

Measurements of Low Gain VHF Antennas in Spherical Multi-Probe NF System

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Abstract — The accurate characterization of low-gain antennas at VHF frequencies is challenging. Such antennas can be tested outdoors for convenience or in very large and thus expensive indoor Far-Field (FF) ranges [1]. Indoor Near-Field (NF) systems are often considered a better cost compromise for such measurements, mainly due to the relaxed requirements on chamber size. However, reflectivity issues and other source of errors such as truncation can compromise the measurement accuracy [2].

Multi-probe NF systems in spherical geometry are optimal measurement solutions for the low frequency characterization of low directivity antennas such as most antennas in automotive applications [3,4,5]. In this paper, we present VHF-band measurements of a low directivity antenna in a hemispherical and quasi full-3D multi-probe system. The VHF antenna in this study is an array element, which has been developed for space applications [6-7]. The different measurements reported are part of the technology development activity of the antenna. For each antenna measurement, the gain and pattern accuracies are investigated by comparison with full wave simulations.

I. INTRODUCTION

Spherical NF multi-probe systems are ideal measurement solutions for the characterization of low frequency, low directivity antennas such as antennas in common automotive applications. The minimized movement of the DUT, due to the probe array, increases the natural attenuation of reflectivity errors, already available in the NFFF transformation. The minimized probe size decreases the requirement on probe-to-DUT spacing, thus reducing the size of the system. Very large systems are often implemented as hemispherical, truncated scan ranges where the DUT is elevated above an absorber covered floor [4]. Smaller systems are often quasi-full 3D scan ranges where the DUT is accommodated on a low dielectric masts to minimize interaction [5].

The antenna in this study is an array element, which has been developed for space based Automatic Identification System (AIS) applications [6-7]. The ground based AIS is a coastal tracking and messaging system used by vessels for maritime traffic monitoring. The European SAT-AIS initiative aims at providing a space-based complementary system to

extend the range of the existing AIS to high seas via a VHF satellite constellation. The AIS Miniaturized Antenna activity (AISMAN), supported by the European Space Agency (ESA) in the frame of the ARTES 5.1 program, was focused on the development of a VHF array elements for mini-satellites in Low Earth Orbit [6].

Mass and volume are critical requirements for space applications and a significant design effort was dedicated to miniaturize the array elements. A fully metallic prototype, based on artificial magnetic materials, was manufactured and tested in the automotive measurement facility at the Renault Technical Centre, Aubevoye in France. Advanced measurement processing based on equivalent current techniques (EQC) was applied to increase the measurement accuracy. The EQC processing was applied to minimize errors coming from the hemispherical truncation and echoes/stray signals. The accurate measurements were a key element to validate the metallic AIS antenna array element [8-13].

A follow-on contract was awarded to MVG by ESA to improve the material and manufacturing process [14]. The improved AIS element from this design activity has been characterized in a quasi-full spherical near field multi-probe system at the China Academy of Space Technology (CAST 501), Beijing, China and are reported in this paper. The measurement accuracy is investigated by comparison with full wave simulations.

The paper is organized as follows: Section II contains a short description of both the developed VHF array elements; Section III summarizes the measurements performed on the metallic AIS element as presented in [6-7]; Section IV reports on new measurements from the validation of the improved element; finally, comments and conclusions are given in Section V.

II. DESCRIPTIONS OF AISMAN ELEMENTS

The real challenge of the AISMAN activity has been the miniaturization of the receiving antenna system through the development of innovative technical solutions. Features of the designed antenna are the electrically small dimensions (with

respect to $\lambda_{VHF} \approx 2 m$), the low profile, the light-weight, the high efficiency and the limited interaction with the platform.

As a result, the designed antenna under test (AUT) shows an overall envelope of $0.25\lambda \times 0.25\lambda \times 0.02\lambda$ (500mm x 500mm x 39mm) and is based on a cross-dipole radiation architecture, slant oriented, mounted over a 16 cells Artificial Magnetic Materials (AMM) surface and over a ground plane. AMM has been chosen as design concept of the baseline radiating element due to the significant size reduction it could offer. The placing of an AMM layer between the dipoles and the ground plane has allowed to reduce the currents due to the dipoles-ground plane close proximity ($\ll \lambda/4$). The designed AMM layout consisted in a periodic structure based on metallic square rings grounded by metallic posts placed at their corners. Further technical solutions, such as slotted ground plane, combined with AMM, allowed for an outstanding profile reduction, while preserving high radiation efficiency and low back radiation. The price to pay was in the reduction of the operating bandwidth, but this was acceptable for AIS applications as the fractional bandwidth required is very small ($< 0.1\%$). The resonance of the element has been tuned @ 162 MHz [1]. The element shown in Figure 1 (left) is made of aluminum and has been manufactured using high precision machining techniques.



Figure 1. AISMAN engineering models: metallic (left); composite material (right).

A further activity, proposed to ESA by a contract extension [8], has led to the design, manufacturing and test of an improved antenna element, a step closer to a possible flight model production. In particular, objectives of the improved model have been the mechanical robustness, weight reduction and the use of more suitable materials for space applications. As a result, an improved engineering model has been designed, considering a multi-layer stack assembly, with metallic parts (AMM surface and ground plane) printed on E-glass skins and bonded to a core material made of RF transparent honeycomb. The improved AIS model is shown in Figure 1 (right).

III. MEASUREMENT OF THE METALLIC AIS ELEMENT IN HEMISPHERICAL AUTOMOTIVE RANGE

The validation measurements of the metallic AIS element have been performed at the automotive measurement facility sited in the Renault Technical Centre at Aubevoye, France. The metallic AIS element during measurement in such system is shown in Figure 2. The range is a hemispherical multi-probe NF system having a measurement radius of 6m. Data acquisition is performed according to a regular sampling of 3.21° with a truncated area of $\pm 75^\circ$ in elevation [3-4].

Besides the chamber reflectivity and scattering from the environment, which are well-known issues at VHF frequencies, the main criticality of this measurement is represented by the above-mentioned truncation of the scanning area. In fact, due to the low directivity of the DUT, the measurement of its radiation pattern is likely to be strongly affected by the truncation errors [9-10] if a zero-padding of the near field (NF) data is performed before the near field to far field (NFFF) transformation, as typically done.

In order to mitigate the truncation errors, the EQC technique, implemented in the MVG software INSIGHT, has been used in the processing of this measurement [5-7]. Based on the measured data samples, the EQCs have been computed on a box closely surrounding the DUT (see Figure 3).

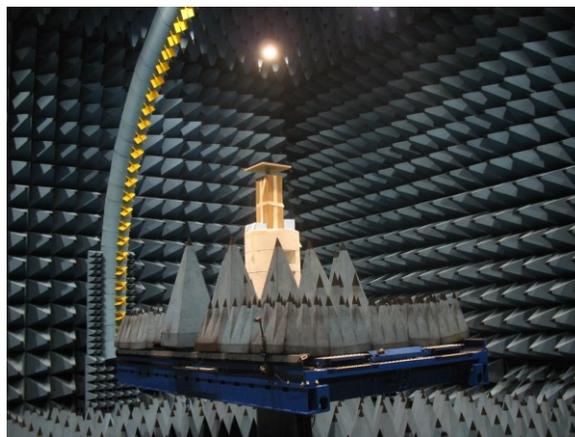


Figure 2. Metallic AIS element during measurement in Renault Technical Centre hemispherical range.

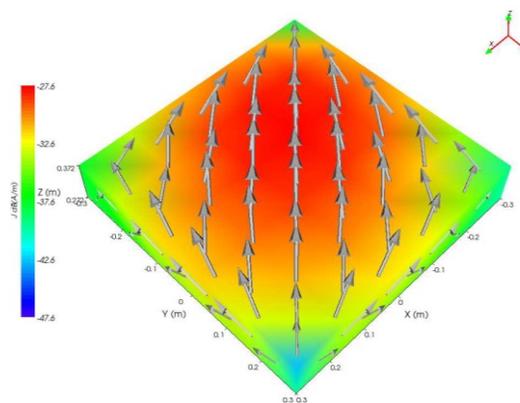


Figure 3. Equivalent electric currents of the metallic AIS element computed with INSIGHT.

From the EQC, the field on the full measured surface has been re-computed extrapolating the missing portion of the scanning area. This operation has allowed the application of the NF/FF transformation without performing the zero-padding and thus reducing the truncation errors [7, 9].

It should be noted that, when the EQC technique is applied, a spatial filtering based on the physical size of the DUT is also performed [11]. This allows to attenuate the unwanted effect of possible scattering contributions such as

echoes and to mitigate the interaction with the supporting structures.

The E-plane, H-plane and inter-cardinal plane directivity comparison are shown in Figure 4, Figure 5 and Figure 6 respectively. The improvements obtained by the EQC/INSIGHT expansion are appreciable. In fact, the FF ripple caused by the truncation of the scanning area and stray signals present in the measurement environment are strongly attenuated by the data processing. It is worth noting that the agreement between simulated [12] and measured data obtained with INSIGHT software is satisfactory even out of the reliable visible region of the measurement sphere, meaning that the equivalent current method has very good extrapolation capabilities.

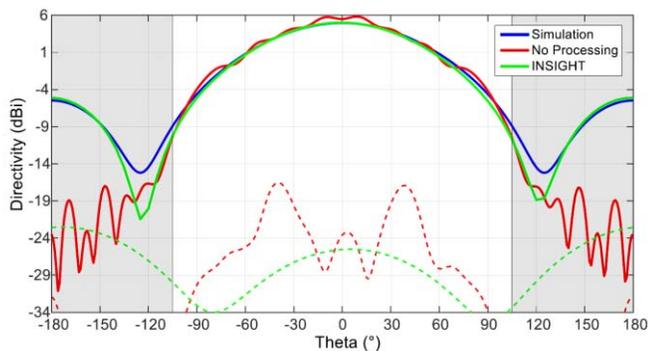


Figure 4. E-plane directivity pattern comparison of the metallic element.

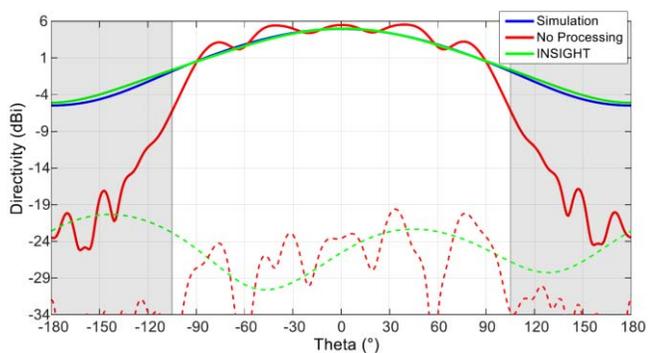


Figure 5. H-plane directivity pattern comparison of the metallic element.

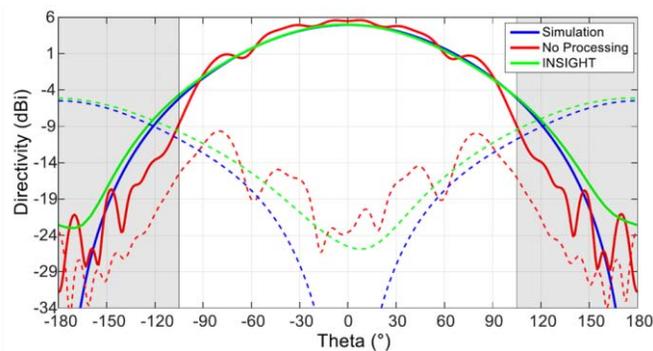


Figure 6. Intercardinal-plane directivity pattern comparison of the metallic element.

IV. MEASUREMENT OF THE COMPOSITE AIS ELEMENT IN FULL 3D SPHERICAL RANGE

The improved AIS element has been tested in the CAST 501 facility sited in Beijing, China, where a spherical multi-probe NF system with a measurement radius of 4.3 meter is present. Thanks to three different probe arrays working in three different frequency bands (70-400MHz, 0.4-6GHz and 6-18 GHz), the system is capable to measure from 70 MHz up to 18 GHz.

Measurement at VHF frequencies are performed with the first probe array, which is composed by 31 probes covering an angular elevation range of ± 150 degrees and thus having a small truncated area (± 30 degrees).

The improved AIS element during measurement in the CAST 501 range is shown in Figure 7. The DUT has been mounted on a mast so that its location coincides with the center of the measuring sphere. In order to minimize the interaction in the proximity of the DUT, the top part of the mast is made of polystyrene material. The bottom part of the mast, being metallic, may act as a scatterer and may compromise the accuracy of the results in case of low gain DUTs, unless a proper filtering is applied in post-processing.



Figure 7. Improved AIS element during measurement in CAST 501 spherical multi-probe range (courtesy of CAST 501).

The directivity pattern comparison between simulated [12] (blue traces) and measured (green traces) data are shown in Figure 8, Figure 9 and Figure 10 respectively for the E-plane, H-plane and inter-cardinal plane cuts.

Measured radiation patterns are obtained applying the standard procedure usually involved in MVG measurements systems without resorting to advanced post-processing technique as done in the previous situation. Basically, the NF/FF transformation has been performed extrapolating the missing portion of the scanning area [9] and applying a modal filtering [11] after the computation of the Spherical Wave

Expansion (SWE) [13]. In order to remove the metallic part of the mast, the filtering has been applied considering an equivalent sphere having a radius of 145 cm. The involved extrapolation technique is based on the SWE of the available measured field points and requires the knowledge of the size of the DUT minimum sphere [13] as additional input. Such technique is very effective and computationally efficient in case of small truncated areas ($< \pm 30$ degrees) and electrically small DUT (as in the present measurement scenario).

The agreement between simulated and measured pattern is excellent. Furthermore, parameters such as peak directivity, front-to-back ratio and on-axis cx-polar discrimination (XPD) are perfectly in line with the expectations.

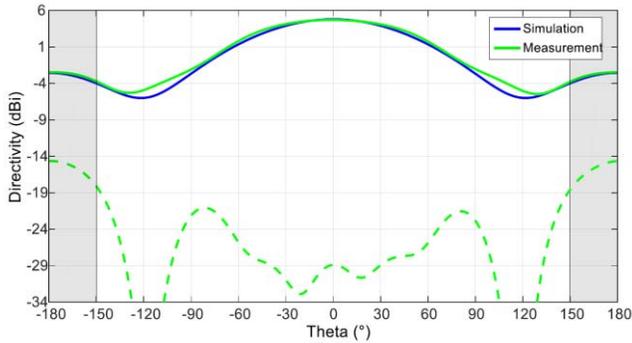


Figure 8. E-plane directivity pattern comparison of the improved element.

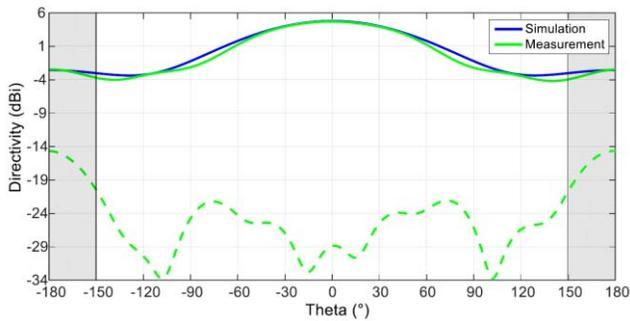


Figure 9. H-plane directivity pattern comparison of the improved element.

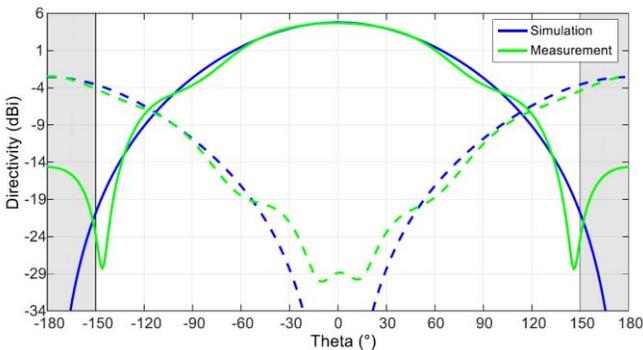


Figure 10. Intercardinal-plane directivity pattern comparison of the improved element.

V. MEASUREMENTS COMPARISON

The collected measurement results have been compared with the reference data (i.e. high fidelity simulations), in the terms of Equivalent Noise Level (ENL), which is expressed by the following formula:

$$ENL = 20 \log_{10} \left(\text{mean} \left| \frac{E(\theta, \varphi) - \tilde{E}(\theta, \varphi)}{E(\theta, \varphi)_{MAX}} \right| \right) \quad (1)$$

where $E(\theta, \varphi)$ is the reference pattern and $\tilde{E}(\theta, \varphi)$ is the reconstructed pattern.

As shown in Table 1, a good agreement with simulations is achieved in all the presented pattern comparison.

TABLE I. ENL COMPARISON

Case	ENL [dB]
Measurement in Renault with zero padding	-27.0 dB
Measurement in Renault with INSIGHT extrapolation	-37.7 dB
Measurement in CAST501 with zero padding	-32.3 dB

VI. CONCLUSION

In this paper, the measured performances of two engineering models of a low gain VHF space antenna have been reported.

The first engineering model has been tested in a multi-probe hemispherical range sized for automotive applications. Due to the wide truncation of the scanning surface, advanced data processing based on the equivalent current technique has been applied on the measured data in order to extrapolate the missing NF samples and thus reduce the truncation errors. The good agreement between measured and simulated results allowed validating the first engineering model remarking the potentialities of the equivalent current technique.

The second model has been measured in a spherical multi-probe system. Standard measurement and post-processing procedure was used in order to obtain the radiating performance of the antenna, which have been shown to be in excellent agreement with the expectations.

The presented results demonstrate the high measurement accuracy of these multi-probe systems when measuring low gain devices even at VHF.

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