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

Publication date:
2012

MEASUREMENT CAMPAIGNS FOR SELECTION OF OPTIMUM ON-GROUND PERFORMANCE VERIFICATION APPROACH FOR LARGE DEPLOYABLE REFLECTOR ANTENNA

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ABSTRACT

This paper describes the measurement campaigns carried out at P-band (435 MHz) for selection of optimum on-ground verification approach for a large deployable reflector antenna (LDA). The feed array of the LDA was measured in several configurations with spherical, cylindrical, and planar near-field techniques at near-field facilities in Denmark and in the Netherlands. The measured results for the feed array were then used in calculation of the radiation pattern and gain of the entire LDA. The primary goals for the campaigns were to obtain realistic measurement uncertainty estimates and to investigate possible problems related to characterization of the feed array at P-band. The measurement results obtained in the campaigns are compared and discussed.

Keywords: On-ground Performance Verification, Large Deployable Reflector, Near-Field Measurements, Comparison Campaign, Uncertainties

1. Introduction

The BIOMASS candidate mission is undergoing its feasibility study in the selection process for the seventh Earth Explorer programme of the European Space Agency [1]. The main payload of the BIOMASS is a P-band (435 MHz) synthetic aperture radar (SAR) with an antenna aperture of approximately 140 m^2 with full polarimetric and multi-pass interferometric capabilities [2]. The antenna configuration selected as the baseline is a large deployable reflector antenna illuminated by a small feed array, as illustrated in Fig. 1.

The deployable mesh reflector has a projected aperture with diameter of 11.5 m and a focal length of 7.5 m. The dual-polarized feed is a 2×2 patch array of about 1 m^2 located atop of the satellite with dimensions of about $1\times1.5\times3$ m^3. The feed and the reflector are folded towards the satellite during the launch and deployed in orbit.

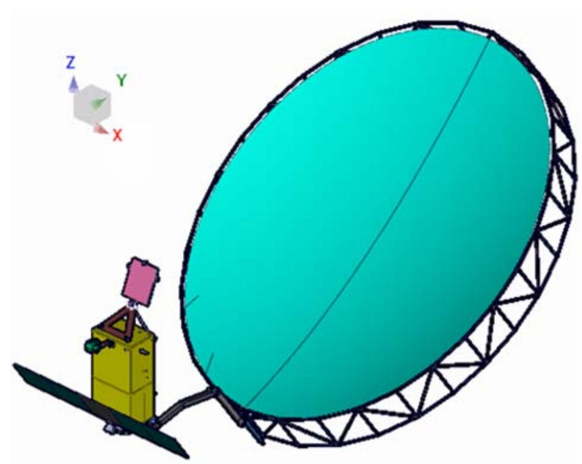


Figure 1 - The BIOMASS satellite with the deployable reflector antenna.

The required one way gain accuracy for the SAR antenna is set to be better than 0.15 dB (1σ), which is extremely challenging to achieve considering the low operation frequency and the 12x14 m^2 size of the offset reflector.

2. On-ground Performance Verification

The on-ground electrical performance verification of such an antenna is associated with serious technical challenges due to the large physical size, low operation frequency, and distortion of the antennas under gravity force. Combination of these three factors implies that it may not be possible to carry out performance verification of the entire antenna, and thus alternative methodologies must be considered.

For this antenna, an on-ground electrical performance verification methodology was proposed, which is based on measurement of the feed characteristics, such as pattern and radiation efficiency, and then calculation of the radiation pattern and gain of the entire antenna with appropriate simulation software. For the detailed description of this approach and the related investigations, see [3].

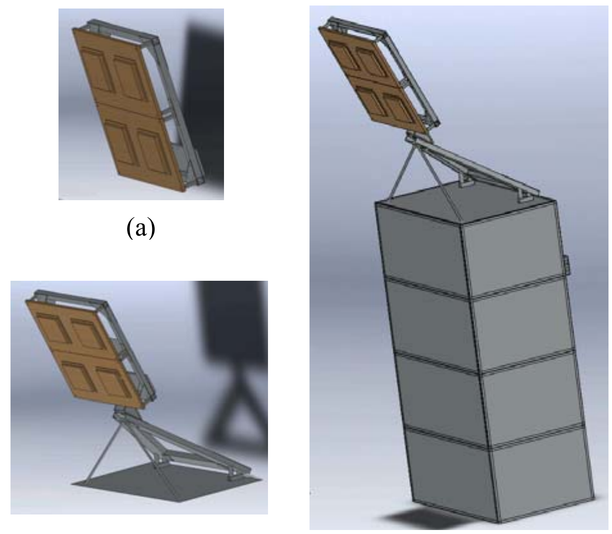
This approach has a series of advantages and disadvantages. The main advantage is, clearly, that the verification measurements are to be done on a much smaller antenna under test, the feed array, which can be accurately characterized by an appropriate measurement technique. The main disadvantage is that the number of uncertainty factors to be taken into account increases substantially and the final uncertainty budget must include rather many additional terms, each of which must be carefully estimated.

3. Uncertainty Budget

The total uncertainty budget for the selected validation approach consists of the following terms:

1. Measurement uncertainty of the feed array
2. Multiple interactions between the reflector and satellite
3. Influence of the reflector support arm
4. Calculation uncertainty of the secondary pattern, depending on the chosen model of the feed
5. Uncertainty related to deployment accuracy and repeatability
6. Uncertainty of the surface modeling
7. Uncertainty of the simulation method

Item 2 comes into consideration, since it is highly preferable to avoid modeling the entire satellite, and just consider scattering of the incident field of the feed, represented in terms of spherical wave expansion, from the bare reflector. In item 3, for similar reasons, the scattering from the support arm is neglected. For item 4, several feed configurations were considered: 1) feed array alone, 2) feed array with its support structure and the top plate of the satellite, and 3) feed array with the entire satellite. Clearly, configuration 1 is the simplest from the viewpoint of measurements, but it provides the worst feed model, since e.g. scattering from the feed support structure and the satellite are not taken into account. Contrary, configuration 3 is the most accurate in terms of the feed modeling, but it is also most challenging for obtaining accurate measurement results due to much larger size of the antenna under test. The feed configurations 1, 2, and 3 are illustrated in Fig. 2.



(a) (b) (c)

Figure 2 - Feed configurations: Conf. 1 (a), Conf. 2 (b), and Conf. 3 (c).

Investigations for most of the terms in the budget were carried out by simulations; the results for these can be found in [3]. Briefly, for the items 2, 3, 5-7, the estimated effects were either negligible or acceptably small. For items 1 and 4, some representative measurement data and typical uncertainties at 435 MHz were required; these items represent the main focus of this paper.

4. Measurement Campaigns

In order to obtain realistic measurement uncertainty estimates and investigate possible problems related to characterization of the feed at P-band, two measurement campaigns were carried out. First campaign included measurements of the prototype feed array in all considered configurations, 1, 2, and 3, at the DTU-ESA Spherical Near-Field (SNF) Antenna Test Facility at the Technical University of Denmark. The DTU-ESA Facility was established in mid-1970s in cooperation between the Technical University of Denmark (DTU) and European Space Agency (ESA) through a series of contracts for development of the SNF technique, very new by that time, to a level suitable for practical application for high-accuracy satellite antenna measurements. The anechoic chamber at DTU has the dimensions of 18×14×12 m^3; it is lined with 48 inch absorbers providing reflectivity level of about –35 dB at

400 MHz. For the measurements in this campaign, a new wideband dual-polarized probe, developed in a parallel ESA project [4], was used. The measurement of the feed array on top of the BIOMASS satellite mock-up (conf. 3) at the DTU-ESA Facility is shown in Fig. 3.

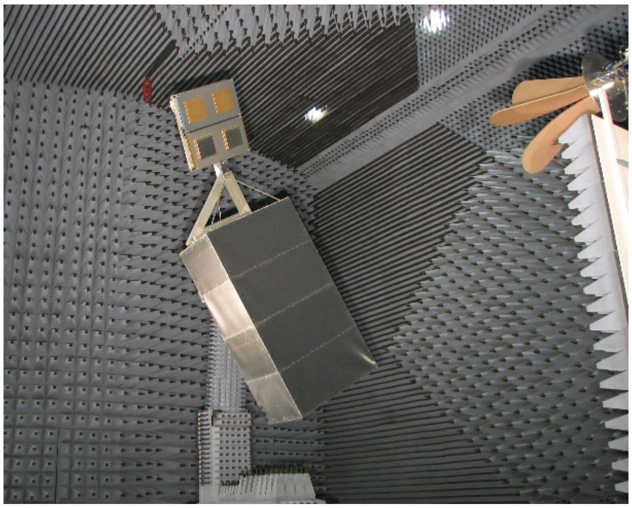


Figure 3 – Measurement of the feed array on top of the BIOMASS satellite mock-up (conf. 3) at the DTU-ESA Facility.

The second campaign included measurements of the feed array in configurations 1 and 2 at the Near-Field facility of the Naval Maintenance Establishment (NME) in Den Helder, the Netherlands, with Planar and Cylindrical Near-Field techniques. The Near-Field facility was established in 1997 by NSI in cooperation with the NME. All necessary antenna measurements needed to maintain the systems of the Royal Netherlands Navy can be performed in the Near-Field facility.

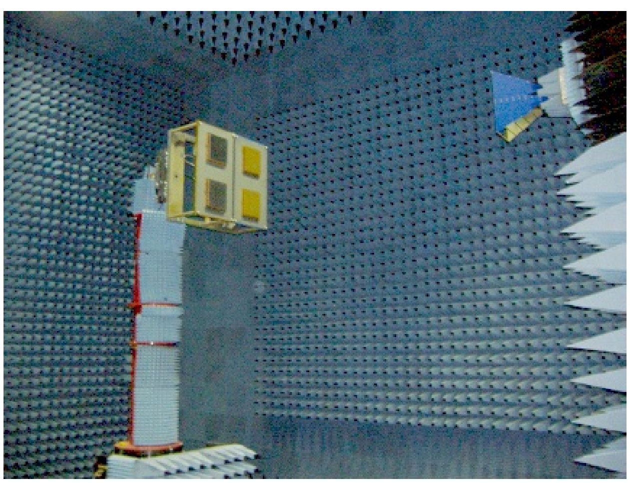


Figure 4 – Measurement of the feed array (conf. 1) at the Naval Maintenance Establishment.

The anechoic chamber has the dimensions of $14\times11\times9.5$ m^3 with a scan plane of 9×6 m^2. The Near-Field facility is qualified for the frequency range from 500 MHz to 40 GHz with absorbers providing reflectivity level of about −40 dB at 500 MHz. The measurement of the feed array (conf. 1) at the NME Facility is shown in Fig. 4.

In each campaign, special attention was given to investigations of measurement uncertainty. In particular, the uncertainty items known to give the largest contributions at these low frequencies were investigated by additional measurements: multiple reflections between the AUT and probe, scattering from the chamber walls, and scattering from the AUT tower. In addition, the effect of the measurement support frame interfacing the AUT and the antenna tower mounting flange was investigated. The effect of this support frame was found to be significant, exceeding twice all other terms in the uncertainty budgets for the feed configurations 1 and 2. This large effect is explained by several factors: non-optimum design of the frame, its proximity to the edges of the feed array carrying rather strong diffraction currents as well as possible scattering of the back radiated fields.

5. Comparison of the Results

The measurement results and uncertainties from the three measurement techniques were analyzed and compared. Comparison of the on-axis directivity values have shown that the measured directivity is noticeably higher from the PNF technique and slightly higher from the CNF technique as compared to the SNF technique; the difference is about 0.4 dB for the port H and about 0.2 dB for the port V. The measured gain for the port H is slightly lower from the PNF and CNF techniques as compared to the SNF technique, the difference is about 0.25 dB, while for the port V an excellent agreement is observed. The over-estimated directivity and under-estimated gain from the PNF and CNF techniques are explained by truncation of the scan surface inherent for these two techniques. For this antenna, the radiated power not taken into account due to the truncation is larger for the PNF technique and smaller, but still significant, for the CNF technique. Since calculation of both directivity and gain relies on the total radiated power, the obtained results are quite expected.

Comparison of the measured co-polar patterns at 435 MHz for the feed alone (conf. 1) is shown in Figs. 5-8. The directivity patterns are shown in the entire ±180° range as well as normalized patterns are shown zoomed around the main beam within ±35°.

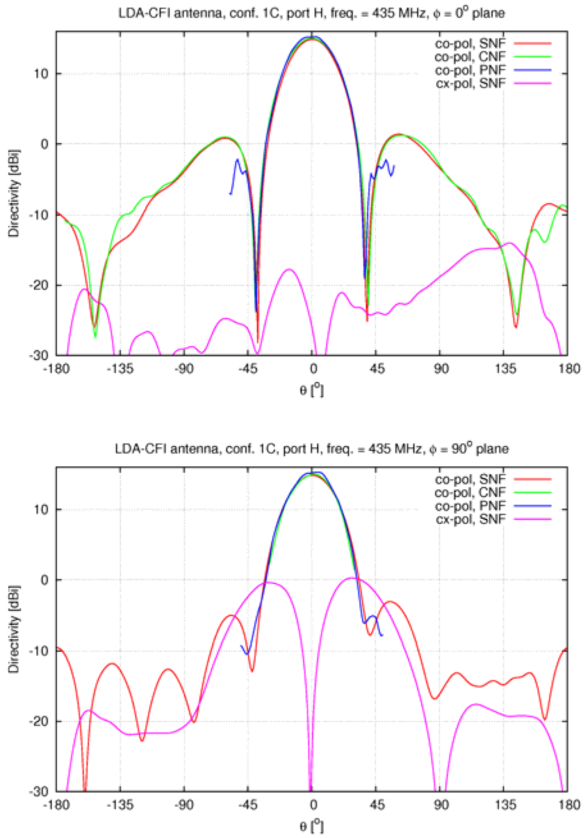


Figure 5 – Comparison of measured directivity: feed conf. 1, port H, full θ range, ϕ = 0° plane (top) and ϕ = 90° plane (bottom)

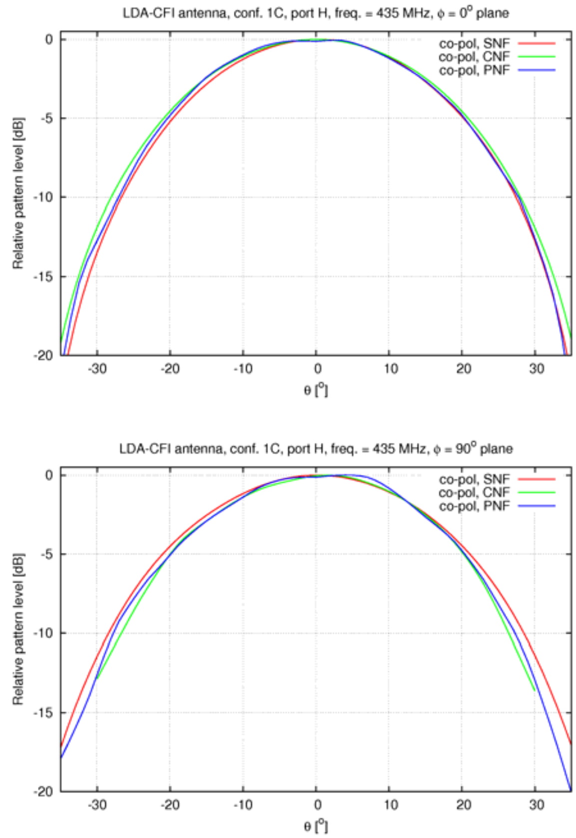


Figure 6 – Comparison of normalized patterns: feed conf. 1, port H, zoom θ = ±35°, ϕ = 0° plane (top) and ϕ = 90° plane (bottom)

It is noted that for the port H the agreement is generally good between the CNF and SNF techniques, while it is slightly worse for the port V. In particular, the side-lobe level for the port V is about 2 dB higher from the CNF technique as compared to the SNF technique.

It is also noted that, generally, in ϕ = 0° plane, the patterns from the PNF and CNF techniques have slightly wider beamwidth as compared to the SNF technique, while in the ϕ = 90° plane, the patterns from the PNF and CNF techniques have slightly narrower beamwidth as compared to the SNF technique. This difference in the beamwidth may be explained by the simplified probe pattern correction (based on cosine probe pattern approximation) performed for the PNF and CNF techniques.

Similar results were obtained and conclusions drawn for the feed in conf. 2 and these results are thus not shown here.

Comparison of the estimated 1σ measurement uncertainties for these three techniques is summarized in Table 1 for the on-axis directivity and in Table 2 for the on-axis gain.

Table 1: Measurement uncertainty in terms of 1σ for the on-axis directivity

	Conf. 1	Conf. 2	Conf. 3
PNF	0.28	0.23	-
CNF	0.20	0.17	-
SNF	0.13	0.13	0.29

Table 2: Measurement uncertainty in terms of 1σ for the on-axis gain

	Conf. 1	Conf. 2	Conf. 3
PNF	0.30	0.25	-
CNF	0.23	0.20	-
SNF	0.18	0.18	0.31

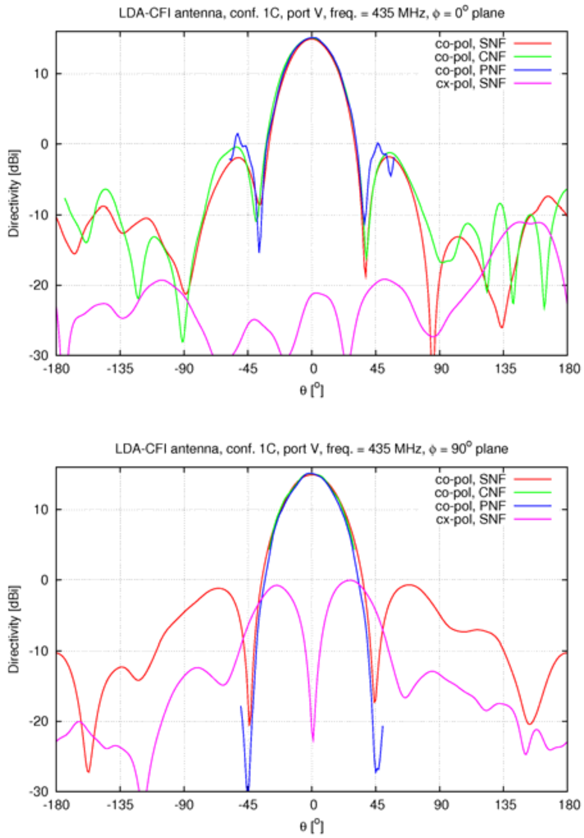


Figure 7 – Comparison of measured directivity: feed conf. 1, port V, full θ range, ϕ = 0° plane (top) and ϕ = 90° plane (bottom)

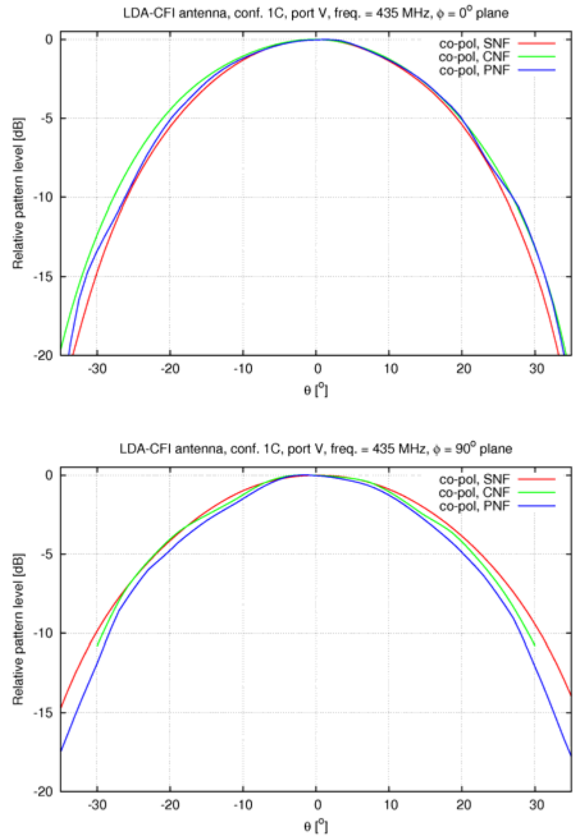


Figure 8 – Comparison of normalized patterns: feed conf. 1, port V, zoom θ = ±35°, ϕ = 0° plane (top) and ϕ = 90° plane (bottom)

It is noted that in configurations 1 and 2 both for the directivity and the gain the smallest uncertainty is obtained with the SNF technique and the largest uncertainty is obtained with the PNF technique, while the CNF technique has the uncertainty values between these two.

6. Analysis

The particular uncertainty values obtained for these measurements depend on several factors, which may be different at other facilities or even at the same facility, if special countermeasures are taken to compensate the identified large effects, e.g. multiple reflections between the AUT and the probe. On the other hand, some terms cannot be compensated, e.g. scan plane truncation error in the PNF technique. Careful analysis of the available uncertainty budgets leads to the conclusion that given about the same AUT-probe distance, similar wall reflectivity level, and similar scattering effects from the antenna tower, the scan plane truncation provides additional uncertainty, thus increasing the overall uncertainty of the PNF and CNF techniques.

Furthermore, the directive probe used in the SNF technique provided noticeable (~10 dB) suppressing of the side-wall reflections and thus the effect of this term was significantly decreased. The only advantage of the PNF technique is that the AUT is not moving during the measurements and thus it is not subjected to dynamic (but static) deformations due to the gravity force. The deformations and their effects are, however, almost negligible for the feed in conf. 1 and 2, taking into account very large wavelength.

Considering the fact that the SNF technique provided the results with the smallest uncertainty and also with full-sphere coverage, this technique was recommended for the on-ground performance verification of the feed array.

In must also be noted that even the smallest values of the estimated measurement uncertainties achieved for the SNF technique in this campaign are rather large and, taking into account the other terms in the total budget explained in Section 3, it is clear that some improvements must be made to the measurement procedures so that the specified accuracy requirement is fulfilled. All large contributions in the measurement uncertainty budget were carefully studied and it was found, as mentioned in Section 4, that the largest effect came from the measurement support frame. Recommendations were given regarding development of a special design of this support frame and modification of the feed array design, if possible, to decrease its back radiation, thus ensuring their minimum interference during the on-ground performance verification.

The obtained measurement uncertainty for the feed array directivity does not contribute with the full amount to the secondary pattern of the entire reflector antenna. Extensive simulations with GRASP software [5] were carried out to clarify different issues related to the calculation of the total pattern of the reflector taking as input the measured feed characteristics, including propagation of the feed measurement uncertainties into the secondary pattern of the reflector [3].

7. Conclusions

The obtained results from the measurement campaigns carried out for the P-band feed array for a large deployable reflector antenna provided much useful experience with measurements at these low frequencies.

Due to the fact that the measurements were performed around 400 MHz, which is outside the qualified frequency range of the near-field facilities, higher measurement uncertainties can be expected. Also, the accuracy of the measured directivity could have been improved for the measurements at the Planar and Cylindrical Near-Field facility, if more measurement time had been available.

One unexpected result was that the effect of the measurement support frame appeared to be the largest term in the uncertainty budget, exceeding the other large terms by a factor of two. It is thus recommended to give special considerations to the measurement support structure to reduce the effect of this uncertainty item.

The SNF technique provided the results with the smallest uncertainty as well as the full-sphere coverage for the measured data and this technique was recommended for the on-ground performance verification of the feed array. Several recommendations were also given regarding improvements of the test procedures in order to reduce critical uncertainty sources in the gain measurement.

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9. Acknowledgements

This work was supported by European Space Agency under the contract No. 4000102325/10/NL/JA “Study of Very Large Aperture P-Band Antenna Performance Verification Methodology and Facilities - BIOMASS”.