Measurements of Low Gain Antennas at VHF Frequencies for Space-Based AIS Applications

A. Giacomini[1], V. Schirosi[1], F. Saccardi[1], F. Rossi[1], N. J. G. Fonseca[2], P. de Maagt[2], L. J. Foged[1]
[1] Microwave Vision Italy s.r.l., Via dei Castelli Romani 59, 00071, Pomezia, Italy
[2] European Space Agency ESTEC, 2200 AG, Noordwijk Zh, The Netherlands
andrea.giacomini@microwavevision.com

Abstract—Measurement of the radiation properties of low gain antennas at VHF frequency is in many cases a challenging task. Measurements performed in shielded anechoic chambers are usually preferred to outdoor ranges because they are not subject to the electromagnetic pollution and less affected by the scattering of the environment. However, different source of errors, such as truncation of the scanning surface and the presence of echoes caused by a poor reflectivity of the anechoic chamber, could affect the measurement results. In such cases, advanced post-processing techniques must be involved.

In this paper, the results of two Engineering Models of a low gain VHF space antenna are reported. The first one has been tested in a multi-probe automotive hemispherical range and applying an advanced processing, in order to mitigate the truncation errors. The second has been measured in a spherical multi-probe system with smaller truncated area applying the standard data processing.

***Index Terms*—Antenna measurement, VHF, Spherical near field, Data processing.**

I. INTRODUCTION

The ground based Automatic Identification System (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 VHF satellite constellation [1].

The AIS Miniaturized Antenna (AISMAN) activity [2], 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 antenna for mini-satellite platforms in Low Earth Orbit. A considerable design effort has been done for the miniaturization of the single antenna element. The design cycle has included preliminary tests on a single element breadboard to validate the proposed approach, followed by manufacturing and testing of a metallic version of the antenna.

A full characterization of the radiation properties of the metallic engineering model has been carried out in the Microwave Vision Group (MVG) SG3000F automotive measurement facility sited in the Renault Technical Centre at Aubevoye, France [3-4]. An advanced data processing based on the equivalent current technique (EQC) [5-7] has been performed in order to reduce the errors coming from the hemispherical truncation and from the presence of echoes and stray signals. This has allowed to validate the metallic AIS antenna element with success.

Therefore, a further iteration on the mechanical and electrical design of the element has been conducted, improving materials and manufacturing process [8]. The improved AIS element has been characterized in a (quasi) full-spherical multi-probe MVG system sited at the China Academy of Space Technology (CAST 501), Beijing, China.

This paper is organized as follows: section II reports a short description of the two VHF devices under test (DUT); section III summarizes the measurement results of the metallic AIS element (presented in [1]); section IV reports the results coming from the validation of the improved element; finally, conclusions are drawn 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 0.25λ x 0.25λ x 0.02λ (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 (<<λ/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 Fig. 1 (left) is made of aluminum and has been manufactured using high precision machining techniques.

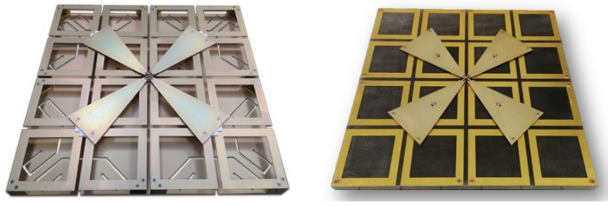

Fig. 1. AISMAN engineering models: metallic (left); composite material (right).

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 Fig. 1 (right).

III. MEASUREMENT OF THE METALLIC AIS ELEMENT IN 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 Fig. 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 ±75° 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 (NF/FF) transformation (as typically done).

In order to mitigate the truncation errors, the –EQC technique, implemented in the MVG software INSIGHT, has been involved 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 Fig. 3).

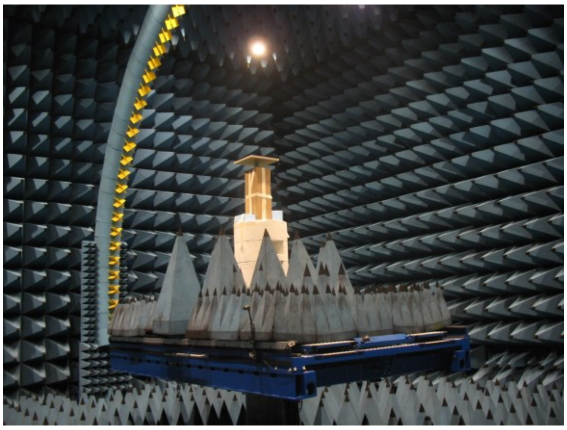

Fig. 2. Metallic AIS element during measurement in Renault Technical Centre hemispherical range.

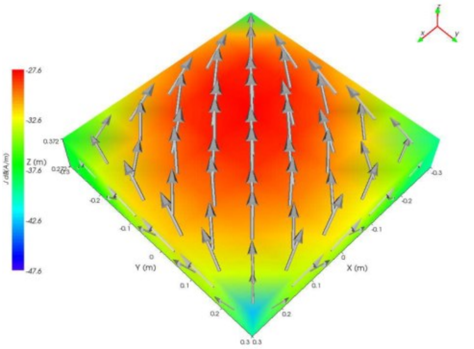

Fig. 3. Equivalent electric currents of the metallic AIS element computed with INSIGHT.

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 Fig. 4, Fig. 5 and Fig. 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.

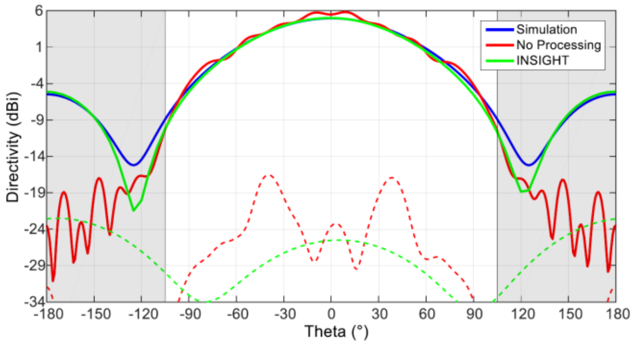

Fig. 4. E-plane directivity pattern comparison of the metallic element.

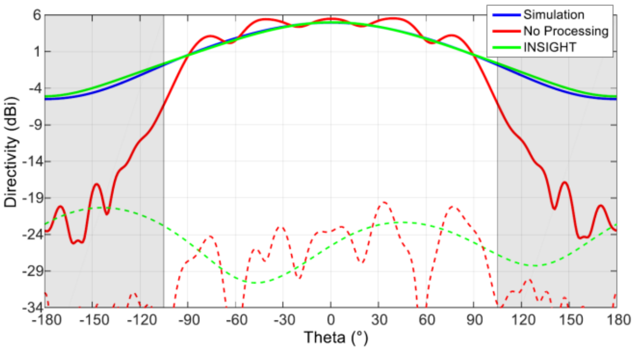

Fig. 5. H-plane directivity pattern comparison of the metallic element.

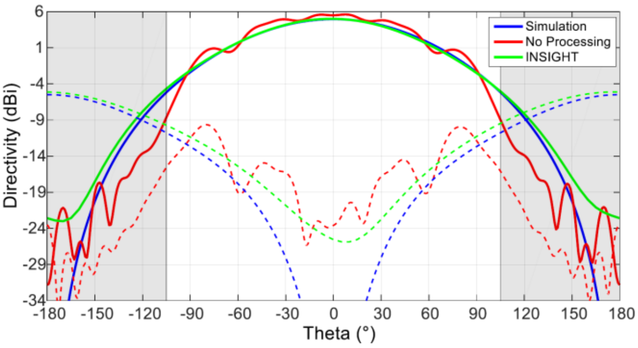

Fig. 6. Intercardinal-plane directivity pattern comparison of the metallic element.

IV. Measurement of the Composite AIS Element in Full 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 Fig. 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 polyester 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.

The directivity pattern comparison between simulated [12] (blue traces) and measured (green traces) data are shown in Fig. 8, Fig. 9 and Fig. 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 (< ±30 degrees) and electrically small DUT (as in the present measurement scenario).

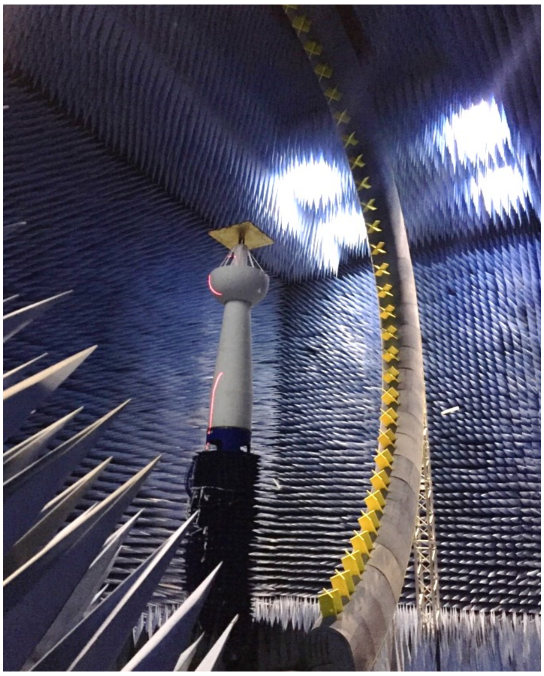

Fig. 7. Improved AIS element during measurement in CAST 501 spherical multi-probe range (courtesy of CAST 501).

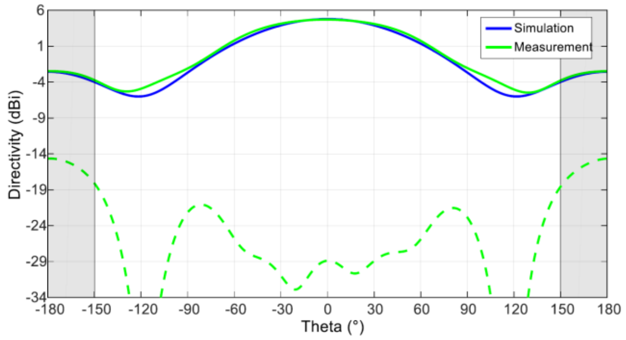

Fig. 8. E-plane directivity pattern comparison of the improved element.

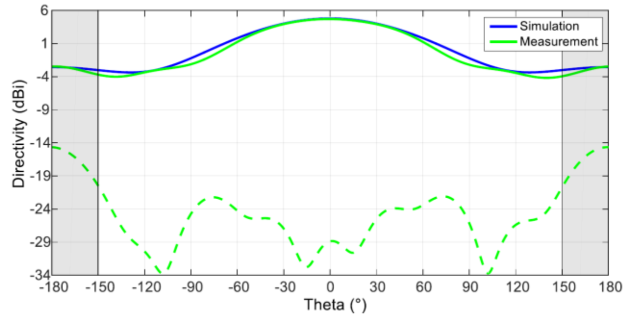

Fig. 9. H-plane directivity pattern comparison of the improved element.

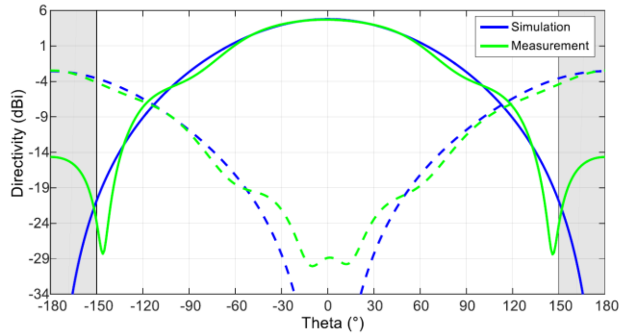

Fig. 10. Intercardinal-plane directivity pattern comparison of the improved element.

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.

V. 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.

ACKNOWLEDGMENT

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