Magnetic solutions towards interoperability for stationary, semi-dynamic and dynamic charging
Factors for EV Market Growth – Ease of use

- **Wireless EV Charging meets our needs**
  - Simple, effortless & convenient

- **Multiplicity of charging opportunities**
  - Charge little, often and everywhere
Interoperability Parameters

- Operating Frequency
- Magnetic Compatibility
- Power levels
- Lateral and Longitudinal Tolerance
- Nominal air-gap, vehicle classes
- Various mounting requirements for base pad (surface, flush, buried)
- Pad positions on vehicle and parking slot
- Efficiency Levels
- EMC and EMF Regulatory Compliance
  - Leads to the requirement to limit leakage of electromagnetic energy and potential requirement for FOD and LOP
- Support of an alignment mechanism
- Communications between EV and EVSE
Standards must ensure that different Z Gaps are supported, circular coils may not meet future requirements.
Comparison of Pad Magnetic Architecture

- Circular
  - Low field emissions
  - Low Coupling
  - Low x/y tolerance
- Solenoid
  - High emissions
  - Shielding required
- Solenoid Multi-Coil
  - Good coupling
  - High emissions
  - Shielding required
- Double D / DDQ
  - Low field emissions
  - High Coupling
  - Superior z-gap
  - Superior x/y tolerance

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Test conditions – 7.7 kW pad topologies

Vehicle Pad

CR

400x400mm

DD

400x400mm

Base Pad

CR

BP

765x575mm

765x575mm

Z_{DVG} (mm)*

Z = 160mm-220mm

*_{DVG} = vehicle to ground distance

<table>
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<th>100</th>
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Test procedure

- Coupling simulation
- Emissions simulation • Determine worst case positions
- Performance measurement
- B-Field measurement • @ worst case pos.
## Magnetic Coupling (Simulation)

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<th>VP</th>
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<th>x = 75</th>
<th>x = 100</th>
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**Z2min = 160 mm**

| CR 575 x 765 | CR 400 x 400 | k  | 0.230 | 0.204 | 0.164 | 0.136 | 0.107 | 0.054 |
| BP 575 x 765 | DD 400 x 400 | k  | 0.273 | 0.230 | 0.225 | 0.209 | 0.194 | 0.177 |

**Z2max = 220 mm**

| CR 575 x 765 | CR 400 x 400 | k  | 0.133 | 0.120 | 0.098 | 0.084 | 0.067 | 0.039 |
| BP 575 x 765 | DD 400 x 400 | k  | 0.153 | 0.133 | 0.130 | 0.125 | 0.116 | 0.100 |

The CR VP has much lower coupling than the DD VP!
Thermal investigations – Maximum operating limits

- **Conditions for base pad:**
  - Size: 756x575x45 (Volume: 19.8l)
  - Ambient temp. base pad: $35\, ^\circ\text{C}$
  - Max. allowed primary pad surface temp: $95\, ^\circ\text{C}$ (according to UL 2750)
    - $\Delta T_{\text{max}} = 35\, ^\circ\text{C}$ to have 25K margin for pad with integrated power electronics

- **Conditions for vehicle pad:**
  - Size: 250x250x20 (Volume: 1.25l)
  - Ambient temp. vehicle pad (under hybrid car): 60°C
  - Max. allowed vehicle pad surface temp: $110\, ^\circ\text{C}$
    - $\Delta T_{\text{max}} = 50\, ^\circ\text{C}$ to meet 110°C max. vehicle pad surface temp. and $120\, ^\circ\text{C}$ max. vehicle pad core temp.)

- **Results for Base pad:**
  - **Max. surface temperature of 70°C is reached at 456 Ampturns (AT) (optimized thermal design of base pad)**
System Performance at max. BP 456AT (maximum operating limit due to thermal constraints)

<table>
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<th>BP</th>
<th>VP</th>
<th>(x = 0)</th>
<th>(x = 50)</th>
<th>(x = 75)</th>
<th>(x = 100)</th>
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<tbody>
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<td>BP 575 x 765 (Turn count 7)</td>
<td>DD 400 x 400 (Turn count 8)</td>
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<td>6600</td>
<td>6600</td>
<td>6600</td>
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<td>57</td>
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<tr>
<td>CR 575 x 765 (Turn count 8)</td>
<td>CR 400 x 400 (Turn count 10)</td>
<td>P (W)</td>
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<td>I (A)</td>
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<td>30</td>
<td>32</td>
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\(Z_{2\text{min}} = 160\) mm

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<tr>
<th>BP</th>
<th>VP</th>
<th>(x = 0)</th>
<th>(x = 50)</th>
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<th>(x = 100)</th>
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<td>CR 575 x 765 (Turn count 8)</td>
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<td>VP AT</td>
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<tr>
<td>BP 575 x 765 (Turn count 7)</td>
<td>DD 400 x 400 (Turn count 8)</td>
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<td>VP AT</td>
<td>304</td>
<td>304</td>
<td>304</td>
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</tr>
</tbody>
</table>

\(Z_{2\text{max}} = 220\) mm

The CR VP performs significantly worse than the DD VP!
Summary

Reduced-size DD (for 3.3 kW and 6.6 kW)

3.3 kW: 250mm x 190mm
6.6 kW: 340mm x 270mm
Different Magnetic Pad Designs Must be Supported

- Circular/Square Coil Secondary Vehicle Pad
- Double D & DD Quadrature Secondary Vehicle Pads
- Single Coil Solenoid Secondary Vehicle Pad
- Bi-Polar Primary Base Pad
## Evolution from Stationary to Dynamic

<table>
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<th>Stationary (*)</th>
<th>Semi &amp; Dynamic (**)</th>
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<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>85 kHz</td>
<td>85 kHz</td>
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<td><strong>Power Classes</strong></td>
<td>3.7 / 7.7 / 20 kW</td>
<td>10 / 20 / 40 / 200 kW</td>
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<tr>
<td><strong>Offset Tolerance (x/y)</strong></td>
<td>±75 / ±100 mm</td>
<td>Not relevant / ±200 mm</td>
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<tr>
<td><strong>Magnetics (vehicle side)</strong></td>
<td>![Images]</td>
<td>![Images]</td>
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</tbody>
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(*)&: Based on worldwide standardization

(**): Proposal for FABRIC project (currently, there are no standards specifying requirements for dynamic charging)
Thank you

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