Idaho National Laboratory

Test Results: PLUGLESS™ Inductive Charging System by Evatran Group Inc.
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Richard “Barney” Carlson
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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
- Narda EM Field Meter (EHP-200a)
- Polycarbonate Primary Coil Stand-off
- Multi-Axis Positioning System
- Fiberglass Channel Strut Supports Secondary Coil
- FLIR IR Camera
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

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)

- 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

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

Power Flow from Generation to Vehicle Operation

- Electricity Generation
- Electricity Distribution
- Electricity Step Down Transformer
- Commercial / Residential Wiring & Receptacle
- PLUGLESS™ Control Panel / Power Electronics
- PLUGLESS™ Primary Coil
- PLUGLESS™ Secondary Coil
- PLUGLESS™ Vehicle Adapter / Power Electronics
- Vehicle On-Board Charge Module (OBCM)
- Vehicle Wiring / Accessory Loads
- Vehicle Traction Battery (ESS)
- Vehicle Propulsion
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

<table>
<thead>
<tr>
<th>Efficiency Results (at 3.3 kW output with <strong>100mm gap</strong>)</th>
<th>Primary Coil position relative to Secondary Coil (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Efficiency (%) 88.8%</td>
<td>(-90,-30)</td>
</tr>
<tr>
<td>Nominal Efficiency (%) 87.0%</td>
<td>(0,0)</td>
</tr>
<tr>
<td>Minimum Efficiency (%) 86.1%</td>
<td>(120,-60)</td>
</tr>
</tbody>
</table>
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)

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<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Maximum H-field (A/m)</td>
<td>21.9</td>
</tr>
<tr>
<td>Nominal H-field (A/m)</td>
<td>12.9</td>
</tr>
<tr>
<td>Maximum E-field (V/m)</td>
<td>35.2</td>
</tr>
<tr>
<td>Nominal E-field (V/m)</td>
<td>22.1</td>
</tr>
</tbody>
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Primary Coil position relative to Secondary Coil (mm)

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<tbody>
<tr>
<td>(0,120)</td>
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<tr>
<td>(0,0)</td>
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<tr>
<td>(60,120)</td>
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</tbody>
</table>
**Coil to Coil Gap Impact on System Efficiency and EM Field**

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

**Impact of Coil Gap (mm) on System Efficiency (3.3 kW Output Power)**

![Graph showing impact of coil gap on system efficiency](image)

**Impact of Coil Gap (mm) on H-field (3.3 kW Output Power)**

![Graph showing impact of coil gap on H-field](image)

**Impact of Coil Gap (mm) on E-field (3.3 kW Output Power)**

![Graph showing impact of coil gap on E-field](image)
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 ($Z=-50mm$)

Impact of Charge Power on System Efficiency (100 mm gap between coils)
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

- 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

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More Information
http://avt.inl.gov