Advances in Antenna Measurement and Characterization 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*— Recent developments in unmanned aerial vehicles (UAVs) hardware and antenna measurement post-processing techniques have fostered the development of in-situ antenna measurements using UAVs. Accurate geo-referring of the measurements is one of the most critical issues faced by these systems in order to increase the upper working frequency limit. In this contribution a novel methodology based on simultaneous acquisition of the near field (NF) amplitude on two measurement surfaces using a dual-probe setup on board the UAV is presented. Thanks to it, acquisition time and measurement uncertainties are greatly reduced. System capabilities have been validated by measuring an offset reflector antenna, comparing the results with measurements at spherical range in anechoic chamber.**

***Index Terms*—in-situ antenna measurement, dual probe, high directive antennas, phaseless techniques, unmanned aerial vehicles, antenna diagnostics.**

I. Introduction

In-situ antenna measurements have gained attention in the last years thanks to recent developments in Unmanned Aerial Vehicles (UAVs) hardware, allowing accurate positioning and geo-referring, as well as longer flight time. State-of-the-art airborne-based systems for antenna measurement have been successfully used for in-situ characterization of antennas, allowing the evaluation of the effect of the environment surrounding the antenna (buildings, ground) and the impact in its performance (radiation pattern, coverage area) [1-5].

Current advances in airborne-based antenna measurements have made possible measuring the near field (NF) radiated by the Antenna Under Test (AUT) by using cm-level positioning and geo-referring systems such as Real Time Kinematic systems (RTK), enabling in-situ measurements up to 5 GHz [3], with potential application at K-band [4,5].

Concerning NF data processing, amplitude-only acquisition is preferred, as phase measurements are more sensitive to geo-referring uncertainties and power sensors are less expensive and bulky than coherent receivers [6]. Thus, phase retrieval techniques are required in order to recover complex NF information from phaseless measurements. Once the phase of the field is retrieved, near field to near field (NF-NF) and near field to far field (NF-FF) transformation techniques can be applied to obtain antenna diagnostics information (detection of malfunctioning elements) and the radiation pattern of the AUT.

Different techniques for phaseless measurements have been developed. On the one hand, iterative techniques based on acquiring the NF at two or more acquisition surfaces enable the use of simple, low-cost hardware. On the other hand, holographic techniques are more accurate than iterative methods, although at the expense of increasing hardware complexity. In consequence, the former have been proved to be more suitable for airborne-based antenna measurement.

Iterative phase retrieval techniques [7,8] require the measurement of the NF in, at least, two acquisition surfaces placed at different distances from the AUT. In the case of airborne-based systems, two measurement grids have to be defined, one for each surface, making the flight time (and thus the measurement time) twice. In this contribution, the use of a dual probe setup connected to a dual channel power sensor is proposed. Thanks to this simple setup, the amplitude of the NF at two acquisition surfaces is done in a single flight.

II. Methodology

As aforementioned, iterative phase retrieval techniques require the measurement of the amplitude of the NF in, at least, two acquisition surfaces. Some of these techniques are able to work with non-uniform acquisition domain, which is of interest for airborne-based antenna measurement systems, as positioning of the airborne in real conditions can lead to measurements over non-canonical surfaces and non-regular grids.

Limited battery life of the UAV typically requires one flight for measuring the NF on each acquisition domain, requiring replacing UAV batteries between flights. Even though positioning systems on board the UAV are accurate enough to ensure proper geo-referring of the NF samples at these acquisition grids, the need for two flights introduce more position uncertainty in the NF data. Furthermore, requiring two flights increases the acquisition time and, eventually, the operational cost.

Recent examples of NF measurements using airborne-based systems show that typical acquisition distances range from 3 to 5 m, and the distance between the two acquisition surfaces (planar, cylindrical domains) is not greater than 1-2 m [3,4]. Thus, the use of two probes located 1 m away from each other with respect to the AUT-UAV line-of-sight, and connected to a dual channel power sensor, allows simultaneous acquisition of the NF samples at two different acquisition domains.

In order to test this measurement setup, the Unmanned Aerial System for Antenna Measurement (UASAM) described in [3] has been modified as shown in Fig. 1: two probes have been placed in opposite sides of the UAV, and they have been connected to a dual channel power sensor. Given the relative position between the two probes (76 cm), both acquisition surfaces can be properly geo-referred.

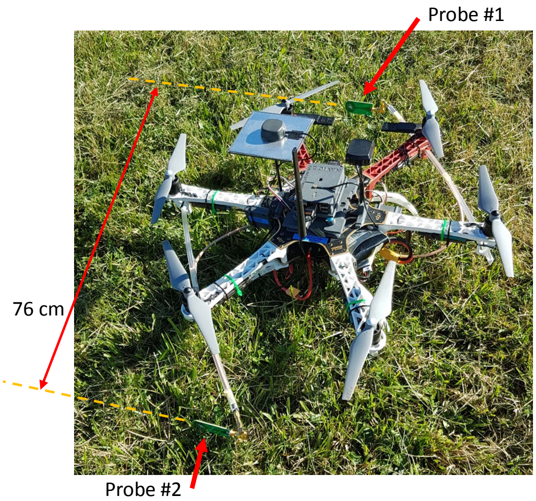

Fig. 1. Picture of the implemented prototype, highlighting the placement of the two probe antennas and the distance between them.

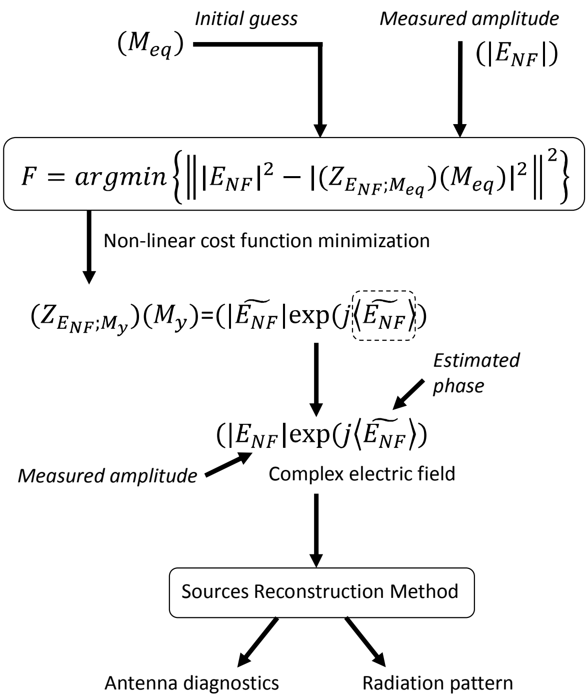

Fig. 2. Phase retrieval algorithm based on non-linear cost function minimization.

NF measurements are processed using an iterative phase retrieval technique that minimizes a non-linear cost function (see Fig. 2) [7]. This cost function relates the NF measured at the two acquisition surfaces with the NF radiated by an equivalent magnetic currents distribution on the AUT aperture plane. The output of the iterative phase retrieval technique is the complex electric field, which will be used as input for NF-NF and NF-FF transformation, in order to recover the electric fields on the AUT aperture as well as to calculate the FF pattern.

III. Experimental Validation

In order to validate the improved version of UASAM prototype, an offset reflector antenna working at 4.65 GHz, and fed with a helix antenna, has been selected as AUT. With these parameters, the AUT has a directivity of ~30 dB, with the main beam (BW_{-10dB} ~12º) tilted θ = 17º. Another reason for the selection of this antenna was to prove UASAM capabilities for high directive antenna measurement, which could be of interest for applications such as radioastronomy [2] or satellite communications.

The AUT was mounted on top of a 2.7 m high metallic mast, and then placed in the airfield of the University of Oviedo. The transmitted signal was a tone generated using an oscillator, and later amplified up to 15 dBm.

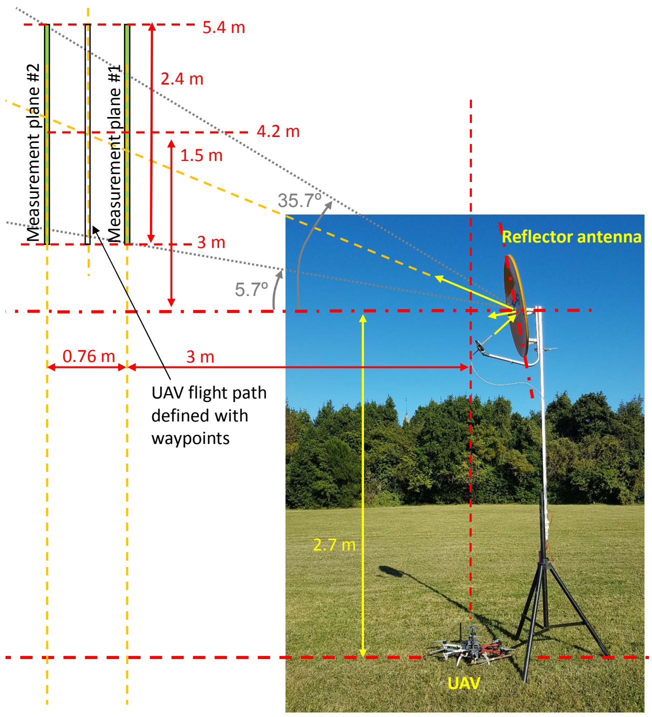

Fig. 3. Picture of the UAV and the reflector antenna placed on top of a 2.7 m high metallic mast, and scheme of the distances and sizes of the measurement domain. The far field angular margin of validity is also depicted using gray dotted lines.

The main beam offset estimation required a preliminary flight along the vertical axis in order to determine the height of the main beam 3 m away from the antenna. Once it was located, the measurement surfaces were defined as shown in Fig. 3 and Fig. 4. Thanks to the use of the two probes and the dual channel power sensor, only one measurement grid had to be set, being the measurement surfaces for each probe equidistant from the UAV flight path defined using waypoints.

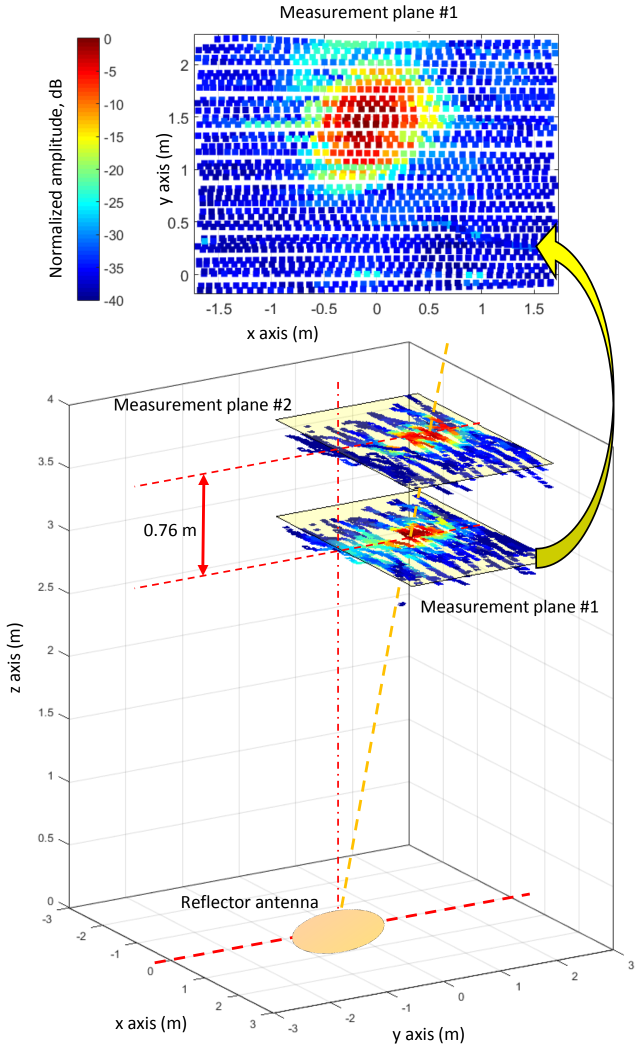

Fig. 4. Amplitude of the NF measured at the geo-referred UAV flight path positions. Notice the offset in the y-axis of the acquisition surfaces in order to capture the tilted main beam of the reflector antenna. Yellow plane represents the theoretical acquisition surface.

In the case of directive antennas, acquisition on planar domains is sufficient for a proper characterization of the main beam and sidelobes, while keeping the complexity of the measurement setup low. Besides, the use of planar acquisition domains allows decoupling the integral equations relating E_x, E_y with M_x, M_y on the AUT aperture plane [7]. In this example, only the x-component of the NF was measured and thus only the x-component of the aperture fields and the radiation pattern will be analyzed. Nevertheless, the y-component of the NF could be acquired as well by simply rotating the two probes 90º.

Fig. 5. Picture of the modified UASAM prototype for simultaneous acquisition of the NF at two surfaces, when measuring the NF radiated by the offset reflector antenna.

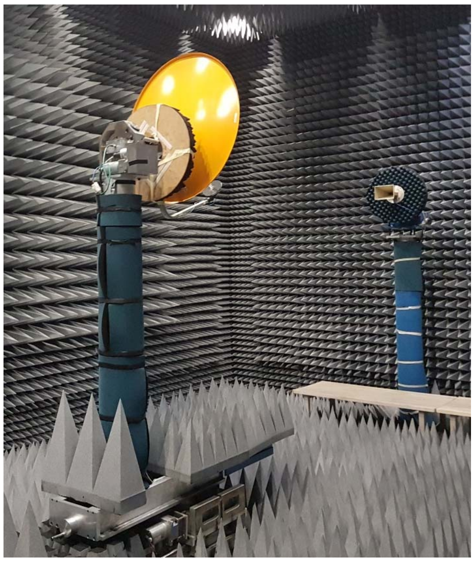

Fig. 6. Picture of the reflector antenna being measured at spherical range in anechoic chamber of the University of Oviedo.

A 5 m x 2.4 m measurement grid was defined, later truncated to 3.4 m x 2.4 m to reduce the amount of NF data. A grid spacing in height (y-axis in Fig. 4) of 6 cm was selected for a preliminary assessment. Geo-referred NF measurements are depicted in Fig. 4, where the main beam of the AUT can be clearly noticed. It is important to remark again that these NF measurements were acquired with a single flight of the UAV that took approximately 12 minutes. 6562 samples per plane were collected, similar to the same number of samples (7842) that would result from uniform $\lambda/2$ sampling of the 3.4 m x 2.3 m plane. A picture of the prototype in operation is shown in Fig. 5.

In order to have a reference for antenna diagnostics and radiation pattern comparison, the AUT had been previously measured at the spherical range in anechoic chamber of the University of Oviedo (Fig. 6).

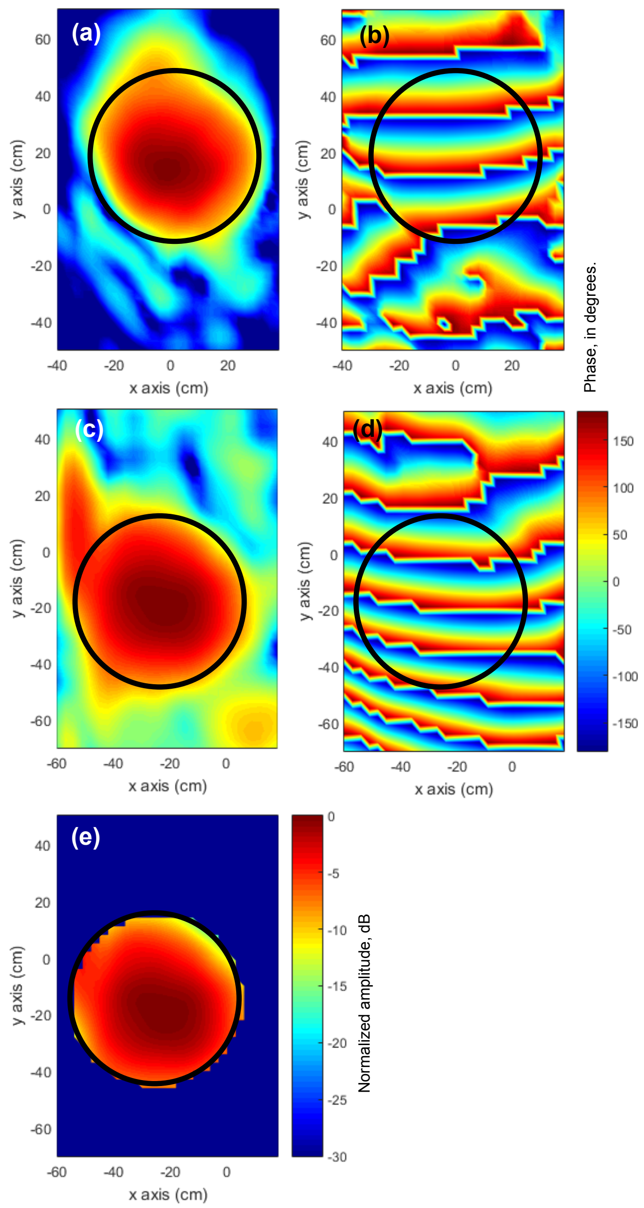

Fig. 7. Amplitude (a) and phase (b) of the reconstructed aperture fields from amplitude-only NF measurements at spherical range in anechoic chamber. Amplitude (c) and phase (d) of the reconstructed aperture fields from in-situ NF measurements using amplitude-only information. (e) Amplitude of the aperture fields after filtering. Solid black line represents the projected profile of the reflector antenna.

Next, amplitude-only NF measurement acquired using the modified setup of UASAM were post-processed using the iterative phase retrieval technique described in Section II. Reconstructed aperture field is depicted in Fig. 7 (c) and (d), comparing it to the one reconstructed using amplitude-only information of the NF measured at the spherical range. In both cases it can be noticed the typical distribution of the aperture fields of reflector antennas (Fig. 7 (a) and (c)). Furthermore, the phase distribution of the aperture fields shows a slope in the y-axis (Fig. 7 (b) and (d)), which is consistent with the tilted beam of the AUT (elevation tilt of the offset reflector antenna). It must be also remarked that the reflector antenna dish was slightly rotated when placed on top of the metallic support in the airfield.

From the fields reconstructed on the reflector antenna aperture, the far field pattern can be calculated. The 2D U-V plot of the radiation pattern is represented in Fig. 8. Fig. 8 (a) corresponds to the radiation pattern calculated from NF measurements acquired at the spherical range, whereas the FF calculated from in-situ NF measurements is depicted in Fig. 8 (b).

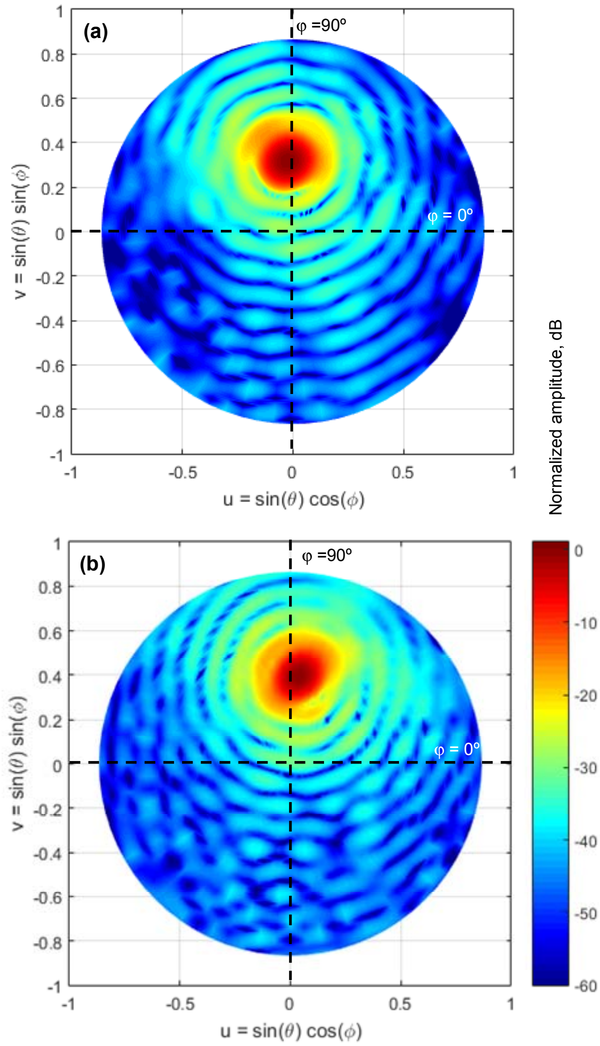

Fig. 8. Far field pattern, u-v representation. (a) Calculated using amplitude-only information from NF measurements at spherical range in anechoic chamber. (b) Calculated from amplitude-only information from in-situ NF measurements. In both cases, the main beam is slightly tilted as the reflector was also tilted with respect to the vertical axis.

It must be clarified that aperture fields were filtered prior to the calculation of the FF, taking advantage of the fact that the size of the reflector dish is known: those fields lying outside the projected shape of the dish were neglected. Thus, Fig. 7 (e) represents the mask considered for filtering the aperture fields depicted in Fig 7 (c). In the case of those aperture fields calculated from NF measurements at the spherical range in anechoic chamber, no filtering mask was applied.

For a better comparison of the FF pattern calculated using amplitude-only anechoic chamber and in-situ measurements, the main beam cut of the radiation pattern is depicted in Fig. 9. It can be noticed the agreement between both patterns within the angular margin of validity of the FF (defined in Fig. 3).

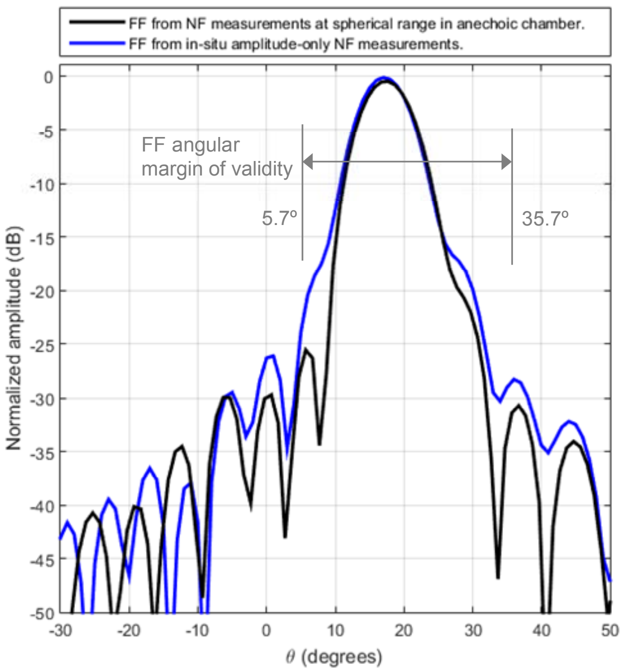

Fig. 9. Far field pattern, cut. Comparison between NF-FF transformation from amplitude-only NF measurements at spherical range in anechoic chamber, and from in-situ amplitude-only NF measurements.

IV. Conclusions

In this contribution an improvement of the UASAM prototype has been presented. It enables the simultaneous acquisition of the amplitude of the NF radiated by the AUT at two acquisition surfaces. Thanks to this, measurement errors due to positioning and geo-referring uncertainties are minimized, and, above all, only one flight of the UAV is needed.

Results confirm also the capability of the improved UASAM system for conducting in-situ measurements of high directive antennas, such as reflector antennas, widely used in several areas (satellite communications, radioastronomy, broadcasting networks, etc.).

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.

References

[1] 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.

[2] 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.

[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] M. García, Y. Álvarez, F. Las-Heras, "On the use of Unmanned Aerial Vehicles for Antenna and Coverage Diagnostics in Mobile Networks," *IEEE Communications Magazine*, Vol. 56, No. 7, pp. 72-78, 2018.

[5] 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).

[6] M. D. Migliore, F. Soldovieri, R. Pierri, "Far-Field Antenna Pattern Estimation from Near-Field Data Using a Low-Cost Amplitude-Only Measurement Setup", *IEEE Transactions on Instrumentation and Measurement*, Vol. 49, No. 1, pp. 71-76, 2000.

[7] 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.

[8] 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.