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“Enlarging e-mobility network”

In-vehicle Assessment of Human Exposure to EMFs from 25-kW WPT System Based on Near-field Analysis

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•² Momentum Dynamics.



Outlines

Introduction

Description of in-vehicle WPT system.

Near field EMF test methodology and setup

EMF test zones and standard safety limits

Results and discussion

Conclusion

Introduction

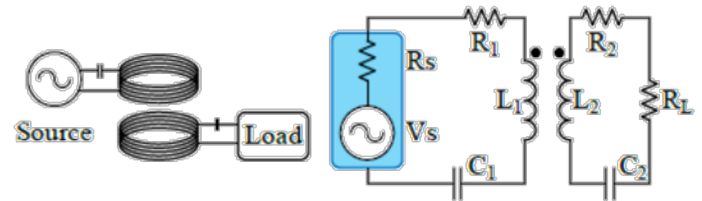
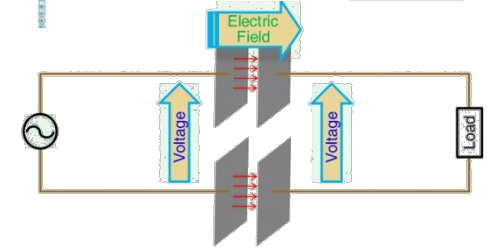
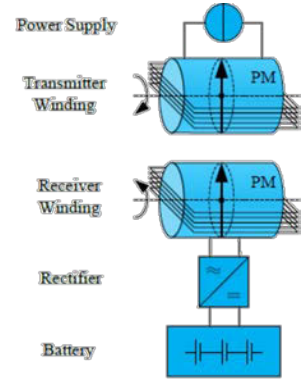
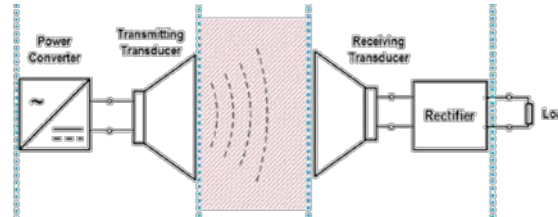
✓ Wireless power transfer (WPT) is a technology that could set human free from the annoying wires.

✓ WPT technologies:

1. Magnetic gear (MGWPT).
2. Acoustic (AWPT).
3. Capacitive (CWPT).
4. Inductive (IWPT).

✓ IWPT is the most attractive for EV applications. **Why?**

1. High power transfer capability.
2. Large air-gap (10-25 cm).
3. Maintenance and noise free.



Visions of WPT for EV

Quasi-dynamic WPT



Stationary WPT



Dynamic WPT



<https://www.nbcnews.com/mach/mach/futuristic-roads-may-make-recharging-electric-cars-thing-past-ncna766456>

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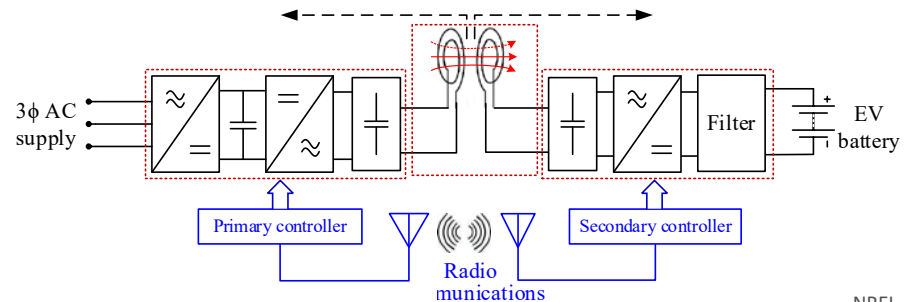
System Description

✓ Wirelessly Charged NREL's Shuttle

- Full electric on-demand
- 16 passenger
- 62.1 kWh battery capacity
- 100 miles range
- 7600 curb weight, including VA
- 6.6 kW on-board charger

✓ Momentum Dynamics WPT system

- 36"x36" symmetrical square pads
- 25 kW maximum power transfer
- 20 (19-21) kHz nominal operating frequency
- 62.1 kWh battery capacity



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Near field EMF test methodology and setup

✓ Test Device

Low frequency isotropic field probe-analyzer EHP-50D, Narda, Germany)

- 5 Hz – 100 kHz
- XYZ field measurements
- Built-in spectrum analyzer
- connected to a PC by a fiber optic cable
- dedicated software manages the probe setting, data acquisition and storage

Parameter	Value
Span	3-100 kHz
Measurement mode	Max RMS over 30 sec.
Hold Maximum	Enable
Showing XYZ measurements	Enable
Measuring Range	Small range
Units	B (μ T) & E (V/m)

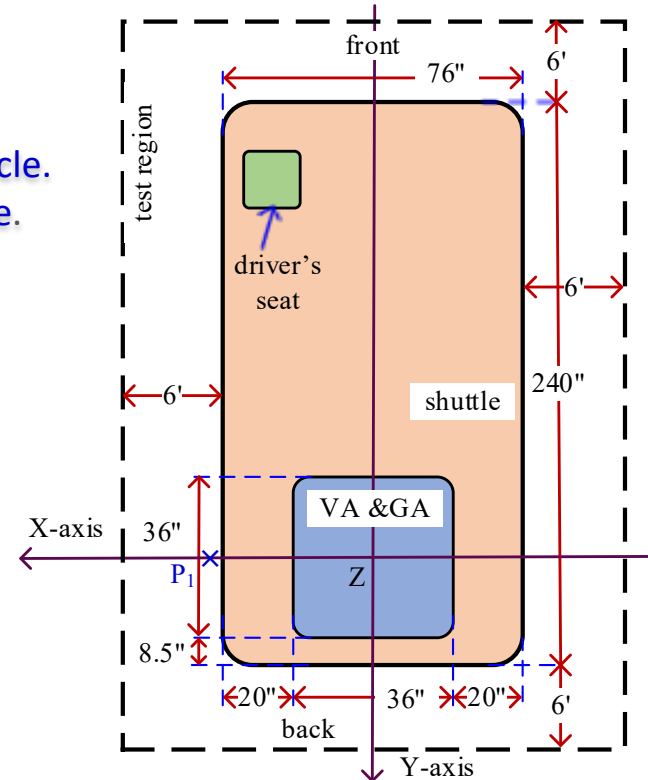


<https://www.narda-sts.com/en/>
<http://www.eenewsautomotive.com/news/one-test-system-analysing-electromagnetic-fields-5-hz-60-ghz>

Near field EMF test methodology and setup

✓ Test Set-Up

- Defining coordinates
 - GA reference coordinates for measurements outside the vehicle.
 - VA reference coordinates for measurements inside the vehicle.
- Defining a marked safety perimeter
 - Establishing a restricted area with a distance $> 3\text{m}$.
 - Measuring the EMFs at the perimeter with at full power operation.
 - Modifying the distance until the fields at the perimeter are with-in the recommended safe limits.
 - If the fields around the vehicle meet the standard limits, the perimeter need to be defined to allow enough test area for the workers (6-7 ft around the system).



Near field EMF test methodology and setup

✓ Defining the Worst Operating Condition

For each test region, the worst alignment conditions need to be defined and considered during the tests.

- Applying different combinations of misalignments (X, Y, Z, pitch, roll and yaw).
- Measuring the EMFs at few points that represent the worst scenarios.
- Comparing the results to define the worst operating condition.

Coupler Offset & Gap			Max Magnetic Field		Max Electric Field	
dX	dY	dZ	Location	B (μ T)	Location	E (V/m)
+max	+max	max				
+max	-max	max				
-max	+max	max				
-max	-max	max				

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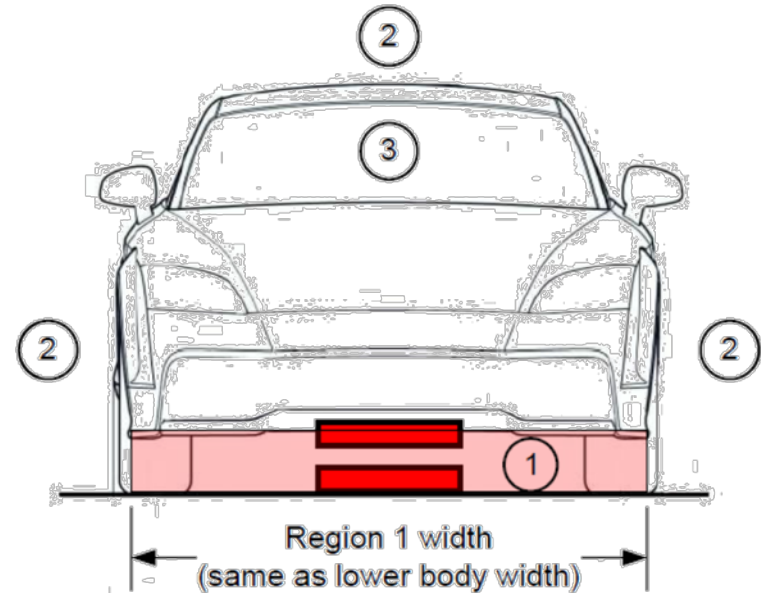
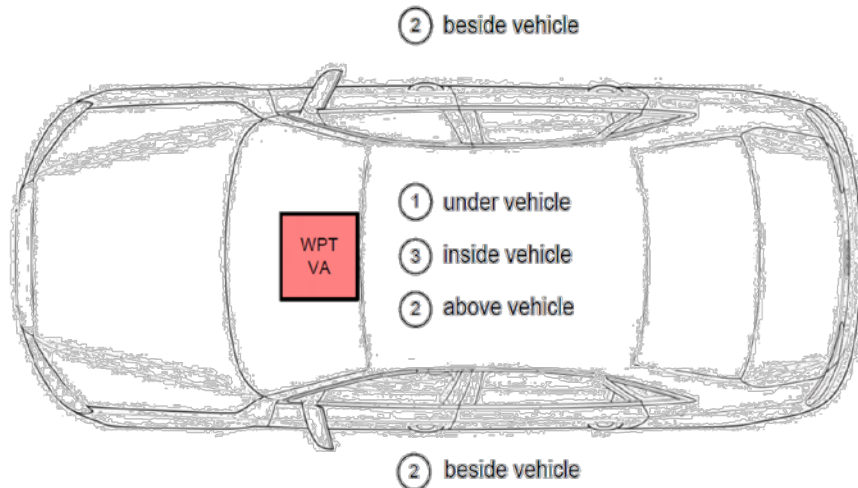
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EMF test zones and standard safety limits

✓ EMF Test Zones (SAE J2954)

- Region I: Under the vehicle
- Region II: Around and above the vehicle
- Region III: Inside the vehicle



"J2954A (WIP) Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology - SAE International."

EMF test zones and standard safety limits

✓ J2954 Standard Exposure Limits (2010 ICNIRP guidelines)

➤ Human Exposure

- General public
- Occupational

➤ IMD Coexistence

✓ EMF Standard Limits

➤ Basic Restrictions

➤ Reference Levels

Ref. Limits for General Exposure

Region	Magnetic Field Limit				Electric Field Limit (E_{peak}) (V/m)
	Human Exposure		IMD Coexistence		
	B_{peak} (μT)	H_{peak} (A/m)	B_{peak} (μT)	H_{peak} (A/m)	
3	38.2 (27 RMS)	29.7 (21 RMS)	21.2 (15RMS)	16.9 (11.96 RMS)	117 (83 RMS)
2	38.2 (27 RMS)	29.7 (21 RMS)	21.2 (15RMS)	16.9 (11.96 RMS)	117 (83 RMS)
1	red	i) Active or passive access control. ii) Detection and shutdown. iii) Meet region 2 EMF limits.			
	green	Meet region 2 EMF limits.			

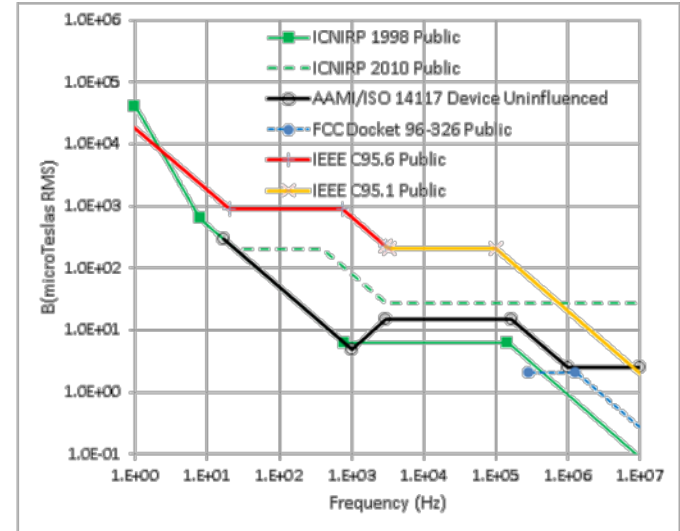
Region	Magnetic Field Limit		Electric Field Limit
	B_{peak} (μT)	H_{peak} (A/m)	E_{peak} (V/m)
3	141.5 (100 RMS)	113.2 (80 RMS)	240.5 (170 RMS)
2	141.5 (100 RMS)	113.2 (80 RMS)	240.5 (170 RMS)
1	red	i) Active or passive access control. ii) Detection and shutdown. iii) Meet region 2 EMF limits.	
	green	Meet region 2 EMF limits.	

Ref. Limits for Occupational

EMF test zones and standard safety limits

✓ Other EMF Standards

- 2010 ICNIRP guidelines
- 1998 ICNIRP guidelines
- IEEE C.95.1-2014
- IEEE C.95.6
- ACGIH TLV 2017



"J2954A (WIP) Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology - SAE International."

Ref. Limits for General Exposure & Occupational

standard	Magnetic field, B_{rms} (μT)		Electric field, E_{rms} (V/m)	
	general public	occupational	general public	occupational
ICNIRP 2010	27	100	83	170
IEEE C.95.1-2014 (3 kHz - 5 MHz)	205	615	614	1842
ACGIH TLV 2017 (2.5-30) kHz	---	200	---	1842

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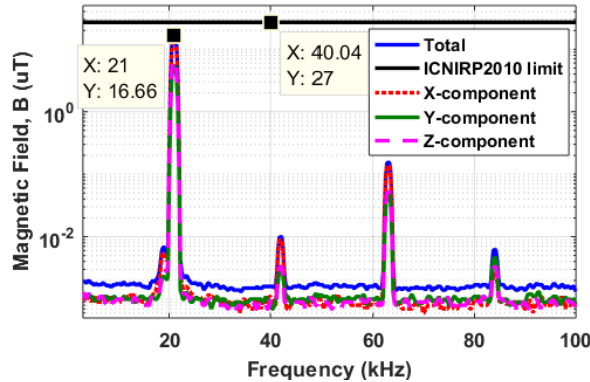
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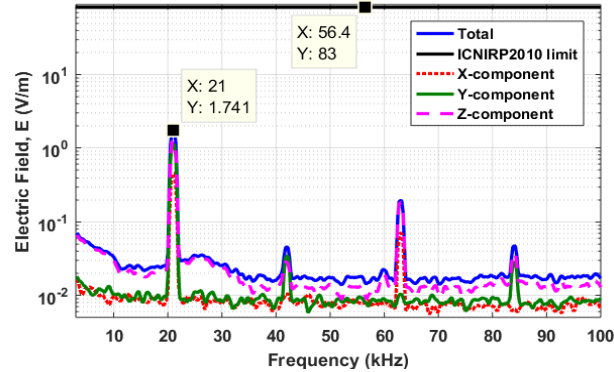
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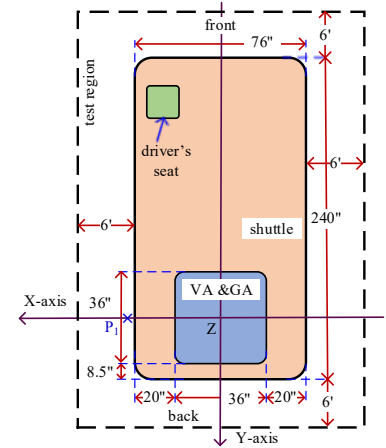
✓ Region 2 Test



Measured FFT of magnetic fields at point P_1 with full power transfer (Height = 6.25").

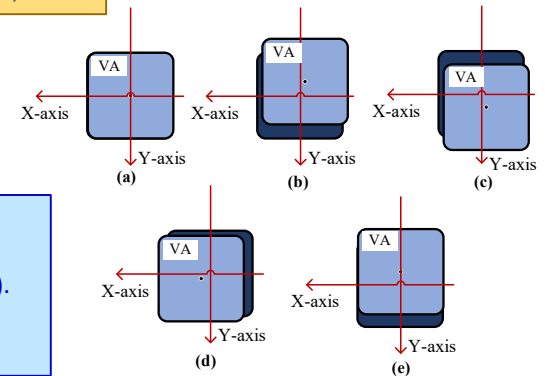


Measured FFT of electric fields at point P_1 with full power transfer (Height = 6.25").



Misalignment	Max B_{rms} (μT)	Max E_{rms} (V/m)
Position I	16.661	1.7414
Position II	18.380	2.4091
Position III	17.696	2.5345
Position IV	17.152	1.7147
Position V	18.526	2.0853

- (a) Position I ($\Delta X=0$, $\Delta Y=0$ and $Z=9.5$ ").
- (b) Position II ($\Delta X=-1$ ", $\Delta Y=-2.5$ " and $Z=9.5$ ").
- (c) Position III ($\Delta X=-1$ ", $\Delta Y=2.25$ " and $Z=9.5$ ").
- (d) Position IV ($\Delta X=1.5$ ", $\Delta Y=-1$ " and $Z=9.5$ ").
- (e) Position V ($\Delta X=0$, $\Delta Y=-2.25$ " and $Z=9.5$ ").

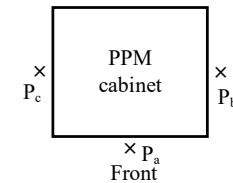


Results and discussion

✓ EMF Test Results around PPM

Test Point	Max B_{rms} (μT)	Max E_{rms} (V/m)
$P_{a,L}$	0.7251	0.1617
$P_{b,L}$	0.3293	0.1469
$P_{c,L}$	0.2375	0.1416
$P_{a,H}$	1.1235	0.1839
$P_{b,H}$	0.5735	0.1125
$P_{c,H}$	0.3472	0.1106

- (L) means 6.25" from the ground; and
- (H), means 26.25" from the ground



Results and discussion

✓ Region 3 Test Results

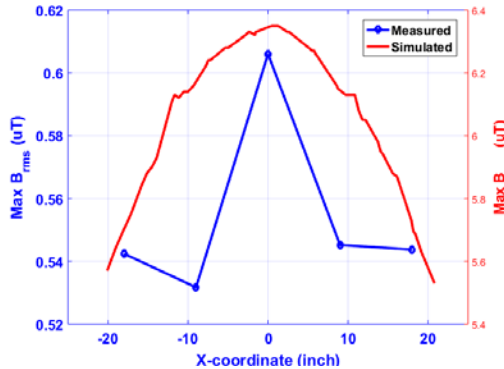
@ ($\Delta X=0$, $\Delta Y=2.25''$ and $Z=9.5''$)

➤ Driver seat test

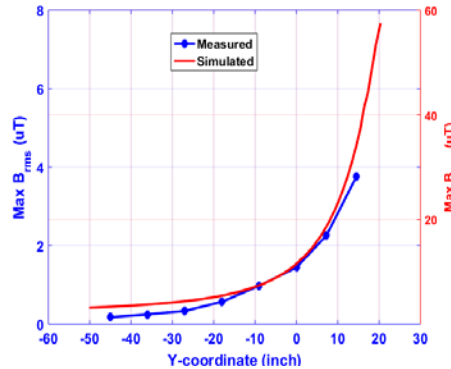
Test Point	Max B_{rms} (μT)	Max E_{rms} (V/m)
P_A	0.0328	0.0633
P_B	0.0068	0.0380
P_C	1.0362	0.0257



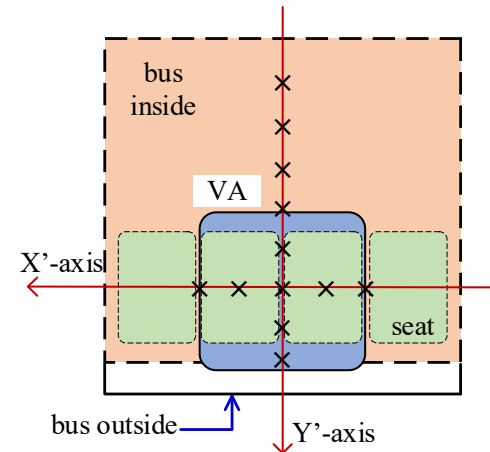
➤ Above the VA tests



Magnetic field along X'-axis at a height of 27.25" from the floor of the bus



Magnetic field along Y'-axis at a height of 6.25" from the floor of the bus



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- ✓ The paper presents a methodology to assess the human exposure to in-vehicle WPT system.
- ✓ Near-field analysis for EMFs due to 25 kW WPT system for medium duty electric vehicles is presented.
- ✓ The tests are conducted with the WPT system physically installed in a NREL electric shuttle.
- ✓ Test results around (region 2), inside (region 3) the bus and around the PPM cabinet are investigated and compared with the standard reference levels 2010 ICNIRP.
- ✓ The experimental results show that the WPT system under test meets the requirements for the human exposure to the EMFs from the WPT system.

Thank you

www.nrel.gov

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