Wireless Charging Test Results:

Vehicle Testing and Standalone Sub-System Testing

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Idaho National Laboratory

Richard "Barney" Carlson
Idaho National Laboratory
Energy Storage & Transportation Systems
Advanced Vehicle Testing Activity (AVTA)

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Outline

- Laboratory equipment, setup, and capabilities

- PLUGLESS™ Test Results (Efficiency and EM field strength)
  - Operation on 2012 Chevrolet Volt
  - Standalone operation (off-board the vehicle)

- Published Results (**http://avt.inel.gov/evse.shtml**)

- Summary
  - Importance of both test methods
    - *Vehicle testing:*
      - shows the interaction of chassis and WPT
      - benchmark the entire system (WPT and vehicle)
    - *Standalone testing:*
      - best used for technology comparison

INL's Electric Vehicle Infrastructure (EVI) *Laboratory*

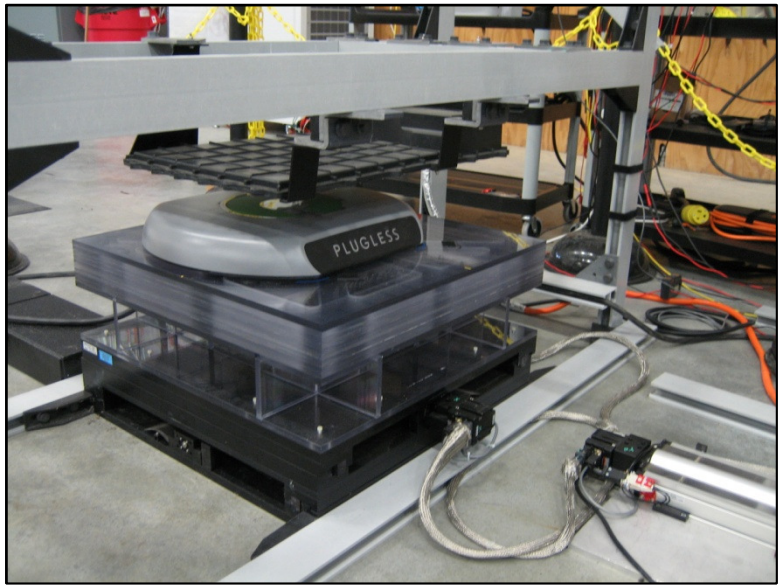
- Evaluate Conductive and Wireless Charging Systems
  - Efficiency and energy consumption
  - EM field emissions (wireless charging only)
  - Power Quality (static and dynamic)
    - Total Harmonic Distortion
    - Power Factor
  - Cyber Security Assessment

- Wide range of power
  - Level 1, 120 VAC
  - Level 2, 208 / 240 VAC
  - DCFC, 480 VAC 3ϕ
  - Variable voltage source
    - Grid Emulator

INL's Wireless Charging Testing and Evaluation

- On-board vehicle testing
  - Integrate and tuned for the vehicle by the WPT manufacturer

- Standalone sub-system testing
  - Fiberglass test fixture supports 2nd coil
  - Other equipment to emulate vehicle functions (comm., power transfer)

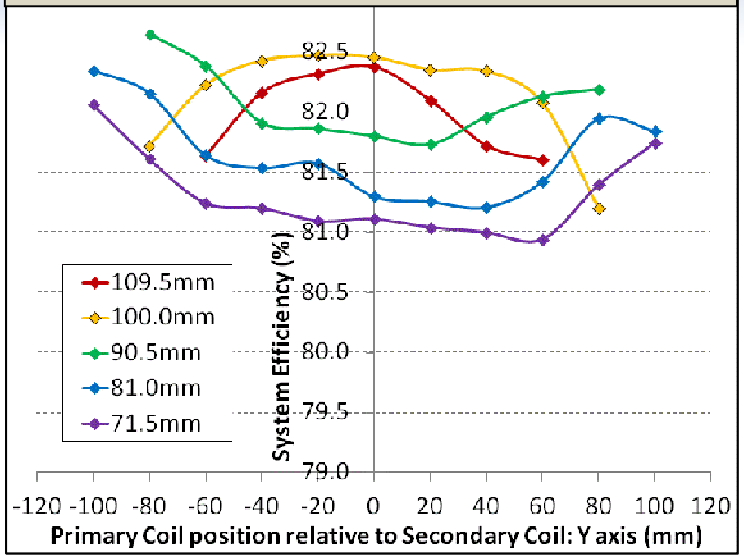


- Multi-axis computer controlled
  - X & Y axis coil alignment to evaluate impact of coil to coil misalignment
  - X & Z axis EM field sensor positioning around the WPT system
  - Manual Z (gap) variation by adding / removing 9.5 mm shims under primary

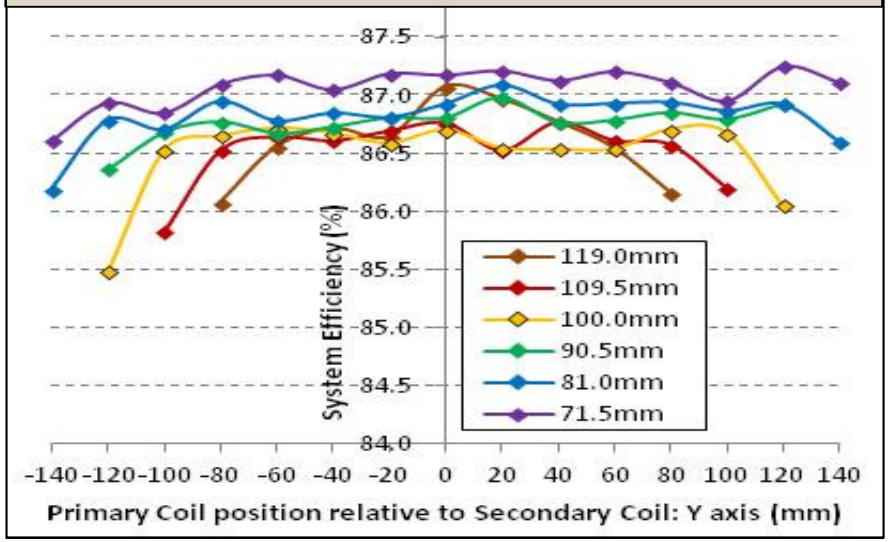
PLUGLESS™ Power Transfer Efficiency

- Comparison of Vehicle and Standalone Test Results
  - 4% to 6% efficiency difference
  - 40 mm difference in maximum coil misalignment operating range
  - Variation in efficiency with change in coil gap
  - Coil gap with highest efficiency when coils are aligned
    - Vehicle: 100 mm gap
    - Standalone: 71.5 mm gap
  - Difference in efficiency and system performance are due to EM field interaction with the steel vehicle chassis

Vehicle Efficiency (Chevy Volt)



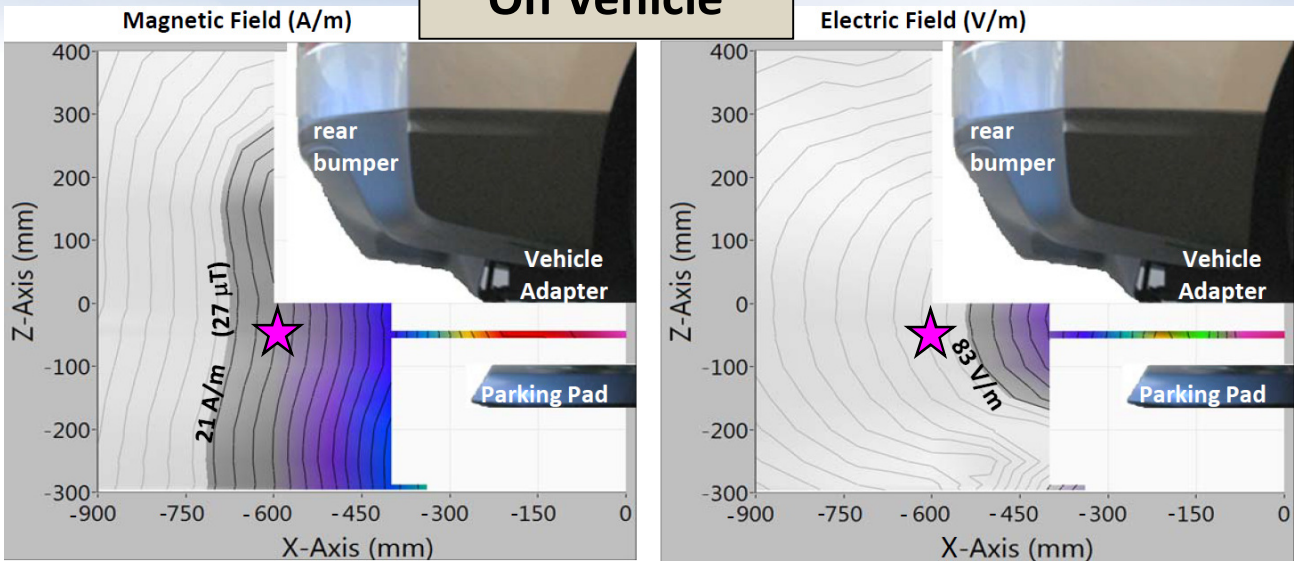
Standalone Efficiency



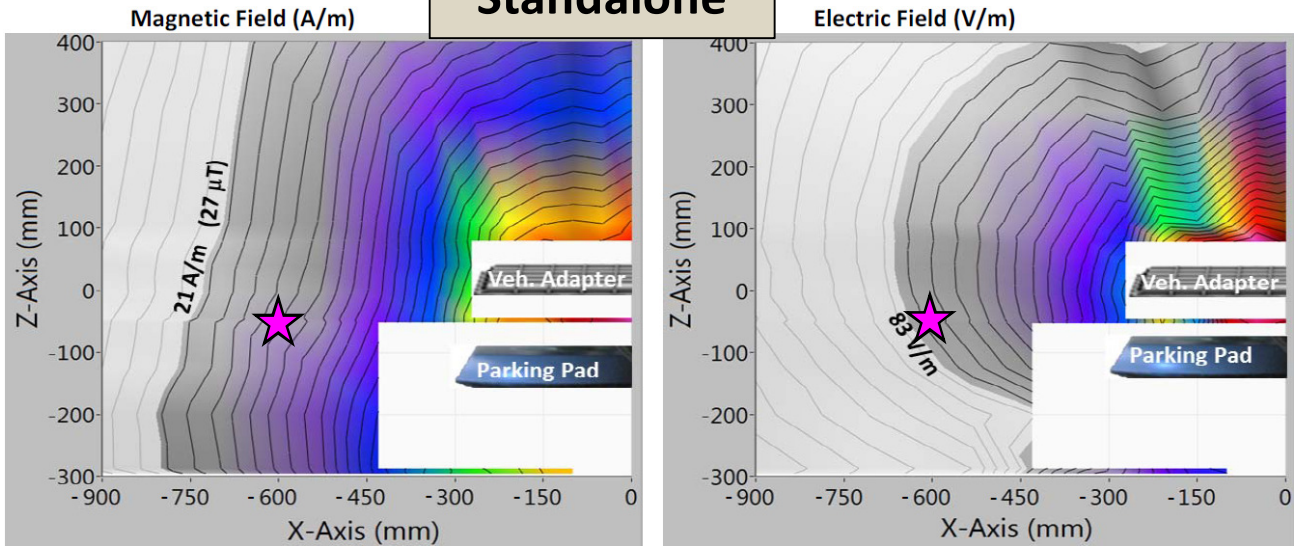
PLUGLESS™ EM-field measurements

- EM field shape is altered by vehicle chassis
- At rear bumper centered between coils (-600, -50)★
  - Vehicle
    - 42.2 µT
    - 57.3 V/m
  - Standalone
    - 53.7 µT
    - 101.5 V/m

On Vehicle



Standalone



Fact Sheet: Vehicle Test Results

Idaho National Laboratory

Advanced Vehicle Testing Activity

PLUGLESS™ Level 2 EV Charging System (3.3 kW) by Evatran Group Inc.

Results from Laboratory Testing as installed on a 2012 Chevy Volt

Description / Specifications [1]

System Input Voltage operating Voltage	208 to 240	VAC
Circuit Breaker Rating	30	A
Nominal gap between coils	100	mm
Rated maximum power output	3300	watts
Parking Pad (Primary Coil system)		
Shape	Approximately Circular	
Size	559 dia. x 470 long	mm
Vehicle Adapter (Secondary Coil system)		
Shape	Rectangular	
Size	762 long x 457 wide	mm

Measured System Parameters during nominal, steady state conditions [2]

Input Power		
Input Voltage	208	VAC
Input Current RMS	28	Amps RMS
Power Factor	0.60	
Voltage Total Harmonic Distortion (THD)	3	%
Current Total Harmonic Distortion (THD)	134	%
Wireless Power Transfer Operation		
Operating Frequency (kHz)	18 - 20	kHz (variable)
DC Output Power (into On-Board Charge Module)		
Output Voltage	215	VDC
Output Current	13.8	Amps
Output Voltage Ripple Factor	0.76	%
Operating Temperature after 4.0 hours at 3.0 kW output		
Parking Pad: Max observed surface temperature	51	°C
Vehicle Adapter: Max observed surface temperature	48	°C

[1] Manufacturer's Specifications: http://www.pluglesspower.com/wp/wp-content/uploads/2014/02/Plugless_Tech_Specs.pdf

[2] Test conducted at nominal conditions (3.0 kW output, 100mm coil gap, coils aligned) unless otherwise specified

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LESS™ Vehicle Adapter into On-Board Charge Module

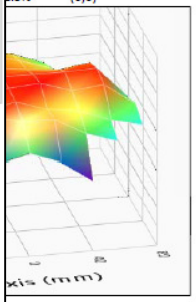
SS™ Control Panel from 208 VAC

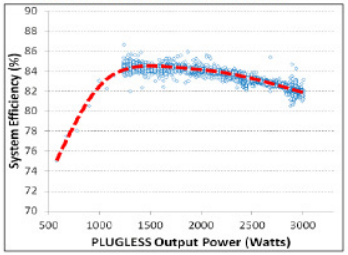
fully recharged)[2]

	15.3 kWh
	12.6 kWh
	82.3 %
	4.5 hours

nt[2] Primary Coil position relative to Secondary Coil (mm)

2.5%	(20,-20)
2.5%	(0,0)





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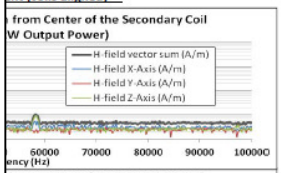
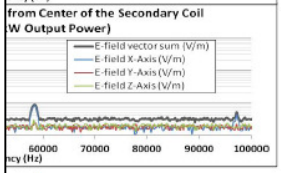
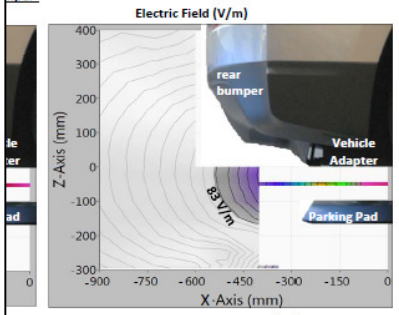
ent (coils aligned)[2,3]





mper[2]



EM Field meter position (X,Z)

1490 A/m (1872 µT)	(0,-50)	centered between coils
6425 V/m	(0,-50)	centered between coils
33.6 A/m (42.2 µT)	(-600,-50)	at rear bumper
57.3 V/m	(-600,-50)	at rear bumper
0.5 A/m (0.6 µT)	(0,250)	inside trunk above charge system
0.8 V/m	(0,250)	inside trunk above charge system

w secondary coil) 0.8m from Secondary Coil Center along X-axis

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Watts

0.0 µT)

EM Field measurement position
top surface center of parking pad
top surface center of parking pad

00mm coil misalignment)

Watts
econds

847 µT)

EM Field measurement position
top surface center of parking pad
top surface center of parking pad

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http://avt.inel.gov/evse.shtml

Fact Sheet: Standalone Test Results

Advanced Vehicle Testing Activity — Idaho National Laboratory

PLUGLESS™ Level 2 EV Charging System (3.3 kW) by Evatran Group Inc.

Results from Laboratory Testing off-board the vehicle

Description / Specifications [1]

System Input Voltage operating Voltage	208 to 240	VAC
Circuit Breaker Rating	30	A
Nominal gap between coils	100	mm
Rated maximum power output	3300	watts
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Power Factor	0.60	
Voltage Total Harmonic Distortion (THD)	3	%
Current Total Harmonic Distortion (THD)	132	%
Wireless Power Transfer Operation		
Operating Frequency (kHz)	18 - 20	kHz (variable)
DC Output Power (into programmable DC electronic load)		
Output Voltage	215	VDC
Output Current	13.9	Amps
Output Voltage Ripple Factor	0.75	%
Operating Temperature		
Parking Pad: Max observed surface temperature	51	°C
Vehicle Adapter: Max observed surface temperature	48	°C

[1] Manufacturer's Specifications: http://www.pluglesspower.com/wp/wp-content/uploads/2014/02/Plugless_Tech_Specs.pdf
[2] Test conducted at nominal conditions (3.0 kW output, 100mm coil gap, coils aligned) unless specifie

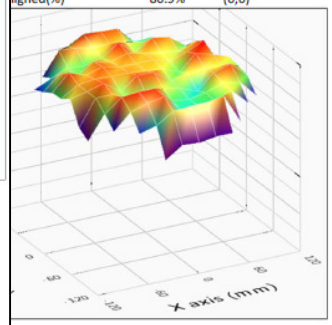
...arging System Efficiency

Energy out of PLUGLESS™ Vehicle Adapter into programmable DC Load
Energy into PLUGLESS™ Control Panel from 208 VAC

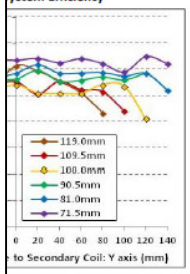
...tion with coil misalignment [2]

...cy (%)	87.3%	(80,20)
...ligned(%)	86.9%	(0,0)

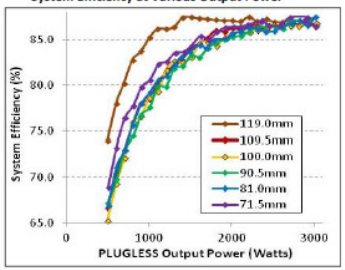
Primary Coil position relative to Secondary Coil (mm)



...ystem Efficiency [2]

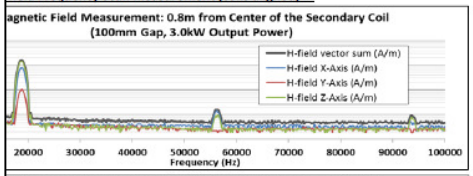


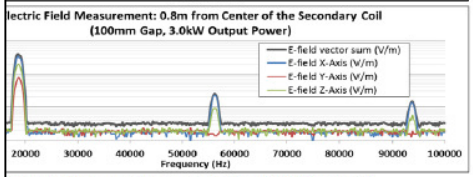
System Efficiency at Various Output Power [2]



...ic and Electric Field

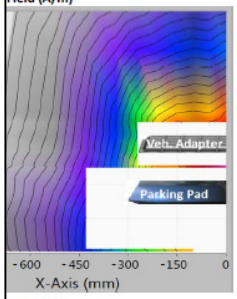
...field Frequency Scan measurement (coils aligned) [2,3]



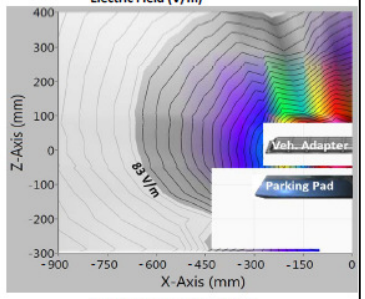


...& Electric fields around the rear side of the PLUGLESS system [2]

...Field (A/m)



Electric Field (V/m)



...rements [2]

...measured H-field	1587 A/m (1994 µT)	(0,-50)	between coil centers
...measured E-field	6833 V/m	(-50,80)	above the vehicle adapter
...m from coil center	42.7 A/m (53.7 µT)	(-600,-50)	at rear of system
...m from coil center	101.5 V/m	(-600,-50)	at rear of system

EM Field meter position (X,Z)

[3] EM field measurement is centered between the gap (50mm below secondary coil) 0.8m from Secondary Coil Center along X-axis

http://avt.inel.gov/evse.shtml

Summary

- Wireless Charging testing and evaluation
  - Importance of both:
    - Vehicle testing
      - Interaction of WPT EM field with the vehicle chassis impacts system performance
    - Standalone testing
      - Best method for technology comparison

- INL's Electric Vehicle Infrastructure Laboratory is the U.S. DOE 'Core Capability' for:
  - Testing and Evaluation of Wireless and Conductive Charging Infrastructure
  - Supports codes and standards development and validation (such as SAE J2954, SAE J2894, etc.)

Acknowledgement

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EERE Vehicle Technologies Program

More Information

http://avt.inl.gov