2014 World Congress and Exhibition

Idaho National Laboratory

Test Results: *PLUGLESS*™ Inductive Charging System by Evatran Group Inc.

2014-01-1824

Richard "Barney" Carlson

April 2014

INL/CON-13-29939

www.inl.gov

Idaho National Laboratory

INL Wireless Charging Testing

- Scope: Provide Results from Testing
  - System Efficiency
  - Electric and Magnetic (EM) Field Strength
  - Impact on Grid (power quality, harmonics, etc.)
  - Support SAE J2954 committee

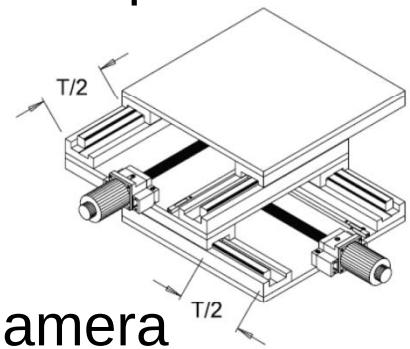
- Factors that impact System Efficiency and EM Field
  - Coil to Coil Position
    - Alignment (X, Y, θ, Tilt)
    - Gap between coils
  - Output Power
  - Temperature (warm-up effects)

- Testing is in accordance with draft SAE J2954 procedures

INL Wireless Charging Test Equipment

- Programmable Loads
  - AC Loads (9.0 kW) Chroma 63804
  - DC loads (58 kW) Chroma 63210

- Hioki 3390 Power Meter
  - 4 channel AC and DC current and voltage
  - Real-time integration for power & energy
- NARDA EHP-200a
  - Electric Field
  - Magnetic Field



- FLIR SC640 Thermal Camera
- Fiberglass channel strut frame with multi-axis positioning table
- CAN communications (as required)
- Custom LabVIEW test control program for data acquisition and test host function to synchronize all test operations

INL Wireless Charging Laboratory Testing

Grid Power
480 & 208 VAC

Hioki Power
Meter 3390

Chroma
AC Load

Chroma
DC Load

Custom LabVIEW Host and
Data Acquisition

FLIR IR
Camera

Multi-Axis
Positioning
System

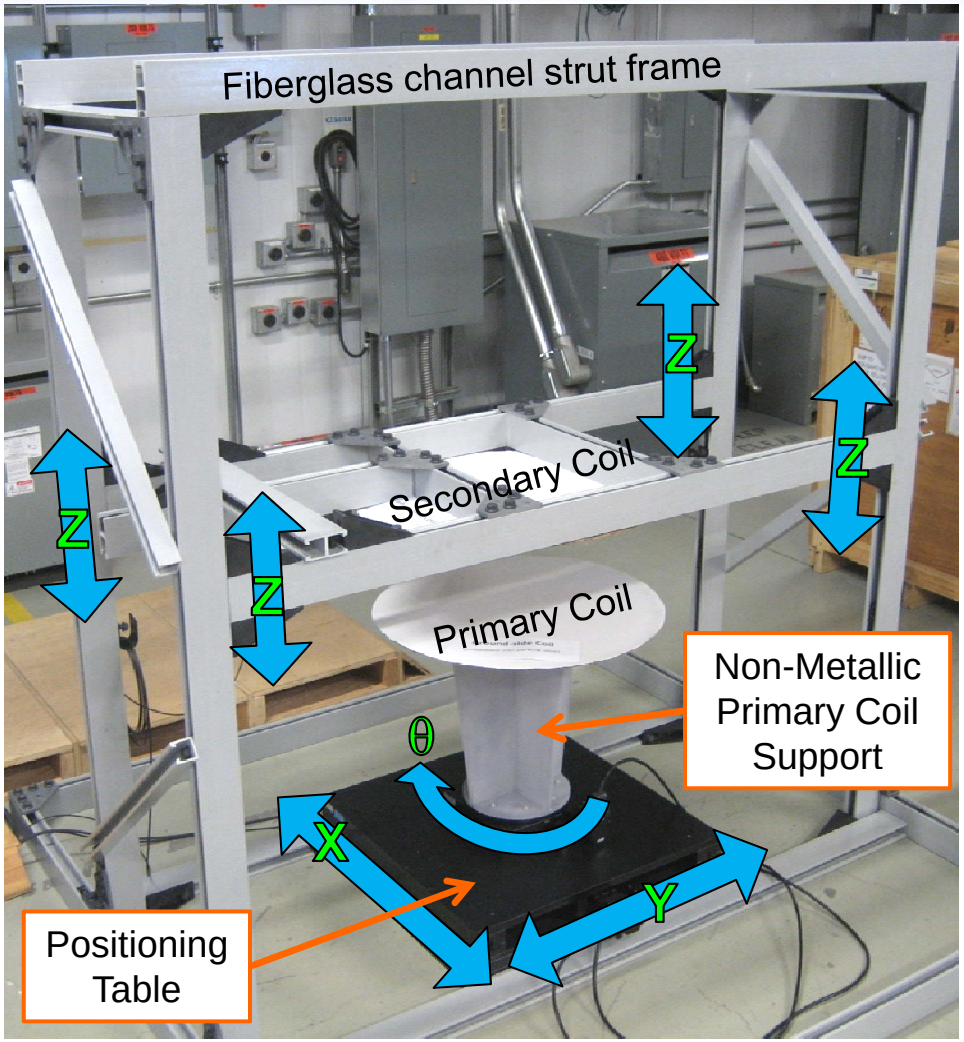
Polycarbonate
Primary Coil
Stand-off

Narda EM Field
Meter (EHP-200a)

Fiberglass
Channel Strut
Supports
Secondary Coil

INL Wireless Charger Coil Positioning

- Primary Coil
  - Software position control
    - Ball-screw positioning table with servo motors
    - X, Y, θ
  - Supported by polycarbonate stand-off
    - Increase distance to the metallic positioning table
- Secondary Coil
  - Suspended from fiberglass channel strut frame
  - Manually adjusted
    - Z position (coil to coil Gap)
    - Tilt by differential Z



PLUGLESS™ Inductive Charging System from Evatran Group Inc.

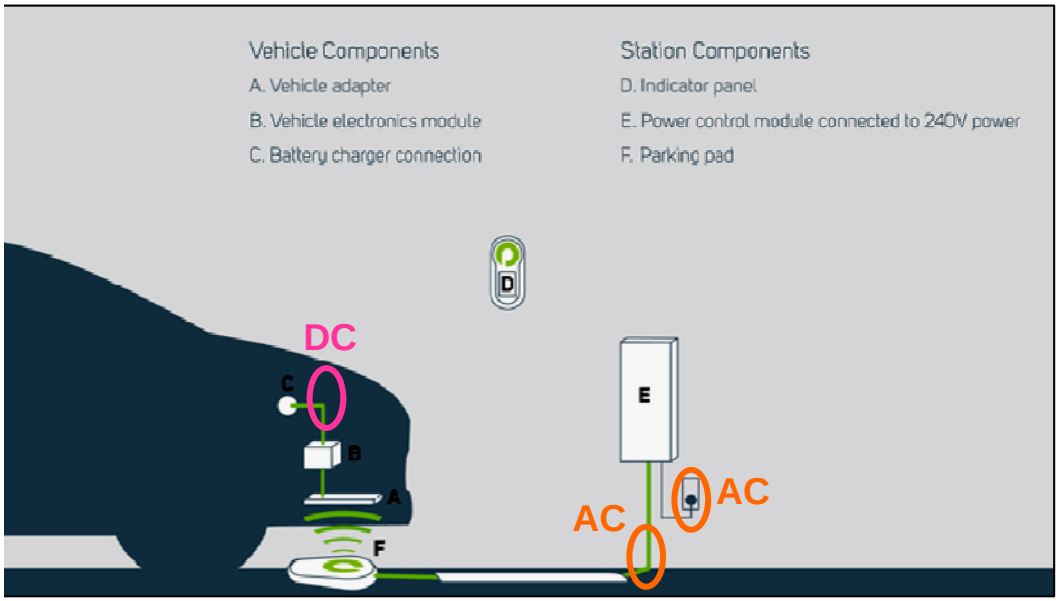
- Rated power: 3.3 kW output (208 VAC input as tested)
- 30 A circuit breaker
- Nominal Gap between coils: 100mm (4.0”)
- Vehicle application: Chevrolet Volt (as tested)
- Dimensions:
  - Primary Coil (circular) above ground installation
    - Approx. Circular: 559mm dia. x 470mm long
  - Secondary Coil (oval) attaches under rear of vehicle
    - Rectangular: 464mm long x 525mm wide

http://www.pluglesspower.com/wp-content/uploads/2013/06/PluglessL2_Specs.pdf

INL Laboratory Test Setup: PLUGLESS™ by Evatran

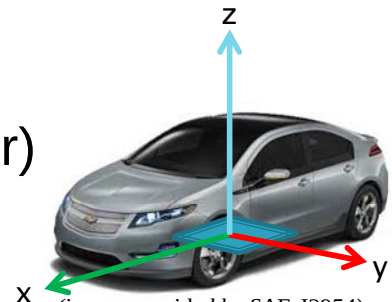
- Three Measurement Nodes
  - AC Grid Input (60 Hz)
  - Control Panel output to Primary Coil (parking pad)
  - DC Vehicle Adaptor output to On-Board Charge Module (OBCM)

  - Secondary coil output was unable to be measured due to sealed vehicle-side enclosure

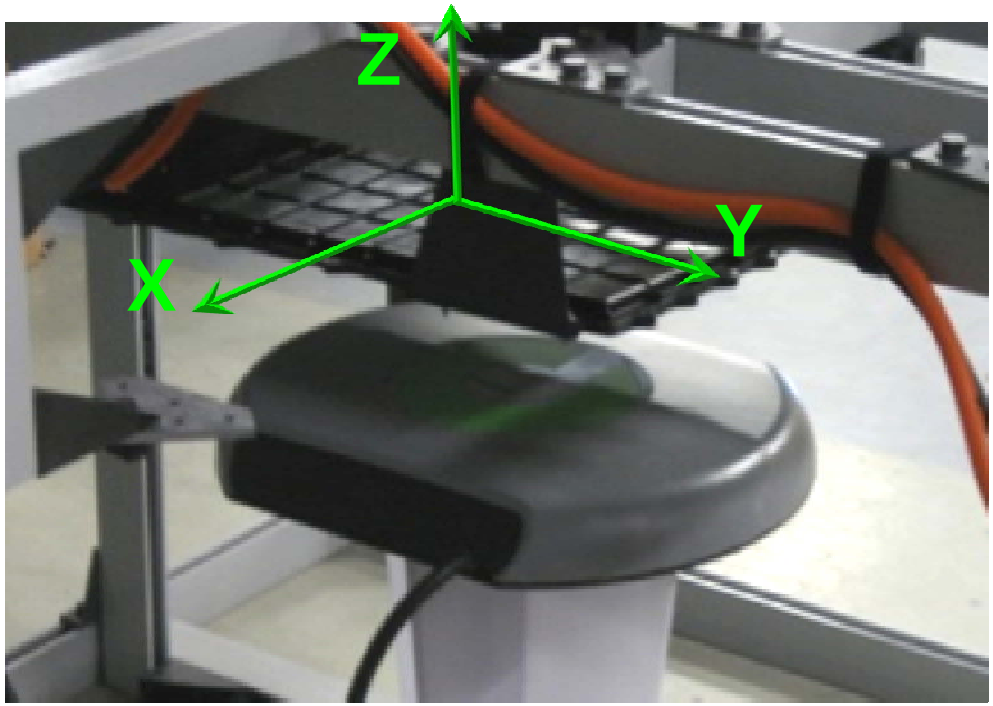


INL Laboratory Test Setup

- Measurement orientation
  - Origin:
    - Bottom face the Vehicle Adapter enclosure
    - Center of the Secondary Coil (inside Vehicle Adapter)
  - X: towards front of vehicle
  - Y: towards drivers side
  - Z: up through roof

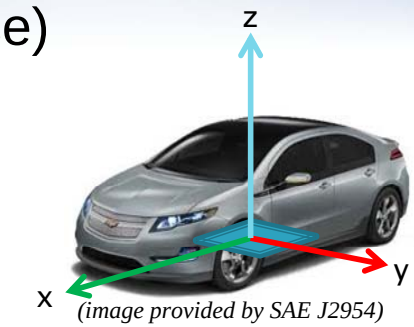


(image provided by SAE J2954)

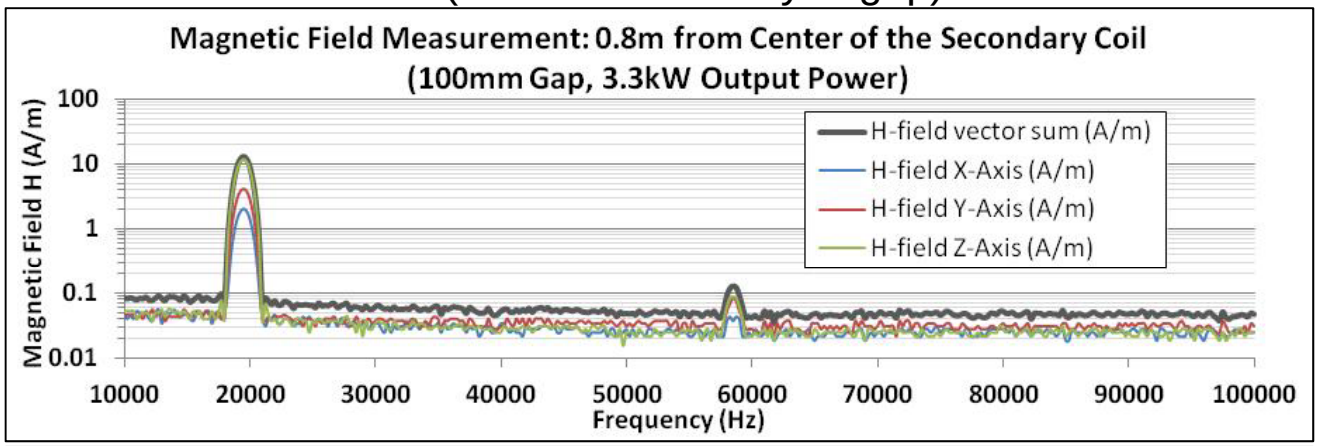


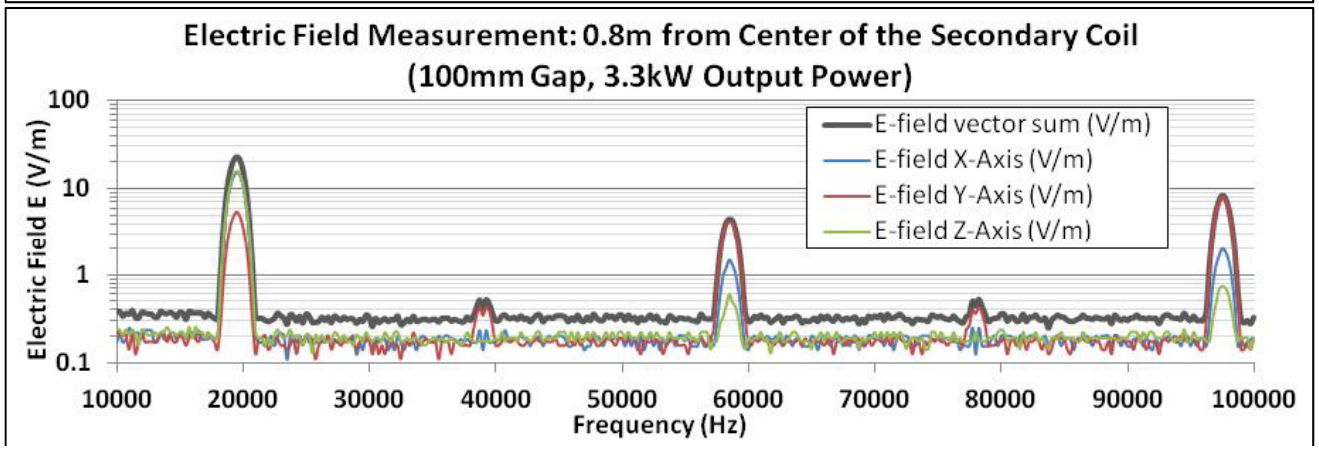
EM Field Frequency Scan 10kHz – 100kHz

- 100mm coil to coil gap, 3.3kW output power (nominal case)
- EM field measurement position (baseline test position)
  - X=0mm
  - Y=800mm (from the center of Secondary coil)
  - Z=-50mm (centered vertically in gap)



(image provided by SAE J2954)



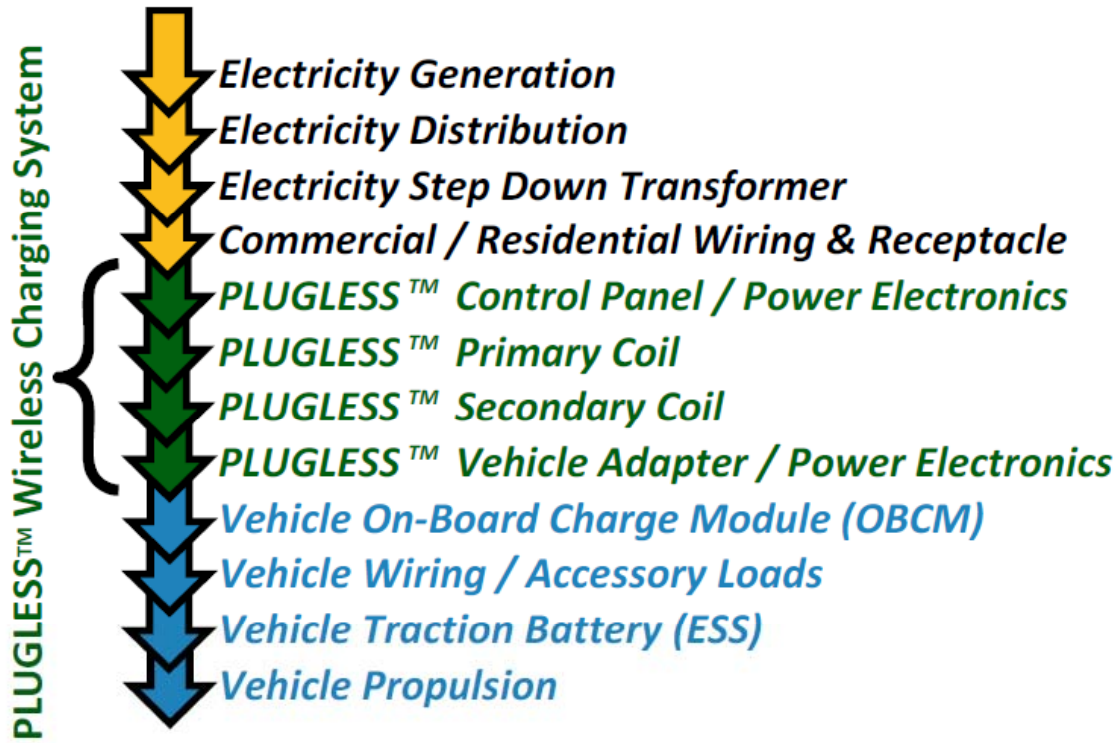


- Operating frequency
  - 19.5 kHz
- Peak Magnetic Field (H-field)
  - 12.9 A/m
  - (16.1 μT)
- Peak Electric Field (E-field)
  - 22.1 V/m

Definition: System Efficiency

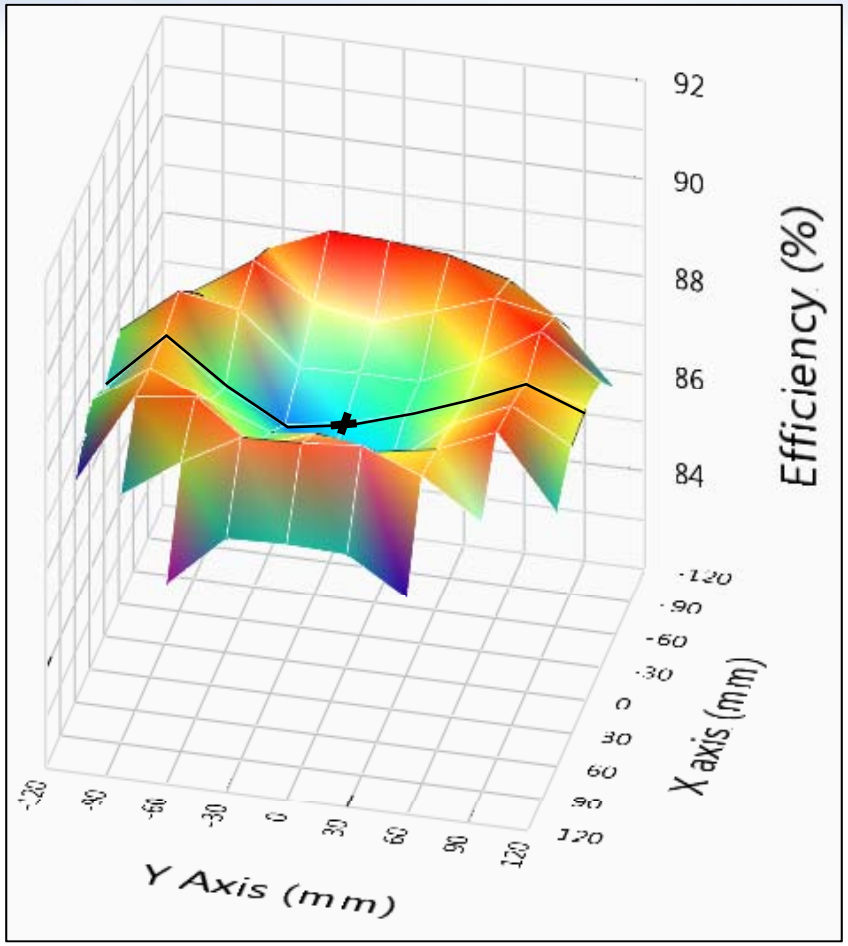
$$\text{System Efficiency} = \frac{\text{Energy out of PLUGLESS}^{TM}\text{ Vehicle Adapter}}{\text{Energy into PLUGLESS}^{TM}\text{ Control Panel}}$$

Power Flow from Generation to Vehicle Operation



System Efficiency Variation with Coil Position

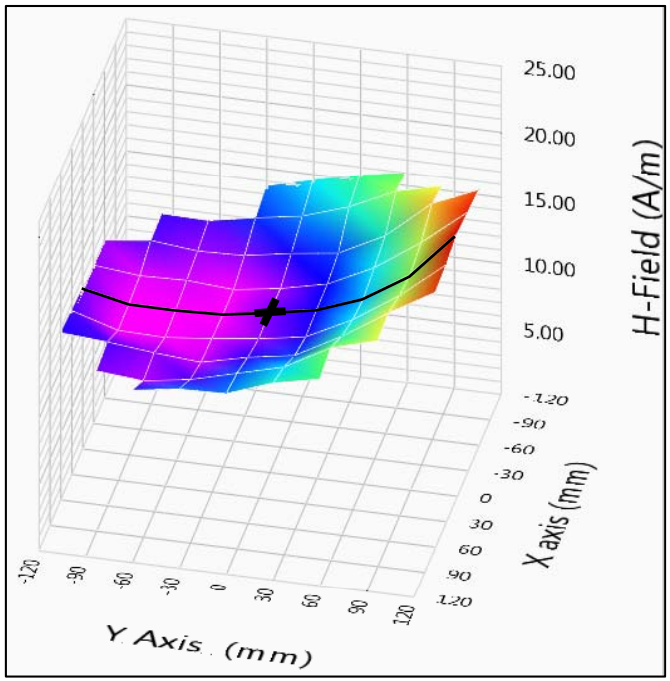
- 3.3 kW output power
- 100mm gap between coils
- X-axis and Y-axis show Primary Coil position relative to Secondary Coil

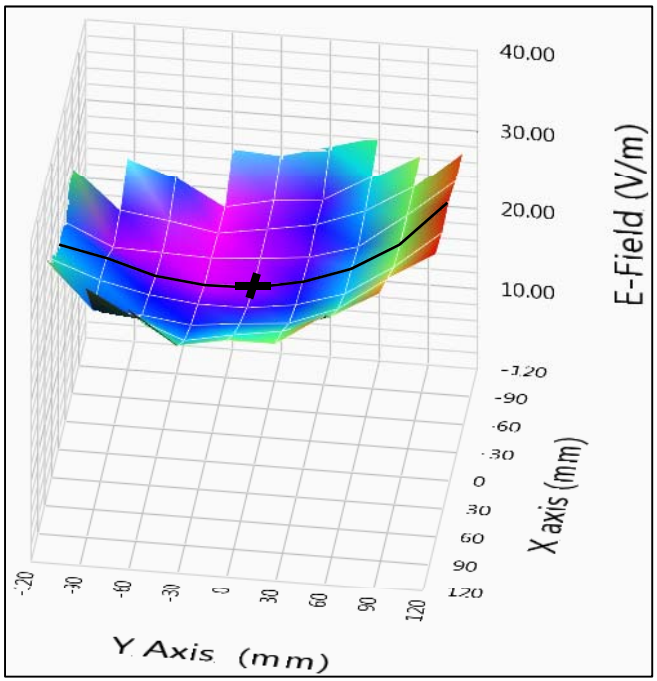


Efficiency Results (at 3.3 kW output with **100mm gap**)		Primary Coil position relative to Secondary Coil (mm)
Maximum Efficiency (%)	88.8%	(-90,-30)
Nominal Efficiency (%)	87.0%	(0,0)
Minimum Efficiency (%)	86.1%	(120,-60)

EM Field Variation with Coil Position

- 3.3 kW output power
- 100mm gap between coils
- X-axis and Y-axis show Primary Coil position relative to Secondary Coil

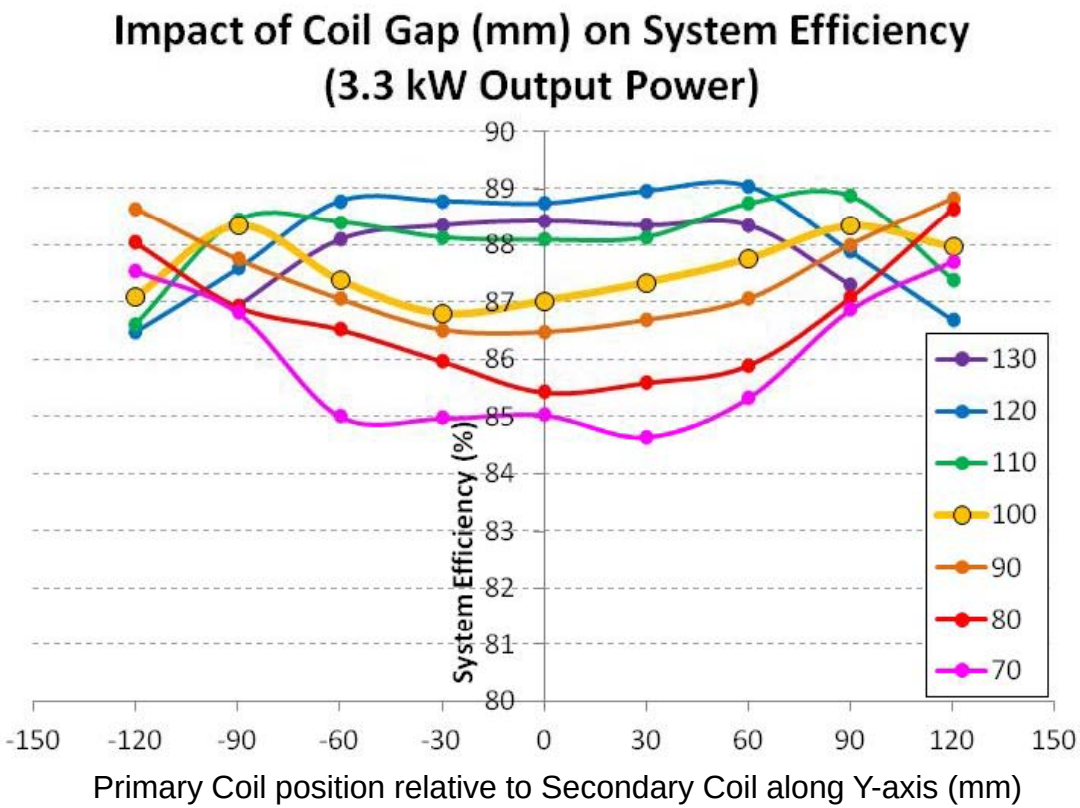


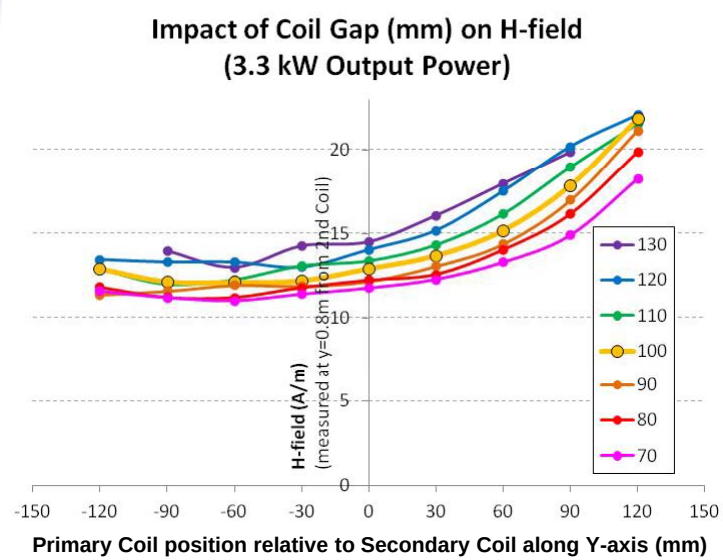


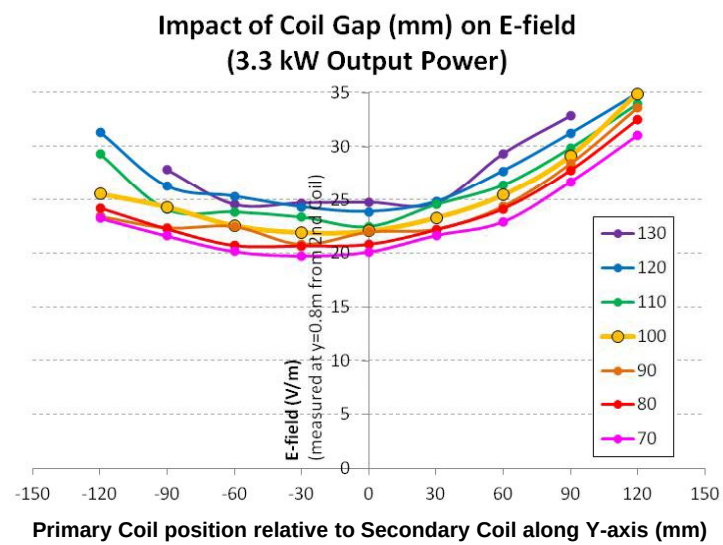
EM Field Results (at 3.3 kW output with 100mm gap)		Primary Coil position relative to Secondary Coil (mm)
Maximum H-field (A/m)	21.9	(0,120)
Nominal H-field (A/m)	12.9	(0,0)
Maximum E-field (V/m)	35.2	(60,120)
Nominal E-field (V/m)	22.1	(0,0)

Coil to Coil Gap Impact on System Efficiency and EM Field

- 3.3 kW output
- EM field measured at
  - X=0.0m Y=0.8m
  - Centered vertically in gap (Z=-50mm)

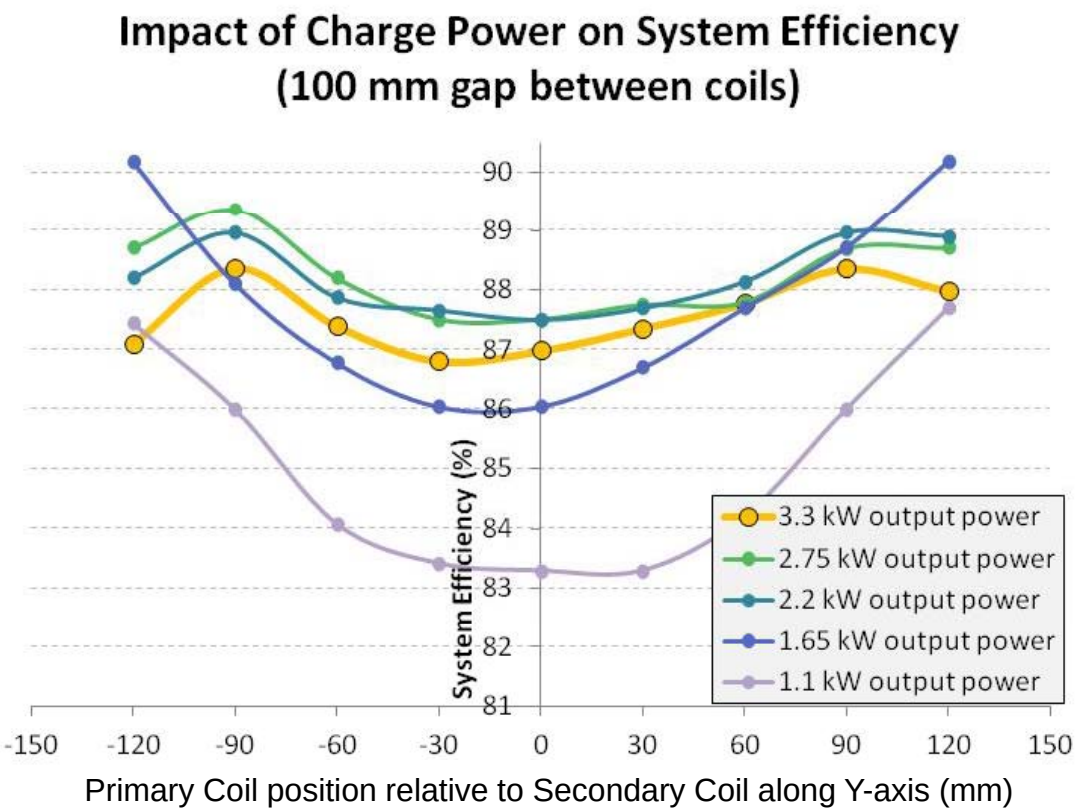


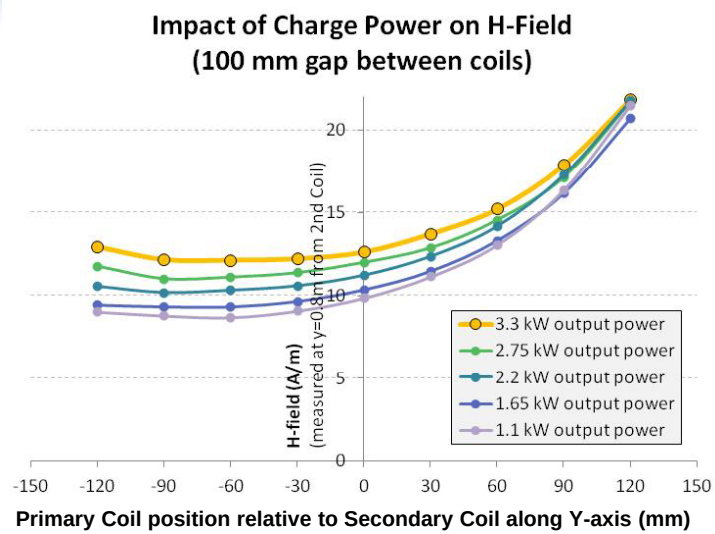


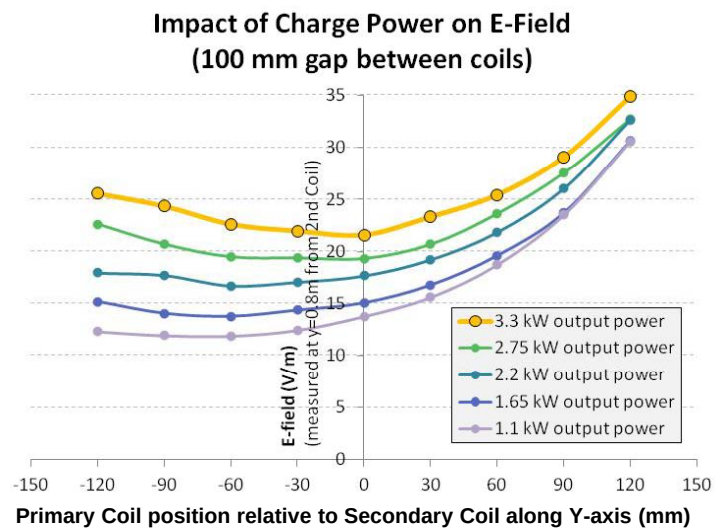


Output Power Impact on System Efficiency and EM Field

- 100mm coil to coil gap
- EM field measured at
  - X=0.0m Y=0.8m
  - Centered vertically in gap (Z=-50mm)







Fact Sheet

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy — VEHICLE TECHNOLOGIES PROGRAM

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

Results from Full System Testing in a Laboratory environment

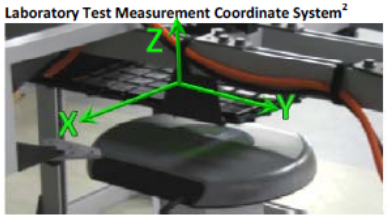
Description / Specifications [1]

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	464 long x 525 wide	mm

Measured System Parameters during Laboratory Testing

Input Power Measurements (at 3.3 kW output, 100mm gap)		
Input Voltage	208	VAC
Input Current RMS	28	Amps RMS
Power Factor	0.65	
Voltage Total Harmonic Distortion (THD)	4	%
Current Total Harmonic Distortion (THD)	112	%
Wireless Power Transfer Operation		
Operating Frequency (kHz)	19.5	kHz
DC Output Measurements (at 3.3 kW output, 100mm gap)		
Output Voltage	214	VDC
Output Current	15.4	Amps
Voltage Ripple Factor	0.75	%
Operating Temperatures at 3.3 kW output		
Parking Pad: Max observed surface temperature	51	°C
Vehicle Adapter: Max observed surface temperature	47	°C

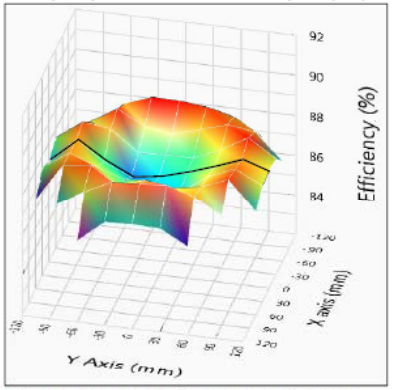
Laboratory Test Measurement Coordinate System[2]



[1] Manufacturer's Specifications: http://www.pluglesspower.com/wp-content/uploads/2013/06/PluglessL2_Specs.pdf
[2] Test Coordinates System Origin: Center of the Secondary Coil at the Bottom Surface of the Enclosure

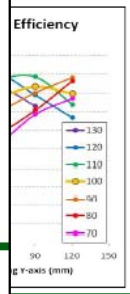
INL/MIS-13-29807 8/14/2013 page 1

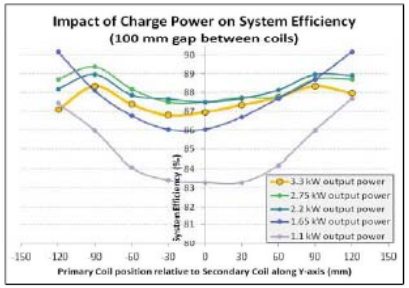
System Efficiency at 100mm gap for 3.3kW output
Primary Coil position relative to Secondary Coil (mm)



th 100mm gap)	Primary Coil position relative to Secondary Coil (mm)[2]
88.8%	(-90,-30)
87.0%	(0,0)
86.1%	(120,-60)

th 110mm gap)	Primary Coil position relative to Secondary Coil (mm)[2]
89.2%	(-60,30)
88.1%	(0,0)
86.2%	(90,90)

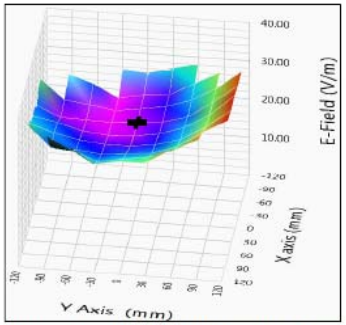




INL/MIS-13-29807 8/14/2013 page 2

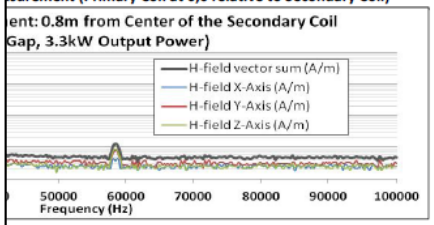
3.3 kW output) for Primary Coil position relative to Secondary Coil

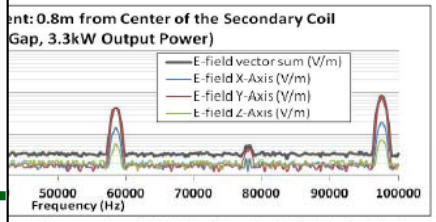
Electric Field (E-field)[3]



0mm gap)	Primary Coil position relative to Secondary Coil (mm)[2]
21.9	(0,120)
12.9	(0,0)
35.2	(60,120)
22.1	(0,0)

asurement (Primary Coil at 0,0 relative to Secondary Coil)[3]





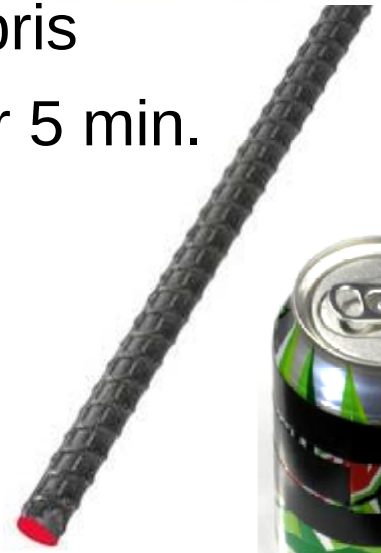
mm below secondary coil) 0.8m from Secondary Coil Center along Y-axis

INL/MIS-13-29807 8/14/2013 page 3

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

Debris Tolerance and System Response

- System Response to debris
- Debris Temperature after 5 min.
  - Paper clips
  - Soda can
  - Aluminum foil
  - Rebar (3/8”)
  - Coins
  - Steel toe shoe
  - CD ROM disk
  - many more…



Laboratory Testing using Mock Floor-pan

- Laboratory Testing
  - Reference Vehicle Floor-pan mock up
    - More representative case than open-air testing
    - Appropriate when no vehicle specific installation is available

Vehicle testing

- Full Vehicle Testing
  - On-vehicle testing (as installed per manufacturer specifications)
    - Actual operation but specific to vehicle type and mounting specifications

Summary / Comments:

- INL's laboratory testing of the PLUGLESS™ Wireless Charging system by Evatran Group Inc. is complete
  - System Efficiency and EM-field measurement impact from
    - Coil to Coil Position
      - Gap
      - Alignment Offset
    - Output Power
    - EM field measurement distance from source
- Fact Sheet has been published
  - **http://avt.inel.gov/evse.shtml**

- Recent testing has been completed:
  - PLUGLESS efficiency & EM-field as installed on a Chevrolet Volt
  - Laboratory testing (no vehicle) using a SAE J2954 mock floor-pan
  - Debris response testing (paper clips, coins, soda can, etc.)

Acknowledgement

This work is supported by the U.S. Department of Energy's EERE Vehicle Technologies Program

More Information

http://avt.inl.gov