Experimental Investigation of Different Floor Materials in Automotive Near Field Antenna Testing

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***Abstract*—In this paper we present the results from scaled automotive spherical near field measurements of a vehicle model conducted on absorbing and conducive floors. The purpose of the study is to compare accuracies of the different floor scenarios in the 84-1500 MHz frequency range. Two different scaled absorbers are considered to emulate full scale 48-inch and 18-inch absorbers. The larger ones ensure good absorption down to 70-80 MHz but are expensive and difficult to handle, leading to longer setup time. It is thus interesting to verify the level of accuracy that can be reached by using the smaller 18-inch absorbers. To cope with the expected performance degradation at low frequencies, measurements with the vehicle in a configuration raised from the floor, combined with a spatial filtering technique, are also performed. The analysis is carried out in the StarLab multiprobe system, considered a 12-time down-scaled version of typical full-size multiprobe automotive systems. Measurement results relevant to three antenna positions on the car body are shown estimating the measurement uncertainties for the peak gain and the Upper Hemisphere Radiated Power (UHRP).**

I. Introduction

Spherical near-field systems installed in shielded anechoic chambers are typically involved in modern automotive antenna measurements [1-4]. Such systems are often truncated at or close to the horizon to host the vehicle under test while limiting the size/cost of the chamber. The vehicle is usually placed on a metallic floor [5] or on a floor covered by absorbers [3] as shown in Figure 1. The latter solution is intended to emulate a free space environment and is a key factor to perform accurate measurements down to 70 MHz. The availability of the free-space response also enables easy emulation of the car's behaviour over realistic grounds [6-7] while such emulations are more complex when a conductive ground is considered [8]. Conductive ground measurements also suffer from a strong interaction between the conductive floor and the measurement system and only in a limited number of situations such types of floor are a good approximation of realistic grounds (such as asphalts). However, the main advantage of conductive floor systems is the ease of accommodation of the vehicle under test which is simply parked in the center of the system. In absorber-based systems, instead, more time is generally needed to remove/place the absorber around the vehicle. Moreover, at low frequencies (70-400 MHz), large and bulky absorbers are normally used to ensure good reflectivity levels and the vehicle needs to be raised to avoid shadowing effect of absorbers.

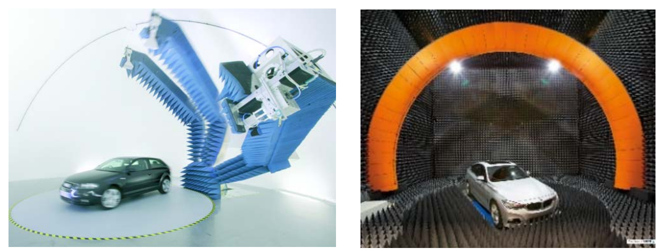

Figure 1. Examples of automotive spherical NF systems: single probe with conductive floor (left); multi-probe with absorbing floor (right).

In this paper we investigate whether the measurement setup in absorber-based systems can be simplified by using smaller absorbers at low frequencies and/or simply using conductive floors. The loss of accuracy in such scenarios is studied considering a scaled vehicle and an implemented scaled automotive system where it is possible to access to the full-spherical, "real" free-space scenario, which will be used to obtain reference data. 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 behaviour of the realistic full-scale 48-inch and 18-inch height absorbers. Measurements over metallic floor are included also in the analysis. The considered vehicle under test is the 12-time scaled car model already presented in [9], where measurement results relevant to one of the antenna positions on the car body were shown. The present paper is an extension of [9] where we present results relevant to three antenna positions on the scaled vehicle. The larger amount of data will be used to derive the measurement uncertainties for the peak gain and the Upper Hemisphere Radiated Power (UHRP).

II. EXPERIMENT DESCRIPTION

Scaled automotive measurement test scenarios characterized by different floors have been considered to compare experimentally their measurement performances. Pictures of the vehicle on different floors during the measurements are shown in Figure 2. The scaled-model technique [10] has been applied. 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 measurements allows to access to full-spherical free-space data, that could be used as a reference, to assess the measurement accuracy of the different scenarios.

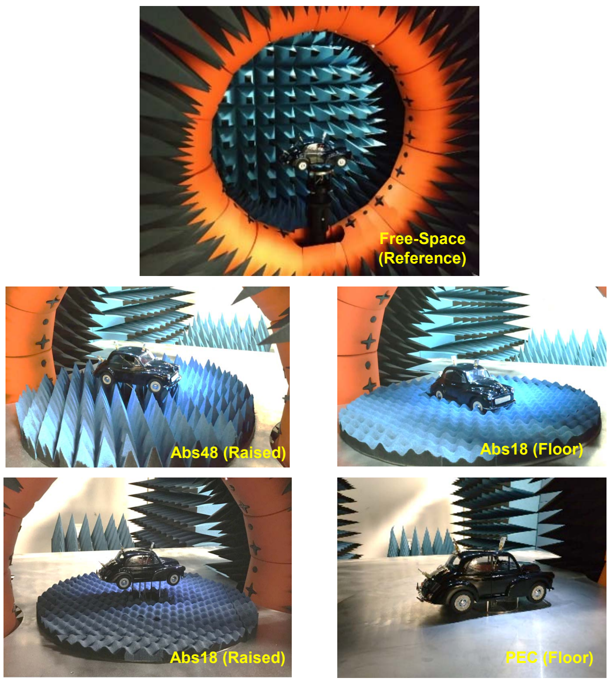

Figure 2. Scaled vehicle measured in free space and on the different floor scenarios: 48-inch (Abs48) and 18-inch (Abs18) scaled absorbers and metallic floor (PEC).

A 12:1 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 Figure 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 Figure 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 (windshield, rear-roof and hood antenna). In each measurement, only one patch is fed while the other two are terminated to 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.

To generate the full-sphere reference data the scaled vehicle has been first measured in free space, as shown in the top part of Figure 2.

To emulate the two typical automotive system floor conditions shown in Figure 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 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. 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 Figure 2, bottom-right). In the data processing the metallic floor is assumed to be a Perfect Electric Conductor (PEC).

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

- 4-inch pyramidal absorbers (Figure 2 center-left);
- 1.5-inch convoluted absorbers (Figure 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 only the physical dimensions of the absorbers are scaled while their reflectivity cannot be scaled as it should, according to the scale-model technique [10]. In this specific case, the reflectivity of the considered scaled absorbers is 5 to 10 dB worse than the one of the full-size absorbers [11] 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 Figure 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 Figure 2, center-left). 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 Figure 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 Figure 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 Figure 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 [8, 12] 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.

As described in detail in [13], each measurement setup has been gain calibrated independently, using horn reference antennas and applying the gain substitution technique [1].

III. Results

Results in terms of accuracy of the measured gain and Upper Hemisphere Radiated Power (UHRP) of the considered scaled vehicle measured with different floor scenarios are reported in this section.

A. Data Processing and Gain Calibration

The Near-Field-to-Far-Field (NF/FF) transformation has been applied to the performed spherical measurements [1-2]. 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 boundary condition has instead been enforced in the NF/FF processing of the PEC-based measurements [5]. To do that the Translated-SWE (TSWE) technique has been used as described in [14] to properly account for the position of the PEC interface.

Gain calibration measurements have been performed in each considered floor setup to apply the substitution method [1] and retrieve the gain and efficiency of antennas installed in the scaled vehicle. The details of such calibration measurements, together with a discussion on the achieved calibration accuracy can be found in [13]. To briefly recall the main outcomes, it was shown that the efficiency of the reference antennas can be used 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, UHE) should be considered during the calibration. On the other hand, 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 was within 0.2 dB in all the considered floor scenarios [13].

B. Gain Results

Examples of gain patterns obtained from the measurements over the different floors are reported in Figure 3. Due to the limited space, only the azimuthal cuts at 5° above the horizon (θ=85°) at 100 MHz (scaled from 1200 MHz) are shown here. More pattern results can be found in [9].

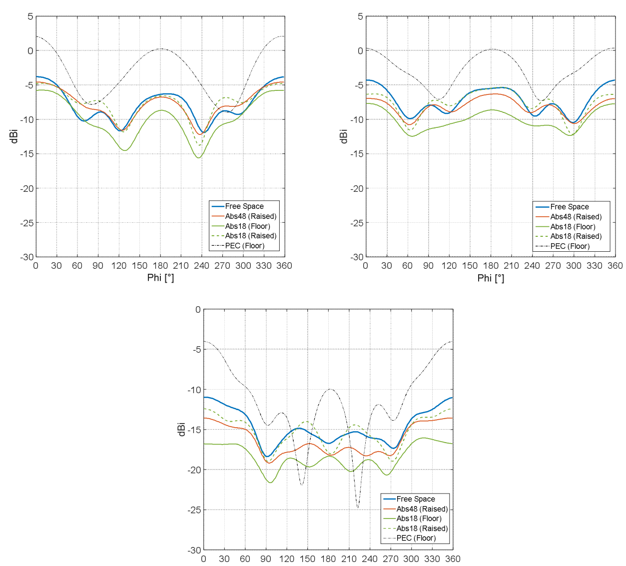

Figure 3. Azimuth gain pattern comparison at 100 MHz (scaled frequency). Windshield (top-left), rear-roof (top-right) and hood antenna (bottom).

The two plots on the top of Figure 3 show the pattern comparison for the windshield and rear-roof antenna, respectively, while the one on the bottom reports the one of the hood antenna. In each plot, the blue traces are the free space measurement considered as the reference, while the black-dashed traces are the PEC-based ones; the solid-orange traces are 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 [12], to mitigate the effect of the poorer reflectivity of the absorbers (modal/spatial filtering). 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 with the windshield and rear-roof antennas where the dynamic range is higher. 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 is worse than -20 dB (see Table I). Finally, it can be observed that by raising the car from the floor and applying Mv-Echo it is possible to improve the accuracy of the 18-inch absorber measurements.

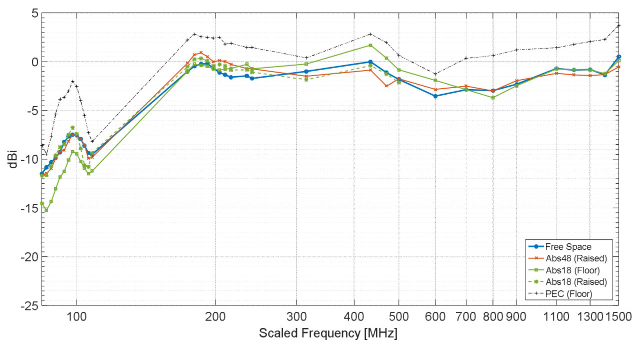

Figure 4. Windshield antenna: comparison of averaged gain at $\theta = 85°$ over frequency.

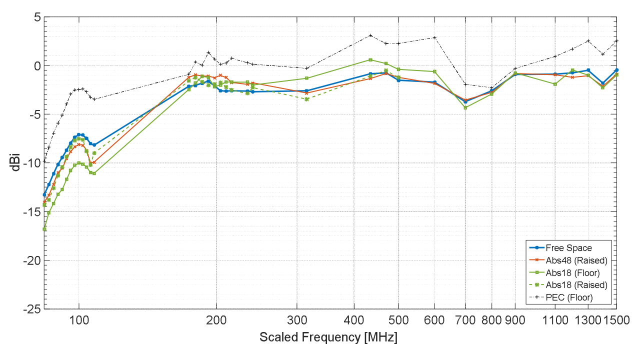

Figure 5. Rear-roof antenna: comparison of averaged gain at $\theta = 85°$ over frequency.

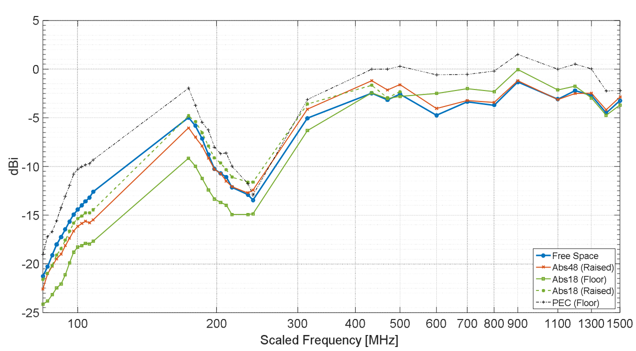

Figure 6. Hood antenna: comparison of averaged gain at $\theta = 85°$ over frequency.

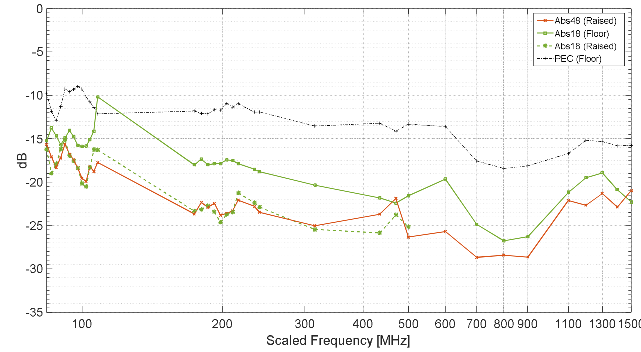

Figure 7. Windshield antenna: ENL over frequency (lower levels correlates better than higher levels).

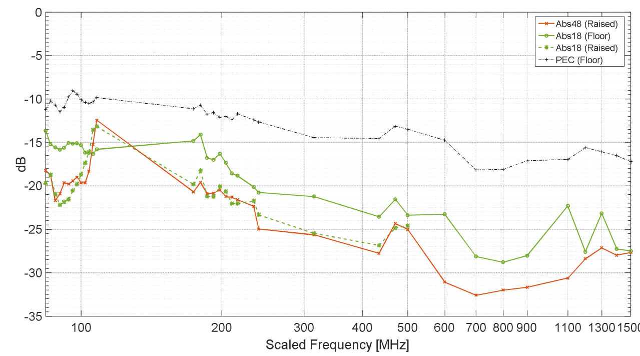

Figure 8. Rear roof antenna: ENL over frequency (lower levels correlates better than higher levels).

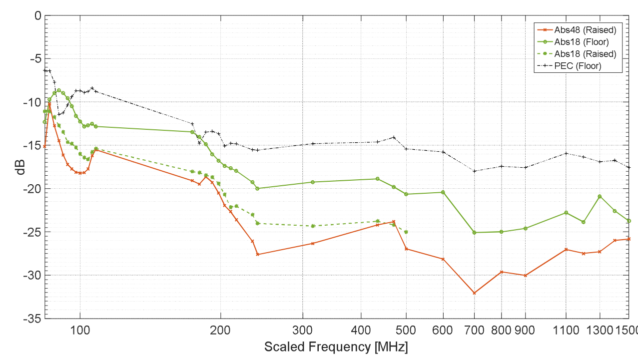

Figure 9. Hood antenna: ENL over frequency (lower levels correlates better than higher levels).

The different measurement configurations and measured antennas are compared over the whole frequency band, considering the average gain evaluated on the azimuth cut at θ=85° (5° above the horizon). Such comparisons are reported in Figure 4, 5 and 6, respectively for the windshield, rear-roof and hood antennas. The same color convention previously used for the pattern comparison has also been adopted here. The large deviations of the PEC-based measurements from free space are confirmed over the entire frequency range and for each considered antenna position. 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 the increasing frequency. If the car is raised over the 18-inch absorbers and the spatial filtering is applied, the performances improve also at lower frequencies, almost reaching the level obtained with the bigger absorbers. This behaviour is also observed for each considered antenna position.

The Equivalent Noise Level (ENL) has also been evaluated for each considered measurement scenario and antenna position. The ENL is 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 gain pattern (free space) and $\tilde{E}(\theta,\varphi)$ is the test gain 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 (from 0° to 360°). The ENL comparisons are reported in Figure 7, 8 and 9, respectively for the windshield, rear-roof and hood antennas. The behaviours of the different floors previously observed with the averaged gain are here confirmed considering the ENL as metric for each antenna position. In particular, the improvements of the 18-inch absorber measurements, when the car is raised from the floor and Mv-Echo is applied, are remarked. The achieved error levels of such measurements are comparable with the ones obtained with the 48-inch absorbers.

C. Upper Hemisphere Radiated Power Results

The Upper Hemisphere Radiated Power (UHRP) results are reported in this section. The UHRP is defined in [15] and is often used in automotive measurements as figure of merit for the antenna coverage above the driving ground. When the antennas are tested together with their generator (active measurement) the UHRP is measured directly and is expressed in dBm. In this study, passive measurements are performed using a Vector Network Analyzed (VNA), hence the obtained UHRP are normalized to the input power (dimensionless quantity). In other words, the Upper Hemisphere Efficiency (UHE) is actually measured. The UHE is directly proportional to the UHRP, thus it is interesting to compute it in the different floor scenarios, as they will affect the UHE and the UHRP in the same way. The UHE (or normalized UHRP) comparisons are shown in Figure 10, 11 and 12, respectively for the windshield, rear-roof and hood antennas. As can be seen the PEC floor overestimate the UHRP as all the power radiated toward the floor is reradiated in the upper hemisphere. Good UHRP agreements are instead obtained between the free space and each measurement performed over the absorbing floor. It should be noted that especially at lower frequencies such UHRP results are better than the gain results reported in the previous section. This is a direct consequence of the fact that the UHRP is an integral quantity and thus is less sensible to measurement perturbation such as ground reflections and truncation errors [16] as discussed in [13].

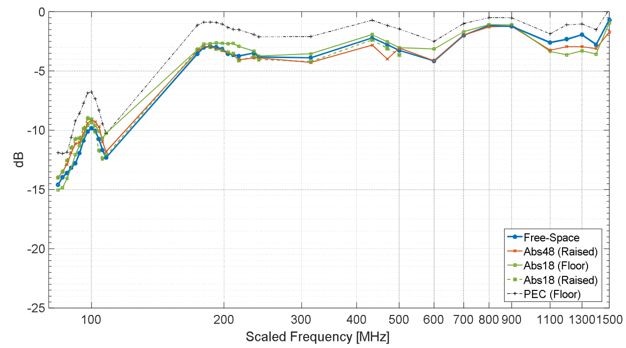

Figure 10. Windshield antenna: Normalized UHRP over frequency.

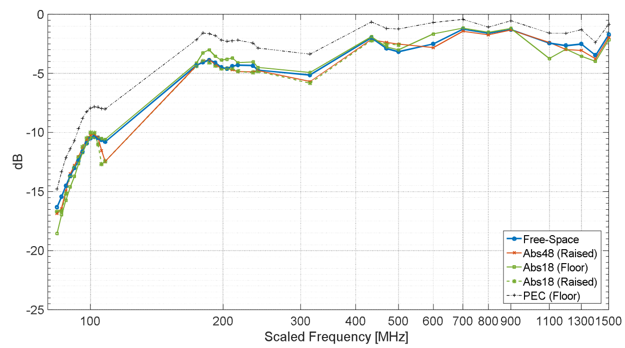

Figure 11. Rear roof antenna: Normalized UHRP over frequency.

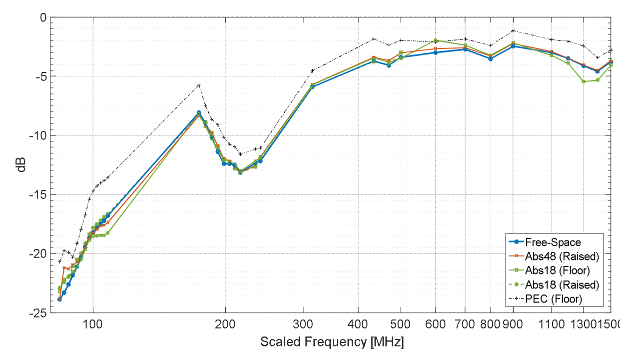

Figure 12. Hood antenna: Normalized UHRP over frequency.

IV. UNCERTANTY ESTIMATION

The estimation of the peak gain and UHRP uncertainty for the different floor scenarios are shown in Table II and III, respectively. Such estimations have been performed independently in the low (LF, 84-315 MHz) and high (HF, 434-1500 MHz) frequency bandwidths.

For the peak gain uncertainty, the ENLs previously shown have been considered, and for each frequency point and antenna position the corresponding peak-to-peak (P2P) errors at 0 dB level (the peak of the pattern) have been computed. The RMS errors have then been computed combining the errors in the specific bandwidth and for each antenna position. It should be noted that in the LF band the uncertainty of the 48-inch absorbers measurements and the one with the 18-inch absorbers with the raised vehicle are comparable. The uncertainty is instead higher if the 18-inch absorbers are used with the vehicle on the floor.

The UHRP uncertainties has been computed in a similar way, by first computing the delta between the reference and test UHRP and then evaluating the RMS errors combining the errors in the specific bandwidth and for each antenna position. At LF, the UHRP uncertainties for each absorber-based measurement are comparable and are lower than the gain uncertainty. Again, this is due to the fact that the UHRP is an integral quantity and thus is less sensible to some measurement errors [13]. At HF, the effects of the reflections and the truncation errors are lower, indeed the gain and UHRP uncertainty are similar. Finally, the gain and UHRP uncertainty of the PEC-based measurements are as expected higher and comparable in both bandwidths.

TABLE II. ESTIMATED PEAK GAIN UNCERTANTY IN THE DIFFERENT FLOOR SCENARIOS (1 SIGMA)

Band [MHz]	**P2P RMS error [dB]**			
	Abs48 (Raised)	***Abs18 (Floor)***	***Abs18 (Raised)***	***PEC (Floor)***
84-315	2.0	3.0	2.3	4.3
434-1500	0.9	1.2	n.a.	2.6

TABLE III. ESTIMATED UHRP UNCERTANTY IN THE DIFFERENT FLOOR SCENARIOS (1 SIGMA)

Band [MHz]	**P2P RMS error [dB]**			
	Abs48 (Raised)	***Abs18 (Floor)***	***Abs18 (Raised)***	***PEC (Floor)***
84-315	1.2	1.4	1.4	4.7
434-1500	0.8	1.3	n.a.	2.5

V. CONCLUSIONS

Scaled measurements of a car model fed by three antennas in different positions have been conducted to compare the accuracies of absorber- and PEC-based spherical near-field measurements in the 84-1500 MHz frequency range. Measurements in free space conditions have been considered as reference.

Two scaled absorbers floor configurations emulating 48-inch and 18-inch height full-scale absorbers have been considered. The 48-inch absorbers provide better performances at lower frequencies, but they are more expensive and lead to longer measurement setup phases. 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.

PEC-based measurements have also been performed. The main advantage of such measurements is the ease of the accommodation of the vehicle, but higher uncertainty is expected due to the strong interaction with the conductive floor. This has been confirmed in this study. As shown in [6], the accuracy of such measurements could also be improved by raising the vehicle from the floor and applying a spatial filtering.

As expected, it has been shown that at lower frequencies, the gain accuracy of scaled measurements with the 48-inch absorbers is better than the one obtained with the 18-inch absorbers. Nevertheless, 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. The normalized UHRP (or upper hemisphere efficiency) results have also been presented. Since the UHRP is an integral quantity, measurement errors like reflections and truncation tend to be averaged out [13]. In fact, it has been shown that, in case of absorber floors, the accuracy of the UHRP at lower frequencies does not change significantly with the different type of absorbing material and is better than the gain accuracy.

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