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Using the 'Test Wire' Method as an Alternative to the CISPR 12 Full Vehicle Measurement Method.

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Abstract—**This paper investigates the use of the 'Test Wire Method' in an attempt to reduce 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. A 'Test Wire' system was originally suggested as method of performing in-situ radiated emissions measurements on physically large electrical machines. The current CISPR 12 test method potentially under-estimates the emissions levels significantly for a representative body-shell model, the results obtained during measurements of a scale model, using the Test Wire Method are discussed and compared to the standard CISPR 12 methods. The initial findings suggest that using the Test Wire Method may offer an improvement (in the region of 4dB) in the error recorded in determining the maximum amplitude of the emissions signature of the vehicle, within the measurement environment being utilised. It is hoped that by the use of an increased number of configurations of the measurement model, further improvements may be recorded. As this paper describes work in progress the measurement results will be validated using simulations of an EM scale model as the next part of this program.**

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 a 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 (no antenna height or azimuth scan are employed) . 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. when performing a CISPR 12 measurement, 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.

The use of electromagnetic (EM) modelling techniques to investigate how the vehicle body shell affects the directivity of the radiated emissions is possible. Much work has been previously carried out in the area of EM modelling of vehicles [5], [6], [7], [8], [9], however, most of this work considers the fields inside the vehicle when it is illuminated by an external RF source.

This paper describes work in progress into investigations into the errors in the full vehicle radiated emissions due to vehicle directivity using the 'Test Wire' method and comparing the results to the current CISPR 12 method. The paper presents further work performed by the authors where the errors in the emissions signature of a representative vehicle bodyshell were investigated [10]. The long term aim of this current work is to determine if the 'Test Wire' method could offer an alternative

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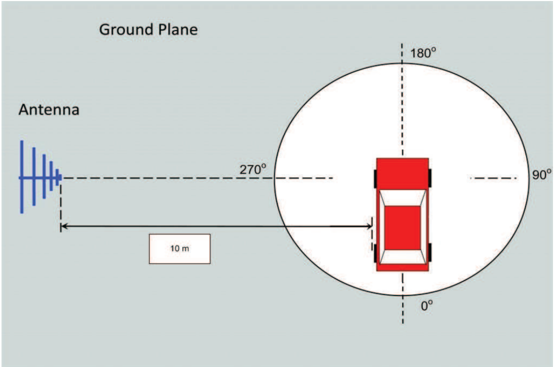

Fig. 1. CISPR 12 Radiated Emissions Measurement Configuration

to the current CISPR 12 procedure and as a consequence, possibly reduce the errors introduced.

A. Test Wire Method

A method proposed for testing the in-situ radiated emissions of large machines was first suggested under a European project known as TEMCA2 carried out in 2003 [11]. The system worked by using a wire stretched over the machine to measure the radiated emissions rather than using a conventional antenna.

The system became known as the 'Test Wire Method' In the initial system the wire was stretched over the machine at a distance of 10 - 50 cm above the surface (the length of the wire was chosen so that this distance could be maintained for different orientations of the wire over the DUT and still maintain the same separation from the largest point of the DUT). The ends of the wire were connected to the metal chassis of the machine using a 150Ω termination . This termination impedance was set to 150Ω at one end and 100Ω in series with with the 50Ω of the measurement system at the opposite end.The voltage (designated U) across the termination impedance, at the measurement equipment end, was measured at each frequency of interest. This voltage was then converted to a field strength by means of a so called 'K Factor', which is analogous to a standard receive antenna factor.

The 'K Factor' was calculated as the ratio between the maximum measured E Field (over a full spherical scan) and the measured voltage U for all test wire configurations. From equation 1 a range of values for K is obtained

The K Factor is defined as:

$$K = 20.log\left(\frac{E(v/m)}{U(V)}\right) \quad (1)$$

where E is the maximum measured E Field (over a full spherical scan) and U is the measured voltage across the termination resistor.

Using multiple orientations of the Test Wire, K Factors were produced at each frequency of interest, which gave a a spread of values from which an average value of K Factor was calculated for each frequency.

The initial studies into the K Factor (Catrysse et al [11]) were performed using EM modelling techniques, this enabled a full spherical scan of the E field to be performed with relative ease (as opposed to the very time consuming methods that would be used if a physical model were measured).

One concern that was raised during the investigations was the 150Ω terminations on the Test Wire. The impedance value was chosen as it was assumed that the characteristic impedance of the test wire was 150Ω. However, it was noted, that care in the setup and positioning of the Test Wire above the DUT was required in order ensure that the impedance was actually 150Ω.

Variations to the Test Wire method have been investigated, in part, to try to alleviate the impedance issue noted above. One alternative method suggested [12] was to use for a 'Micro-strip' arrangement by placing the Test Wire directly onto the surface of the machine, with the wire gauge and the insulation thickness being chosen to produce a characteristic impedance of 50Ω, this would enable the the measurement equipment to be more easily interfaced to the wire.

B. Simulation Model

Work has begun in an attempt to investigate if the errors introduced by using the current CISPR 12 test can be reduced by the use of an alternative methodology. For the initial investigations a simplified vehicle body shell has been modelled using CONCEPT II [13] . The model was designed to represent the size and shape of the passenger compartment of a typical family car. It was built using simple geometric shapes with the main panels forming a simple rectangular box shape, and consists of a central passenger compartment with apertures to represent windows. The apertures were left un-filled (no attempt has been made to simulate the window glass). 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 peformed as the next part of this program of work and reported on at a later date.

The EM model is 4.5 m x 1.7 m x 1.5 m (l x h x w) a representation of which can be seen in Figure 2. A series of small monopole antennas (270 mm long) were positioned inside the model to excite an electric field within the enclosure. The monopoles were driven by a 1V source with an internal source impedance of 50Ω. The position of the monopoles were chosen to offer an variety of places where electronic devices could be positioned inside a typical passenger vehicle.

Details of the relative position of the monopoles are shown in Table I and Figures 3 :

1) Simple Vehicle Test Case Physical Model: In order to validate the Simle Vehicle Test Case (SVTC) simulations a $\frac{1}{3}$ scale model was built. the body of the physical model was constructed from 9 mm MDF sheets , the sheets were glued together using PVA glue and a minimal amount of panel pins to hold the structure together whilst the glue dried. Once the basic shell was built BNC sockets were mounted in the base

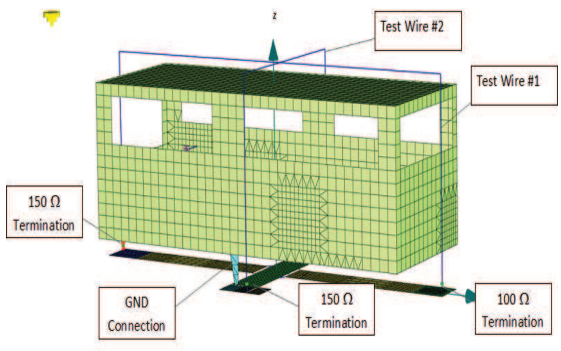

Fig. 2. Simple VehicleTest Case 'Simulation' Model', Showing 'Test Wires'

Relative Harness Positions and Dimensions		
Description	X Position (m)	Y Position (m)
Monopole 1	-1.88514	0.607143
Monopole 2	-1.76351	-0.121429
Monopole 3	-0.485714	-0.790541
Monopole 4	0.668919	0.121429
Monopole 5	1.39865	-0.607143

TABLE I
RELATIVE MONOPOLE POSITIONS

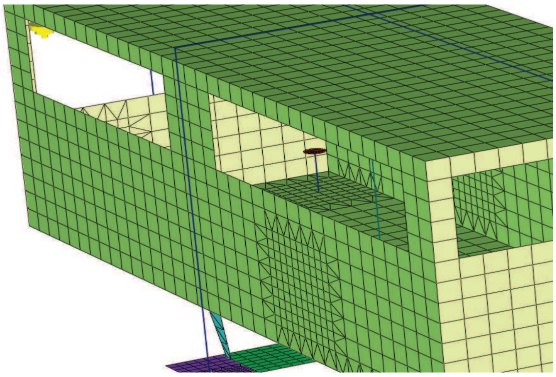

Fig. 3. Floor Pan of Simple Vehicle Test Case Passenger Compartment Showing 'typical' Monopole Location

of the model, at the same position as the monopole sources in the EM model. A total of 5 BNC sockets were mounted, to each socket a length of screened coaxial was attached to allow a signal source (YORK EMC CNE III) to be connected. It is planned that a small signal source that can be connected directly to the BNC socket (dispensing with the need for the coaxial cable) will be built and the measurements repeated to determine if the results are affected by the wire connection between the source and the BNC. A 270 mm long top-hat radiator was then connected to each of the BNC sockets in turn. The outer surface of the model was covered with aluminium foil with all seams covered in conductive copper tape to ensure continuity from one piece of foil to the next. The internal base of the model was also covered in aluminium foil (which was also bonded to the outer surfaces). The outer terminal of each BNC connector was bonded to the metallic base of the model. Two test wires were suspended 67 mm above the surface of the model using nylon spacers ($\frac{1}{3}$ the height of the full size EM model). Each end of the Test Wire was terminated to the body of the model through a resistor (220Ω at one end and 170Ω at the end that the measurement system would be connected to. The impedance was 'adjusted' from the values used in the simulation model to compensate for the Test Wire being 67 mm above the surface and not 200 mm). Test Wire 1 was positioned parallel to the length of the model(along the centre line), test Wire 2 was positioned parallel to the width of the model. Details of the physical model can be seen in Figures 4 to 5.

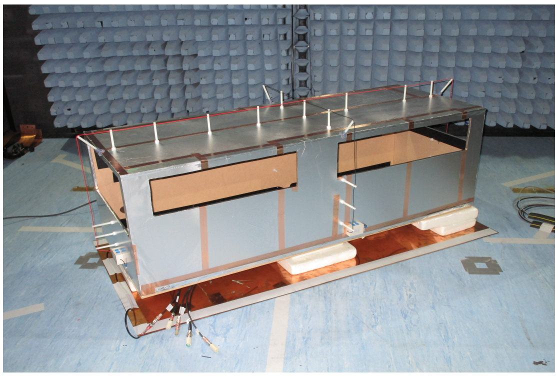

Fig. 4. Third Scale Physical Model

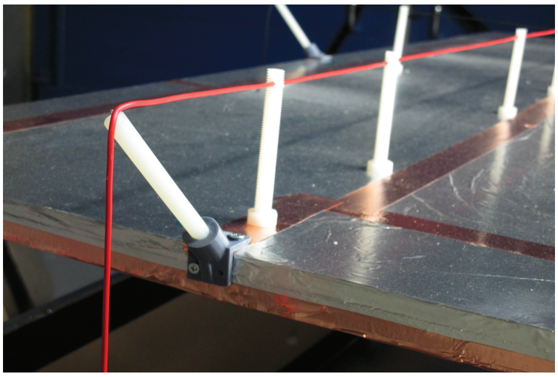

Fig. 5. Close Up Detail Showing Test Wire Spacers

The impedance of the test wire was measured before tests began, as can be seen in Figure 6 the the impedance was not 250Ω at all frequencies as calculated. This was due to the fact that there was not a solid groundplane under the full length of the Test Wire (due to the window cutouts). Further investigations are planned to determine if alternative routing of the Test Wire could possibly reduce the resonances on the Test Wire and give an impedance closer to the nominal 250Ω across the frequency range being considered.

2) Simple Vehicle Test Case Simulation Model: The initial investigations performed were to determine the amplitude of the emissions that would be recorded during a typical CISPR 12 test setup (from either side of the vehicle). An EM

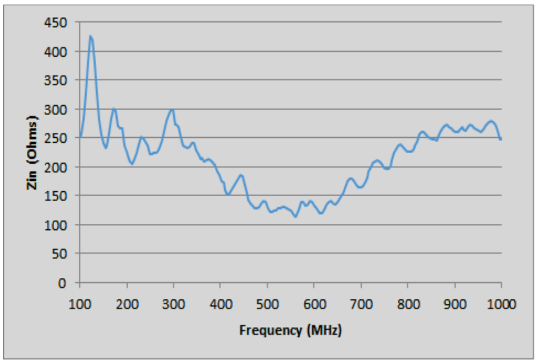

Fig. 6. Measured Input Impedance of Test Wire

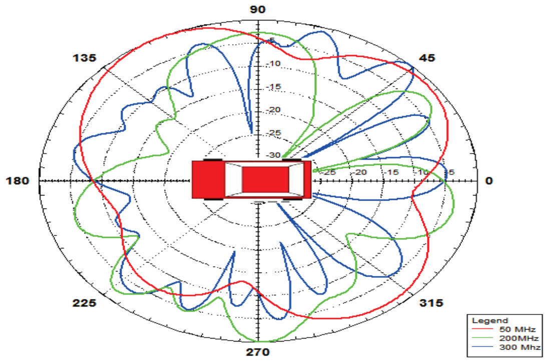

Fig. 7. Polar Diagram of E-Field Emissions from Source 1 at 50, 200 and 300 MHz

model was initially built using the discretisation tools within CONCEPT II . The mesh size used was 0.122 m x 0.115 m, in areas of predicted high surface current density or rapid spatial rate change of the current, a finer mesh size has been utilised (0.06 m x 0.06 m). 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). At this stage the simulations have been performed to a maximum frequency of 300 MHz, firstly to limit the size of mesh required and also to concentrate on the frequency range where the highest percentage of vehicle emissions occur (for current vehicle technologies).

The model was positioned 0.3 m above an infinite Perfect Electrical Conductor (PEC) ground plane, this height was used to represent the height the floor pan of a typical commercial vehicle above the ground. As noted earlier the model was excited with a number of 270 mm long top-hat monopole antennas situated at various positions on the 'floor' of the model.

C. Results

1) EM Model Simulated Results: The purpose of the initial results recorded from the EM model was to determine 3-D polar patterns of the radiated emissions from each of the five monopole antennas. These polar patterns would then be used to record the 'maximum' amplitude of the emissions over the range of values recorded. This maximum will then be used (along with the results of the voltage recorded across the termination of the 'Test Wire') to produce the K Factors for this particular model in the next phase of the investigation.

Data was recorded from simulations performed on the model at six discrete frequencies (50, 100, 150, 200, 250 and 300 MHz). A small number of frequencies has initially been used in order to minimise simulation and analysis times. Further frequencies will be investigated as the program of work progresses.

An example plot of the normalised far field emissions from Source 1 is shown in Figure 7 below. .

Once the simulations had been performed the results were analysed. The maximum value (over a sperical scan) of the horizontal and vertical component of the electric field were compared to the value that was recorded at the 90^0 and 270^0 positions relative to the vehicle model, these positions represent the directions in which a standard CISPR 12 measurement would be performed. A typical CISPR 12 measurement would be performed using an antenna height of 3 m above the ground.

The E-field recoded at 90^0 and 270^0 was compared to the maximum E-field recorded over a full spherical scan (Max_{Sp}) for the model, from this data a measure of the difference between the 'CISPR 12' equivalent measurement and the Max_{Sp} was calculated, designated Error Bias Scan (EBS).

Figure 8 below shows the the range of values recorded for the EBS for Source 1 (for each azimuth angle used) compared to Max_{Sp}, A maximum value of approximately 30 dB was recorded for this source, with this overall maximum of being similar across all five sources simulated. The coloured symbols in the diagram show the error bias for each azimuth angle recorded for each of the six frequencies investigated.

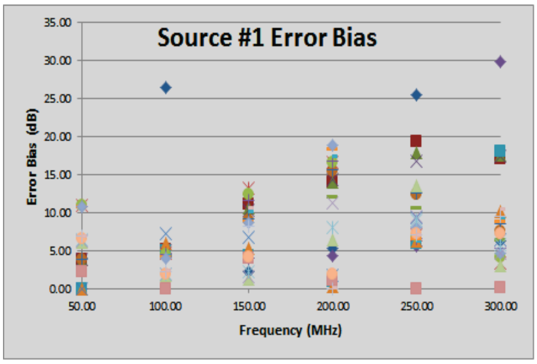

Fig. 8. Error Bias EB_{Sp} for Source 1 (50 -300 MHz)

When the data from just 90^0 and 270^0 were considered the maximum Error Bias (EB_{CISPR}) was still approximately 26 dB (across the five sources), highlighting that the current CISPR 12 method has the potential to under-estimate the emissions recorded significantly (as previously reported by the author).

2) Physical Model Results: As the model being used was a $\frac{1}{3}$ scale of the simulation model, measurements were performed on the model at frequencies between 200 MHz and 1 GHz, in 100 MHz steps (giving a scaled frequency range of 66 MHz to 334 MHz approximately). Due to time constraints the number of frequencies investigated was limited. Once the proof of concept has been performed further frequencies will be investigated. The model was setup 100 mm above the turntable (supported on foam) inside the semi anechoic chamber at the 'Motor Industry Research Agency' (formerly known as 'MIRA', now known as 'HORIBA MIRA'). Initial measurements were performed with the model rotated through 360^0 in 10^0 increments (the increment angle was chosen in order to minimise measurement time). The receive antenna was positioned 3 m away from the model at a height of 1.8 m above the facility floor. E Field data (both horizontal and vertical polarisation of the receive antenna) was recorded using each of the five source positions and from this and simplified polar plots were produced, Figures 9 and 10 below shows a typical example plot. Using this coarse azimuth increment still recorded a maximum Error Bias of approximately 25 dB (again validating the simulation results noted earlier). As we were only interested in comparative levels between different sources antenna factors were not accounted for.

Example plots of the measured electric field for Source position 1 are shown in Figures 9 and 10. In order to better visualise the shape of the radiation patterns between results all data plots have been normalised to a maximum value of 0 dB:

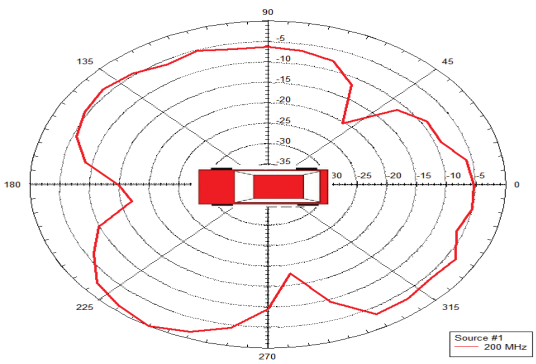

Fig. 9. Polar Diagram of Measured E-Field Emissions from Source 1 at 200 MHz

Due to the azimuth increment angle used the polar patterns may be considered as under-sampled. Future work will repeat these intial measurements using a finer azimuth increment (1 degree).

As well as recording the received E field from each source, the voltage across the termination resistor for each of the Test Wires was also recorded for each source. This voltage was then used to determine the K Factor for each measured frequency (as detailed in Equation 1).

The range of values was obtained at each frequency (based upon the source used in the model, the receive antenna

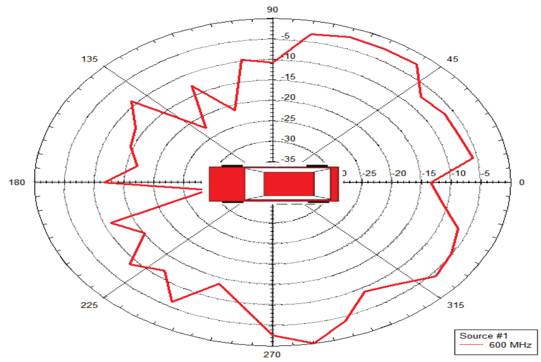

Fig. 10. Polar Diagram of Measured E-Field Emissions from Source 1 at 600 MHz

polarisation and the voltage across the Test Wire termination). This is shown graphically in Figure 11 below.

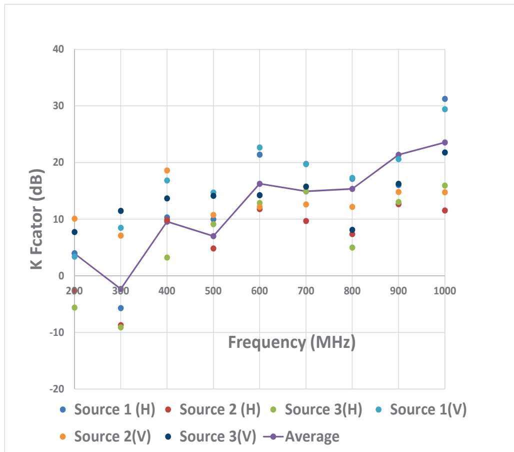

Fig. 11. Measured K Factor for Source Positions 1 to 3

Across all the recorded data the averaged value of the K Factor was found to vary in value by between 5 dB and 10 dB. The average of all values recorded at each frequency was used for the initial investigation into whether the Test Wire Method offered any improvement in the Error Bias recorded compared to a standard CISPR 12 measurement program. Based on the K Factor calculated the difference between the Error Bias recorded during a CISPR 12 type measurement and using the Test Wire method was compared. The graph in Figure 12 below shows how the average Error Bias recorded using the Test Wire Method is typically lower than that when the CISPR 12 method is employed. Across all frequencies and source positions an average Error Bias of 10 dB was recorded using the CISPR 12 setup compared to approximately 6 dB using the Test Wire Method.

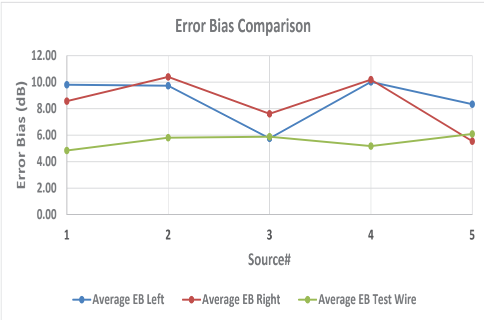

Fig. 12. Comparison of the Average CISPR 12 Method Error Bias with an Example Test Wire Method

It is planned that as future measurements are performed on different source configurations (and other models) the K Factors will be evaluated in order to see if reduction in Error Bias noted above can be further improved. Statistical analysis of the range of K Factor values will be performed and the results again compared to those recorded during a CISPR 12 measurement. It is hoped that as further configurations of source antenna and Test Wire orientations are included further improvements in the Error Bias will be recorded.

D. Conclusions

The use of the Test Wire Method has been investigated as a possible alternative to the current CISPR 12 full vehicle radiated emissions test procedure. As has previously been shown the current method can potentially significantly underestimate the maximum emissions recorded during the test due to using single receive antenna height and only two azimuth positions to perform the measurement. Initial investigations into the use of a Test Wire system for performing radiated emissions on a scale vehicle bodyshell representation have shown promising results, with a reduction in the error of recording the maximum amplitude of the emissions signature of the vehicle within the measurement environment being utilised. Additional work is planned to investigate reducing the resonances on the Test Wire in order to give a more consistent input impedance and possible further reductions in the error by using more data (further source positions and Test Wire configurations) to produce the K Factor profile. Statistical analysis will then be applied to the range of K Factor values recorded to determine the optimum value to use for each frequency. The final stage of the programme will be to investigate the Test Wire method on a real, full size vehicle in an attempt to determine if the scale model improvements are still recorded.

E. Acknowledgements

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