Mojo Mobility Inc.

Advanced EV Wireless Charging

Conference on Advanced Roads and Vehicles (CERV-2016)

Logan, Utah
May 16, 2016

Mojo Mobility

Developing advanced wireless power systems for mobile, Automotive and other applications since 2005

- **Advanced WPT technology**
  - ***10 kW Wireless EV charging systems;***

    Moving to 20 kW
  - ***93% Grid to Battery efficiency***
  - ***Position freedom up to ±70 cm***
  - ***Real-life testing on fleet of 5 vehicles in 2016***
  - ***Performance testing at INL: Q2, 2016***
- ***US DOE, Automotive, and Tier-1 partners***
- **A broad patent portfolio (43+ filings)**

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Stages of Electric Vehicle Charging

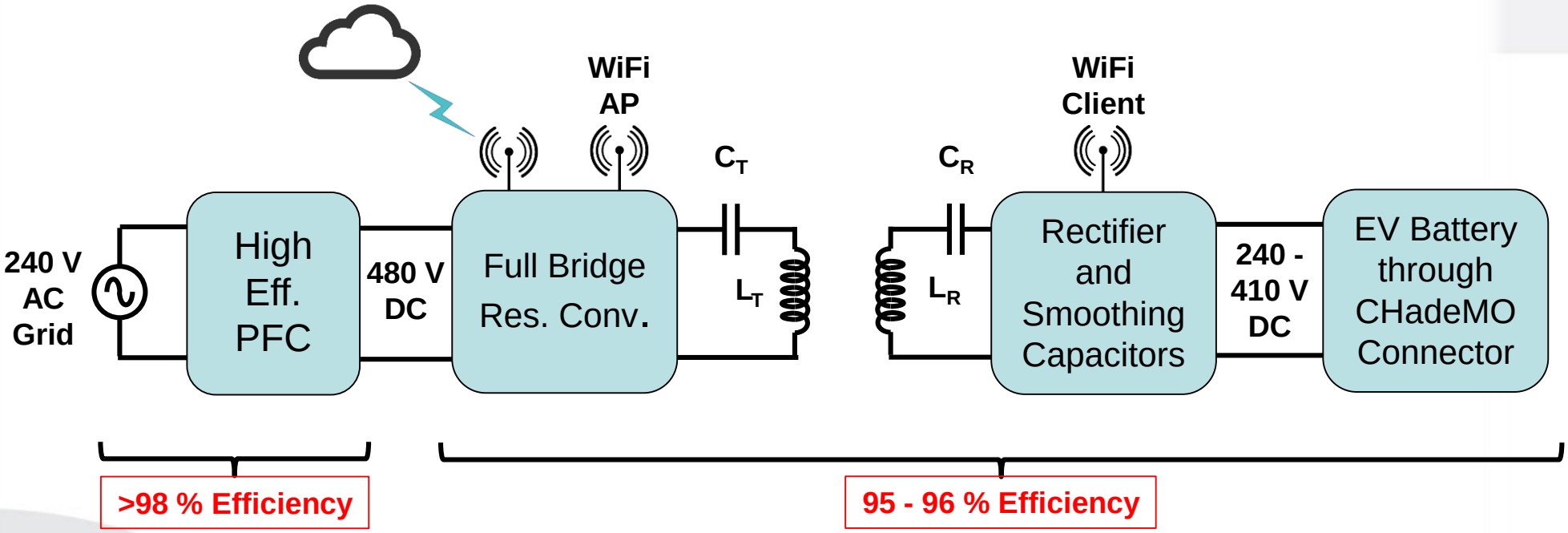
Wireless Charging adoption in stages:

- **Static Charging: Charging while parked**
  - Convenience and safety
  - Automatic billing in public locations
  - Fast charging and high efficiency are key

- **Semi-dynamic charging: Charging at stop signs and traffic lights**
  - Extend driving range
  - Position freedom & high power are key

- **Dynamic charging: Charge while you drive**
  - Extend driving range
  - Lighter batteries / lower EV cost
  - Position freedom, high power, infrastructure cost become important

Components of the Mojo WPT System



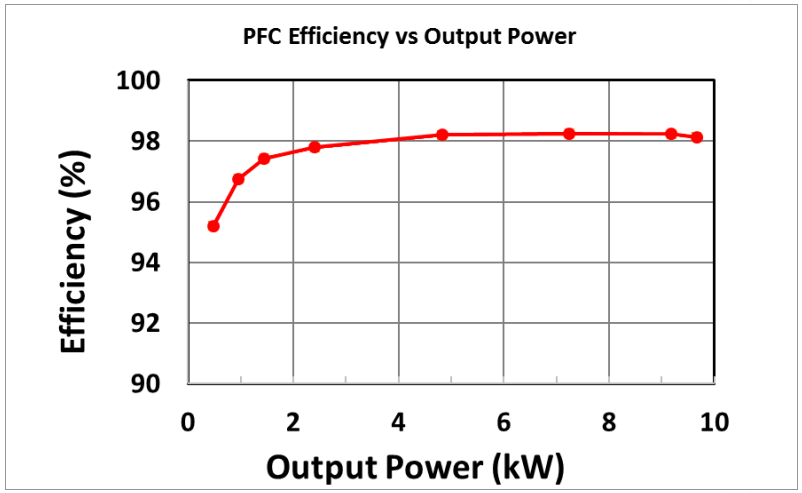
Efficient High Power System

- Transfer over 10 kW power to EV battery – Fast Charging
- High efficiency (93% Grid to Battery)
- High Position Freedom

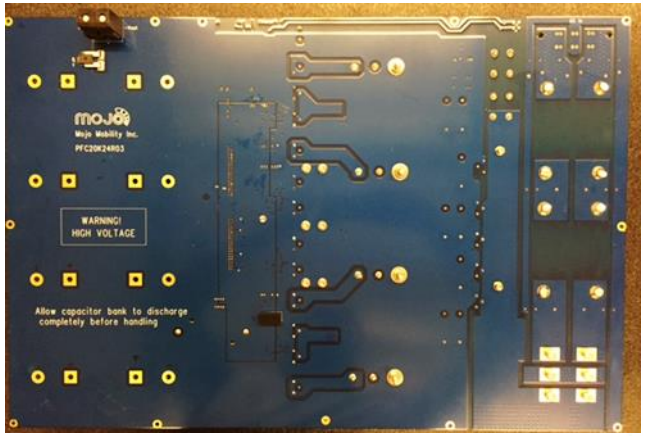
25 kW AC/DC PFC Front End

High Efficiency (**98.3% measured**) AC/DC Power Factor Correction (PFC) front end:

- 240 V AC input to 480 V DC output
- PFC performance into Electronic Load
- Up to 25 kW output
- **0.9998 Power Factor**
- Interleaved 4 phase operation
  - Reduced current through each switch
  - Reduced output ripple of PFC

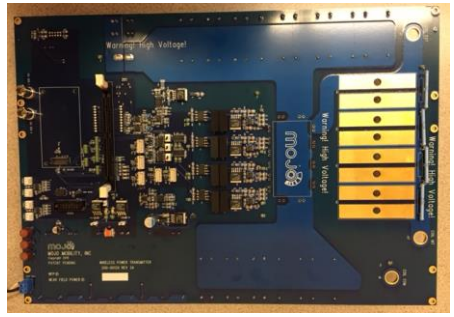


- Micro-controlled with firmware for startup, control of stand-by power, and interface with charger
- Small volume design (60 x 40 x 12 cm)
- Single board construction – Low cost assembly
- Fan cooled



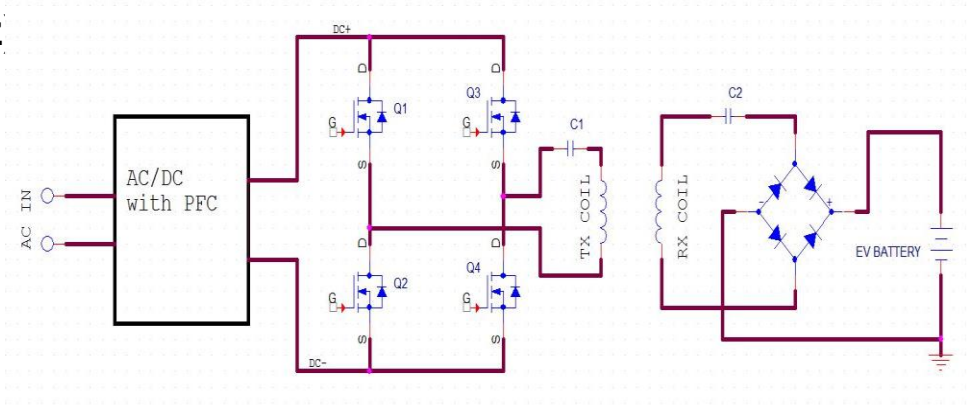
Top View of PFC

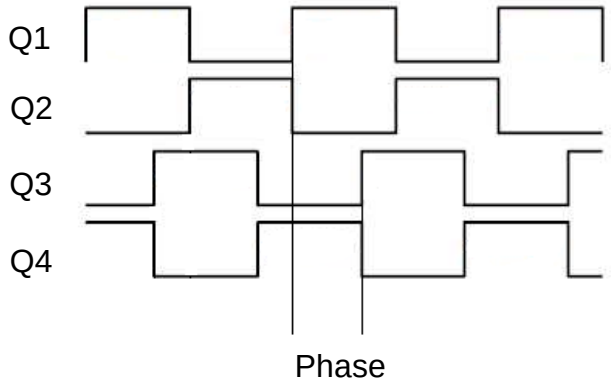
Transmitter & Output Power Control



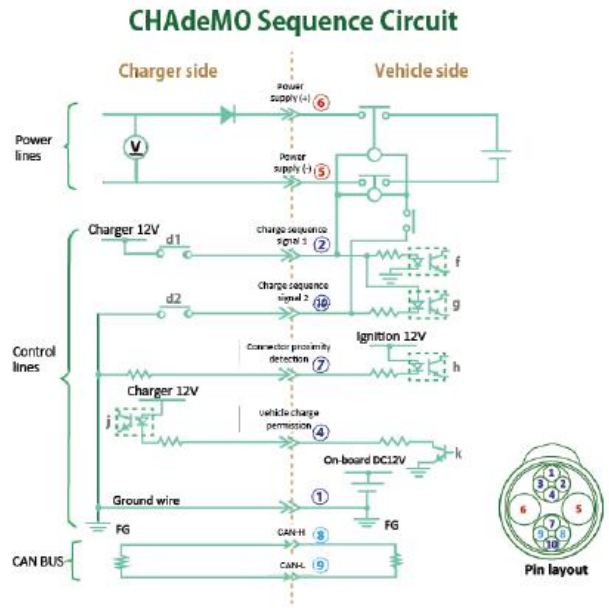
Full bridge resonant converter geometry with Phase Control

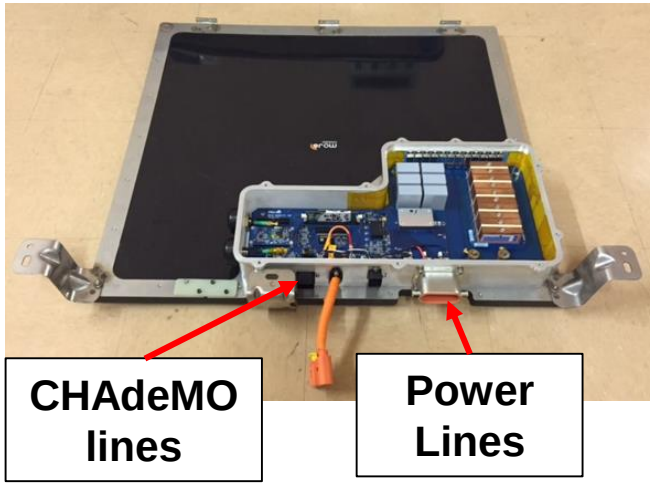
- Operate at optimum frequency (around 85 kHz
- Phase shift in switching of Transmitter FETs changes WPT output power.
- Can control phase shift to <0.03°
- Closed loop control based on feedback from WPT Receiver





WPT and CHAdeMO for Kia Soul EV





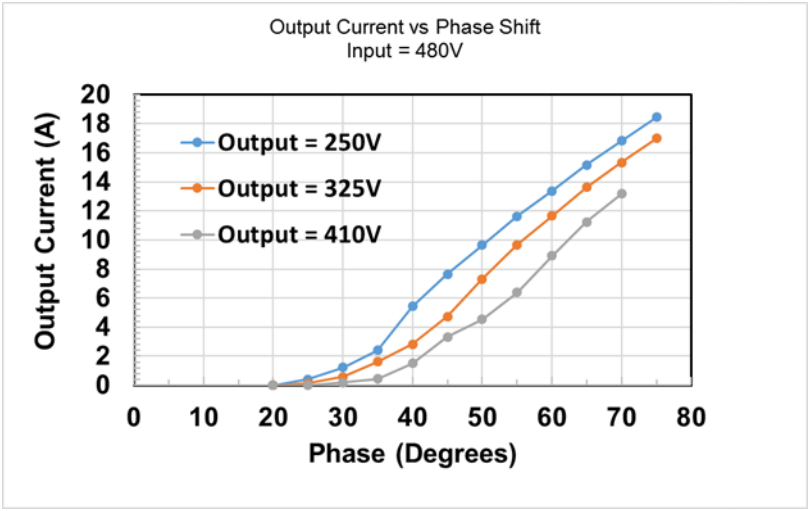
Mojo WPT emulates CHAdeMO to allow fast charging

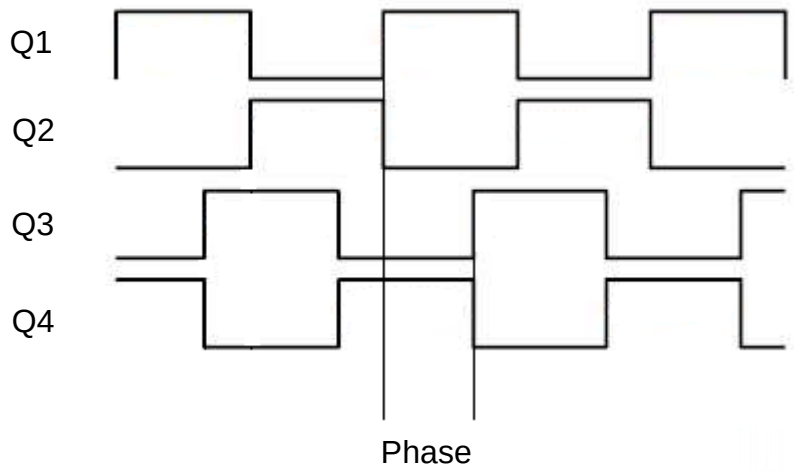
- Target EV (Kia Soul EV) can be charged at up to 100 kW with its DC CHAdeMO connector
- WPT receiver
  - includes CHAdeMO charger side circuit for control and communication
  - emulates CHAdeMO charger through Control lines
  - receives CHAdeMO messages and sends to Transmitter through WiFi

Output Power Regulation

Controlling Current into EV

- **EV battery requires 240 to 410 V WPT output to charge**
- **Required current is requested by EV through CHAdeMO every 200 msec.**
- **WPT receiver receives CHAdeMO messages and sends to Transmitter through WiFi**
- **Transmitter calculates required phase through PID control and adjusts Resonant Converter Phase delay to desired output current**

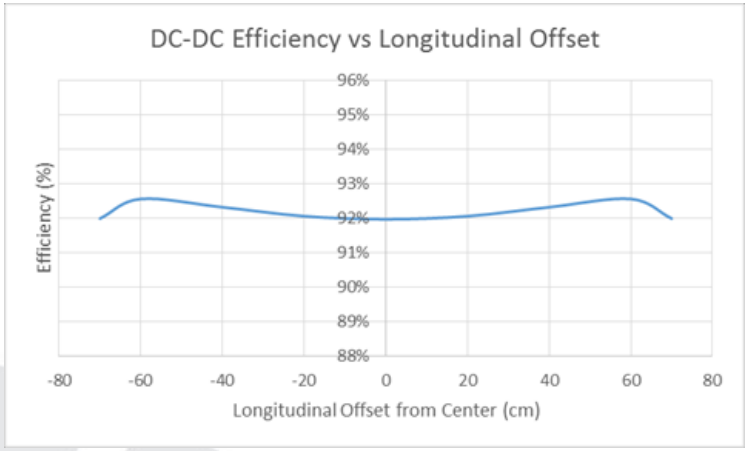




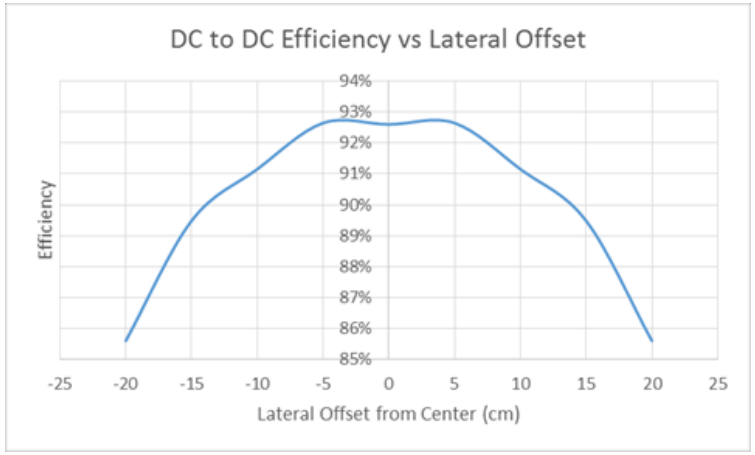
WPT– Large Positioning Freedom Tx Coil

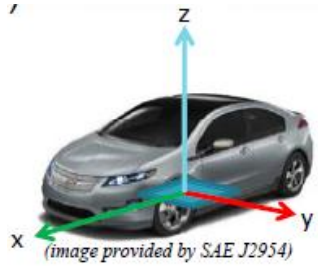
Large positioning freedom for semi-dynamic and dynamic charging

X Offset



Y Offset





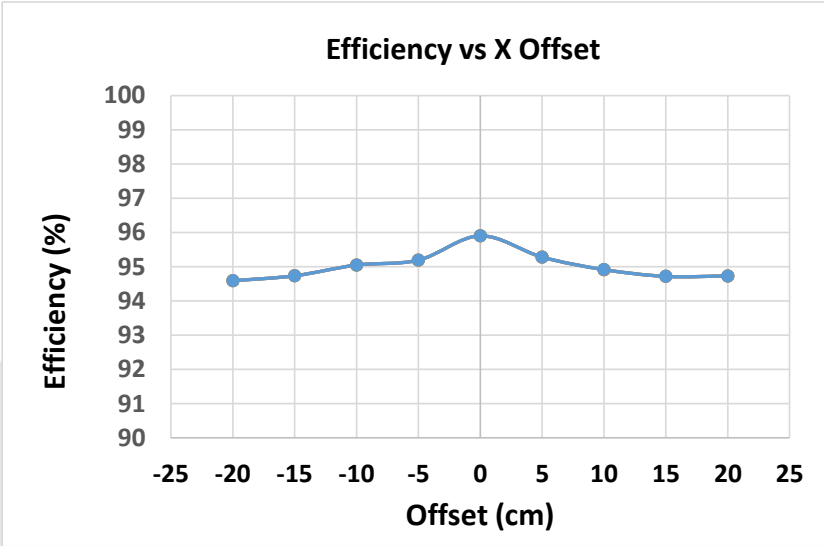
(image provided by SAE J2954)

- **200 cm long Transmitter coil – Large position freedom**
- **20 cm coil to coil separation**
- **360V output load voltage; 6.6 kW power Transfer**
- **87kHz switching frequency**
- **Coil design allows very large longitudinal offset while maintaining high system efficiency – important for quasi-dynamic and dynamic charging**

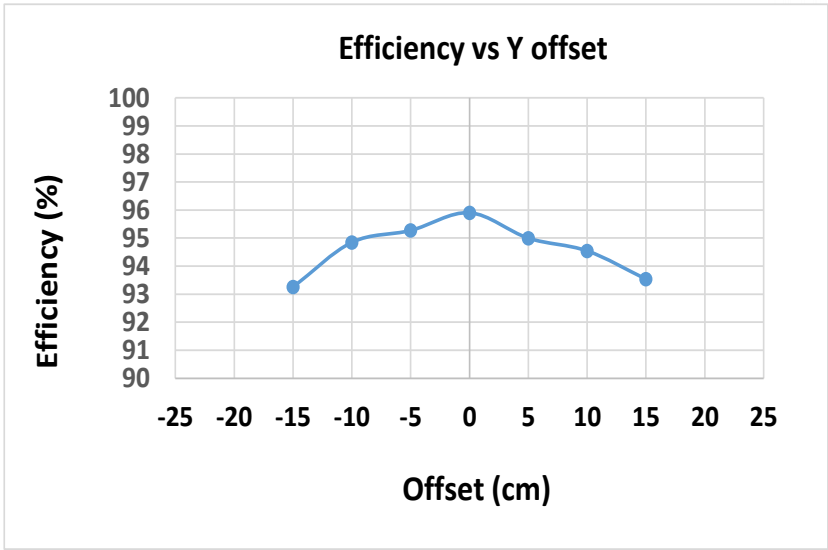
Coils Optimized for the Target EV

Optimized Coils for Static charging

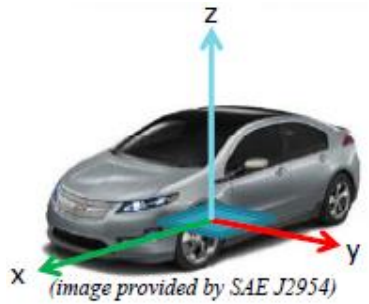
X Offset



Y Offset

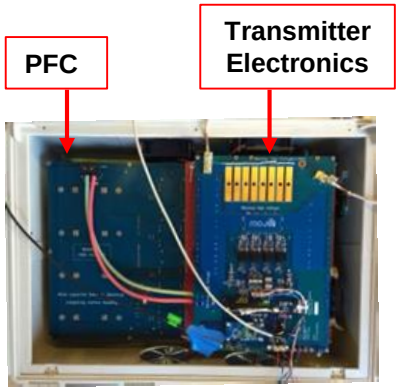


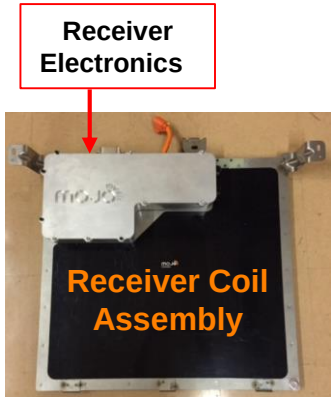
- **Smaller Transmitter coil for Static Charging**
- **20 cm coil to coil gap**
- **360V output load voltage; 6.6 kW power Transfer**
- **96% DC-DC Efficiency**
- **Position freedom over ±20 cm**



(image provided by SAE J2954)

Wireless EV Charging Components





Charging a Kia Soul EV wirelessly

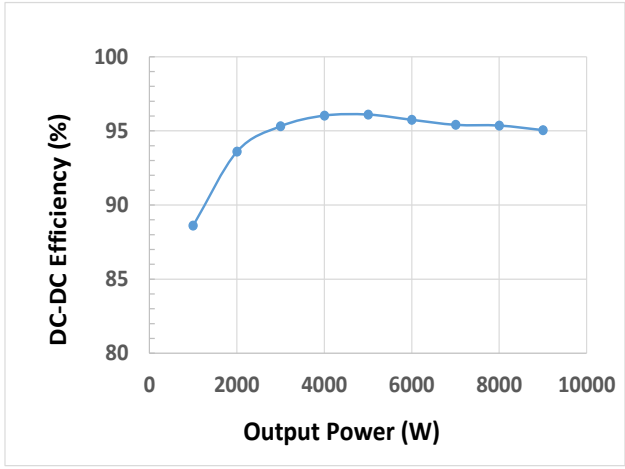
- PFC and Transmitter combined and controlled by Tx Microcontroller
- Receiver Electronics integrated on top of Coil Assembly (2 cm thick)
  - Integrated to EV in front

Wireless EV Charging (US DOE and Hyundai Motors Group)

Charging a Kia Soul EV wirelessly

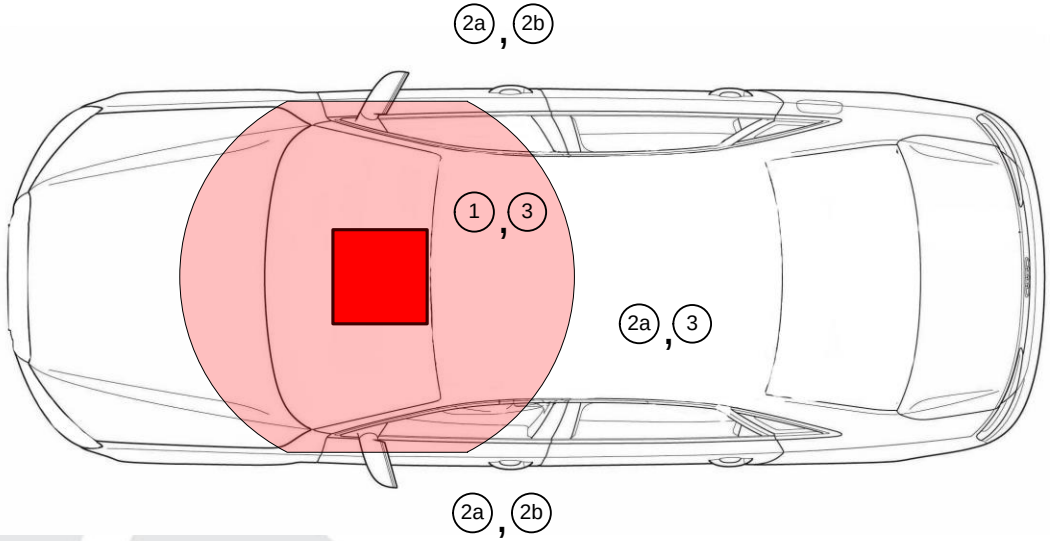
- Up to 10 kW power transferred at high efficiencies (>95% DC-DC)
- Full efficiency (Grid to battery >93%)
- Position freedom >±20 cm in each direction

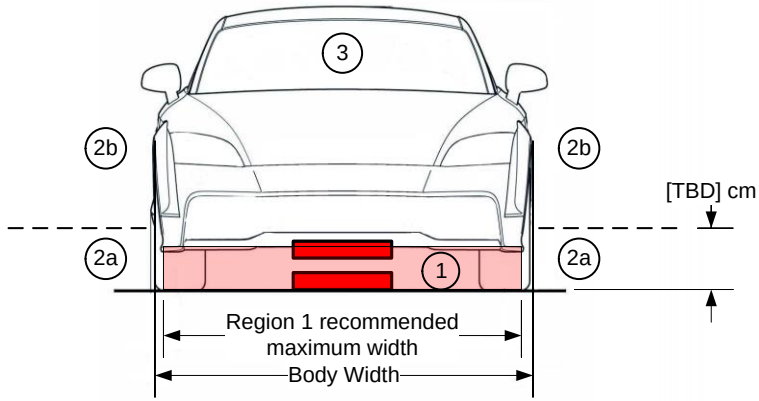
- High efficiency and large position freedom



Human & Implanted Medical Devices Exposure to EMF

SAE J2954 TIR





SAE has been working hard to define EMF exposure limits as it relates to the automotive environment.

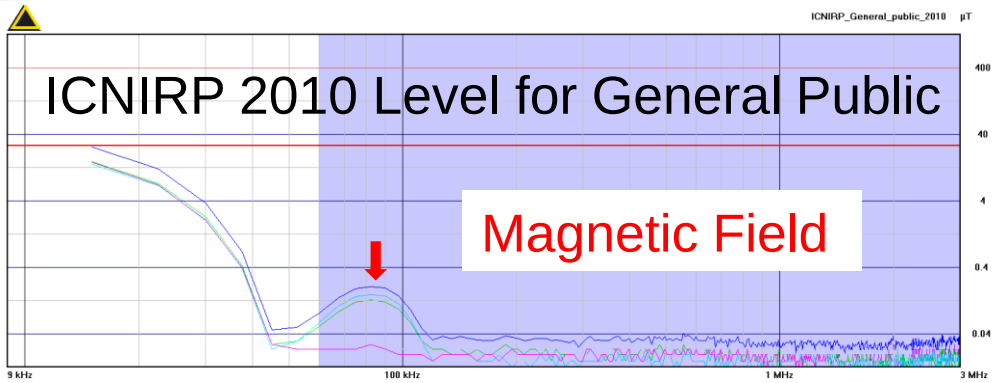
Region 1: Underneath the vehicle and near the wireless power pads.

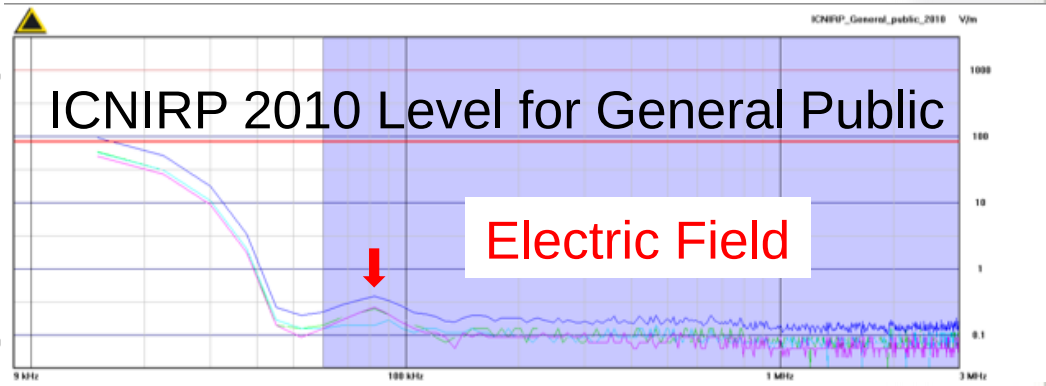
Region 2a: Around the vehicle at heights less than 20cm above the ground.

Region 2b: Around the vehicle at heights greater than 20cm above the ground.

Region 3: Vehicle interior.

Measured Emissions at 10 kW Power Transfer

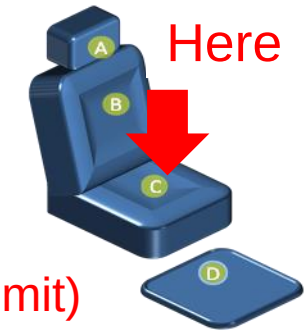




Very Low Electric and Magnetic Stray Fields at 10 kW power transfer:

- Receiver integrated into Vehicle
- NARDA EM detector at driver seat at 10 kW WPT power transfer
- Magnetic field at driver seat ~ 0.22 μT (<1% of 26 μT ICNIRP Limit)
- Electric field at driver seat ~ 0.4 V/m μT (<0.5% of 83 V/m ICNIRP Limit)

Measured Here



- E and M fields measured 1 m away from front of car; <5% of ICNIRP limits

Values inside the car are comparable to EM exposure to a light bulb at 1 m distance

High Power EV Charging

Mojo EV wireless charging parameters

- Operating frequency: (80-90 kHz)
- Output power: (over 20 kW)
- Efficiency: (93% Grid to Battery)
- Transmitter / Receiver communication: (802.11n)
- Receiver / Vehicle Communication: (CAN)
- Receiver / BMU Communication: (CHAdeMO)
- Z – Vertical offset tolerance: (20 cm ± 10 cm)
- X/Y – offset tolerance: (up to ±70 cm & ±20 cm)

- Output current range: (0 to 50 A)
- Output voltage range: (240 to 410 V)
- Output current ripple: (<1%)
- Passive cooling
- PFC Power Factor: 0.9998
- EMI; Safety (< 1% of ICNIRP)
- EV: Kia Soul EV: 28 kWH battery

Mojo EV Wireless Charging

- ✓ **EV Wireless Power Transfer (WPT) can provide**
  - ➢ ***High efficiency and power transfer***
  - ➢ ***Safe operation***
  - ➢ ***Large position freedom***
  - ➢ ***Compact integration into EV***
- ✓ **Testing in vehicle fleet in ‘16**
  - ➢ ***Test environmental and road test operation***
- ✓ **Industry Partnerships**
  - ➢ ***Co-Development and testing with DOE, automotive OEMs and Tier-1 suppliers***

Mojo Mobility Inc.

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