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An Investigation into the Errors in the CISPR 12 Full Vehicle Radiated Emissions Measurements Due to Vehicle Directivity

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***Abstract*—This paper investigates the errors in the current CISPR 12 full vehicle radiated emissions tests due to the vehicle directivity . CISPR 12 measurements are performed using a fixed geometrical configuration, this method is different to many other radiated emissions standards where receive antenna height scan and device under test azimuth rotation through 360 degrees is employed in an attempt to maximise the emissions recorded. Numerical results of a simplified vehicle body shell are discussed. Data recorded between 100 MHz and 500 MHz shows that the current CISPR 12 test method potentially under-estimates the emissions levels by up to 17dB for a representative body-shell model, suggesting that the existing version of CISPR 12 may require further development in order to more closely determine the maximum amplitude of the emissions signature of the vehicle, within the measurement environment being utilised.**

I. Introduction

Any electronic device can be considered to be an unintentional transmitter of radio frequency energy. This energy will propagate away from the device with unknown directions and amplitudes, in order to ascertain the direction at which the maximum amplitude occurs a full spherical scan of the device with the measurement system is required. This method is both costly and time consuming. The aim of performing radiated emissions measurements of a device is to attempt to record the maximum amplitude of the emissions, however, due to the time and cost involved in performing a full spherical scan a reduced measurement method is normally utilised.

The current international standard used when measuring the radiated disturbance from vehicles is CISPR 12 [1]. The standard sets out to :-

> 'Provide protection for broadcast receivers in the frequency range of 30 MHz to 1000 MHz when used in the residential environment'.

The methodology stated within CISPR 12 differs from many other Standards (EN 55022 [2], CISPR 16-2-1 [3], ANSI 63.4 [4] for example) in a number of ways. The two parameters that have possibly the largest effect on the overall emissions signature recorded are the orientation of the receive antenna with respect to the vehicle and the height of the receive antenna above the measurement facility groundplane. The receive antenna is positioned normal to the side of vehicle, in line with the centre of the engine block at a preferred distance of 10 m ($\pm 0.2m$), see Figure 1 for details. A distance of 3 m ($\pm 0.05m$) may be used as long as the length of the vehicle is not greater than the 3dB beamwidth of the receive antenna. The height of the receive antenna is fixed at 3 m ($\pm 0.05m$) for the 10 m measurement distance or 1.8 m ($\pm 0.05m$) in the case of a 3 m measurement distance. The majority of other international standards (EN 55022 [2], CISPR 16-2-1 [3], ANSI 63.4 [4] for example) concerning the measurement of the radiated emissions signature of an item utilise a method whereby the Device Under Test (DUT) is rotated through 360^o(initially using an angular step size of no more than 15^o) in the azimuth plane and the receive antenna height above the ground is a scanned between 1 m and 4 m in order to maximise the emissions. The use of just two azimuth angles and one fixed antenna height in the automotive standard limits the possibility that the maximum emissions of the DUT will be recorded. For clarity throughout this paper the two angles (as shown in Figure 1) used during a CISPR 12 measurement will be referred to as 0^o and 180^o respectively.

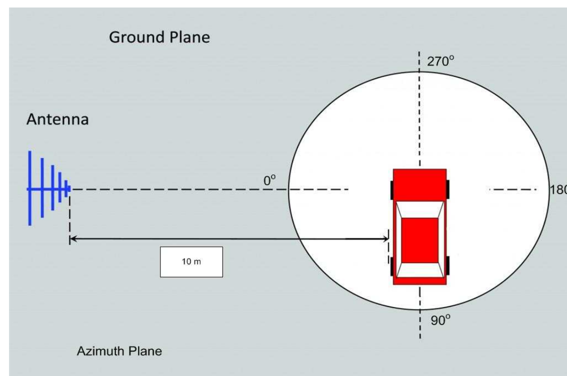

Fig. 1. CISPR 12 Radiated Emissions Measurement Configuration

Previous investigations into the measurement process [5] have achieved inconclusive results. Measurements were performed using the height / azimuth scanning approach of ANSI C63.4 [4] on a number of modern vehicles, it was found that due to drift in the frequencies of the emissions from the vehicle it was not possible determine if 'maximising' the recorded amplitude using azimuth rotation of the vehicle actually resulted in the maximum emissions being more closely recorded.

As previously noted: performing full spherical scan measurements is both time consuming and expensive. The use of electromagnetic (EM) modelling techniques to investigate how the vehicle body shell affects the directivity of the radiated emissions is possible. EM modelling can be performed using either a frequency or time domain solver, for the purposes of this investigation a frequency domain, boundary element method based solver was employed. The advantage of the boundary element method approach over the time domain is that only the model of interest needs to be discretized and not the complete volume domain. Much work has been previously carried out in the area of EM modelling of vehicles [6], [7], [8], [9], [10], however, most of this work considers the fields inside the vehicle when it is illuminated by an external RF source. After reviewing the literature, it was found that some work has been carried out to investigate the external field radiated from the vehicle [5], however, very little regarding the directivity of the emissions pattern has been published. The majority of published work examines the directivity of installed antennas on the outside of the vehicle [11], [12], [13]

This paper constitutes work in progress in attempting to quantify the errors in the current CISPR 12 method for recording full vehicle radiated emissions due to vehicle directivity, with a long term aim of determining the limits of the errors introduced and then possibly providing an alternative method that would more closely determine the maximum amplitude of the emissions signature of the vehicle in question, within the measurement environment being used.

A. Simulation Model

Work has begun in an attempt to initially quantify the errors introduced by using the two receive antenna azimuth angles, relative to the vehicle under test (as opposed to a 360^o rotational scan) and not using receive antenna height scanning as used in other Standards described earlier . For the initial investigations a simplified vehicle body shell has been modelled using CONCEPT II [14] . The model was designed to represent the passenger compartment of a typical family car. It was built using simple geometric shapes, and consists of a central passenger compartment with apertures to represent windows. The model was built using planar panels, and the apertures were left unfilled (no attempt has been made to simulate the window glass). Small details that are not important from an electromagnetic point of view have been removed from the model at this initial stage.The simple vehicle shape was chosen not only to act as a representation of a vehicle but was also designed to enable a scale physical model to be built with relative ease. The purpose of the physical model will be to act as a validation method for the simulation model, this will be investigated in the next phase of this work. The EM model is 2.7 m x 1.17m x 1.55 m (l x h x w) a representation of which can be seen in Figure 2. A wire harness was implemented into the model (along the Y axis, as detailed in Figure 3 , situated 10 mm above the body shell 'floor' running parallel to the length of the body shell (designated as 'Harness A'). The harness was driven by a 1V source with an internal source impedance of 50Ω, the opposite end of the harness was un-terminated . The position was designed to represent a harness running along the foot-well , a common route for much of the wiring harness in a vehicle. The harness consisted of a single conductor with out a dielectric covering. Future investigations will be performed using alternate harness configurations (terminated, twisted pair, orientated along multiple axes).

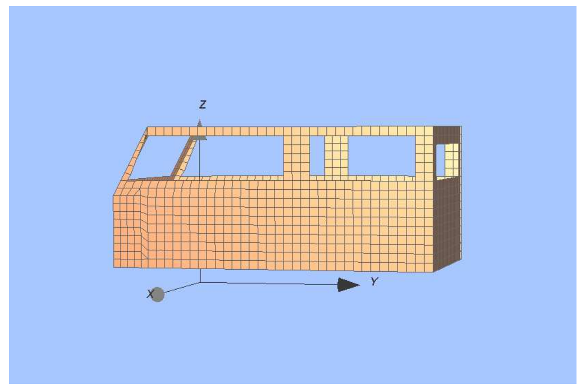

Fig. 2. Simple VehicleTest Case 'Simulation' Model'

Details of the size and relative position of the harness are shown in Table I and Figures 3 and 4:

Relative Harness Positions and Dimensions						
Description	X1	Y1	Z1	X2	Y2	Z2
Harness A	0.100 0.100	0.101 0.100	0.273 0.273	0.100 0.100	2.100 0.101	0.273 0.273

TABLE I
RELATIVE HARNESS POSITIONS AND DIMENSIONS

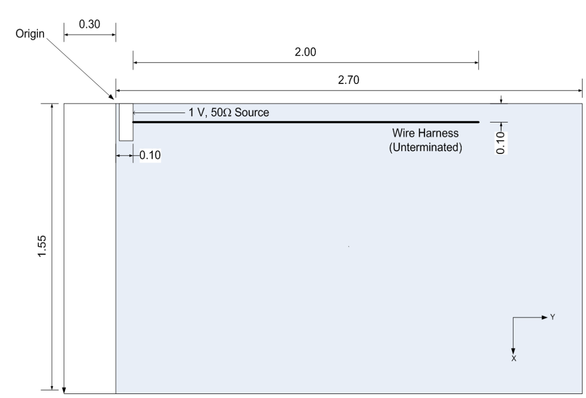

Fig. 3. Floor Pan of Simple Vehicle Test Case Passenger Compartment Showing Wire Harness Location

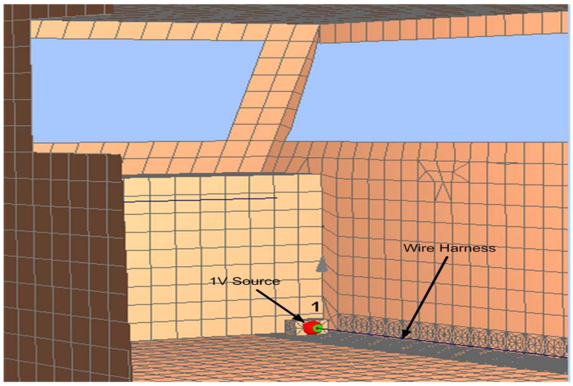

Fig. 4. Cut Away View of Test Harness in Simple Vehicle Test Case Passenger Compartment

1) Simple Vehicle Test Case Simulation Model: The overall aims of the Simple Vehicle Test Case (SVTC) are to initially investigate the affect the vehicle bodyshell has upon the directivity exhibited by a simple radiating harness .

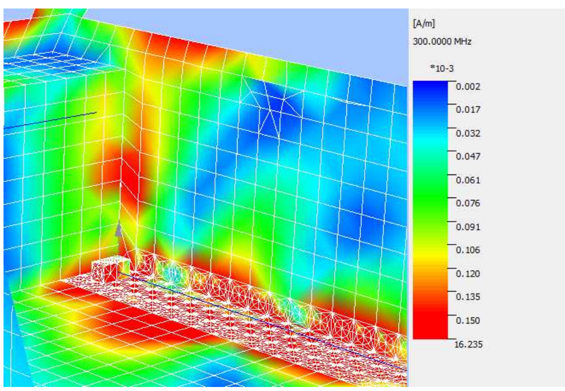

Fig. 5. Surface Current Distribution at 300 MHz, the Mesh Refined Near the Wire Can Also Be Seen

The model was initially built using the discretisation tools within CONCEPT II . As the surfaces of the body shell did not have any curvature it was possible to construct it using the plate facility. Each side of the body shell was constructed from a basic rectangular plate. Each individual plate was then combined in CONCEPT II to form a complete surface. A small box (100 mm x 100 mm x 100 mm) was also built into the model which was placed at the source end of the harness to act as the connection point for the 'antenna'. The model was built using a mesh size of 0.06 m x 0.06 m, the dimensions were chosen in order to meet the suggested minimum mesh size of $\frac{\lambda}{10}$ at the maximum frequency of interest (500 MHz in this case). In areas of predicted high surface current density or rapid spatial rate change of the current, a finer mesh size has been utilised (0.03 m x 0.03 m), as shown in Figure 4. The use of localised refinement of the mesh enables these areas to be more accurately modelled without significantly affecting the overall simulation time (as would be the case if an overall finer mesh were to be used). As vehicles get more complex with the inclusion of items such as adaptive cruise control, drive by wire and infotainment systems there will be a need to consider emissions at higher frequencies than currently covered by CISPR 12. Future investigations will be extended initially to 1000 MHz to encompass the current CISPR 12 requirements, higher frequencies will then be examined).

The model was simulated in free space initially, the simulations were then repeated with the model positioned 0.245 m above an infinite Perfect Electrical Conductor (PEC) ground plane.

B. Results

1) Simulation Model in Free Space: The free space environment is not representative of either the test environment typically used for automotive measurements (generally a semi anechoic chamber or OATS would be used) or the actual environment the vehicle will be used in once it is in production (tarmac roads). The purpose of the initial simulations is to gain baseline data without the added influence of ground reflections. The polar diagrams in Figures 6 to 11 show the amplitude of the electric field recorded during the simulations at a distance of 10 m from the vehicle body shell for a selection of the frequencies investigated. The green trace is the data simulated for the harness within the body shell compared to that of the harness alone (red trace), simulated without the body-shell being present. In the plots below 0^0 and 180^0 represent broadside to the simulated model, the front of the vehicle faces 270^o (this is shown graphically in Figure 1. In order to better visualise the shape of the radiation patterns between the results all data plots have been normalised to a maximum value of 0 dB.

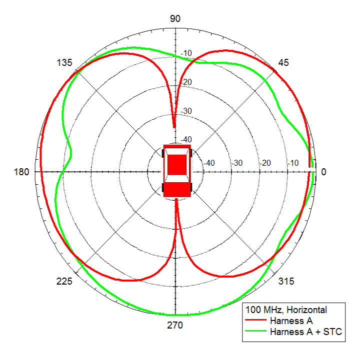

Fig. 6. Polar Plot of Horizontal E-Field at 10 m (100 MHz), Comparing Harness A Inside SVTC to Harness A Alone

Once the simulations had been performed the results were analysed. The maximum amplitude of the horizontal and vertical components of the electric field (in the azimuth plane) over a 360^o rotation were compared to the value that was recorded at 0^o and 180^o relative to the vehicle model (the orientation that would be measured during a CISPR 12 compliance measurement as shown in Figure 1). Table II details how the values differed at the frequencies investigated, the results are shown graphically in Figures 12 and 13.

The data shown in Figures 6 to 11 highlights that when harness A is configured inside the body-shell the worst case

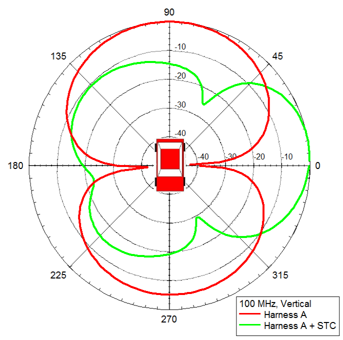

Fig. 7. Polar Plot of Vertical E-Field at 10 m (100 MHz), Comparing Harness A Inside SVTC to Harness A Alone

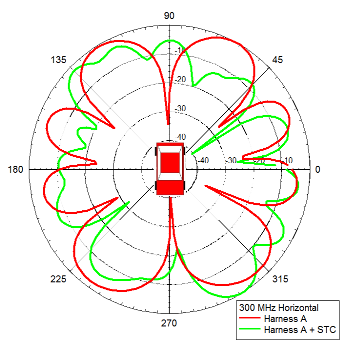

Fig. 8. Polar Plot of Horizontal E-Field at 10 m (300 MHz), Comparing Harness A Inside SVTC to Harness A Alone

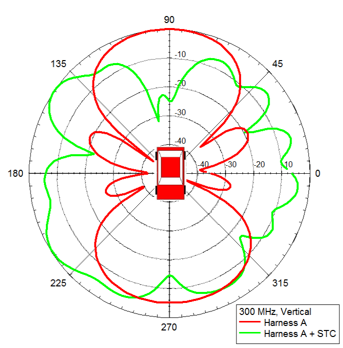

Fig. 9. Polar Plot of Vertical E-Field at 10 m (300 MHz), Comparing Harness A Inside SVTC to Harness A Alone

error in the horizontal component of the amplitude of the electric field recorded broadside (left hand side) to the vehicle, (as per CISPR 12 guidelines), when compared to the maximum amplitude of the electric field recorded over a 360^o rotation would be 12.92 dB. The worst case error recorded broadside (right hand side) to the vehicle would be 16.14 dB in the azimuth plane. The corresponding worst case for the vertical component of the electric field recorded was 13.12 dB (left hand side) and 20.14 dB (right hand side). These figures are only based upon the five frequencies where simulations have been performed, further investigations will be required to determine if these values are representative when more frequencies are considered.

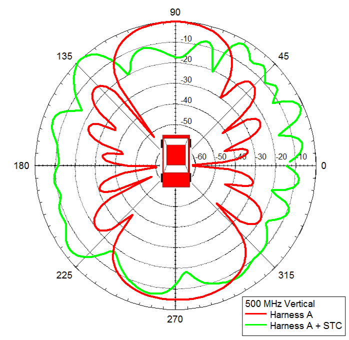

Fig. 10. Polar Plot of Horizontal E-Field at 10 m (500 MHz), Comparing Harness A Inside SVTC to Harness A Alone

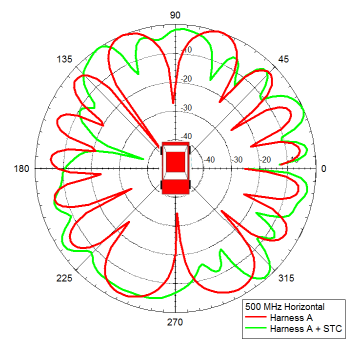

Fig. 11. Polar Plot of Vertical E-Field at 10 m (300 MHz), Comparing Harness A Inside SVTC to Harness A Alone

Harness A (Simple Vehicle Test Case), Free Space						
$Freq$ MHz	Hor Ver	E_{max} $dB\mu V/m$	E_{av} $dB\mu V/m$	E_{max} $\backslash E_{av}$ dB	E_{max} $\backslash E_{left}$ dB	E_{max} $\backslash E_{right}$ dB
100	Hor	-43.76	-45.96	4.38	1.12	9.06
100	Ver	-36.86	-43.68	13.64	0.22	20.14
200	Hor	-35.50	-39.28	7.56	5.80	12.90
200	Ver	-33.15	-36.04	5.76	4.06	2.42
300	Hor	-28.07	-32.94	9.72	12.32	11.22
300	Ver	-28.72	-32.98	8.50	8.08	5.52
400	Hor	-18.92	-23.26	8.68	0.00	16.14
400	Ver	-18.50	-22.87	8.72	5.20	6.74
500	Hor	-24.58	-28.36	7.54	12.92	9.88
500	Ver	-24.49	-29.39	9.78	13.12	10.36

TABLE II
WORST CASE ERRORS DUE TO VEHICLE DIRECTIVITY, FREE SPACE

2) Simulation Model above PEC: The plots in Figures 14 to 16 show the simulation results of the Simple Vehicle Test Case recorded 2.45 m above a PEC. When these results are compared to those recorded in free space the overall results are similar.

When the harness and body shell are modelled above a PEC the worst case error in the horizontal component of the amplitude of the electric field recorded broadside (left hand side) to the vehicle was 12.46 dB and broadside (right hand side) to the vehicle was 16.32 dB. The worst case error in

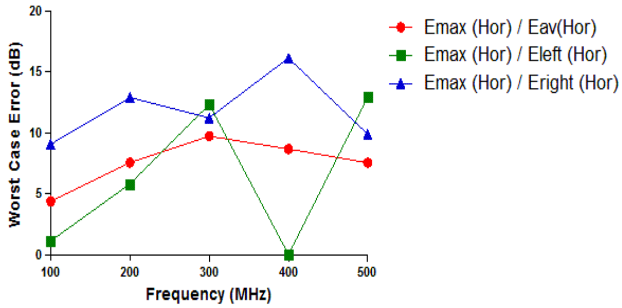

Fig. 12. Horizontal Polarisation Worst Case Error Due to Vehicle Directivity (Free Space)

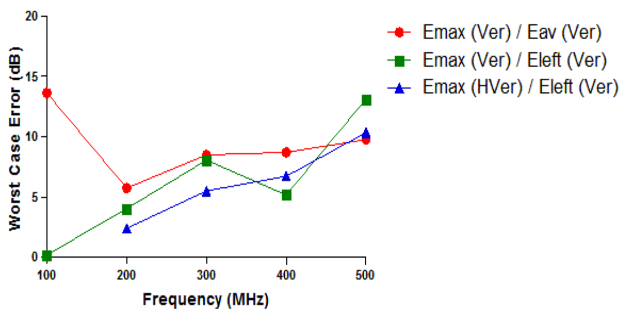

Fig. 13. Vertical Polarisation Worst Case Error Due to Vehicle Directivity (Free Space)

the vertical component of the amplitude of the electric field recorded broadside (left hand side) to the vehicle was 17.36 dB and broadside (right hand side) to the vehicle was 15.80 dB.

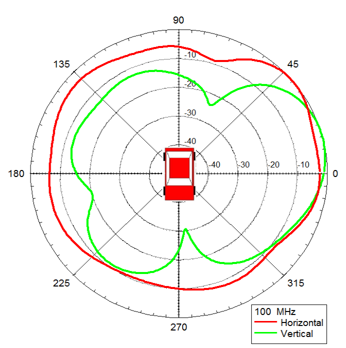

Fig. 14. Polar Plot of Horizontal & Vertical E-Field at 10 m (100 MHz) SVTC with Harness A

Table III shows the error introduced in the full vehicle radiated emissions results due to vehicle directivity through the use of the two azimuth angles specified in CISPR 12, for each of the 5 frequencies considered in this report. The results are also shown graphically in Figures 17 and 18. Further work will be performed to examine frequencies up to 1 GHz at a later date.

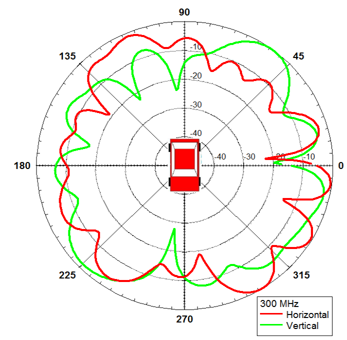

Fig. 15. Polar Plot of Horizontal & Vertical E-Field at 10 m (300 MHz) SVTC with Harness A

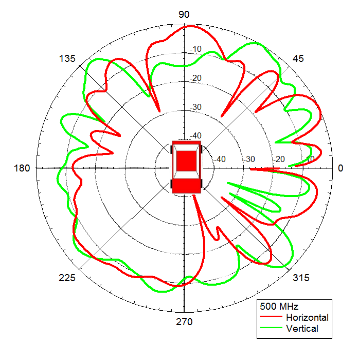

Fig. 16. Polar Plot of Horizontal & Vertical E-Field at 10 m (500 MHz) SVTC with Harness A

Harness A (Simple Test Case), Above PEC						
$Freq$ MHz	Hor Ver	E_{max} $dB\mu V/m$	E_{av} $dB\mu V/m$	E_{max} $\backslash E_{av}$ dB	E_{max} $\backslash E_{left}$ dB	E_{max} $\backslash E_{right}$ dB
100	Hor	-40.15	-43.18	6.06	2.50	6.38
100	Ver	-33.64	-39.92	12.56	1.10	15.80
200	Hor	-32.56	-36.90	8.68	3.32	16.32
200	Ver	-29.70	-34.00	8.60	0.58	9.34
300	Hor	-27.32	-31.28	7.92	7.32	10.58
300	Ver	-26.77	-30.87	8.20	17.36	6.38
400	Hor	-17.73	-23.24	11.02	11.82	5.70
400	Ver	-14.79	-19.88	10.18	4.18	10.82
500	Hor	-23.05	-28.41	10.74	12.46	12.44
500	Ver	-22.36	-27.03	9.34	14.78	8.18

TABLE III
WORST CASE ERRORS DUE TO VEHICLE DIRECTIVITY, ABOVE PEC

II. CONCLUSION

The effects of the vehicle body shell on the radiated emissions signature are discussed. EM simulations have been performed using a full scale electromagnetic model. The results show that using the current CISPR 12 methodology for measuring the radiated emissions of a representative vehicle body shell passenger compartment does not record the maximum amplitude of the emissions (in cases it under estimates them by as much as 17dB). The results show the need for

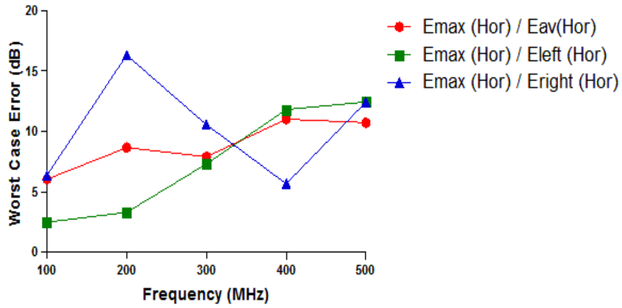

Fig. 17. Horizontal Polarisation Worst Case Error Due to Vehicle Directivity (Above PEC)

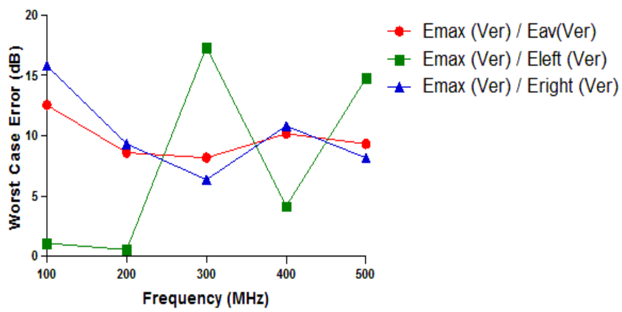

Fig. 18. Vertical Polarisation Worst Case Error Due to Vehicle Directivity (Above PEC)

Worst Case Comparisons Basic Harness compared to Simple Test Case (Free Space) and Simple Test Case (Above PEC)		
Config	Worst Case (L) dB	Worst Case (R) dB
Basic Harness (Hor)	20.08	25.26
Basic Harness (Ver)	32.72	41.24
SVTC FS (Hor)	12.92	16.14
SVTC FS (Ver)	13.12	20.14
SVTC PEC (Hor)	12.46	16.32
SVTC PEC (Ver)	17.36	15.80

TABLE IV
WORST CASE COMPARISONS

further investigations to improve the current method. The current investigation has only considered five frequencies up to 500 MHz, as previously stated advances in technology have resulted in modern vehicles containing equipment that could result in potential emissions that could extend to several GHz.

Future work will consider higher frequencies and then continue using a more detailed vehicle model (using CAD data of a 'real' vehicle) to perform EM simulations. The current simulations have utilised a simple wire harness running parallel to one axis, further simulations will be explored using a more representative harness (multiple lines, twisted pairs, multiple directions e.t.c). A reduced complexity half scale model of the vehicle passenger compartment has been constructed and measurements will be performed at an Open Area Test Site.

A further development of the measurement program will begin to characterise a wide range of production vehicles using both a 'simple' wire harness as discussed in this paper and using the wiring harness of the vehicle (excited by a suitable noise source). As part of the vehicle characterisation program a data base of emission frequencies will be compiled in an attempt to define a frequency range of typical emissions from production vehicles. The data recorded during the characterisation program will be used to define the scope of both the EM simulations and further measurements to be investigated.

Initial measurements will be performed using a fixed antenna height of 3 m (as specified in the current CISPR 12 specification). Once the range of frequencies has been further researched, the receive antenna height will be scanned between 1 m and 4 m to attempt to maximise the emissions at those frequencies (based on the theory proposed by Kelong and Yougang [15].

REFERENCES

[1] CISPR, *Vehicles, Boats, and Internal Combustion Engines, Radio Disturbance Characteristics-Limits and Methods of Measurement for the Protection of Off-Board Receivers*, CISPR Std. 12, Rev. Edition 6, 2007.

[2] BSI, *Information Technology Equipment. Radio Disturbance Characteristics. Limits and Methods of Measurement*, British Standard Std. EN55 022, Rev. 1998, 1998.

[3] CISPR, *Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods*, CISPR Std. 16-2-1, Rev. Edition 1.1, September 2005.

[4] ANSI, *American National Standard for Methods of Measurement of Radio Noise Emission from Low Voltage Electrical Equipment in the Range 9 kHz to 40 GHz*, ANSI Std. C63.4, 2001.

[5] A. Ruddle, "Investigation of Automotive Emission Measurement Frequencies, Test Methods and Operating Modes." Laboratory for Electromagnetic Fields and Microwave Electronics, 2005.

[6] ——, "The EU Framework V project "GEMCAR" Guideleines for Electromagnetic Compatibility Modelling for Automotive Requirements." Zurich: International Zurich EMC Symposium, February 2003.

[7] ——, "The EU Framework V Project "GEMCAR": Practical Aspects of the Development of Whole Vehicle Electromagnetic Models." Zurich: International Zurich EMC Symposium, February 2003.

[8] F. Canavero, J. Kedzia, P. Ravier, and B. Scholl, "Numerical Simulation for Early EMC Design of Cars," Auto EMC European Project, Tech. Rep., Unknown.

[9] GEMCAR, "Guidelines for Electromagnetic Compatibility Modelling for Automotive Requirements," Tech. Rep. GRD1-1999-10453, April 2003.

[10] Ruddle, "Validation of Automotive Electromagnetic Models," Ph.D. dissertation, University of Loughborough, September 2002.

[11] M. L. L. Low, "Hidden Antennas for Automobiles," Ph.D. dissertation, University of Kent, September 2005.

[12] M. Cerretelli and G. Gentili, "Accuracy in Modelling Conformal Window Glass Automotive Antennas by EM Numerical Solvers," European Microwave Conference. European Microwave Conference, 2009, pp. 1472–1475.

[13] H. Zhang, L. Low, J. Rigelsford, and R. Langley, "Effects of Vehicle Furnishings on Performance of Aperture Mounted Multi-Band Conformal Automotive Antenna," in *Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on*, march 2009, pp. 2694 –2697.

[14] H. Bruns and C. Schuster. (2011, August) Concept II Electromagnetic Simulation Software. Technische Universtat Hamburg-Harburg. [Online]. Available: http://www.tet.tu-harburg.de/concept/index.en.html

[15] Y. Kelong and G. Yougang, "Research for the Radiated Emission Test," in *Environmental Electromagnetics, 2003. CEEM 2003. Proceedings. Asia-Pacific Conference on*, November 2003, pp. 613 – 616.