Numerical Assesment & Feasibility Study of Farfield Automotive Antenna Measurement Concept

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***Abstract*— This paper presents a numerical assessment and feasibility study of a far-field (FF) measurement technique for vehicle-mounted antennas, employing a 3D movable plane wave generator (PWG). Given the physical size of standard vehicles, antennas can be considered small on a large platform, with their radiation predominantly contributed by the antenna and its immediate surroundings. This insight is leveraged to significantly reduce the size of the plane wave generator, enhancing its agility in movement. The method's feasibility is numerically investigated on a realistic vehicle with antennas in various locations. A physically displaceable PWG is employed to measure the 3D radiated performance in FF conditions. The paper details the test vehicle, introduces the 0.6-6GHz PWG, validates the assumption linking radiation to a limited area around the antennas, and reports the method's achievable accuracy through comparison with reference radiation.**

I. INTRODUCTION

Automotive antennas share a common characteristic with personal communication antennas, they are designed to radiate in a broad angular region to ensure effective communication and are often very compact in size. The comprehensive characterization of these antennas poses a challenge as they can be generalized to measurement of small antennas and devices on large platforms. Full 3D antenna/device measurements are often needed to fully understand performance of the vehicle.

Traditionally, automotive antenna testing occurs in a near-field (NF) antenna test facility, coupled with a subsequent numerical transformation from near-field to far-field (NFFF) [1]. NF testing is advantageous due to its compact facility, noise resilience, and minimal chamber interaction, making it widely recognized as one of the most accurate antenna testing techniques. However, dense sampling of the vehicle is needed, leading to extended test times but it provides the full 3D radiation pattern. Certain techniques, such as those presented in [2][3], enable far-field inspection in a limited angular range, from limited NF sampling. The measurement time can be significantly improved by adhering to multi probe technology rather than performing the scanning with a single probe [4].

For standard Over-The-Air (OTA) testing, specialized techniques are imperative to account for the finite test distance, as highlighted in [5]. The access to a highly accurate numerical model of the measured antenna device through NF testing opens avenues for various post-processing techniques, facilitating the emulation of the true environmental conditions, from different ground conditions to direct emulation of the measured vehicle in its final operating environment, often referred to as "virtual drive" [5],[3].

FF testing methodologies are often direct FF where the FF condition is achieved by ensuring a sufficient distance between the vehicle and the probe, adhering to the FF test condition criteria [3] imposing an upper bound on measurement error due to distance. While easy to implement, this method requires a large space, typically an anechoic chamber or, in some cases, an outdoor facility. Challenges include high noise levels attributed to interaction with the measurement environment and a poor dynamic range due to the considerable distance. Common for all FF testing methodologies is the requirements for tedious manual manipulation of the vehicle to be able to perform 3D testing and the standard implementation is often reduced to azimuth testing only.

An alternative, though less common, method involves the use of a tapered chamber [6], were the probe and anechoic environment enable FF condition at a reduced distance. Despite the more compact testing environment than direct FF testing, such facilities are much larger than their NF counterparts and generally permit testing only within a limited azimuth range.

Indirect far-field ranges utilize plane wave generating equipment to achieve FF testing conditions at a reduced distance [7]. The standard approach involves a reflector illuminated by a feed, transforming the spherical wavefront into a plane wave approximation at a shorter distance. However, these systems are typically much larger than the tested vehicle, requiring a large anechoic environment and the reflector edge scattering necessitates physically large countermeasures, such as rolled or serrated edges, to address measurement in the lower frequency range.

In this paper, we introduce an innovative automotive measurement concept with a movable plane wave generator (PWG). This novel approach enables the measurement of true FF performance within the constraints of a limited anechoic environment and minimal mechanical movement. The PWG, assumed a true 3D mechanical scanner captures the complete far-field radiation pattern in any desired direction, as illustrated in Fig 1. The concept is evaluated numerically to investigate feasibility and achievable accuracy.

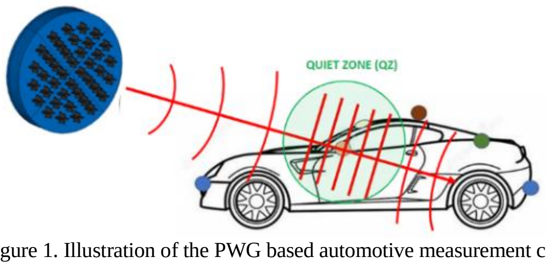
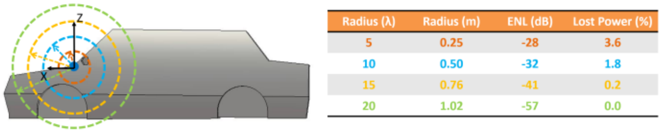


Figure 1. Illustration of the PWG based automotive measurement concept.

II. INVESTIGATION ON SOURCE OF RADIATION ON VEHICLE

The foundation of the automotive measurement concept in this paper rests on the premise that automotive antennas, given their relatively small size on a large platform, have their radiation primarily contributed by the antenna and its immediate surroundings [3]. The validity of this assumption has been investigated by numerical simulation involving a vehicle with various monocone antennas, as depicted in Fig. 2. Leveraging the spherical wave expansion of the radiated field [1], enabling to filter the source region by modal filtering, the source region of each antenna and its contribution to the total radiated power are evaluated. For instance, the numerical simulation reveals that, at 5.9GHz, approximately 98.2% of the power from a monocone antenna on a vehicle is radiated from a region with a 10λ radius or 0.5m. The Equivalent Noise Level (ENL) on the full radiated pattern, corresponding to this configuration, is measured at -32dB. This input was used to dimension the PWG for the far-field automotive antenna measurement concept.



Radius (λ)	Radius (m)	ENL (dB)	Lost Power (%)
5	0.25	-28	3.6
10	0.50	-32	1.8
15	0.76	-41	0.2
20	1.02	-57	0.0

Figure 2. Small antenna installed on a vehicle at 5.9 GHz with illustration of contribution to radiated power from immediate surroundings.

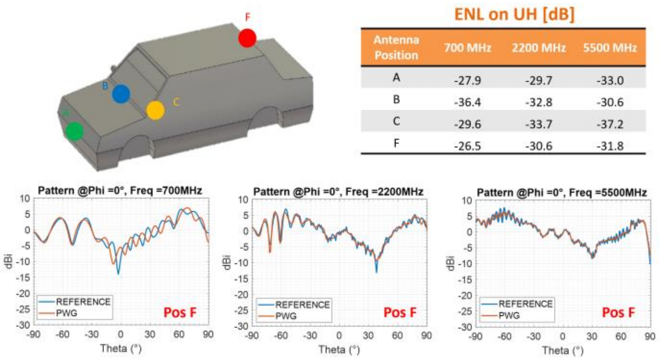
III. PWG DESIGN

The Plane Wave Generator (PWG) utilized in this investigation, illustrated in Fig. 1, is constructed with sixty Gaussian elements distributed across five rings within a diameter of 1.4m. Each element on a ring maintains equal amplitude and phase, while complex weights on each ring are enforced by an external Beamforming Network (BFN) to generate an approximated far-field (FF) condition. The FF condition is achieved at a distance of 5m within a diameter of 1.2m. Further details regarding the design concept of the PWG can be found in [8]. The approximation to true FF condition within the QZ is ±0.25 dB and ±2.2° on a sphere of 1.2m diameter in the range 0.6-6GHz. Among several design parameters, it is here highlighted the importance low PWG sidelobe in order to avoid the illumination of other parts of the vehicle and consequent distortion of the measured patterns.

IV. NUMERICAL VALIDATION OF THE FARFIELD AUTOMOTIVE ANTENNA MEASUREMENT CONCEPT.

The accuracy of the automotive antenna measurements concept depicted in Fig. 1 is assessed through measurements emulation of vehicle-based antenna by the designed PWG. Both the vehicle-based antenna and PWG radiation, described by known spherical wave coefficients, are predetermined through numerical simulations. The emulation process relies on the Spherical Wave Expansion (SWE) transmission formula, which expresses the received complex signal by a probe with known spherical wave coefficients when an antenna or device, often characterized by unknown coefficients, is transmitting [1]. In spherical near-field (NF) measurements, this equation is inverted to determine the coefficients of the measured antenna. However, leveraging the known spherical coefficients of the numerically simulated vehicle and PWG, the same equation is utilized to assess the coupling between the PWG and the vehicle-based antenna, allowing for the effective emulation of a measurement scenario.

The target vehicle, of dimension 5m x 2m x 1.8m is numerically simulated with four different monocone antennas on the front and the back of the vehicle indicated as A, B, C and F positions in Fig. 3. The measured and reference upper hemisphere (UH) radiation pattern for antenna "B" is reported at three frequencies 700MHz, 2.2GHz and 5.5GHz showing a very good correlation. The pattern correlation expressed as ENL is very good for all antenna positions and correlates well with the expected values for source radiation described in paragraph II.



ENL on UH [dB]

Antenna Position	700 MHz	2200 MHz	5500 MHz
A	-27.9	-29.7	-33.0
B	-36.4	-32.8	-30.6
C	-29.6	-33.7	-37.2
F	-26.5	-30.6	-31.8

Figure 3. Validation of the field automotive antenna measurement concept by numerical simulation. The measured and reference upper hemisphere (UH) radiation pattern for antenna "B" is reported at three frequencies 700MHz, 2.2GHz and 5.5GHz.

CONCLUSION

The farfield automotive antenna measurement concept utilizing a Plane Wave Generator (PWG) has been successfully validated through numerical simulations. Experimental exploration of this concept is ongoing, and the results will be presented in the future.

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