Chambers for the Evaluation of Vehicle Mounted Antennas

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***Abstract*— The increasing demand for sensors and systems that use RF communication in one form or another in modern vehicles is driving the growing degree of complexity and control system density. For many of these systems, it is necessary to perform some level of individual performance evaluation that may involve an over the air component in the performance assessment. Although this may be just one aspect of the overall system operation, it could be a vital part since there are many external environmental factors outside the control of the system that could have a profound impact on performance. The importance of over the air propagation for sensors and infotainment, including the legacy radio channels has intensified the need for measurement facilities with enhanced sensitivity, capability and increased frequency coverage. One of the developing test techniques are presented along with a discussion on the merits of free space versus measurements over a reflective and lossy ground plane.**

***Index Terms*—Automotive antenna, Full vehicle antenna pattern, embeded antenna, propagation, measurement, tapered chamber.**

I. INTRODUCTION

The development of autonomous vehicles has been a latent adoption by many of the legacy vehicle manufacturers around the world, but has served as a key design objective for some of the comparatively new designers and manufacturers in the automotive manufacturing market. A key component of vehicle autonomy will be the use of systems with the ability to acquire spatial information from which a reasonably detailed map of the immediate environment. Where this information on the surrounding environment needs to be acquired in a reasonable amount of time. The sensitivity of the system to the elapsed time from initial acquisition to action, will depend on the type of action if any that needs to be taken as a result of the acquisition. A collision avoidance system for example, is typically designed to reduce the vehicle speed as quickly as possible to avoid a collision all together, or at least reduce the speed at collision. This means that the brakes are under the control of the system and overall response time is a critical component of the effectiveness of the system.

Many manufacturers have started rolling out elements of these sensory performance features as part of the growing adoption of advanced driver assistance systems (ADAS), aimed at sharing the burden and even removing some responsibility from the driver. While some of these ADAS features provide convenience and reduce driver load, the significant contributors are designed to reduce the risk of collision with other objects or pedestrians, thereby reducing the number of incidents and accidents caused by driver error. Three of the current and most widely adopted ADAS features include adaptive cruise control (ACC), lane departure warning (LDW), and autonomous emergency breaking (AEB). Most of these are being implemented under different manufacturer specific definitions, with varying degrees of sensory and control functionality, but perform basically similar functions in terms of their design objectives, the types of sensors used, and the vehicle control functions that may be affected.

A significant part of the implementation of these features is based on the use of on-board sensors of different types that map different components of the environment. The most relevant portions of this information is then presented to the control system for analysis, interpretation and action. The validity of the decisions made by the control system is in large part dependent on the quality and fidelity of the information received by the various sensors. In the systems that rely on RF propagation, the performance of the antenna is an important component in the overall over the air behavior. Although the gain and transmit power can be measured from the antenna pattern, there are other feature related measurements that can also be performed as discussed later.

II. ANTENNA TEST FACILITIES

There are different types of antenna measurement facilities in common use for measuring the pattern of passive and active antennas and arrays. The type of facility used for any particular pattern measurement depends in large part on the type of antenna under test and the operating frequency range of interest. In all of the measurement systems, the aim is to derive the radiating pattern of the antenna in the true far field of the antenna, which is understood to be the distance beyond which the pattern of the antenna does not change with distance. The measurement facilities include different types of free space ranges which include the far field outdoor range, far field indoor range, and compact range. Then there are a number of options for near field ranges, or some combination of these. The far field ranges are characterized as having a measurement range length (r) related to the aperture (D) of the antenna under test (AUT) and wavelength by the simplified in relationship in (1) [1].

$$r \geq 2D^2/\lambda \ \ or\ \ 3\lambda \qquad (1)$$

In the context of vehicle testing, the aperture of the AUT could effectively be the entire vehicle at low frequencies. Indoor far field ranges [2] are typically built in RF shielded rooms with RF absorber material lining all of the internal surfaces of the chamber to reduce reflections to an acceptable level. At frequencies where the chamber can be made large enough to meet the requirements of (1), a measurement antenna can be positioned at one end of the chamber and the AUT mounted on a multi axis positioner as shown in Fig. 1. The compact range can also be installed in an absorber lined chamber and lends itself very well to high gain antenna measurements. The use of the reflector to create the planar wavefront significantly reduces the range length needed and the lowest operating frequency range is limited by the practical size limitations of the reflector.

Near field (NF) measurement systems [3] make use of a measurement probe moved over a surface surrounding the AUT at a distance of at least one to four wavelengths from the antenna aperture. For a discrete version of the measurement, the magnitude and phase is sampled at a number of discrete points in space over a planar, cylindrical or spherical surface about the AUT. This data is then transformed from the points in the near field to give the points in the far field. The near field measurement technique requires spatial measurements to be made at intervals of less than $\lambda/2$ to satisfy the Nyquist theorem and this drives the accuracy of the positioning systems needed. Although the sensitivity of the system to accuracy increases with frequency, it has the advantage of supporting measurements on large aperture antennas with very short measurement distances. Another benefit is the ability to use advanced gating techniques to reduce errors due to the measurement environment. NF measurements are made using planar, cylindrical or spherical scans and the type of scan can be selected based on the type of pattern of the AUT.

The various communication systems used in the automotive industry, cover a wide frequency range that according to the office of spectrum management in the US, extends from around 535 KHz for the AM radio band [4], through to broadcast TV from 54MHz. The FM band starts from 88MHz to about 108MHz. More recent communication bands, include cellular from the 700MHz band with allocations up to 5.7GHz. The GPS system used in the US operates from 1.2GHz, with other GNSS systems operating from 1.1GHz to 1.6GHz. Wireless LAN allocations use the 2.4GHz and 5.6GHz bands.

The 5.9GHz band (5.850GHz to 5.925GHz) has been allocated for Dedicated Short Range Communication (DSRC) in the US, covered under the IEEE 802.11P standard. This is intended to support the emerging vehicular networks to be used as part of the developing Intelligent Transport System (ITS). Vehicle to vehicle (V2V) and vehicle to everything (V2X) are an important part of this communication link with implications for an early warning element of collision avoidance and other safety related, convenience and maintenance features.

Several of the ADAS systems mentioned earlier, use RADAR as a key component in the detection and measurements performed as part of their operation. The operating frequency bands cover the older 24GHz with newer systems using the 79GHz and 81GHz bands. Other detection and measurement techniques used are based on LIDAR, vision/video and ultrasound.

There is a broad range of RF frequencies used in the various infotainment, ADAS, autonomous and navigation systems installed in modern vehicles. In all of these cases, some performance evaluation of the complete system is necessary, and this is done at different stages, including at module level and also at full vehicle level.

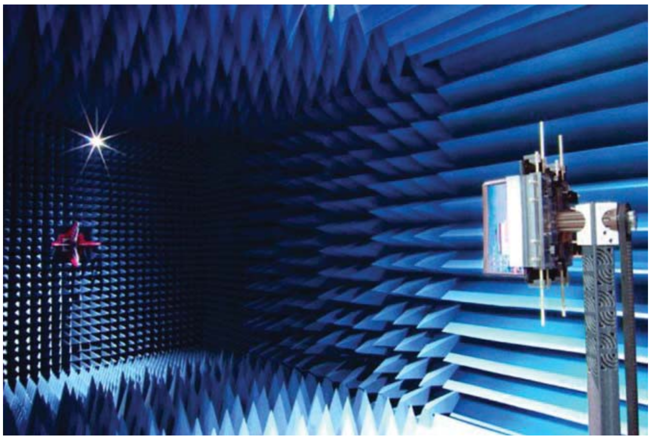

Fig. 1. Typical Far field antenna chamber.

III. LOW FREQUENCY ANTENNA MEASUREMENT

Traditional tapered far field chambers have been used for several decades for the measurement of antenna patterns. They rely on the images of the source antenna at the taper acting as an array to create a planar wavefront at the quiet zone. The symmetry of the chamber and absorption from the absorber lined surfaces are also critical in controlling the resonances due to reflections. The AUT is then positioned on the chamber center line for optimum performance.

For vehicle mounted antennas, the setup requirements are a little different in some cases. The antennas used for FM and other broadcast reception are typically mounted in one of several locations on a vehicle. The most common mounting locations are at high level in the rear windshield, on the roof or trunk lid. Depending on the size and type of antenna, the radiating performance can be influenced by the location of the radiating elements relative to the ground plane, especially if the ground plane is not an inherent part of the antenna structure. The size of the ground plane is also dependent on the operating frequency and this can be appreciable for low frequency antennas.

The antennas used for the FM bands through most of the terrestrial bands up to 1GHz, when mounted on a vehicle are expected to perform adequately at distances that are relatively close to the ground in some cases less than 1m. We therefore looked at the influence of the floor treatment on the performance of a tapered anechoic chamber, in the area where the antenna measurements are to be made with the AUT mounted relatively close to the ground. In the case of this vehicle chamber analysis, we are more interested in the behavior of the vehicle mounted antenna in an environment that more closely represents the use case.

In characterizing the performance of a chamber, the behavior of the wave in the quiet zone can be measured. In an ideal chamber where only the direct wave arrives in the quiet zone (QZ), a transverse scan across the wavefront should show little variation in magnitude and phase. In a real chamber, there will be some RF energy reflected from all surfaces of the chamber and this reflected energy arrives in the QZ to form an interference pattern. The severity of the unwanted reflections can be measured in the magnitude of the ripple.

The chamber shown in the model layout in Fig. 2 has overall dimensions of 50m x 20m x 12m high. The test volume considered is 7m wide and positioned at a height of 2.5m above the chamber floor. The side walls, and ceiling are modelled as covered with 36" pyramidal absorber material. The rear wall is covered with 72" pyramidal absorbers. The dielectric properties of the different absorbers are based on modelling and measured data. A source antenna is positioned at the apex and modelled as a very large high gain antenna horn including the calculated pattern information. This is used for the analysis over the 400MHz to 1GHz frequency range. The quiet zone was scanned in three planes, (a) Transverse over ± 3.5m from the chamber center line, (b) ± 3.5m from the test volume center line and (c) ± 2.0m about the AUT height of 2.5m over the entire frequency range. The three scans were performed for three different floor treatments where the floor coverage was changed over the entire floor surface. The floor conditions were a perfect electrically conducting (PEC) floor, a lossy floor and an absorber lined floor.

The lossy floor is modelled as covered with a lossy material with dielectric properties of 5.6 dielectric constant and 0.1 loss tangent. For the absorber lined floor the 36" pyramidal absorber is modelled.

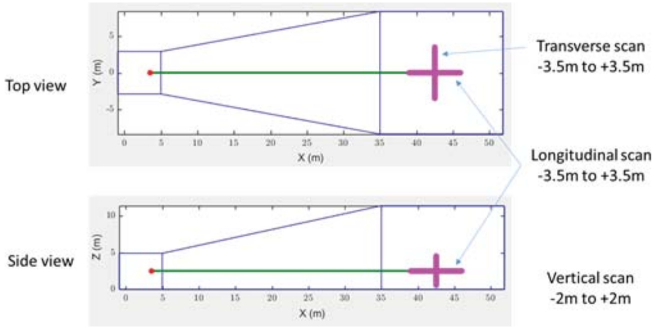

Fig. 2. Model layout of semi tapered Chamber.

IV. RESULTS

For the transverse scan, the results show little change in the magnitude of the ripple for the three different floor treatments. This is likely because the phase relationship between the direct and reflected rays remain largely unchanged across the scan plane for the different floor treatments. This suggests that most of the ripple is caused by reflections from the floor with little influence from the walls. The resonance plots shown in Fig. 3, 4, and 5 show little variation in the ripple magnitude for both the horizontal and vertical polarizations. Note that the plots show the normalized ripple for the three floor conditions, but does not show the relationship with the average power received, which as expected is greatest for the PEC and least for the absorber lined floor where the absorption provided is greatest.

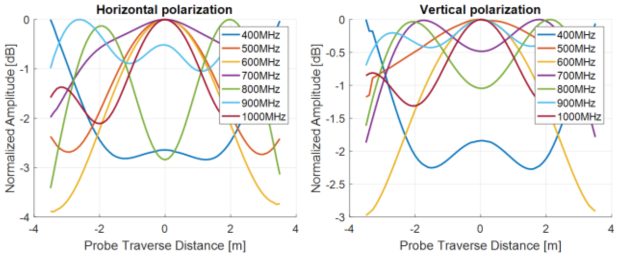

Fig. 3. Transverse scan with PEC floor.

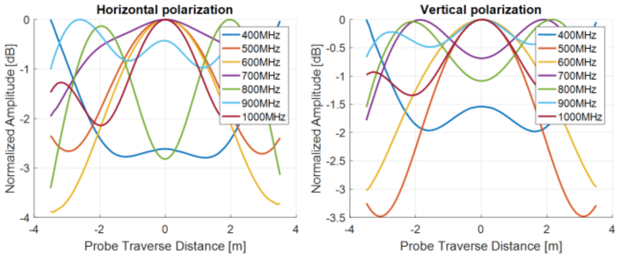

Fig. 4. Transverse scan with Lossy floor

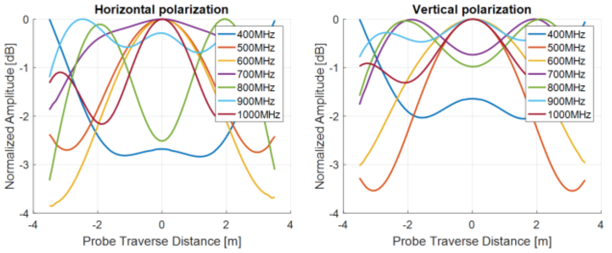

Fig. 5. Transverse Scan with Absorber treated floot

The longitudinal scan measured the resonant behaviour along the 7m section on the center line of the chamber. This showed a very different result. For the horizontal polarity, the madnitude of the ripple was seen to vary from 10.4dB for the PEC floor (Fig.6), to 8.4dB for the lossy floor (Fig.7) to 5.9dB for the absorber treated floor shown in Fig.8. For the vertical polarity, the variation was even greater where there was a resonant peak of 46dB at 500MHz for the PEC floor, 3.5dB. and 5.7dB for the absorber treated floor. It is clear from the plots that the periodicity appears to be outside of the scan range and the peak magnitudes measured may not be a true reflection of worse case condition. The 46dB resonance seen in Fig.6 is caused by a null that coincidentally falls within the scan range at 500 MHz.

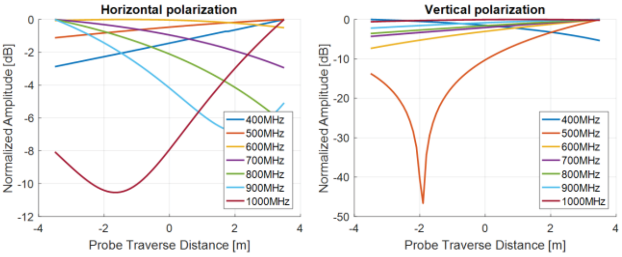

Fig. 6. Longitudinal scan with PEC floor

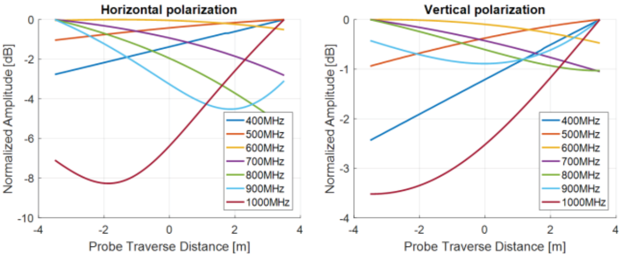

Fig. 7. Longitudinal scan with lossy floor.

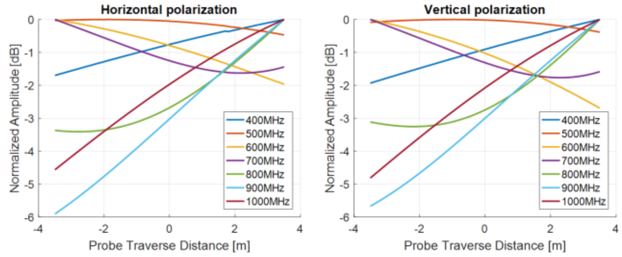

Fig. 8. Longitudinal scan with absorber treated floor.

The vertical scan shows a ripple magnitude variation from 22dB for the PEC floor (Fig.9), through 17dB for the lossy floor (Fig.10), to 8.8dB for the absorber lined floor (Fig.11) over the horizontal polarization. For the vertical polarization, the variation is from 40dB to 9dB to 10dB. It is again clear from the plots of both the horizontal and vertical polarity that the scan is through an assymetrical region of the interference pattern with the largest ripple potentially falling outside of the scanned plane. For the vertical polarity the largest deviation is measured at the minimum height of 0.5m above the floor.

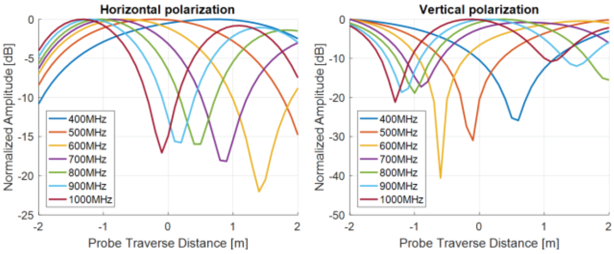

Fig. 9. Vertical scan with PEC floor.

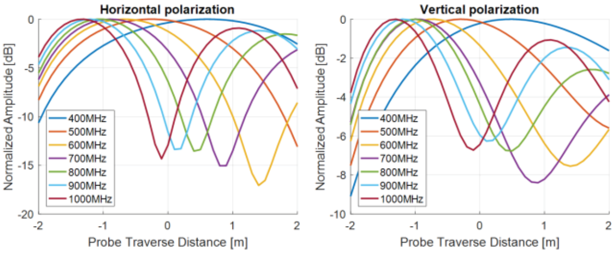

Fig. 10. Vertical scan with lossy floor.

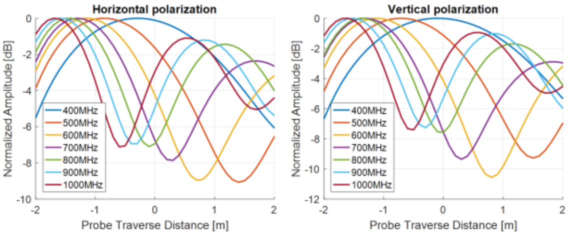

Fig. 11. Vertical scan with absorber treated floor.

V. CONCLUSIONS

The measurement of an antenna pattern while the antenna is mounted close to a reflective ground plane, is likely to differ greatly from the true free space performance due to resonances caused by the interaction of the direct ray and the dominant floor reflections. While it is clear from the simulation that the absorber lined floor reduces the magnitude of the reflected ray, at low frequencies, the limited absorption provided at the large incident angles could still result in significant amounts of ripple. The more relevant difference in antenna behaviour when the antenna is mounted close to a more reflective ground can certainly be seen. At low frequencies where far field distances could be several tens of meters, the interactions between the direct and reflected rays could be appreciably different to interactions that could be seen in the shorter range lengths used in typical measurement ranges. There may be some merit in performing antenna pattern measurements over a partially reflective ground plane since this is likely to be more representative of the real world use case. However, the potential for large errors in the measured pattern due to some of the high Q resonances seen could be misleading and merit further investigation.

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