Antenna measurement and diagnostics processing techniques using unmanned aerial vehicles

María García Fernández, Yuri Álvarez López, Fernando Las-Heras Andrés
Área de Teoría de la Señal y Comunicaciones, Universidad de Oviedo (TSC-UNIOVI), Gijón (Asturias), Spain,
garciafmaria@uniovi.es, alvarezyuri@uniovi.es, flasheras@uniovi.es

***Abstract*—In-situ antenna measurements using unmanned aerial vehicles (UAVs) has become a research topic of great interest thanks to recent developments in UAV hardware and antenna measurement post-processing techniques for arbitrary geometry acquisition domains. Improvements in UAV positioning and geo-referring systems have enabled in-situ antenna measurements in the near field (NF) region of the Antenna Under Test (AUT). These NF measurements can be post-processed for antenna diagnostics and for radiation pattern evaluation. This contribution focuses on the analysis and comparison of post-processing techniques for in-situ antenna measurement using amplitude-only information, and the impact of the NF measurement domain in the post-processed results, namely aperture fields and radiation pattern. Two iterative phase retrieval techniques are compared using an offset reflector antenna as AUT.**

***Index Terms*—in-situ antenna measurement, phaseless techniques, unmanned aerial vehicles, antenna diagnostics.**

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs)-based applications and services have experienced a significant development in the last years, contributing to advances in fields such as remote sensing, civil engineering, and security and defense. The cost reduction of UAV-related electronical devices and batteries has definitely contributed to the rapid growth of UAV applications [1].

In the area of antenna and electromagnetic measurements, UAVs have been proved to be of great interest for in-situ measurement of the radiated fields [2-4], allowing the evaluation of the impact of the environment surrounding the antenna (buildings, ground) on its performance (radiation pattern, coverage area).

Current state-of-the-art systems mainly consist of power sensors or spectrum analyzers on board UAVs. Most of the developed systems are devoted to work in the far field (FF) region of the Antenna Under Test (AUT) due to the accuracy of the positioning and data geo-referring subsystem. This accuracy is usually limited by the performance of Global Navigation Satellite Systems (GNSSs), which is 1-2 m in best case scenarios. Recently, UAV-based measurement systems providing cm-level accuracy have been developed [3,4], introducing post-processing techniques capable of performing near-field to far-field (NF-FF) transformation or antenna diagnostics from measured amplitude-only information. The capability of in-situ antenna diagnostics is of interest for detecting malfunctioning elements in antenna arrays, incorrect antenna tilting, or defects and deformations in reflector antennas, avoiding the need of stopping operation of the communications system.

Phaseless antenna measurement techniques have received attention in the last years due to the challenges presented by measurements at millimeter and sub-millimeter wavelengths, where thermal stability and phase errors involved in moving transmission lines of the measurement system make phase measurements difficult.

Among the different techniques for phaseless measurements, iterative techniques based on the NF acquisition at two or more acquisition surfaces are suitable for in-situ antenna characterization using UAVs [5,6] as they allow using simple, low-cost hardware (e.g. a power detector). Besides, computational complexity associated to iterative techniques is not a major issue nowadays thanks to the advances in computational capabilities of conventional computers. However, these techniques are quite sensitive to measurement uncertainties and to the initialization (initial guess) of the iterative method. As an alternative, holographic techniques [7] exhibit greater accuracy than iterative methods, although at the expense of increasing hardware complexity.

In this contribution a review of phaseless iterative techniques applied to UAV-based antenna measurement systems is presented. The proposed methodology can be used for a-priori assessment of the impact of different parameters in the performance and accuracy of the developed airborne-based system [3,4].

II. POST-PROCESSING TECHNIQUES

A. Description of the methodology

In-situ antenna measurement systems mounted on UAVs are affected by UAV positioning errors (with respect to the pre-defined flight path) that will result in a non-uniform acquisition domain [3]. Thus, it is needed to develop and/or employ antenna post-processing techniques capable of working with arbitrary geometry acquisition domains. In particular, iterative techniques based on recovering an equivalent currents model of the AUT from NF measurements have been proved to be successful when working with not only amplitude and phase, but also with phaseless data acquired on arbitrary geometry domains [5].

NF airborne-based antenna measurement systems require the definition of at least two acquisition surfaces (e.g. two cylindrical domains [3]), which can be set using waypoints. If the AUT is not well characterized, the definition of these domains, and thus the UAV flight path, may be inaccurate (that is, relevant features of the NF pattern might not be measured), requiring a trial-and-error procedure for this task. For this reason, enabling the possibility of a-priori assessment of the NF grid using an antenna model similar to the one to be measured would make this step easier.

The antenna model can be obtained from computer simulation, or from previous measurements conducted in an antenna measurement facility. In this contribution, the antenna is modelled using an equivalent currents distribution calculated from NF measurements, as shown in Fig. 1. These equivalent currents allow evaluating the NF at any point, and thus, at the NF acquisition grids to be tested. Next, the amplitude of the NF evaluated at the acquisition grids is used as an input for the iterative phaseless retrieval techniques.

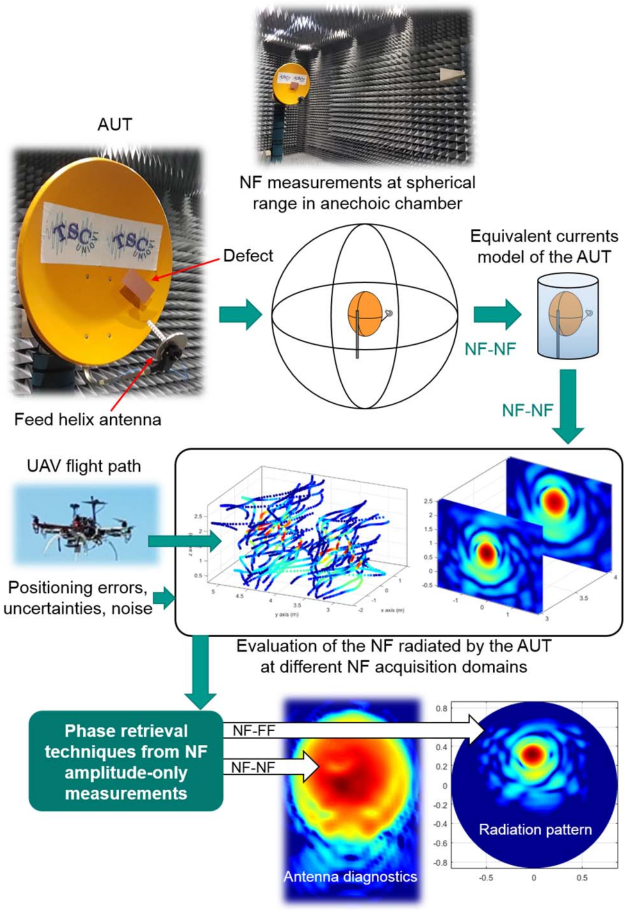

Fig. 1. Scheme of the proposed methodology for the analysis of the airborne-based system for in-situ measurement system.

B. Iterative phase retrieval techniques

Two iterative phase retrieval techniques are compared, both based on the reconstruction of an equivalent magnetic currents distribution on the aperture plane of the AUT (which corresponds to the aperture fields of the AUT). In the first technique, a nonlinear cost function relating the amplitude of the measured NF, and the amplitude of the NF radiated by the equivalent magnetic currents distribution, both evaluated at two acquisition surfaces, is minimized. In the case of acquiring $|E_x|$,$|E_y|$ at two planar domains, the integral equations relating E_x, E_y and M_x, M_y can be decoupled [5], as shown in Fig. 2.

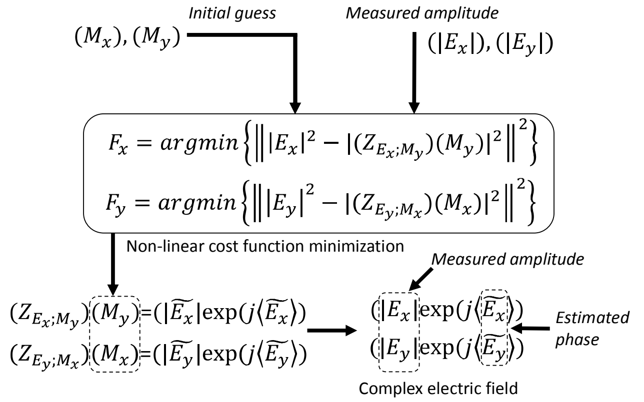

Fig. 2. Phase retrieval algorithm based on non-linear cost function minimization.

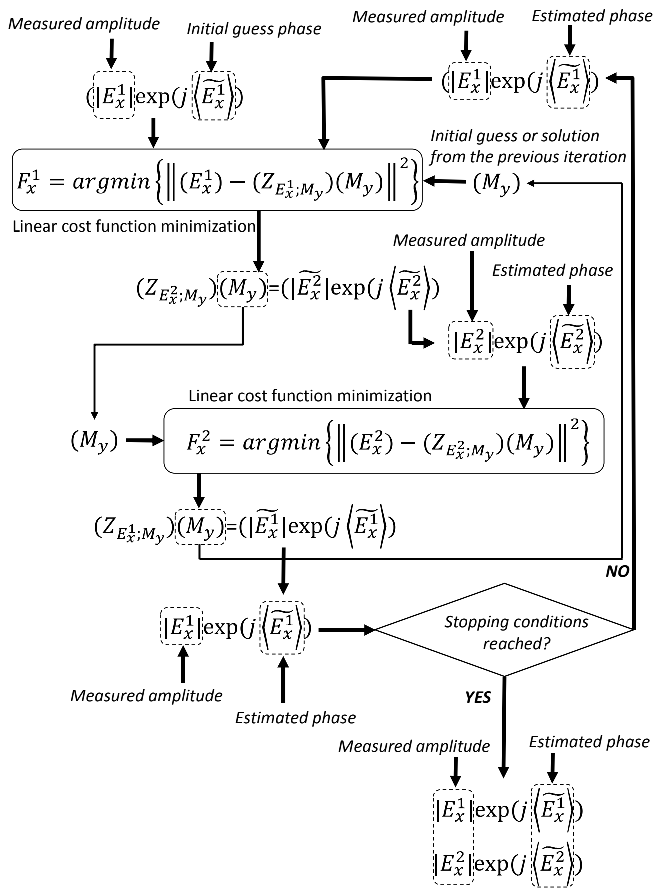

Fig. 3. Phase retrieval algorithm based on an iterative forward-backward method (only algorithm for Ex-component retrieval is shown).

The second algorithm, described in Fig. 3, consists on an iterative forward-backward procedure (similar to the Iterative Fourier Technique [7]) that minimizes a linear cost function that uses the measured amplitude and the estimated phase of the NF at two acquisition surfaces as input. At each iteration, the phase of the NF in one acquisition surface is estimated from the equivalent currents reconstructed using the estimated NF in the other acquisition surface. This algorithm is less computationally expensive than the first one, as it requires the minimization of a linear cost function.

In both cases, several stopping criteria can be set, such as residual threshold, stagnation threshold, and maximum number of iterations. Besides, these iterative techniques require a first guess that can be generated from the theoretical distribution of the aperture fields of the AUT.

As shown in Fig. 2 and 3, the output is the complex NF at the acquisition domain, formed by the acquired amplitude and the estimated phase.

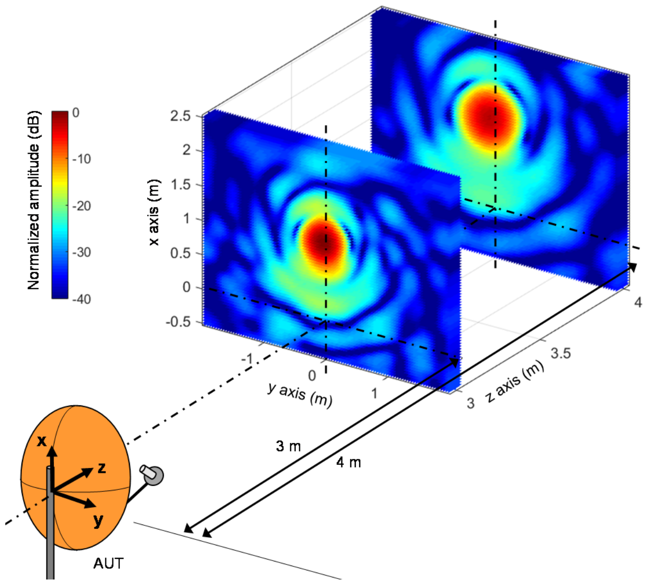

Fig. 4. Near field radiated by the AUT evaluated at two planar surfaces. Note that the main beam is tilted with respect to the z axis.

It must be remarked that acquisition on planar surfaces is sufficient, in the case of directive antennas, for a proper characterization of the main beam and sidelobes. This also helps to keep the complexity of the measurement setup low. Besides, as mentioned before, integral equations can be decoupled, allowing independent (and thus faster) recovery of E_x and E_y components. In the case of circularly polarized antennas, E_{RHC} and E_{LHC} are calculated from E_x and E_y.

III. Application Example

The proposed methodology has been evaluated using an offset reflector antenna as AUT, depicted in Fig. 1. The reason of choosing this AUT is the growing interest on in-situ testing of reflector antennas for radiocommunications and radioastronomy [8]. The reflector antenna dish has been distorted with a metallic plate to test the diagnostics capabilities.

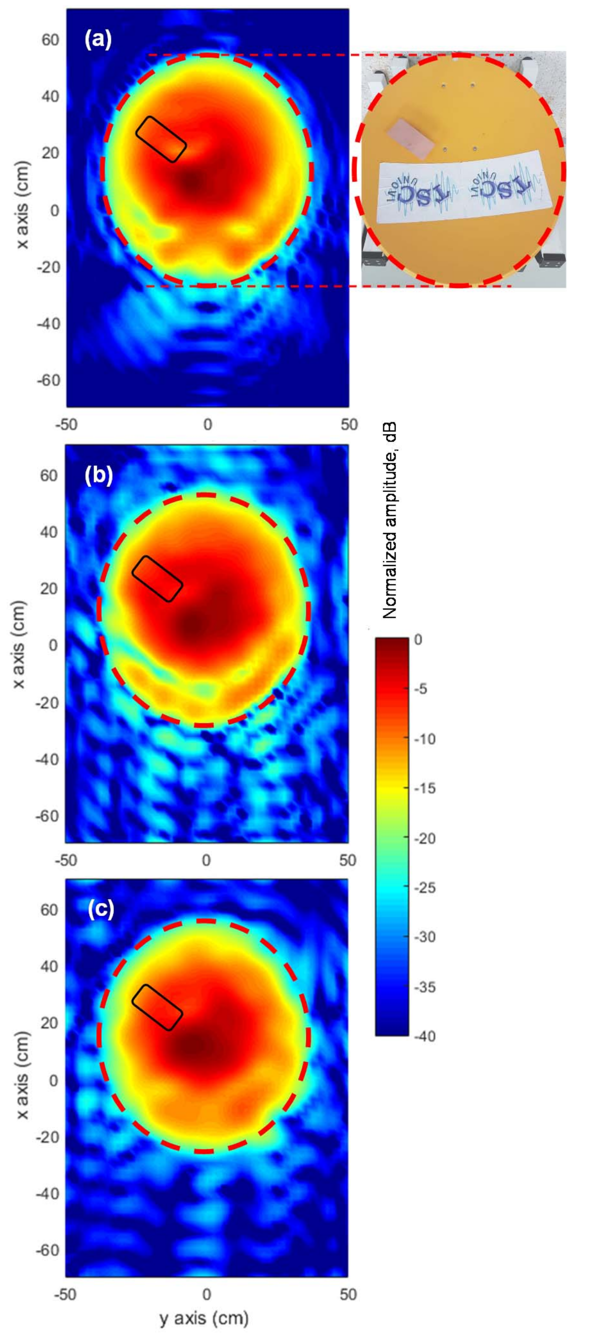

Fig. 5. Reconstructed field on the AUT aperture plane, copolar component (E_{RHC}). (a) Using NF amplitude and phase information. (b) Using amplitude-only information, nonlinear cost function minimization. (c) Using amplitude-only information, iterative forward-backward algorithm. Dashed red line represents the contour of the reflector dish, and the solid black line represents the metallic plate attached to the dish.

In this example, the reflector has been fed with a helix antenna to achieve circular polarization. A working frequency of f = 4.65 GHz has been selected, yielding a theoretical directivity of ~30 dB.

The methodology depicted in Fig. 1 has been followed. First, the AUT has been measured at the spherical range in anechoic chamber of the University of Oviedo. Next, an equivalent currents model of the AUT has been retrieved so that the NF radiated by the AUT can be evaluated at different acquisition surfaces.

A. Comparison of iterative phase retrieval techniques

The two iterative phase retrieval techniques described in Section II.B have been compared. In this test, the NF is evaluated at two 4 m x 3 m planar surfaces, placed 3 m and 4 m away from the AUT. As shown in Fig. 4, the reflector antenna main beam is tilted, so the measurement planes are off-centered in the y-axis. Sampling rate is 3 cm, resulting in 13534 acquisition points on each plane.

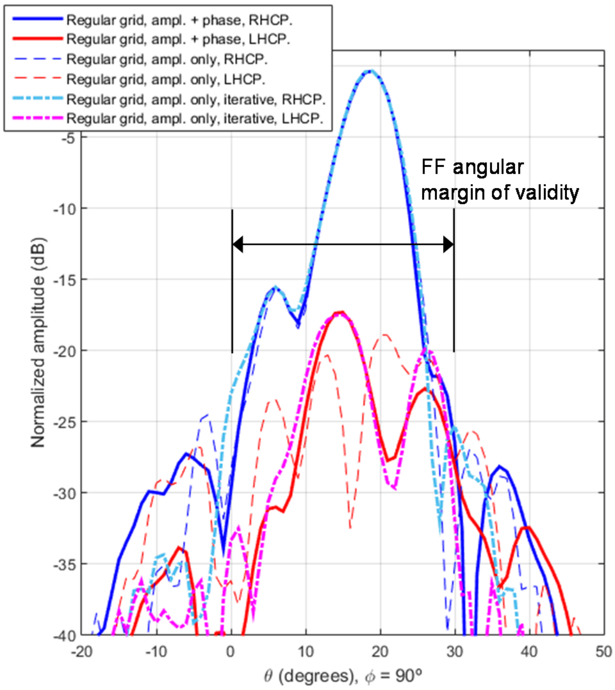

Fig. 6. Far field pattern, cut φ = 90º. Comparison between NF-FF transformation using amplitude and phase information, and using amplitude-only information (dashed line: non-linear cost function minimization, dash-dotted line: iterative forward-backward method).

From the evaluated NF at the two planar domains, the fields on the AUT aperture plane have been recovered. Reconstruction using amplitude and phase information (Fig. 5 (a)) is taken as reference. Fig. 5 (b) shows the reconstructed aperture fields using the algorithm based on nonlinear cost function minimization, and Fig. 5 (c) corresponds to the aperture fields reconstructed using the iterative forward-backward method. In all the cases, the asymmetry due to the presence of the metallic plate on the reflector dish can be noticed.

Next, the radiation pattern is calculated from these aperture fields. The cut at φ = 90º is depicted in Fig. 6, comparing the radiation pattern from NF amplitude and phase measurements, with the pattern calculated from amplitude-only acquisition. In the case of the copolar component (RHCP, blue lines), there is a good agreement within the FF angular margin of validity.

B. Testing using in-situ acquisition grid data

As aforementioned, the methodology described in Fig. 1 enables a-priori assessment of the accuracy of the in-situ antenna measurement system, provided a realistic model of the AUT is given. For example, this methodology allows evaluating different measurement grids that will be later converted into waypoints for the airborne-based system. Thus, it can be used to select the grid that best fits (i.e. gives more accuracy) to measure a particular kind of antenna.

In this example, the grid to be tested has been extracted from a former UAV flight path positions from the in-situ measurement of a 2-element horn antenna array [3]. The initial grid consisted of two 4 m x 2 m planes placed at z = 3 m and z = 4 m away from the AUT. In practice, UAV positioning errors resulted in a non-uniform measurement grid, as observed in Fig. 7. Nevertheless, positioning differences with respect to a canonical surface and a regular grid do not have a significant impact in the accuracy of the in-situ measurement system, provided that those measurement positions are accurately geo-referred [3,4].

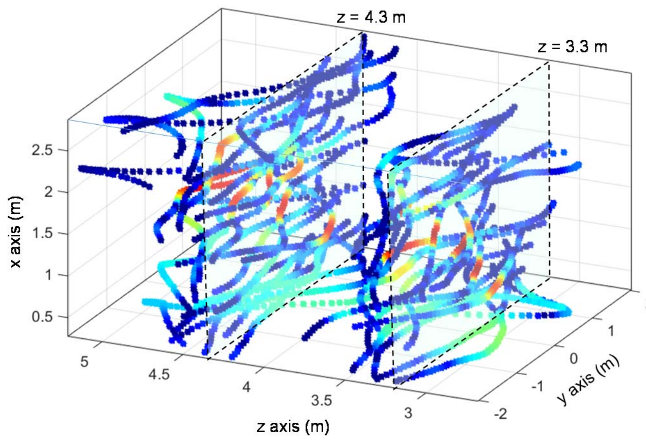

Fig. 7. NF evaluated at the grid consisting on geo-referred flight path points. Average position in *z* for each measurement surface is shown.

The NF radiated by the AUT has been evaluated at the geo-referred positions of the UAV flight path as depicted in Fig. 7. Then, the fields on the AUT aperture have been reconstructed: results considering amplitude and phase information (as a reference) and amplitude-only information are shown in Fig. 8. In this example, the algorithm based on nonlinear cost function minimization performed better (i.e. it had better convergence) than the forward-backward algorithm, so just the results for the former are shown. It can be noticed the agreement with the diagnostics results depicted in Fig. 5 using the regular grid.

Finally, the far field pattern is calculated from the aperture fields. φ = 90º cut is plotted in Fig. 10, comparing the NF acquired on a regular grid using amplitude and phase and amplitude-only information, with the NF acquired on the UAV flight path points also using amplitude and phase and amplitude-only information. The main beam and the sidelobe at θ = 5º are in good agreement. It can be observed that both copolar and crosspolar components match if the phase of the NF is available regardless the NF acquisition domain.

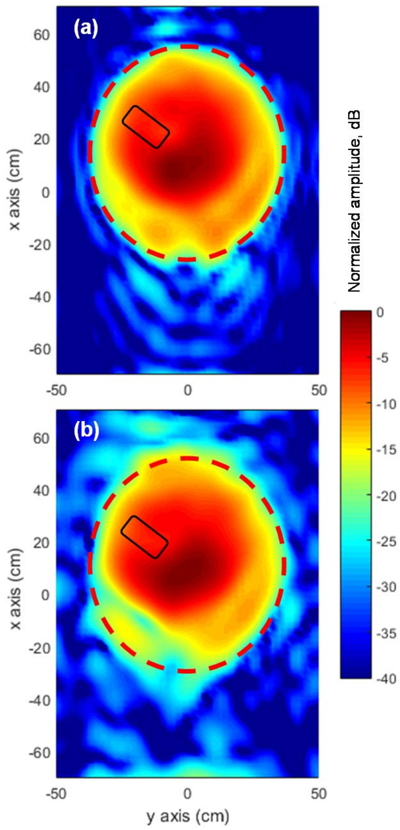

Fig. 8. Reconstructed field on the AUT aperture plane, copolar component (E_{RHC}). (a) Using NF amplitude and phase information. (b) Using amplitude-only information, nonlinear cost function minimization.

IV. Conclusions

Results presented in this contribution prove the capability of the implemented iterative phase retrieval techniques for antenna diagnostics and radiation pattern evaluation for a challenging problem consisting of a high directive circularly polarized off-centered reflector antenna. Even for non-uniform acquisition domains, as in the case of airborne-based antenna measurements, it is possible to accurately estimate the radiation pattern from phaseless NF measurements taken at UAV flight path positions.

Acknowledgment

This work has been supported in part by the Ministerio de Economía, Industria y Competitividad of Spain/FEDER, under projects TEC2014-54005-P (MIRIIEM), TEC2015-73908-JIN, Project TEC2014-55290-JIN, GRUPIN-18-000191, and grant FPU15/06341.

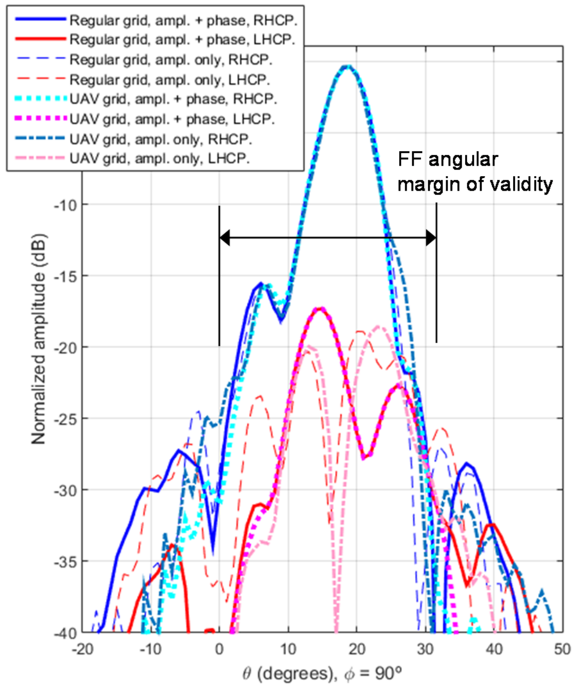

Fig. 9. Far field pattern, cut φ = 90º. Comparison between NF-FF transformation using amplitude and phase information, and using amplitude-only information. Results considering NF measurement domains on Section III.A (regular grid) and Section III.B (UAV grid) are shown.

References

[1] K. P. Valavanis G. J. Vachtsevanos *UAV Applications: Introduction.* In Handbook of Unmanned Aerial Vehicles. Springer, 2015.

[2] G. Virone, A. M. Lingua, M. Piras, A. Cina, F. Perini, J. Monari, F. Paonessa, O. A. Peverini, G. Addamo, R. Tascone, "Antenna pattern verification system based on a micro unmanned aerial vehicle (UAV)", *IEEE Antennas and Wireless Propagation Letters*, Vol, 13, pp. 169-172, 2014.

[3] M. G. Fernández, Y. A. López, A. Arboleya, B. González-Valdés, Y. R. Vaqueiro, M. E. de Cos Gómez, F. Las-Heras, "Antenna Diagnostics and Characterization using Unmanned Aerial Vehicles," *IEEE Access*, Vol. 5, pp. 23563-23575, 2017.

[4] Y. Alvarez, M. García, A. Arboleya, B. González, Y. R. Vaqueiro, A. Pino, F. Las-Heras, "Sistema aerotransportado y método para la caracterización y medida de antenas o sistemas radiantes," Patent PCT/ES2018/000015. Priority date: 03/03/2017 (ES P201700209).

[5] Y. Alvarez, F. Las-Heras, M. R. Pino, "The sources reconstruction method for amplitude-only field measurements," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 8, pp. 2776-2781, 2010.

[6] S. F. Razavi, Y. Rahmat-Samii, "A new look at phaseless planar near-field measurements: limitations, simulations, measurements, and a hybrid solution," *IEEE Antennas and Propagation Magazine,* Vol. 49, No. 2, pp. 170-178, 2009.

[7] J. L. Martínez, A. Arboleya-Arboleya, Y. Álvarez-López, C. García-González, F. Las-Heras, "Phaseless antenna diagnostics based on off-axis holography with synthetic reference wave," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 43-46, 2014.

[8] C. Chang, C. Monstein, A. Refregier, A. Amara, A. Glauser, S. Casura, "Beam calibration of radio telescopes with drones," *Publications of the Astronomical Society of the Pacific*, Vol. 127, No. 957, pp. 1131-1143, 2015.