資料4－7

2014 年1月

第4回MIC WPT WG資料:
電気自動車用ワイヤレス給電システムの
磁界放射エミッション評価
-日本語要約版-

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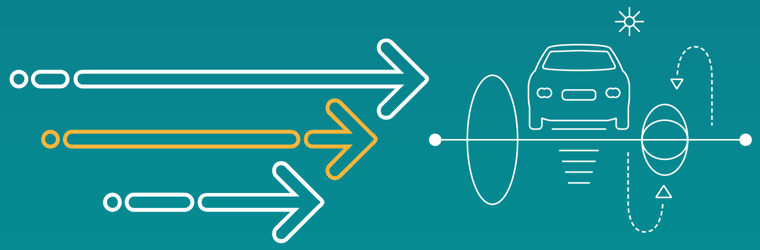
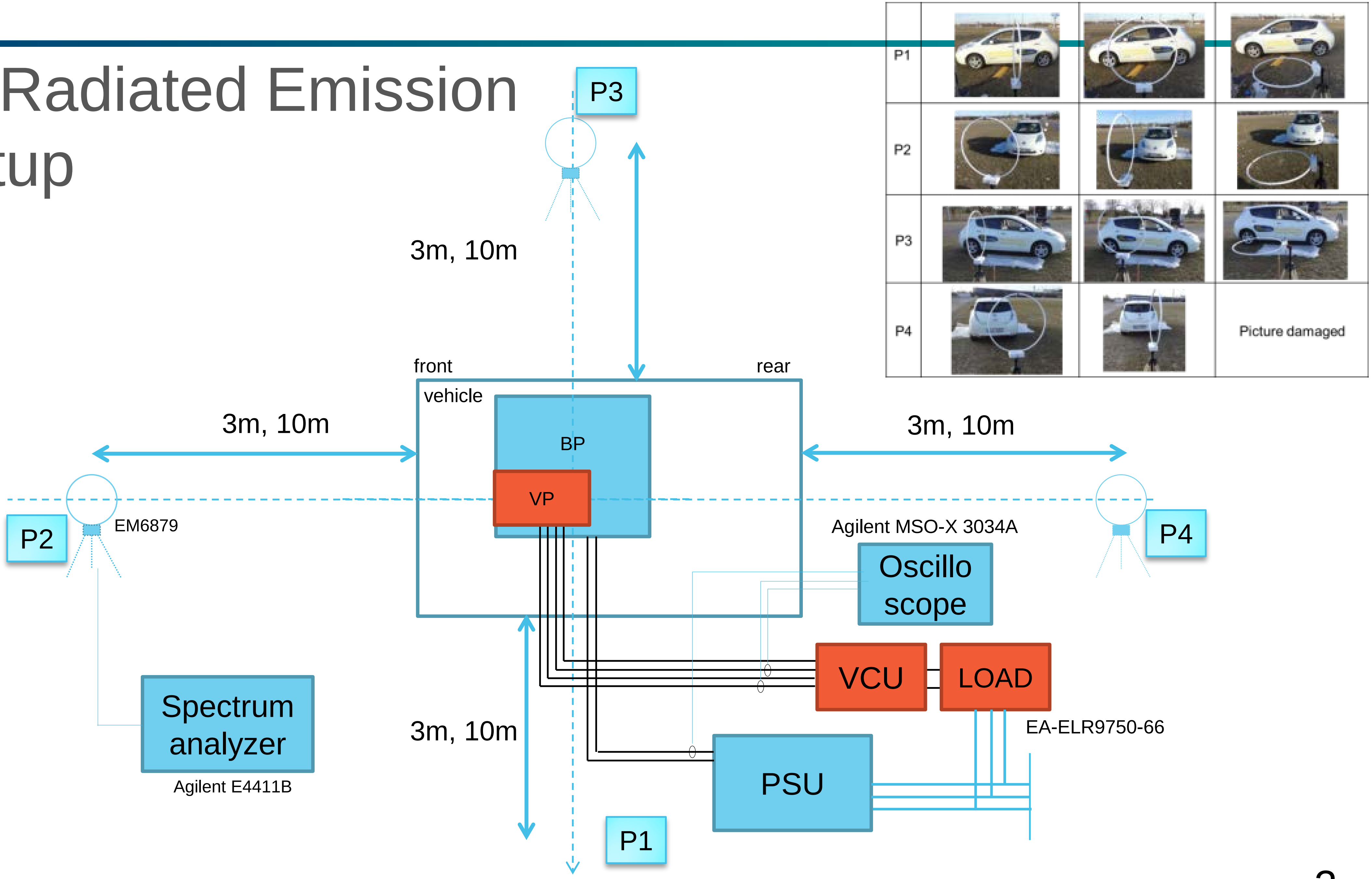


H-Field Radiated Emission Test Setup



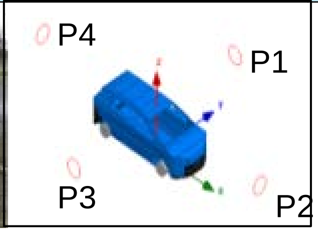
概要

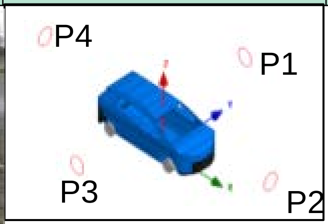
- 本資料では、電気自動車用ワイヤレス給電(Wireless Electric Vehicle Charging: WEVC)における磁界放射エミッションの一例として、弊社で開発中のプロトタイプシステムについて市販車両を用いた結果を示す。また作業班で合意された模擬車両を用いたシミュレーション検討結果も示す。
- WEVCシステムにおける放射磁界は様々な要因によって影響を受けるため、法規適合性評価のために実測で最悪ケースを特定する事は困難である。そこで、実践的なEMC評価において最悪ケースを特定するために数値解析手法を用いた結果も示す。
- 数値解析データの妥当性を検証するために、不確かさの総合評価も行った。規制値を確立する上では、この不確かさも考慮する必要がある。
- 今回のデータは、6.6kWDC出力, 85 kHzのプロトタイプシステムであり、実応用上最低限の要件を満足している初期的検討結果である。将来的な規制値としては、既存システムに対する有害な干渉検討を行った上で、今後のWEVCシステムのロードマップ(セミダイナミック給電やダイナミック給電も踏まえたより高出力、より大きな位置ずれ及びギャップ長)が考慮されるべきと考えている。

数値解析値と実測値の整合性

- 以下の表に、基本波における数値解析値と実測値(6.6kW output power@85kHz)を示すが、その誤差は最大でも3dB以内である。
(誤差評価については、英文版の不確かさに関する章を参照)
- 高調波については解析を行っていない。

Misalignment (X,Y,Z) [mm]	Antenna position	3m correlation (85kHz Fundamental)			10m correlation (85kHz Fundamental)		
		Measured H_total at 3m (dBuA/m)	Simulated H_total at 3m (dBuA/m)	Delta (dB)	Measured H_total at 10m (dBuA/m)	Simulated H_total at 10m (dBuA/m)	Delta (dB)
$(X_{max}, Y_{max}, Z_{max})$	P2 (front, x)	80.5	*80.0*	-0.5	*58.2*	*57.2*	-1.0
$(X_{max}, Y_{max}, Z_{max})$	P3 (right, -y)	83.3	*85.9*	2.6	*56.9*	*59.9*	3.0





January 2014

Contribution to MIC WPT WG: WEVC H-Field Radiated Emissions Assessment

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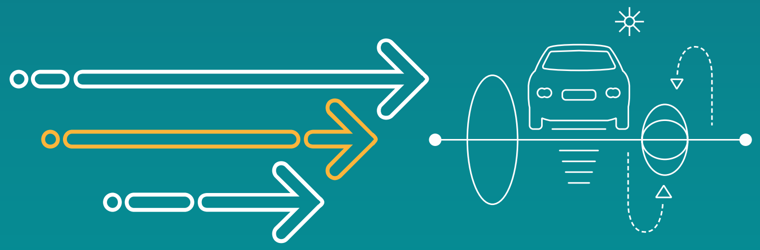

Qualcomm Technologies, Inc.

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Background

- Automotive OEMs increasingly view WEVC as the preferred future EV charging technology
- Currently systems are being developed, integrated and tested on EVs at varying power levels from 3.3kW, 6.6kW and 20kW
- Currently target vehicles include small to medium-sized passenger vehicles, LGV, larger PHEVs, SUVs, HGV and even buses
- Vehicle uses considered today include private vehicles, car share schemes, taxis, also with public transport and goods vehicles
- Modes of charging considered important include stationary charging, and semi-dynamic and dynamic charging where vehicles charge-on-the-move
- A comprehensive electric transport system will include many different vehicle types and modes of charging
- Regulations for WEVC deployment should consider the current specifications but MUST also consider future higher power, larger vehicle and dynamic deployments

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H-Field Radiated Emissions

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Influence of Test Car Models

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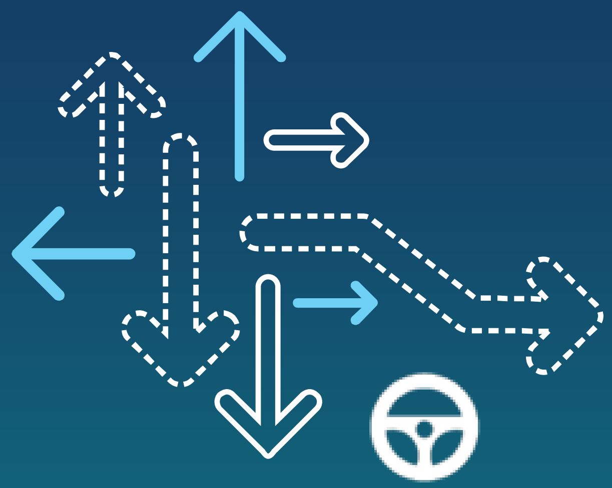
MIC Rulemaking Considerations

Agenda

Introduction

- The radiated emissions associated with WEVC are influenced by many factors thereby making it challenging to determine the worst case conditions for measurement and assessment for regulatory compliance
- This contribution examines a simulation approach for determining worst case conditions to then be used for practical EMC measurements of a WEVC system
- In addition to providing measured and simulated data this contribution also provides a view of overall uncertainty that should be considered when establishing regulatory limits for WEVC
- The data presented in this contribution is based on a 6.6kW, 85 kHz development system with minimal practical x,y and z gap. Regulatory limits should consider WEVC roadmap for higher power, greater off-sets x,y and greater z gap offset with semi dynamic and dynamic charging configurations



H-Field Radiated Emissions

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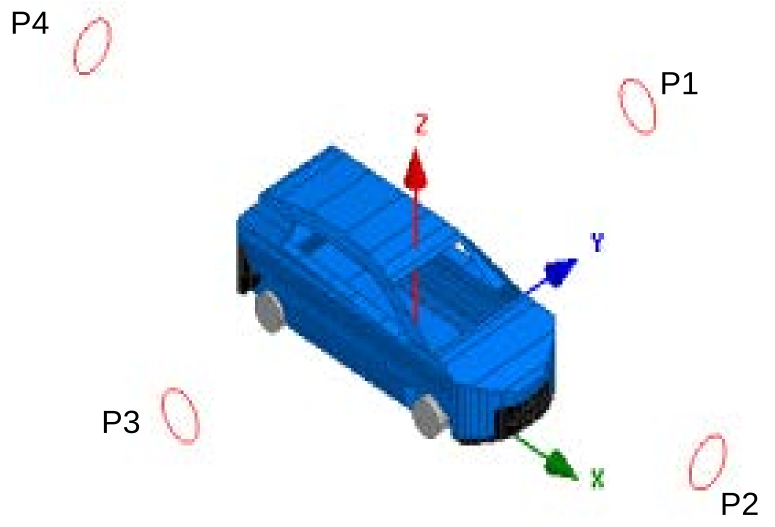
Practical Approach to Emissions Measurement

- WEVC radiated emissions can be influenced by many factors including, but not limited to:
  - Alignment
  - Air-gap
  - Car geometry and materials
  - Output-voltage
  - Pad mounting positions
- It is not practical to measure every configuration in order to obtain the worst case emissions required for an effective compliance assessment
- A validated simulation approach is effective in identifying the worst case configuration(s) for measurement
- The measurement data represents worst case emissions to be used in assessing compliance with defined regulatory limits

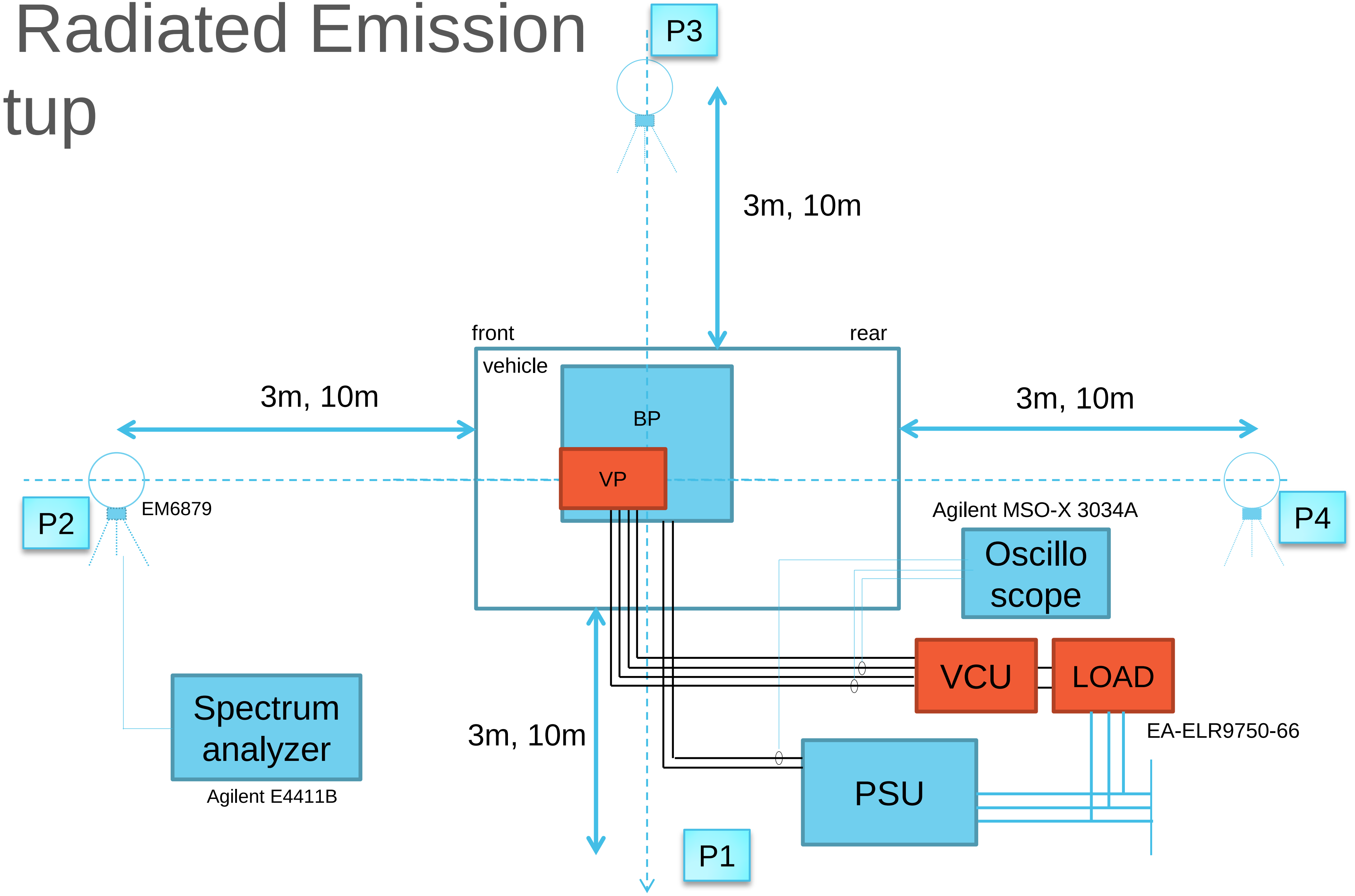
Worst Case Identification

- Equipment Under Test (EUT): WEVC 6.6 kW @ 85 kHz mounted on EV
- 6 configurations were pre-selected based on highest Amp-turns and maximum offset from all 37 possible alignments/air-gap/Output-voltage combinations.
- To identify the worst case(s) for measurement, a preliminary analysis was performed using simulation to obtain H-field emissions from all 4 directions (indicated in the figure) at a distance of 3m, 10m and 30m.
- In this example two worst cases were identified and recommended for measurement –
  - Case 1 (along Y)
    - Offset: $(X_{max}, Y_{max}, Z_{max})$
    - Measurement direction: P3 (-Y)
  - Case 2 (along X)
    - Offset: $(X_{max}, Y_{max}, Z_{max})$
    - Measurement direction: P2 (+X)

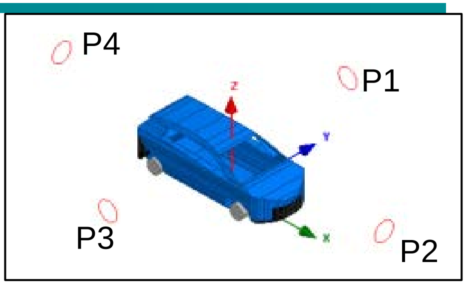


Open Area Measurement Site: Munich Messe

H-Field Radiated Emission Test Setup

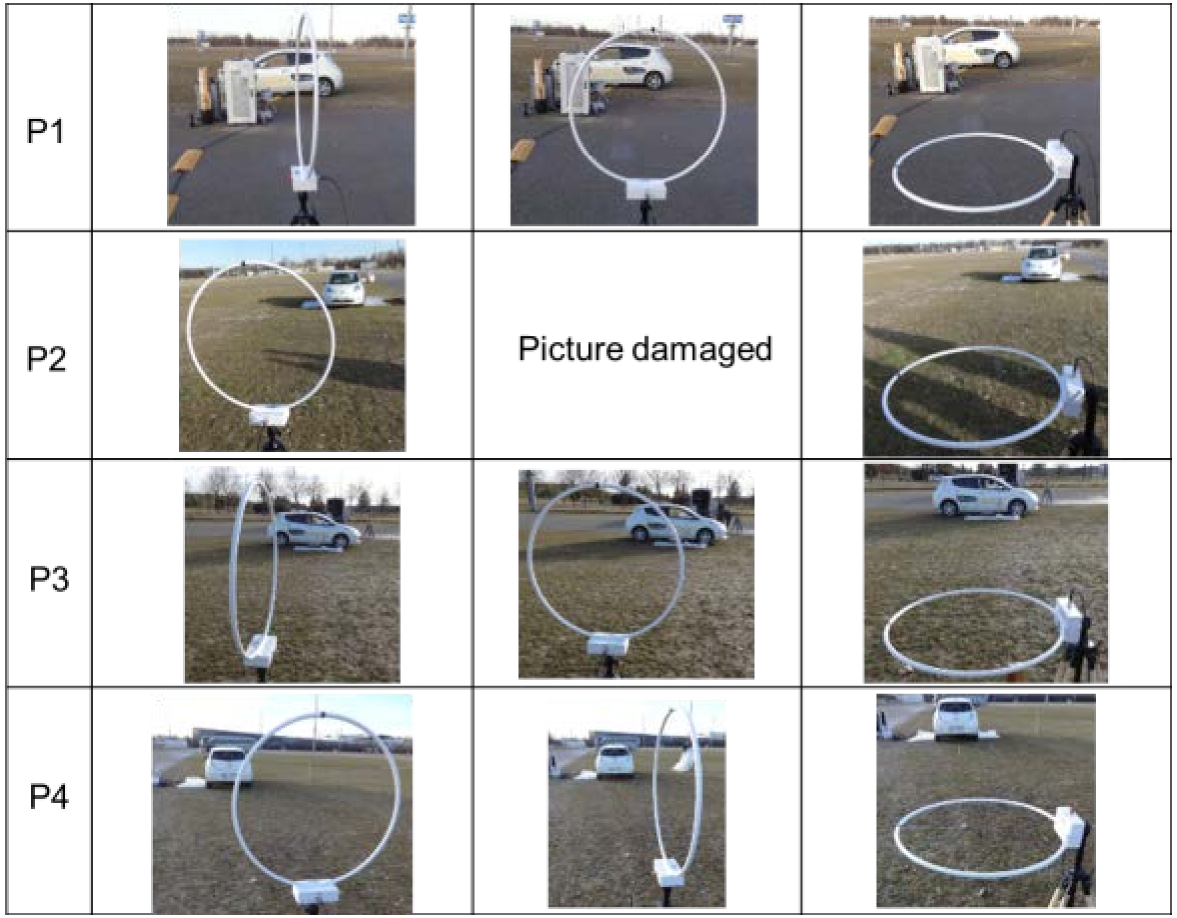


H-Field Radiated Emission Test Conditions



- All testing performed solely by Qualcomm Technologies, Inc. using a commercially purchased Nissan Leaf as a test vehicle
- WEVC system under test operates at 85kHz with power transfer up to 6.6 kW output power

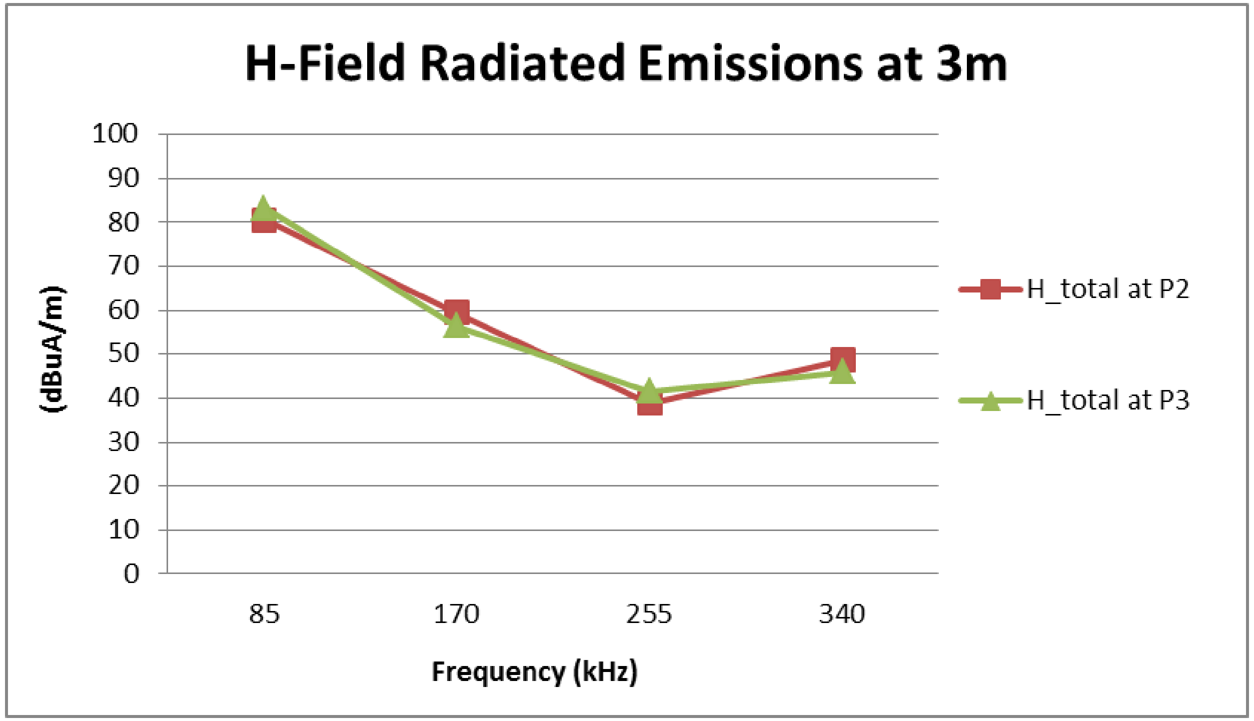
3m

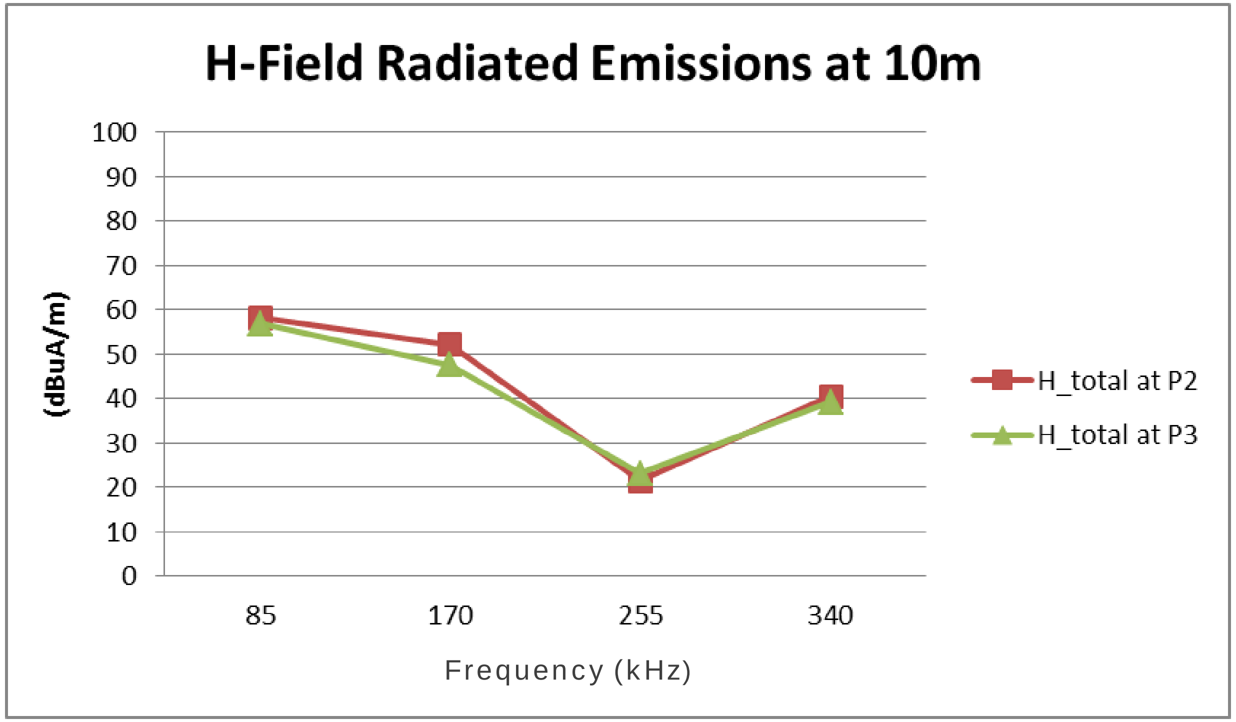


10m

H-Field Radiated Emission Measurement Results

- The measurement was performed at 3m & 10m from the car in all 4 directions and tested up to 4th harmonic of the fundamental frequency (6.6kW output power@85kHz)
- Measured emissions shown below at the worse-case positions identified by the simulation





Correlation of Measurement and Simulation

- Table below shows that the measurement and simulation correlation at the fundamental frequency (6.6kW output power@85kHz) is within 3dB for the identified worst case scenarios
- No simulations performed for the harmonics at this time

Misalignment (X,Y,Z) [mm]	Antenna position	3m correlation (85kHz Fundamental)			10m correlation (85kHz Fundamental)		
		Measured H_total at 3m (dBuA/m)	Simulated H_total at 3m (dBuA/m)	Delta (dB)	Measured H_total at 10m (dBuA/m)	Simulated H_total at 10m (dBuA/m)	Delta (dB)
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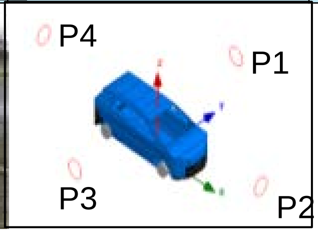
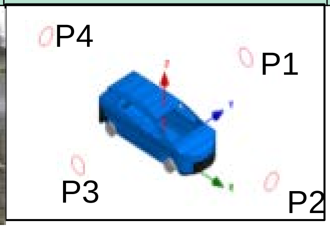
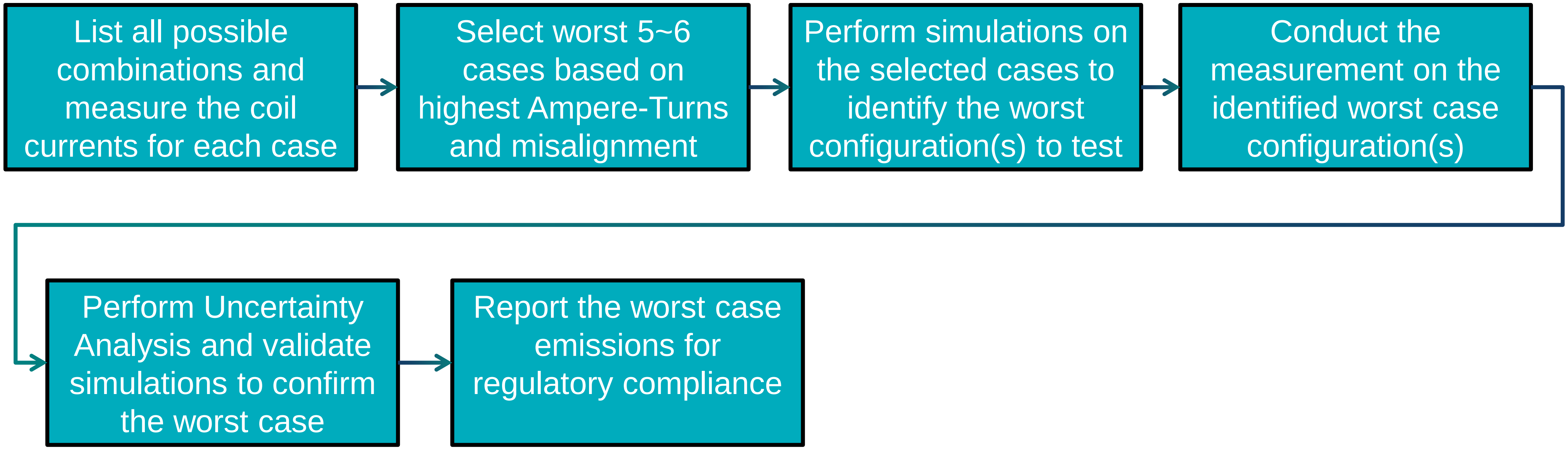


Flow Chart Summarizing Procedure for H-Field Radiated Emission Assessment of WEVC



Influence of Test Rig & Mock Wagon

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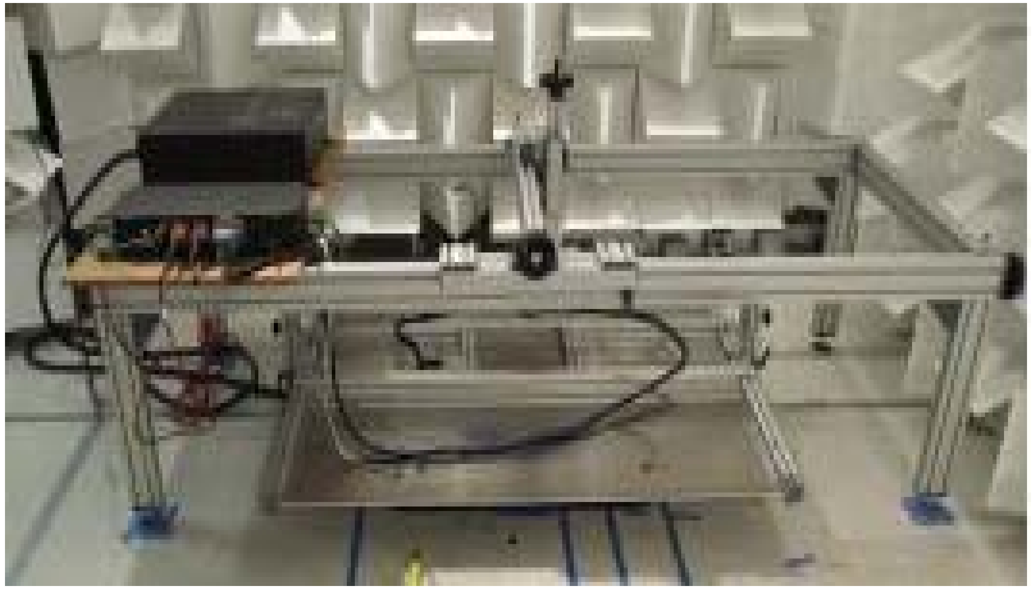
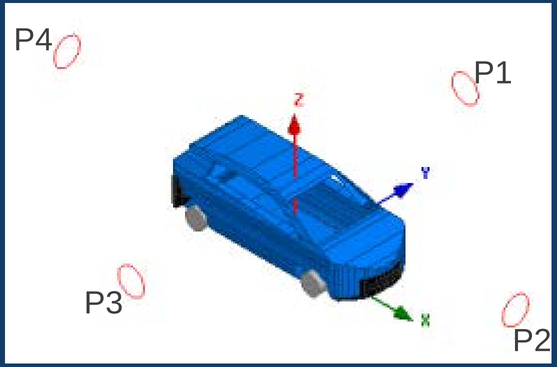
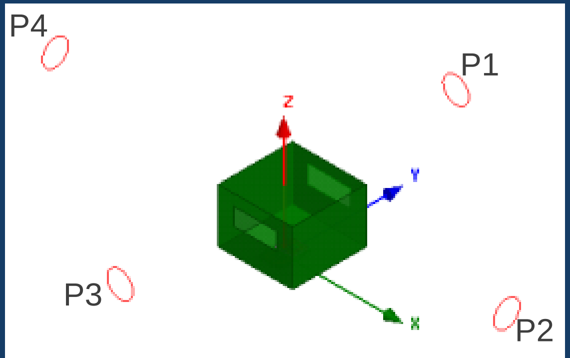
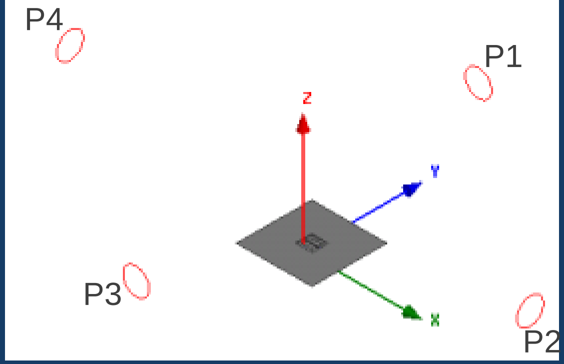
Background

- Three test set-ups are being discussed for use in H-field radiated emission measurements
  - Vehicle level test: WEVC tested using commercial electric vehicle (EV)
  - Sub-system level test: WEVC tested using Mock Wagon
  - Sub-system level test: WEVC tested using test rig (frame + shield)



Comparison of H-Field Emission from 3 Test Set-Ups

- The H-field emissions are assessed using the validated simulation approach
  - The same WEVC system is defined for all test set-ups
  - P3 is selected for comparison as the width of the car, wagon and rig are similar

<table>
<tr><th></th><th>Actual Car</th><th>Mock Wagon</th><th>Test Rig</th></tr>
<tr><td>Configuration</td><td>
</td><td>
</td><td>
</td></tr>
<tr><th>Distance At P3</th><th colspan="3">Simulated H-Field (dBuA/m)</th></tr>
<tr><td>3m</td><td>85.9</td><td>85.3</td><td>82.0</td></tr>
<tr><td>10m</td><td>59.9</td><td>59.2</td><td>55.9</td></tr>
</table>

- The radiated emissions compared among all three models (actual car, Wagon and Rig) are within 4dB

Uncertainty Budget

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Numerical Uncertainty

Error Description	Uncert.	Prob. Dist.	Div.	Std. Unc.	Std. Unc. (dB)
FEM Mesh Density[1]	18.0%	Rect	$\sqrt{3}$	10.4%	0.9
Boundary Condition[2]	0.64%	Norm	1	0.6%	0.1
WEVC Coil Structure Modeling[3]	5.62%	Norm	1	5.6%	0.5
WEVC Current Source[4]	33.41%	Norm	1	33.4%	2.5
Convergence of the numerical method[5]	0.25%	Norm	1	0.2%	0.0
Ground Modeling[6]	35.16%	Rect	$\sqrt{3}$	20.3%	1.6
Combined Std. Unc.				40.9%	**3.0**
Expanded Std. Unc.				81.7%	**5.2**

1. Mesh density with max length of 20mm around coils region was compared with auto mesh function in Ansoft HFSS v15.0
2. Boundaries set at 50m away from the edge of the simulation model were moved by ±20%.
3. Base pad and vehicle coils contain many turns made up of litz wire. Simplified numerical model turns were increased from 1 to 4 turns for base pad and from 1 to 2 turns for vehicle pad.
4. Uncertainty in measured current amplitude and phase used as WEVC current source in simulations for various loading/misalignment conditions
5. Convergence setting was increased from 3 to 4 number of passes with max energy delta set to <0.1
6. Earth ground has varying conductivity depending on region and weather conditions (wet/dry/snow). Two extreme conditions of PEC and free space were simulated to determine uncertainty.

Measurement Uncertainty

Error Description	Uncert.	Prob. Dist.	Div.	Std. Unc.	Std. Unc. (dB)
Passive loop[1]	--	--	--	5.2%	0.44
Cable loss[1]	--	--	--	5.9%	0.50
Spectrum analyzer[1]	--	--	--	13.5%	1.10
Oscilloscope[1]	--	--	--	0.25%	0.02
Passive loop distance[2]	1.80%	Norm	1	1.8%	0.15
Passive loop tilt angle[3]	1.75%	Norm	1	1.8%	0.15
Combined Std. Unc.				15.7%	**1.3**
Expanded Std. Unc.				31.4%	**2.4**

1. Provided by manufacturers.
2. Calculated using H-field roll off over the distance uncertainty of <0.3m at 50m.
3. H-field variation from tilting the passive loop antenna by ±10 degrees.

Test Set-Up Uncertainty

- There are three options to test radiated emissions with: actual electric vehicle, Mock Wagon or test rig. Table below shows the uncertainty that could result in different test car model selection

Error Description	**Uncert.**	**Prob. Dist.**	**Div.**	**Std. Unc.**	**Std. Unc. (dB)**
Test set-up model	22.5%	Rect	$\sqrt{3}$	15.9%	1.3
Combined Std. Unc.				15.9%	**1.3**
Expanded Std. Unc.				31.8%	**2.4**

Overall Uncertainty

Error Description	Std. Unc. (%)	Std. Unc. (dB)
Simulation Uncertainty	41%	3.0
Measurement Uncertainty	16%	1.3
Test Set-Up Model Uncertainty	16%	1.3
Combined Overall Std.Unc.	47%	**3.3**
Expanded Overall Std. Unc.	94%	**5.7**

- The correlation between measurement and simulation in slide12 is within 3dB, which is within the total uncertainty (without test car set-up uncertainty). This validates the simulation approach used

Additional Comments: QC Considerations for Rulemaking

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Establishing a Radiated Emission Limit for WEVC

- Regulatory limits for WEVC should consider the following points:
  - The compliance limit should be defined as an H-Field (dBuA/m) limit at a specified distance
  - WEVC operate at low frequency (<150kHz) and measurements up to 100m will be in the near field for which roll off factors and corrections using free-space impedance can not be applied
    - Note: In the near field it is magnetic leakage field distribution that is being measured
  - The overall uncertainty as discussed in this contribution must be considered when establishing a radiated emission limit for WEVC
- For the entry level WEVC system presented in this study the emission amplitude for assessing against a regulatory limit should be defined as follows:
  - Highest measured emission level (83.3dBuA/m @ 3m) + overall uncertainty(6dB)= 89.3dBuA/m

Future Proofing Regulatory Limits

- The consideration for the regulatory limit should consider both the current WEVC offerings and future development
- The final regulatory limit should be based on known interference thresholds for services operating in the band and offer maximum allowance for WEVC development up to higher powers (>20kW) and greater offsets in x, y and greater z gaps with semi dynamic and dynamic configurations
- To future proof regulatory limits to allow for further development of WEVC technology, while preventing harmful interference, it is estimated that H-field limits in the order of 120 dBuA/m or greater (85 kHz band) should be considered

Thank you

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