Experimental Comparison of Vehicular Antenna Measurements Performed over Different Floors

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***Abstract*—Large truncated spherical near-field systems with conductive or absorbing floors are typically involved in the measurement of the performances of vehicle installed antennas. The main advantage of a conductive floor systems is the ease of accommodation of the vehicle under test, but their performances are often degraded by the strong interaction with the reflecting floor. Instead, absorbing-based systems emulating free-space conditions ensure better accuracy, but generally require longer setup times, especially at lower frequencies (70-400 MHz), where bulky absorbers are typically used to ensure good reflectivity levels. Considering scaled measurements of a vehicle model, the performance of these two typical implementations are analysed in the 84-1500 MHz range and compared to free-space measurements. Absorbers with different dimensions and reflectivity have been installed in the scaled measurement setup, and measured data have been investigated with proper post-processing to verify the applicability to realistic systems.**

***Index Terms*—automotive, vehicle test, spherical near field, absorbers, PEC, reflectivity, truncation.**

I. Introduction

Spherical near-field systems installed in shielded anechoic chambers are typically involved in modern automotive antenna measurements [1-2]. Such systems are truncated at or close to the horizon, in order to host the vehicle under test while limiting the size/cost of the chamber. As shown in Fig. 1, the vehicle to be tested is placed on a metallic floor or on a floor covered by absorbing materials. The latter solution is intended to emulate a free space environment [3] and is a key factor to perform accurate measurements at low frequencies (down to 70 MHz). The availability of the free-space response also enables easy emulation of the car behaviours over realistic automotive floors with commercially available tools [4-5]. As detailed in [6], such emulations are more complex when a conductive ground is considered, and such type of floors are a good approximation of realistic grounds (such as asphalts) only in a limited number of situations. Moreover, conductive ground measurements suffer from a strong interaction between the conductive floor and the measurement system; thus, the quality of the measurements is often degraded, especially at lower frequencies. On the other hand, the main advantages of these type of systems are the ease of the accommodation of the vehicle under test, and the simplification of the NF/FF transformation [7], enabling the mitigation of the truncation errors [8].

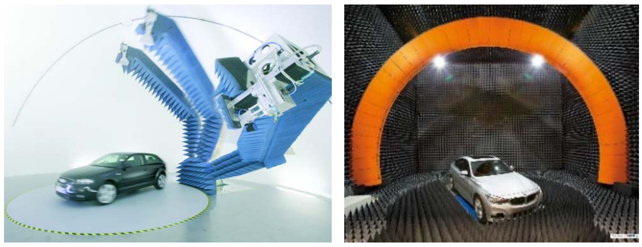

Fig. 1. Examples of automotive spherical NF systems: single probe with conductive floor (left); multi-probe with absorbing floor (right).

In this paper, measurements over conductive and absorbing floors using a scaled vehicle model and a scaled automotive system are compared to free space measurements of the same test object, in order to assess the accuracy of the different configurations. The analysis is carried out considering (scaled) frequencies relevant to automotive applications in the 84-1500 MHz range. Two types of scaled absorbers, of different size and reflectivity, are considered to emulate the behaviours of the realistic full-scale 48-inch and 18-inch height absorbers. 48-inch absorbers usually have a good reflectivity down to 70-80 MHz [9] but, due to their size, they are difficult to move, and the vehicle normally needs to be raised from the floor to avoid the shadowing effect. Consequently, more time is generally needed to setup a measurement with 48-inch absorbers, unless special “car-feeding” mechanisms are employed as shown in [3]. On the other hand, the nominal reflectivity of the 18-inch absorbers is relatively high at lower frequencies (70-400 MHz). Nevertheless, their use at such frequencies, would offer some interesting advantages including cost reduction and optimization of the time needed to setup the measurements. For these reasons they have been also included in this analysis. To deal with the poor reflectivity of the 18-inch absorbers at lower frequency, the scaled measurements are also performed with the vehicle raised from the floor; spatial filtering [6, 10] is then applied to the measured data in post-processing to mitigate the effect of the interaction with the floor.

II. EXPERIMENT DESCRIPTION

Scaled automotive measurement test scenarios with different floors like those shown in Fig. 1 have been implemented in order to compare experimentally their measurement performances. The scaled-model technique [11] has been considered. Such technique is based on the basic concept that the EM performance of a generic antenna system depends on its dimensions in terms of wavelengths (electrical size). Therefore, if the physical dimensions are divided by a factor N and the frequency is multiplied by the same factor N, the electromagnetic behaviour is maintained for fully metallic objects. The application of the scaled-model technique to this scaled automotive measurement facilitates access to full-spherical free-space data to be used as a baseline/reference in order to assess the measurement accuracy of different scenarios.

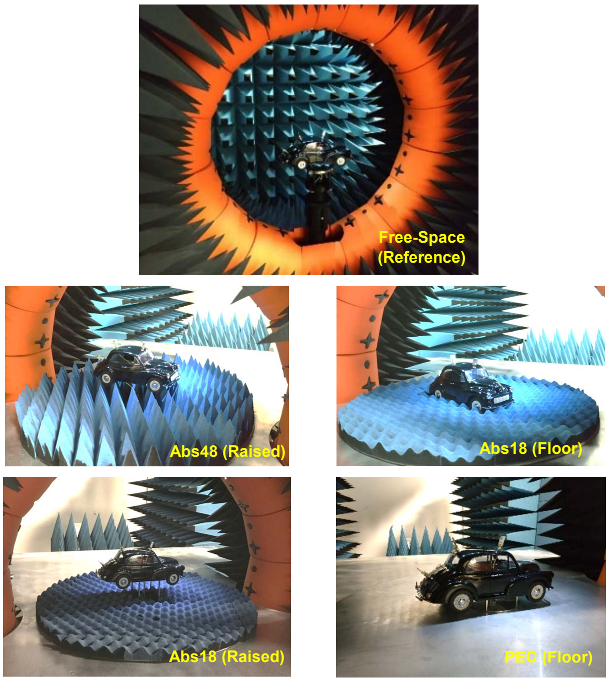

Fig. 2. Scaled vehicle measured in free space and on the different floor scenarios: 48-inch (Abs48) and 18-inch (Abs18) scaled absorbers and metallic floor (PEC).

A 1:12 scaled-car model (Morris Minor 1000 of 1965) fed by patch antennas has been measured in the StarLab-18GHz (SL18GHz) multi-probe system in different configurations (see Fig. 2). The SL18GHz is comprised of two interleaved probe arrays capable of performing measurements in the frequency ranges from 0.4-6 GHz and 6-18 GHz respectively. The measurement radius of the system is 45 cm. As can be seen in Fig. 2, three similar wideband patch antennas have been installed in three different positions on the car model: close to the windshield, on the rear part of the roof, and on the hood of the scaled vehicle, respectively. In each measurement, only one patch is fed while the other two are terminated with a matched load. Measurements have been performed in the frequency band 1.008 -18 GHz. With the considered $N = 12$ scaling factor, the performed measurements are equivalent to the ones of a full-size vehicle (real dimensions of L x W x H = 3.76 x 1.55 x 1.52 m) measured in a system with a 5.4m radius in the 84-1500 MHz band.

In this analysis, only the measurements relevant to the patch installed in the hood position have been considered. It should be noted that the chosen antenna location represents a worst-case scenario, since it is closer to the floor and possibly more coupled with it.

The scaled vehicle has been first measured in free space conditions over the full sphere, as shown in the top part of Fig. 2. Such measurements are considered as the reference.

To emulate the two typical automotive system floor conditions shown in Fig.1, a metallic ground has been introduced inside the system. Such metallic ground floor is composed by a 75-cm diameter turntable which rotates with the antenna, and by a fixed metallic part which extends outside the system. Conductive contacts have been included in the junction between the two metallic parts in order to ensure the electrical continuity. The metallic floor is placed 11 cm below the center of the scanner (corresponding to a position of 1.32 m in real dimensions) to emulate real automotive systems where the top of the car is located close to the center of the spherical scan (see also the schematic illustrations in Fig. 3). This displacement allows for measurements down to approximately 10° below the horizon (corresponding to approx. 100° of elevation scanning). Measurements over a conductive floor have been carried-out with this extended setup by placing the scaled vehicle at floor level (see Fig. 2, bottom-right and Fig. 3, left). In the data processing the metallic floor is assumed to be a Perfect Conductor (PEC).

Absorber-based systems have been emulated considering two types of absorbing materials:

- 4-inch pyramidal absorbers (Fig. 2 center-left);
- 1.5-inch convoluted absorbers (Fig. 2 center-right and bottom-left).

TABLE I. NOMINAL REFLECTIVITY AT NORMAL INCIDENCE OF THE CONSIDERED ABSORBERS [9].

Measured Frequency	Scaled (1:12) Frequency	4-inch absorbers (Abs48)	1.5-inch absorbers (Abs18)
1 GHz	83MHz	n/a	n/a
3 GHz	250 MHz	-30 dB	n/a
6 GHz	500 MHz	-35 dB	-20 dB
10 GHz	833 MHz	-40 dB	-30 dB
15 GHz	1250 MHz	-45 dB	-35 dB
18 GHz	1500 MHz	-50 dB	-36 dB

The nominal reflectivity at normal incidence of the considered absorbers is reported in Table 1. It should be noted that with this type of approach only the physical dimensions of the absorbers are properly scaled. The conductivity (losses) of the absorbers cannot be scaled (as it should be, according to the scale-model method [11]). In this specific case, the reflectivity of the considered scaled absorbers is 5 to 10 dB higher than the one of the full-size absorbers [9] meaning that a "worst-case" scenario is considered with respect to the real one. Nevertheless, this has been assumed to be a reasonable approximation, providing a representative emulation of the real scenario.

As depicted in Fig. 2, the absorbers have been placed only on the top of the turntable as done in any full-scale system of this kind [3]. The remaining part of the metallic floor has not been covered by absorbers as done in other type of absorber-based systems [3].

With the considered scaling factor ($N = 12$), the 4-inch absorbers are equivalent to 48-inch (Abs48) height full-size absorbers, which are typically used down to 70-80 MHz. Due to the height of these absorbers, the car has been raised from the floor of 7.5 cm (0.9 m in real dimensions) to avoid the shadowing effect of the absorbers (see Fig. 2, center-left and Fig. 3, right). This is a conventional displacement when absorbers with this height are used [3].

The 1.5-inch absorbers are instead equivalent to 18-inch (Abs18) height full-size absorbers. The reduced height of these absorbers enables placement of the car directly on the floor, as depicted in Fig. 1 (left), simplifying the setup phase of the measurement. Such absorbers are typically used starting from 400-500 MHz. Despite this, they have been considered over the whole tested frequency range (84-1500 MHz), since they could be an attractive solution at lower frequencies (80-500 MHz) due to their cost advantage and ease of installation with respect to the 48-inch absorbers. Scaled measurements with the 18-inch absorbers have been performed with the vehicle at two different distances from the ground:

- Vehicle on the floor ("floor" configuration) as shown in Fig. 2 (center-right); performed over the whole frequency range;
- Vehicle raised 7.5 cm (0.9 m) from the floor ("raised" configuration) as shown in Fig. 2 (bottom-left); performed in the lower frequency range (84-500 MHz);

In this case, the "raised" measurements have been performed in order to verify if the expected worse performance caused by the poor reflectivity of the 18-inch absorbers at lower frequencies can be improved by increasing the electrical separation of the vehicle from the ground, and applying a spatial filtering in a post-processing step (see [6, 10] for more details). Such raised measurements have not been performed above 500 MHz because of the well-established good behaviour of the 18-inch absorbers at such frequencies.

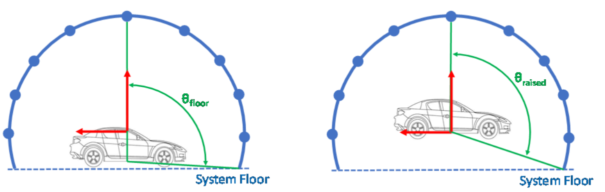

Fig. 3. Schematic illustrations of the "floor" and "raised" configurations ($\theta_{raised} > \theta_{floor}$).

Simplified illustrations of the "floor" and "raised" configurations are shown in Fig. 3. The reference coordinate system is reported in red, and is in both cases centered in the center of the measurement sphere. It is highlighted that when the car is raised, a larger "equivalent elevation" area can be covered ($\theta_{raised} > \theta_{floor}$).

As described in detail in [12], each measurement setup has been gain calibrated independently, using a horn reference antenna and applying the gain substitution technique [1].

III. Results

Results in terms of accuracy of the gain calibration and measured gain patterns of the considered scaled vehicle measured with different floor scenarios are reported in this section.

A. Gain Calibration

The accuracy of the gain calibration of the considered measurement setups with different floors has been described in detail in [12]. In this paragraph, only the main concepts and results are recalled for completeness. Each measurement setup has been calibrated using the gain substitution technique. Therefore, reference antennas with known gain/efficiency have been measured to generate reference data. It has been shown that considering the efficiency of the reference devices, it is possible to accurately calibrate each scenario independently of the floor type (absorbing or conductive). Since in absorber-based systems, the power radiated in the lower hemisphere is lost, only the efficiency relevant to the upper hemisphere (upper hemisphere efficiency) should be considered during the calibration. Conversely, in PEC-based systems the total radiated power is collected because the field on the lower hemisphere is fully reflected by the metallic floor, thus the full efficiency of the reference antenna should be used in the calibration. Following these guidelines, the obtained gain calibration error in all the considered floor scenarios and at (almost) all the considered frequencies was within 0.2 dB [12].

B. Gain Pattern Measurements

The performed spherical NF acquisitions in the different floor scenarios have been transformed to the Far Field (FF) with NF/FF transformations [2]. Free-space and absorber-based measurements have been processed with the conventional Spherical Wave Expansion (SWE) NF/FF approach [2], simply considering zero-padding in the truncated areas. The PEC-based measurements have instead been processed enforcing the PEC boundary condition during the NF/FF [7]. To do that the Translated-SWE (TSWE) technique [13] has been used to translate the reference system along the z-axis in order to have the PEC interface at $z = 0$. For each measurement configuration, the obtained patterns have been properly scaled with the gain calibration coefficients obtained during the calibrations of the system.

Elevation gain pattern comparisons along the vehicle's longest dimension at 210 MHz (scaled from 2520 MHz) is reported in Fig. 4. The blue trace is the free space measurement considered as the reference, while the blackdashed trace is the PEC-based one; the solid-red trace is the measurement performed over the 48-inch absorber; the solid-green and dashed-green traces are the measurements over the 18-inch absorbers in “floor” and “raised” configurations respectively. The latter has also been post-processed with Mv-Echo tool [10], in order to mitigate the effect of the poorer reflectivity of the absorbers. The shadowed areas indicate the unreliable FF regions associated to the scan truncation (at 100°). As expected, the deviations between the free-space and the PEC-based measurements are quite large. Instead, measurements over the 48-inch absorbers agrees well with the free space especially within $|\theta| = 90°$. More deviations are instead observable when the car is measured over the 18-inch absorber in the “floor” configuration. This is due to the higher reflectivity of the absorbers which (see Table I) is greater than -20 dB. It should be noted that in such case, due to the reduced “equivalent elevation” scanning area (see Fig. 3), the pattern levels drop down at smaller elevations angles than in the case of the measurements with the 48-inch absorbers. Instead, by raising the car over the 18-inch absorbers, the pattern exhibits the same level of free space up to larger elevation angles. Moreover, for the raised vehicle the increased electrical distance with respect to the floor and the application of the spatial filtering with Mv-Echo allow to improve the agreement with the free space.

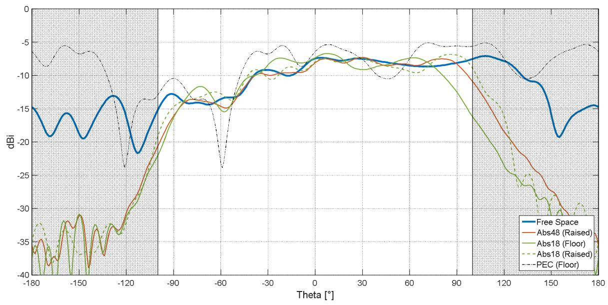

Fig. 4. Elevation gain pattern comparison at 210 MHz (scaled frequency).

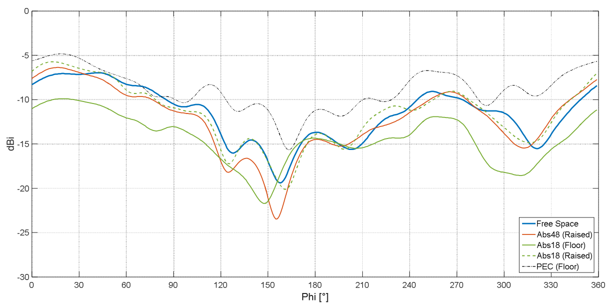

Fig. 5. Azimuth gain pattern comparison at 210 MHz (scaled frequency).

A similar comparison is reported in Fig. 5 for the azimuthal cut at 5° above the horizon (θ=85°). Even along this cut the two “raised” measurements agree well with the free space while more deviations are observed in case “floor” measurements over the PEC and the 18-inch absorbers.

Elevation and azimuth pattern comparisons along the same two cuts previously shown at 210 MHz are now reported in Fig. 6 and Fig. 7 respectively, at 1200 MHz. In this case the interaction with the conductive floor is even more evident and it shows up in the elevation pattern as a significant ripple. It should be noted that the interaction with a PEC floor can also be strongly mitigated applying a spatial filtering [6, 10]. Such mitigation is more effective at higher frequencies (e.g. 1200 MHz) and if the car is raised from the PEC floor. More details and examples regarding this topic can be found in [6]. On the other hand, at this frequency both absorbers exhibit a good reflectivity (see Table I), therefore the agreement of absorber-based with the free space measurements is good. It should be noted that also in this case a larger reliable FF area is obtained with the “raised” measurement over the 48-inch absorber because of the larger “equivalent elevation” scanning (see also Fig. 3).

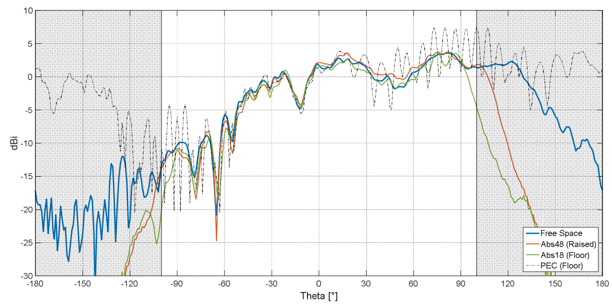

Fig. 6. Elevation gain pattern comparison at 1200 MHz (scaled frequency).

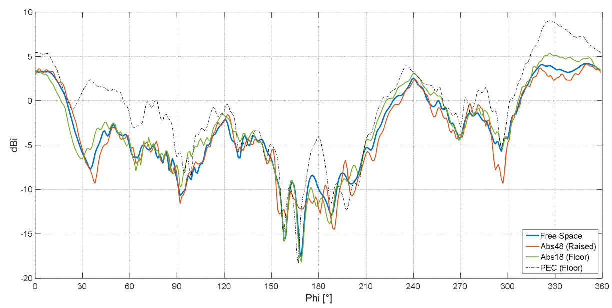

Fig. 7. Azimuth gain pattern comparison at 1200 MHz (scaled frequency).

C. *Gain vs. Frequency results*

The different measurement configurations are compared over the whole frequency band, considering the average gain evaluated on the azimuth cut at θ=85° (5° above the horizon) and the Equivalent Noise Level (ENL) defined as

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

where $E(\theta,\varphi)$ is the reference (free space) and $\tilde{E}(\theta,\varphi)$ is the test pattern. The ENL has been evaluated over the 100° angular elevation range (from the zenith down to 10° below the horizon) and over the full azimuthal range.

The average gain comparison over frequency is shown in Fig. 8, while the ENL over frequency is shown in Fig. 9. The color-code for the traces is the same as was adopted in the pattern comparisons. The large deviations of the PEC-based measurements from free space are confirmed over the entire frequency range. As expected, the best agreement with the free space is reached when the 48-inch absorbers are used. The performances of the 18-inch absorbers with the car placed on the floor are worse at lower frequencies, and gradually improves with increasing frequency. If the car is raised over the 18-inch absorbers and the spatial filtering is applied, the performance improves also at lower frequencies, almost reaching the level obtained with the bigger absorbers.

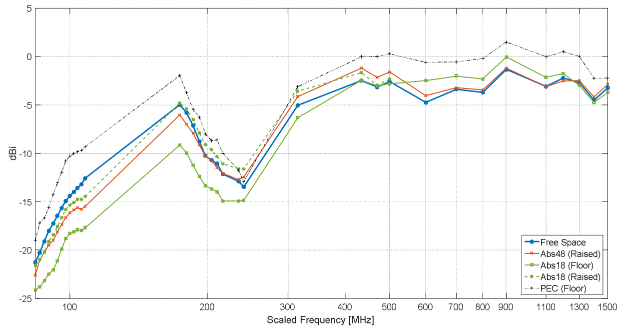

Fig. 8. Comparison of averaged gain at $\theta = 85°$ over frequency.

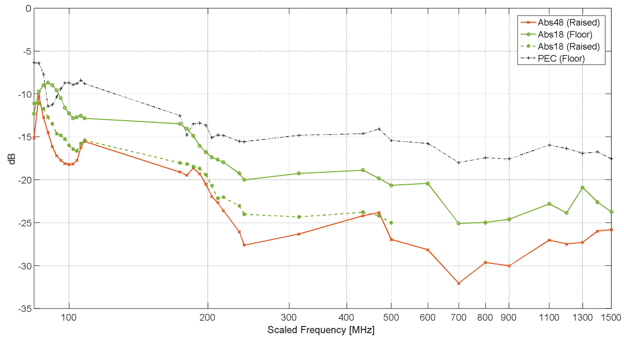

Fig. 9. Equivalent noise level over frequency (lower levels correlates better than higher levels).

IV. Conclusions

Scaled automotive measurements have been conducted in order to compare the measurement accuracies of absorber- and PEC-based spherical near-field systems in the 84-1500 MHz frequency range. Measurements in free space conditions have been considered as reference.

Three configurations have been considered: two scaled absorbers emulating 48-inch and 18-inch height full-scale absorbers, and a conductive floor. The 48-inch absorbers provide better performances at lower frequencies, but they are more expensive and lead to longer measurement setup phases because they are more difficult to handle and imply measurements with the car raised from the ground. On the other hand, the 18-inch absorbers would allow for faster measurement setups, but with a higher measurement uncertainty at lower frequencies, due to their worse reflectivity. As a practical compromise, scaled measurements with the 18-inch absorbers at lower frequencies have also been performed with the car raised from the floor, in order to reduce the interaction with the floor itself and to apply a spatial filtering in post-processing.

The main advantage of the PEC-based measurements is the ease of the accommodation of the vehicle, which is normally simply placed in the center of the system. In this paper it has been shown that such type of measurements leads to poor accuracy because of the strong interaction with the conductive floor. As shown in [6], the accuracy could be improved by raising the vehicle from the floor and applying a spatial filtering.

As expected, the scaled measurement with the 48-inch absorbers resulted in the best agreement with the free space reference. The accuracy obtained with measurements conducted with the 18-inch absorbers is good at higher frequencies but, as expected, is degraded at lower frequencies. Finally, it has been shown that by raising the vehicle from the floor and applying a spatial filtering, it is possible to improve the quality of the measurements with 18-inch absorbers at lower frequencies.

References

[1] IEEE Std 1720-2012 “Recommended Practice for Near-Field Antenna Measurements”

[2] J. E. Hansen (ed.), “Spherical Near-Field Antenna Measurements”, Peter Peregrinus Ltd., on behalf of IEE, London, United Kingdom, 1988

[3] P. Noren, Ph. Garreau, L. J. Foged, “State of the art spherical near-field antenna test systems for full vehicle testing”, EuCAP, March 2012, Prague, Czech Republic

[4] F. Saccardi, F. Mioc, A. Giacomini, L. J. Foged, “Estimation of the Realistic Ground Effect in Free-Space Automotive Measurements”, 40th AMTA symposium, Nov 2018, Williamsburg, Virginia, USA

[5] L. Scialacqua, L. J. Foged, F. Mioc, F. Saccardi, “Link Between Measurement and Simulation Applied to Antenna Scattering and Placement Problems”, EuCAP 2017, 19-24 March, Paris, France

[6] F. Saccardi, et al., “Comparative Investigation of Spatial Filtering Techniques for Ground Plane Removal in PEC-Based Automotive Measurements”, AMTA 2019, 6-11 October, San Diego, CA, USA

[7] R. A. M. Mauermayer and T. F. Eibert “Spherical Field Transformation for Hemispherical Antenna Measurements above Perfectly Conducting Ground Planes”, AMTA, October 2016, Austin, TX, USA

[8] F. Saccardi, F. Rossi, L. Scialacqua, L. J. Foged, “Truncation Error Mitigation in Free-Space Automotive Partial Spherical Near Field Measurements”, AMTA 2017, 15-20 October, Atlanta, GA, USA

[9] https://www.mvg-world.com/en/products/field_product_family/absorber-6 (accessed September 2019)

[10] https://www.mvg-world.com/en/products/field_product_family/antenna-measurement-2/mv-echo (accessed September 2019)

[11] ANSI/IEEE Std 149-1979 “IEEE Standard Test Procedures for Antennas”

[12] F. Saccardi, et al., “Accurate Calibration of Truncated Spherical Near Field Systems with Different Ground Floors using the Substitution Technique”, AMTA 2019, 6-11 October, San Diego, CA, USA

[13] L. J. Foged, F. Saccardi, F. Mioc, P. O. Iversen, “Spherical Near Field Offset Measurements Using Downsampled Acquisition and Advanced NF/FF Transformation Algorithm”, EuCAP, Davos, Switzerland, 10-15 April 2016