Analysis of Flush-Mounted Antenna Placement via Huygens Source Reconstruction from VHF Measurements

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***Abstract*—The Huygens Box (HB) technique offers an accurate and computationally efficient approach for antenna placement within computational electromagnetic solvers. This paper presents an experimental validation of the HB method for low-frequency, flush-mounted antennas using measured radiation patterns of a monocone antenna mounted on a 4-meter ground plane, acquired with a multi-probe system. The Infinite Plane Boundary Condition (IPBC) pre-processing is applied to minimize edge diffraction effects from the finite ground plane. The HB model is integrated onto an aircraft geometry and evaluated using full-wave simulations across the 100–200 MHz band. Results show strong agreement with reference data, confirming findings from a recent parametric study on HB dimensioning for low-frequency measured sources. Repeating the analysis with the known CAD model of the source shows minimal deviation from measured data, demonstrating robustness against typical low-frequency measurement errors. These results confirm the HB method as a reliable tool for low-frequency antenna modeling.**

***Index Terms*— Huygens Box, antenna measurement, equivalent currents, VHF/UHF, low frequency, infinite ground plane.**

I. Introduction

The Huygens Box (HB) approach offers an efficient and accurate framework for antenna placement and coupling studies within Computational Electromagnetic (CEM) solvers by addressing the limited availability of detailed antenna CAD models, as antenna suppliers are often unwilling to share proprietary geometries to protect their intellectual property. To overcome this limitation, the HB method reconstructs Equivalent Currents (EQCs) from measured Near-Field (NF) or Far-Field (FF) data of the standalone antenna, enabling high-fidelity electromagnetic modeling without requiring large and costly measurement facilities. This link, or hybrid, approach provides an accurate representation of the real antenna, including its mechanical design, materials, and feeding conditions, and has been successfully applied to a wide range of complex platforms such as spacecraft, satellites, and vehicles [1]–[3].

In this method, the measured radiation pattern of an isolated antenna is converted into EQC using an inverse source formulation [4], implemented in the commercial available Insight software by MVG [5]. The derived HB models can then be imported into various CEM solvers [6]-[11] to evaluate antenna integration performance on realistic structures.

For antennas mounted on conductive surfaces, nearby metallic structures significantly influence the current distribution, often making standalone antenna measurements insufficiently accurate. The correct local boundary condition is typically enforced by measuring the source antenna over finite ground planes, though such setups introduce diffraction effects at the plane edges. The Infinite Plane Boundary Condition (IPBC) correction, implemented in Insight [12], compensates for these effects, approximating the response of an ideal infinite ground plane. Nevertheless, at low frequencies (VHF/UHF), HB generation becomes challenging due to the impractical size of the required ground planes, size of the HB, and truncated scan regions.

Our previous work [13] presented a simulation-based parametric assessment of HB accuracy for low-frequency flush-mounted antennas, focusing on the influence of HB dimensions, ground-plane size, and measurement scan area truncation considering a single blade antenna and 2-element blade antenna array configurations at 100 MHz.

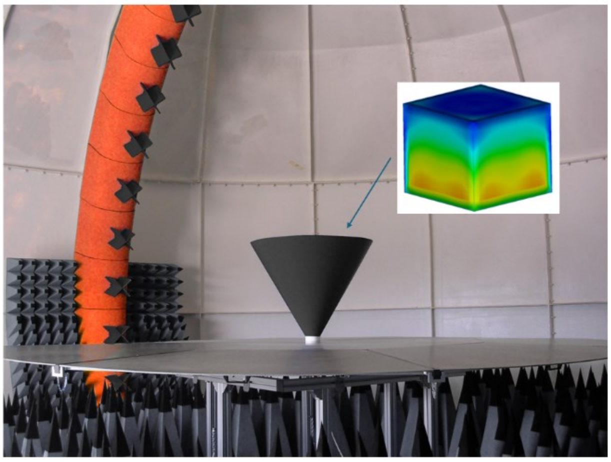

Fig. 1. Example of a multiprobe system tailored for VHF/UHF antenna measurements. SMC70 antenna with GP400 is inlcuded in the setup.

This study builds upon the previous work by introducing several key aspects. First, it incorporates actual measured radiation pattern data acquired using a Multi-Probe Array (MPA) system (Fig. 1), which inherently includes typical low-frequency measurement imperfections, such as residual reflections, offering a more realistic evaluation compared to purely simulated scenarios. Second, the frequency range is extended to 100–200 MHz, enabling analysis across a broader operational bandwidth relevant to VHF applications. Third, the SMC70 monocone antenna is used in place of the previously studied blade antennas, allowing the methodology to be tested with a different antenna type with distinct electromagnetic characteristics. By integrating practical measurements, expanding the frequency range, and introducing a new antenna geometry, this study aims to validate and refine the HB methodology for accurate low-frequency antenna placement analysis. The results contribute to establishing the HB approach as a robust and reliable tool for realistic modeling in complex electromagnetic environments.

II. TEST CASE DESCRIPTION

A. Measurement of the Source Antenna

The radiation pattern of the SMC70 monocone antenna [14], mounted on a 4-meter diameter ground plane (GP400), was measured using a Spherical Near-Field (SNF) Multi-Probe Antenna (MPA) system, similar to the one illustrated in Fig. 1. The measurement setup is schematically shown in Fig. 2. The considered MPA system is designed for characterizing antennas mounted on large and complex structures such as vehicles, across a wide frequency range, spanning approximately from 60 MHz to 6 GHz [15].

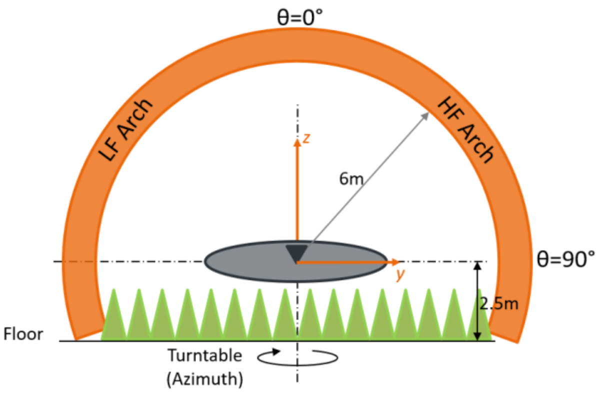

Fig. 2. Skecth of the measurement setup of the SMC70 monocone mounted on the GP400.

The hemispherical arch of the system comprises two distinct probe arrays. The first array includes 22 dual-polarized probes covering the 60–400 MHz band. The second array consists of 111 dual-polarized probes operating in the 0.4–6.0 GHz range. The truncated arch design enables elevation coverage up to 110°, ranging from zenith (θ = 0°) to 20° below the horizon (θ = 110°). The distance between the center of the measurement sphere and the probe aperture is 6 meters.

Three-dimensional radiation pattern acquisition is achieved through a combination of electronic scanning in elevation (θ) via the probe arrays and mechanical rotation in azimuth (φ) using a turntable. The chamber floor, located 2.5 meters below the center of the measurement sphere, along with the walls and ceiling, is lined with 48” and 60” RF absorbers to emulate free-space conditions.

For this measurement, the low-frequency probe array was employed to characterize the radiation pattern in the 100–200 MHz band. As shown in Fig. 2, the antenna ground plane is positioned at z=0. Notably, the SNF acquisition was completed in under 3 minutes.

Examples of the resulting radiation patterns, obtained after NF/FF transformation [16], are presented in Fig. 3. The shaded regions indicate areas affected by truncation, where the radiation pattern is known to be unreliable. Additionally, some ripples observed in the pattern are attributed to truncation errors, which can propagate into the reliable regions [17]. As discussed in [17], these ripples can be significantly reduced by applying the EQC approach, which is used in the following section to generate the Huygens boxes.

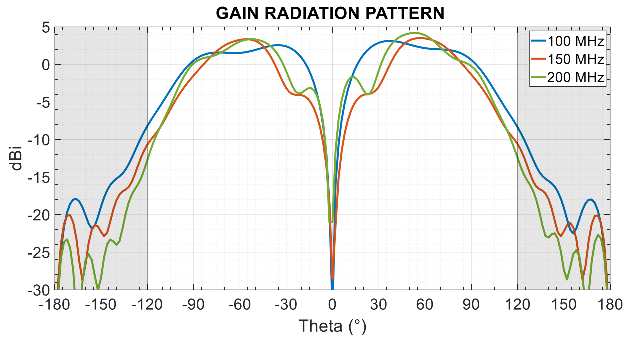

Fig. 3. Measured radiation pattern cuts of the SMC70 monocone mounted on the GP400.

B. Huygens Box Modeling

The measured FF pattern of the SMC70 monocone antenna was imported into MVG Insight software, where the IPBC was applied. Edge diffraction from the finite measurement ground plane was mitigated by superimposing the input radiation pattern with its mirrored image, effectively creating a virtual infinite ground plane [12]. This processed radiation pattern was then used to compute the HB. Following the guidelines outlined in [13], a HB with dimensions 0.9 m × 0.9 m × 0.7 m was constructed, as shown on the left side of Fig. 4. Notably, these dimensions include a 3 cm margin (equivalent to λ/100 at 100 MHz) to account for potential positioning inaccuracies of the source antenna within the measurement setup.

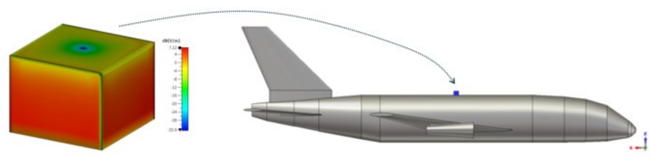

Fig. 4. Huygens box (left); integration of the Huygens box on the aircraft CAD geometry (right).

C. Placement of Huygens Boxes on an Aircraft Model

The HB of the SMC70 monocone antenna was mounted on an aircraft model with dimensions approximately 72m in length, 71m in width (wingspan), and 21m in height. The HB was centrally positioned along the fuselage, as shown on the right side of Fig. 4. Full-wave simulations were carried out using a time-domain solver [6] with a mesh resolution of λ/10 to capture the interaction between the HB and the aircraft. For validation, reference radiation patterns were obtained from full-wave simulations of the actual SMC70 antenna CAD model mounted on the aircraft, providing a benchmark for assessing HB accuracy.

D. Error Metric

The accuracy of the output radiation patterns obtained from the HB mounted on the aircraft was evaluated using the Equivalent Noise Level (ENL), defined as:

$$ENL = 20log_{10}\left(RMS\left|\frac{E(\theta,\phi) - \tilde{E}(\theta,\phi)}{E(\theta,\phi)_{max}}\right|\right) \qquad (1)$$

where $E(\theta,\phi)$represents the reference radiation pattern from the full-wave simulation of the antenna CAD model installed on the aircraft, and $\tilde{E}(\theta,\phi)$is the corresponding radiation pattern computed from the HB mounted on the aircraft.

III. Results

Fig. 5 compares the directivity patterns of the SMC70 monocone antenna in the φ= 0°cut plane (aligned with the aircraft longitudinal axis), based on three different computational approaches: full-wave simulation of the complete source and aircraft configuration (reference, black); HB generated from measured radiation pattern and integrated onto the aircraft (red); HB derived from the CAD model of the source antenna and integrated onto the aircraft (green). In the latter case, the measurement truncation effect inherent to the MPA system has been emulated to match the conditions of the measured data. This approach enables a clear separation between the intrinsic accuracy of the HB method and the influence of potential errors in the measured data, such as residual reflections, or manufacturing tolerances of the source antenna.

At 100 MHz, 150 MHz and 200 MHz, the directivity patterns generated from HBs based on measurements and emulations exhibit strong agreement with the full-wave reference. The main lobes and lower-energy radiation pattern regions are accurately reproduced, with minor discrepancies appearing mainly in the null regions. The consistency across frequencies confirms that the HB approach effectively captures the radiation behavior of the antenna installed on the aircraft.

Fig. 6 shows the ENL as a function of frequency, quantifying the deviation between full-wave reference simulations and directivity patterns obtained using two HB models: one based on measured data ($HB_{Measurement}$, red), and one based on the emulation of the source antenna including scan area truncation ($HB_{Emulation}$, solid green). The ENL remains below –30 dB across the analyzed frequency points, indicating excellent agreement with the reference.

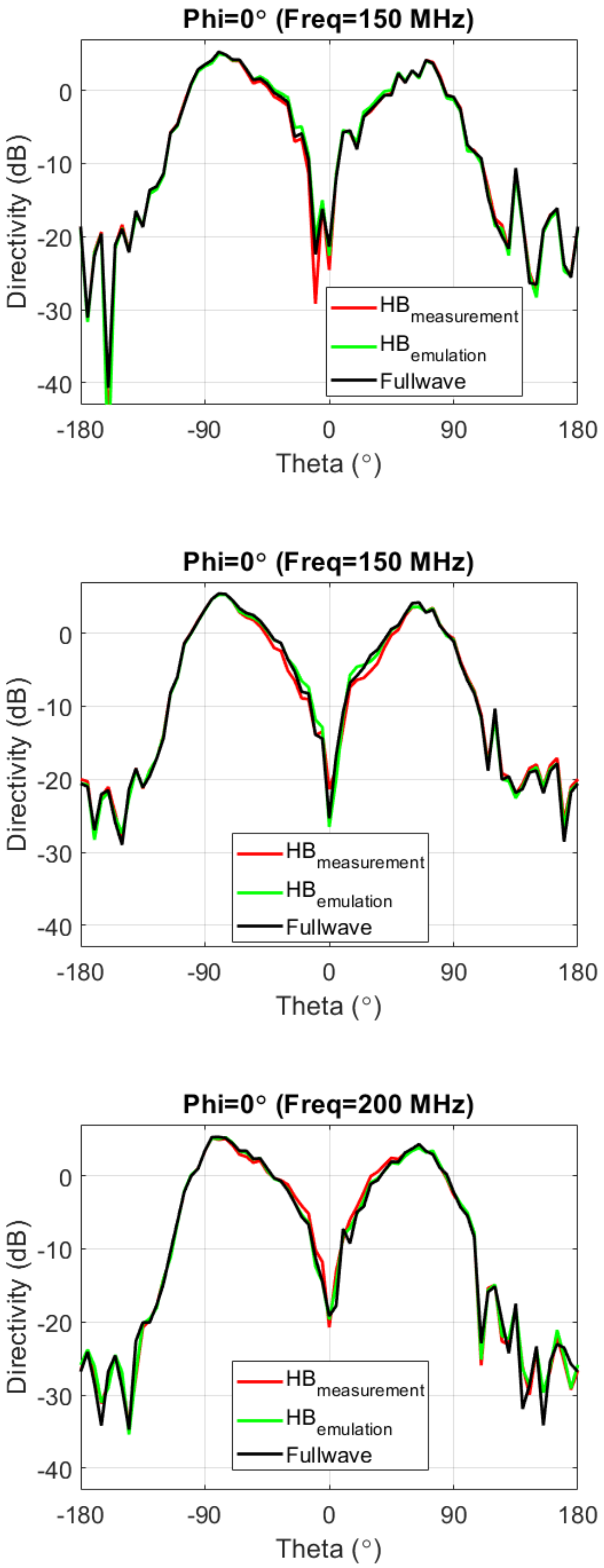

Fig. 5. Comparison of directivity pattern at 100 MHz (top), 150 MHz (middle) and 200 MHz (bottom).

Notably, especially in the lower part of the band, $HB_{Emulation}$ results closely match those from the previous parametric study [13], conducted under similar conditions of HB margin, ground plane size, and scan truncation. Differences between the two ENL curves, attributed to measurement uncertainties and minor manufacturing tolerances, are minimal, with estimated error levels ranging from -33 dB to -50 dB. This result demonstrates the robustness of the HB method against typical low-frequency measurement errors.

A third ENL curve (dotted green) represents the same emulated-based HB model but without scan truncation, allowing isolation of truncation effects, considered one of the most critical error sources when the IPBC is applied. The deviations with respect to the corresponding HB including the truncation effect range from –33 dB and –50 dB.

Overall, these results confirm that the HB method, when applied to measured data and enhanced with IPBC correction, can accurately reproduce the far-field behavior of low-frequency flush-mounted antennas. This validates its suitability for realistic aircraft integration and antenna placement studies in the VHF/UHF range, where truncation and finite ground-plane effects are significant.

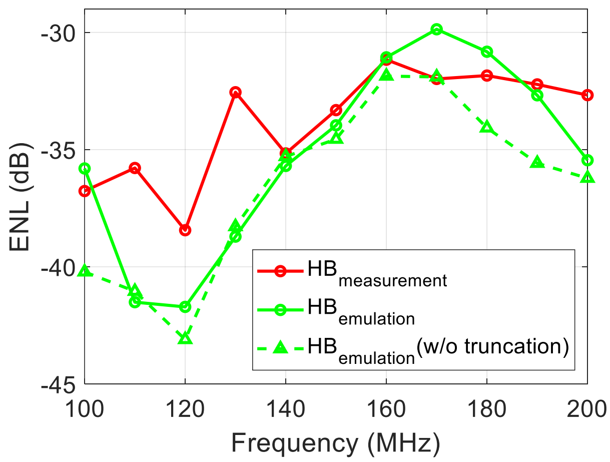

Fig. 6. Equivalent noise level versus frequency.

IV. Conclusion

Experimental evaluation confirms that the Huygens box method, when combined with the IPBC processing, can accurately reproduce the radiation characteristics of low-frequency antennas mounted on large conductive structures. Across the 100–200 MHz band, HB results show excellent correlation with full-wave simulations, reflected in consistently low equivalent noise levels. A comparative analysis using a HB derived from simulated, noise- and reflection-free data of the same source antenna reveals minimal deviations from the measurement-based HB, demonstrating the method's robustness against typical low-frequency measurement errors.

These findings highlight the HB approach as a precise and resource-efficient alternative to full CAD-based simulations. Its ability to maintain accuracy under realistic conditions makes it particularly well-suited for VHF/UHF antenna placement and integration studies on aircraft and other electrically large platforms, where effects such as ground plane truncation and measurement imperfections are non-negligible. Furthermore, by eliminating the need for detailed antenna CAD models and large-scale measurement campaigns, the HB approach significantly accelerates antenna integration and optimization workflows, thereby reducing overall development cycles.

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