two-step approach was thus developed with high-accuracy measurement of the primary pattern of the feed antenna, including support and satellite structure, and subsequent calculation of the secondary radiation pattern of the reflector using a high-accuracy simulation tool [9].

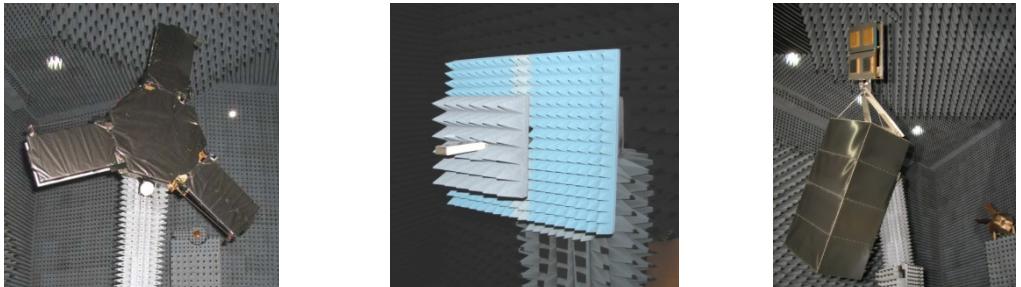


Figure 2: High-accuracy measurements of antenna systems for ESA's SMOS, SENTINEL-1 and BIOMASS missions at the DTU-ESA Facility; the accuracy requirements are listed in Table 1.

3. Scalable 1:3 Bandwidth Dual-Port Range Probes

The range probes used in spherical near-field antenna measurements are usually conical horns excited through a circular waveguide by the fundamental TE_{11} -mode; these are so-called first-order ($\mu = \pm 1$) probes possessing only the first-order azimuthal mode in the spherical wave expansion and thus facilitating the use of the traditional probe correction in the near-field to far-field transformation [1]. Alternatively, rectangular waveguide probes are used since these are approximate first-order probes. In either case, their limited operation bandwidth necessitates the use of several separate probes during measurement of a broadband AUT.

In [10-12] we reported the design, development, and testing of a scalable 1:3 frequency bandwidth dual-port quad-ridge probe; see Figure 3. Its pattern has been optimized in the whole operational frequency band to ensure suppression of the wall reflections by at least 10 dB; thus reducing the effect of the increased reflectivity at low frequencies. First, the design was validated by measurements at the frequency range 1-3GHz [10]. This prototype was made of



Figure 3: 1-3GHz and 0.4-1.2GHz dual-port quad-ridge probes.

aluminum with a weight of 3.5kg. Subsequently, the probe was scaled to the frequency range 0.4-1.2GHz [11]. A composite design employing carbon fiber reinforced polymer (CFRP) was implemented to reduce the weight to manageable 22kg, as compared to 50kg if made of aluminum. To ensure a proper surface conductivity, the CFRP part of the ridges was covered by a conductive paint and a thin protective layer of a transparent lacquer. Since the probes are wideband, their spherical mode spectrum contain higher order azimuthal modes, thus requiring a higher-order probe pattern correction technique [12] for the near-field to far-field transformation; see Section 4.

4. Higher-Order Probe Correction in Near-Field to Far-Field Transformation

Higher-order probes possess higher-order ($\mu \neq \pm 1$) azimuthal modes in the spherical wave expansion of the radiated field; these exclude the traditional probe correction in the near-field to far-field transformation [1]. In recent years, there has been a significant interest in developing probe correction techniques for such higher-order probes; see [13-15] and references therein. The FFT/matrix inversion technique [14] developed at the DTU-ESA Facility is based on the Fourier transform of the probe signal measured during phi-scanning of the AUT whereby the transmission formula takes the form of a set of over-determined systems of linear equations which are solved numerically in a least square sense. This technique is applicable for general dual-port higher-order probes and it has been tested experimentally at different frequencies with medium to strong higher-order probes for AUTs with large truncation number in the spherical wave expansion (up to 120); in particular, for AUTs offset from the measurement coordinate system origin whereby a significant part of the probe radiation pattern comes into play during scanning [12].

5. Metamaterial-Inspired Super-directive First-Order Probe

In order to experimentally test the 0.4-1.2GHz higher-order probe, see Section 3, in P-band, a narrowband first-order probe was developed [16]. This represents a superdirective magnetic dipole array on a circular ground plane [17]; see Figure 4. Its weight is only about 2kg, determined by the ground plane, since the magnetic dipoles are etched on a standard dielectric substrate. The return loss is better than 30dB at resonance and the bandwidth at -10dB level is about 1MHz. The peak directivity is around 9dBi, cross-polarization is below -45dB , and the suppression of the wall specular reflections in the angular range $\theta = [50,76]^\circ$ is more than 6dB. The radiation efficiency is around 60%. This antenna was designed to satisfy the $\mu = \pm 1$ requirement for standard spherical near-field antenna measurement probes as detailed in [17]. The measurements show that the power in the higher-order modes with indices $\mu \neq \pm 1$ is about 40dB down as compared to the $\mu = \pm 1$ modes; this agrees very well with the simulations and it is acceptably low.

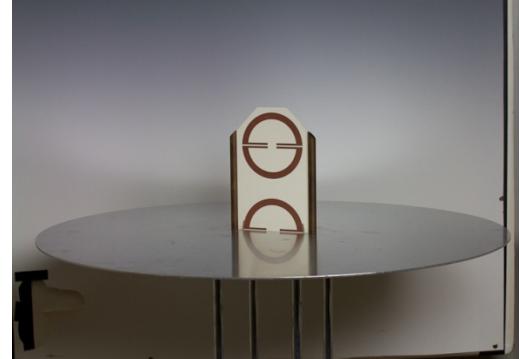


Figure 4: 435MHz superdirective first-order probe; a two-element magnetic dipole array (height 185mm) on a circular ground plane (diameter 720mm).

6. Summary

The performance requirements for advanced satellite antenna systems become increasingly stringent, and thus do the accuracy requirements for the antenna measurements involved in the development, validation, and calibration of such antenna systems. High-accuracy antenna measurements with 1σ - uncertainty of a few hundredths of dB for directivity and gain are necessary for many modern-day wireless technologies; in particular, satellite-based sensing systems. Spherical near-field antenna measurements in radio-anechoic chambers are capable of achieving such high accuracy, and the DTU-ESA Spherical Near-Field Antenna Test Facility aims to provide the best possible measurement accuracy. This necessitates a steady development of theory and practice of spherical near-field antenna measurements as outlined in this paper where we have presented some recent developments in range probe technology and near-field to far-field transformation algorithms as well as their application in high-accuracy antenna measurement projects for ESA.

7. Acknowledgments

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