Project ID: VSS102

High Efficiency, Low EMI and Positioning Tolerant Wireless Charging of EVs

Presenter: John Robb
Principal Investigator: Allan Lewis
Hyundai America Technical Center Inc (HATCI)
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Overview

Timeline

- Start date – Oct. 2012
- End date – Sept. 2015
- Percent complete – 50%

Budget

- **Total funding: $6,014,868.00**
  - Government* share: $4,215,593.00 (DOE obligations thru Oct 2013: $1,472,922.00)
  - Contractor share: $1,799,275.00
- Expenditure of Gov't funds in
  - FY13: ~$727,664.48 (10/12-9/30)
  - FY14: ~$800,000.00 (10/1-Present)

* Thank you to the DOE Vehicle Technologies program for their support and funding of this project

Partners

- Mojo Mobility

Technical Barriers

- Conductive charging stations introduce limitations regarding access, range, and usability.
  - ADA access
  - Cord length and inconsistent vehicle port placement
  - Overall usability
- Wireless charging systems are prone to EMI, position intolerance, and low efficiency.

Technical Targets

- Transfer power at over 6.6kW.
- Total system efficiencies of more than 85%.
- Achieve real world position and gap tolerance.
  - ±0.25 m along the width of the vehicle.
  - ±1 m along the length of the vehicle.
  - Greater than 20 cm coil to coil gap.

Relevance

Objectives

The objective of this project is to develop, implement, and demonstrate a wireless power transfer system with total system efficiencies of more than 85%, power transfer at over 6.6 kW, and maximum positioning tolerance that can be achieved while meeting regulatory emission guidelines.

Addresses Technical Barriers

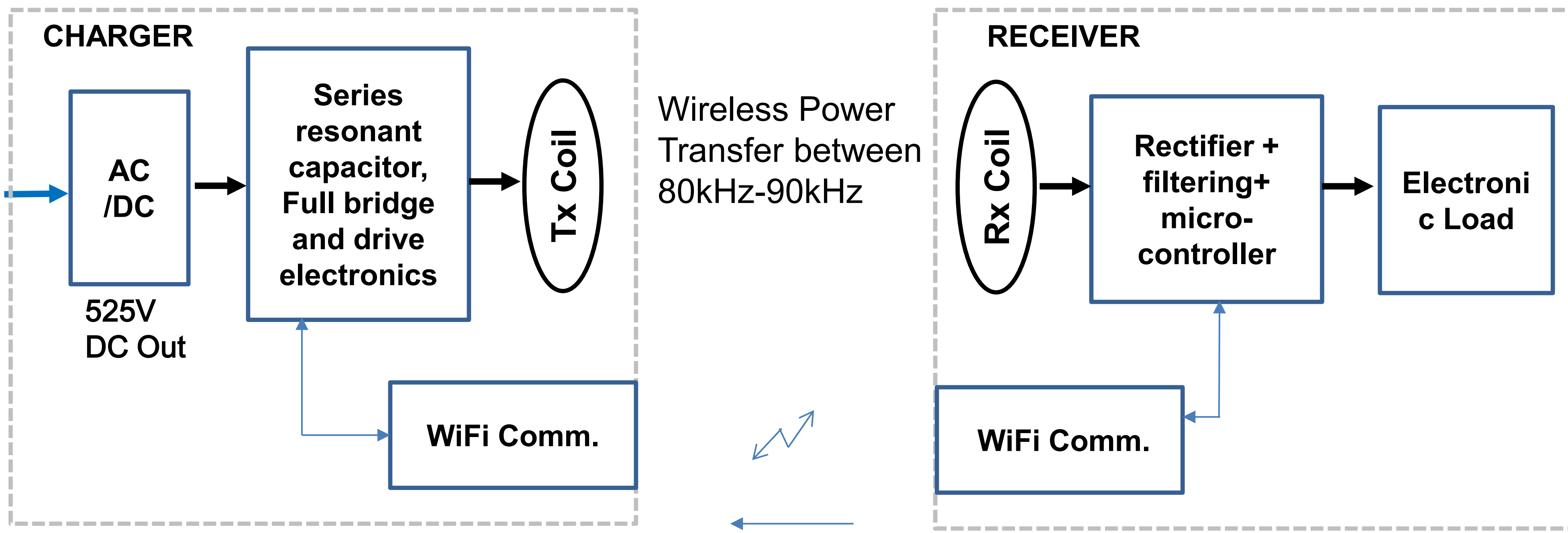
- Reduce the dependence on conductive charging stations which will allow more convenience to the user, increased access and usability in support of ADA, and provide a charge with potentially no action required by the driver.
- Develop a wireless charging system that meets industry guidelines, while operating with position tolerance and efficiency of more than 85%.

Milestones

Month/ Year	Milestone or Go/No-Go Decision	Description	Status
02/2013	Milestone	Design of Initial WPT Prototype System.	✓
06/2013	Milestone	System Test and Corrections.	✓
07/2013	Milestone	Design of Second Generation WPT Prototype System.	✓
09/2013	Milestone	System Test and Corrections.	✓
09/2013	Go/No-Go Decision	Demonstrate the wireless power transfer system and perform a power transfer of at least 6.6 kW with an efficiency of at least 85% with at least a 20 cm coil to coil gap.	✓
12/2013	Milestone	Design of Third Generation WPT Prototype System.	⟳
05/2014	Milestone	Vehicle Integration and Test.	
09/2014	Go/No-Go Decision	Demonstration of the wireless power transfer system integrated into an electric vehicle with performance as defined in phase 1 Go-No-Go criteria.	
06/2015	Milestone	The Project team will build five WPT-enabled EVs based on the EV and WPT chargers using system specifications developed in Phase II.	
09/2015	Milestone	The Project team will deliver one WPT-enabled EV and wireless charging station to the Department of Energy for National Laboratory testing.	
09/2015	Milestone	The Project team will perform vehicle and product tests as specified in Test Plan and provide data to a DOE national laboratory as specified in the data collection plan.	

Phase 1 Development

- Initial System Design
  - System Requirement Specification
  - Defined end-to-end block diagram and control interfaces
  - Modeled and developed high efficiency coil and magnetics



Output current/voltage Measurements for feedback loop

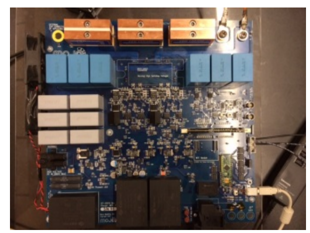
Phase 1 Development

▪ Development Stages

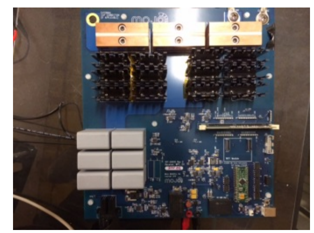
- First Generation WPT Prototype System
  - Initial proof of concept
    - Basic board layouts with little consideration for real estate constraints
    - Heavily populated with test points
    - Allowance for external gate drive
  - Variable DC power supply
    - Initial focus on charger and receiver board design
  - Symmetric coil design
    - Initial focus on control system development
- Second Generation WPT Prototype System
  - Optimized charger and receiver boards
    - Board size reduction
    - Trace and component optimization
  - Integrated DC power supply
  - Asymmetric coil design
    - Geometrically designed for position freedom

Gen. 1 Charger

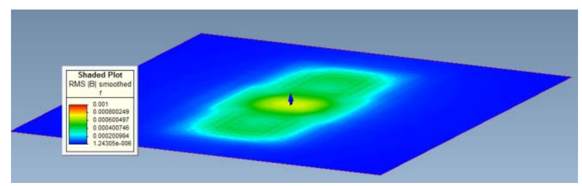
Gen. 1 Receiver



Gen. 2 Charger

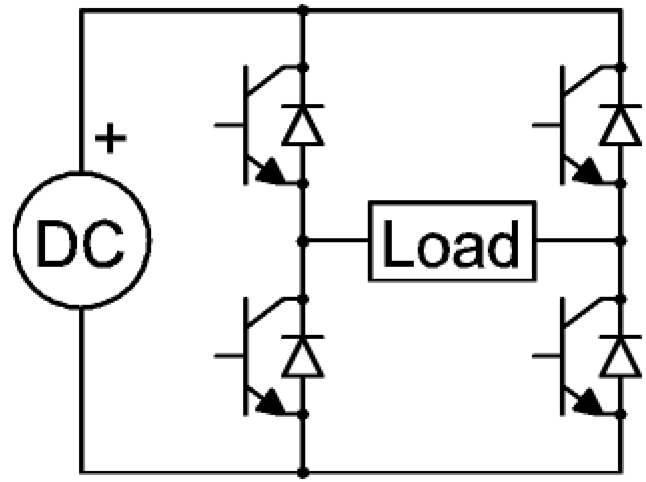


Gen. 2 Receiver



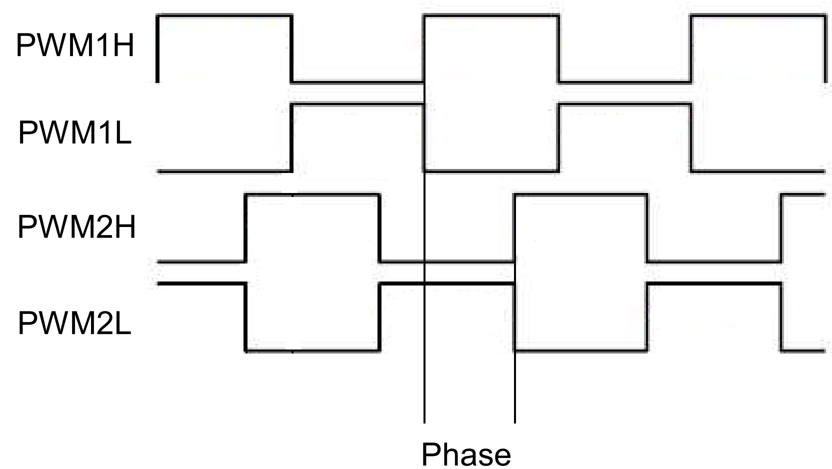
Phase 1 Development

Output Power Regulation



Phase I:

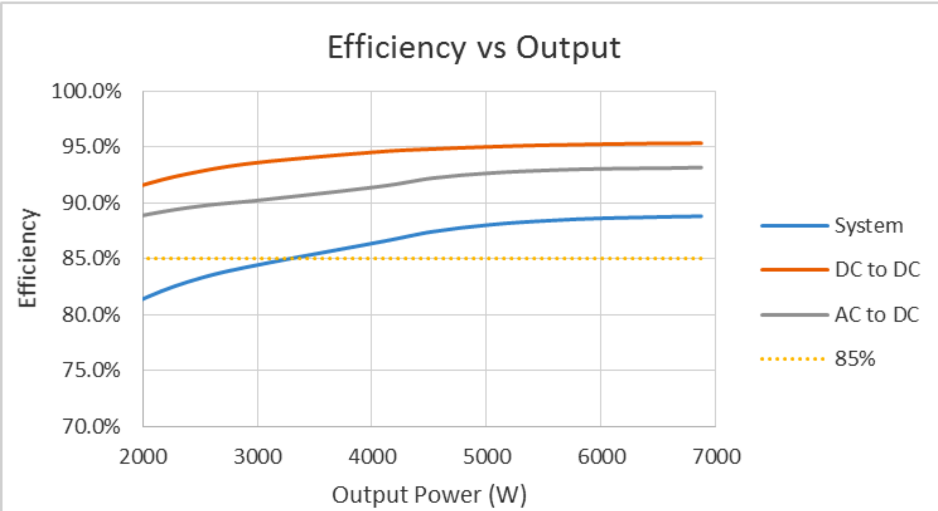
- Utilize fixed frequency PWM switching of full bridge circuit for power transfer across coupled resonant circuits
- Regulation of output current achieved through full bridge phase modulation based on current and voltage feedback from the receiver
- Firmware utilizing incremental updates to phase angle based on polarity of error between reference and measured output current



Phase 1 Development

Efficiency Data

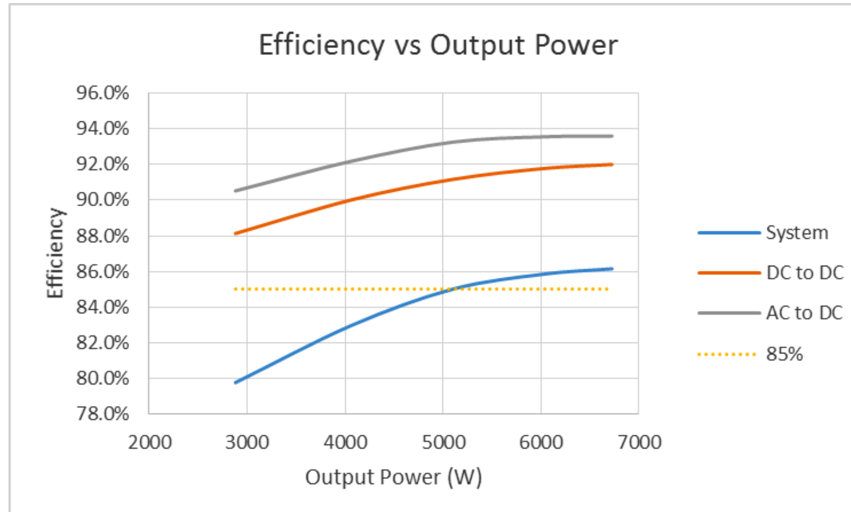
Symmetric Coils



Conditions:

- 88kHz switching frequency
- 525V Tectrol AC/DC Supply
- Coils concentric
- 21cm coil to coil separation
- 360V output load voltage

Asymmetric Coils

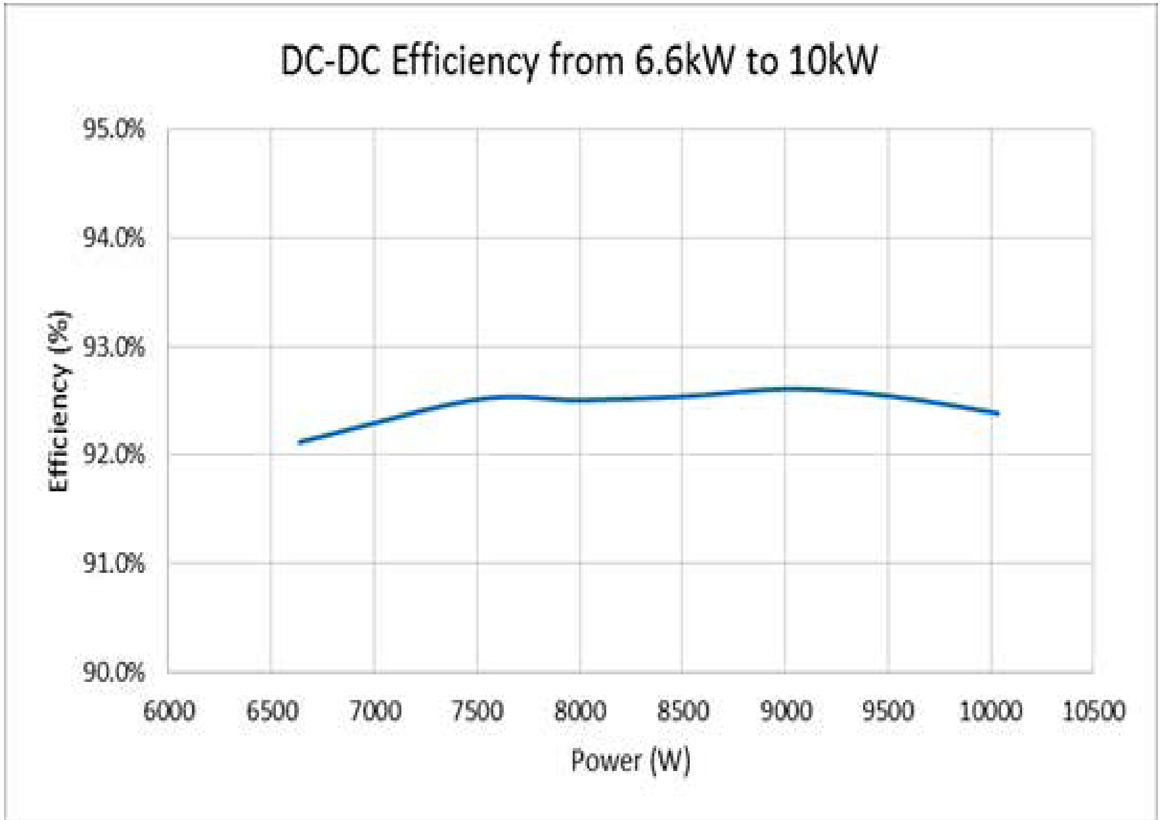


Conditions:

- 87kHz switching frequency
- 525V Tectrol AC/DC Supply
- Coils concentric
- >20cm coil to coil separation
- 360V output load voltage

Phase 1 Development

Efficiency Data at higher powers – Asymmetric Coils



Conditions:

- 87kHz switching frequency
- Use 480 V AC/DC supply to reach higher power levels
- Output power limited by electronic load used. Higher powers can be reached by connecting 2 loads in series.

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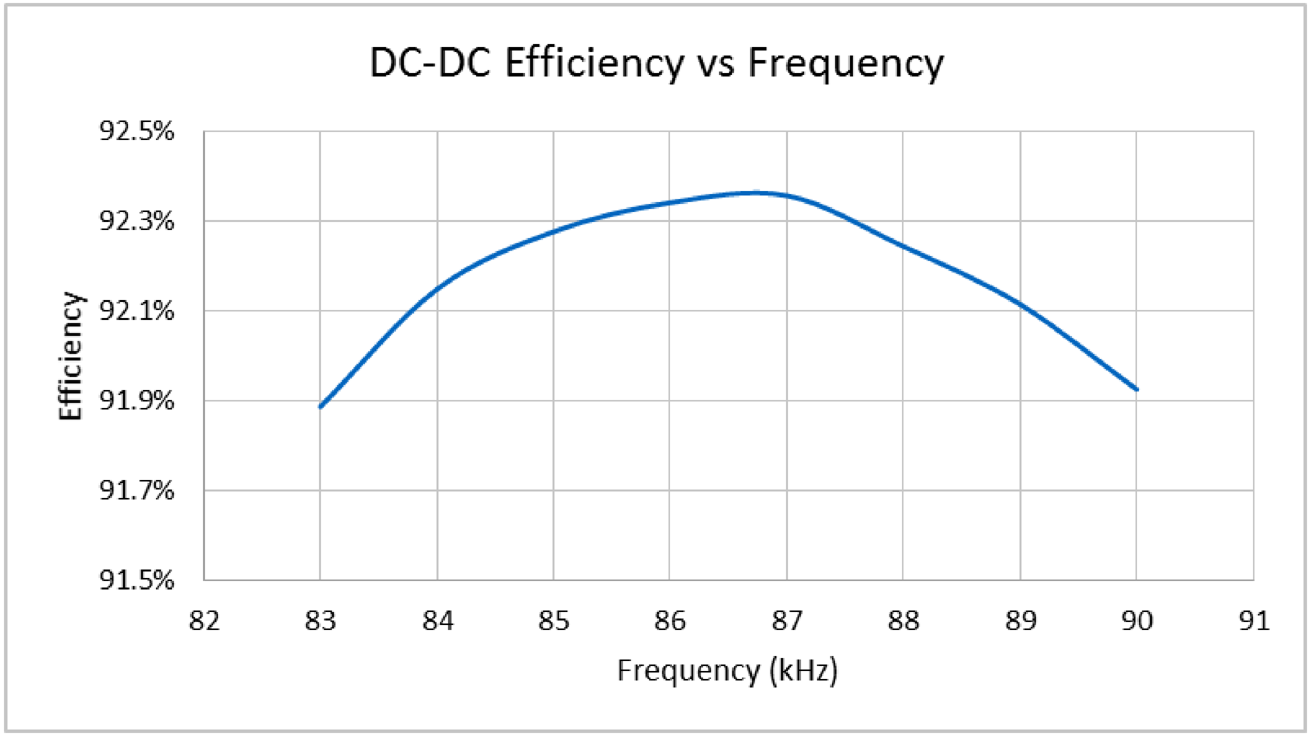
Phase 1 Development

Efficiency Data - Asymmetric Coils



Conditions:

- Adjustable DC volts in
- >20cm coil to coil separation
- 360V output load voltage

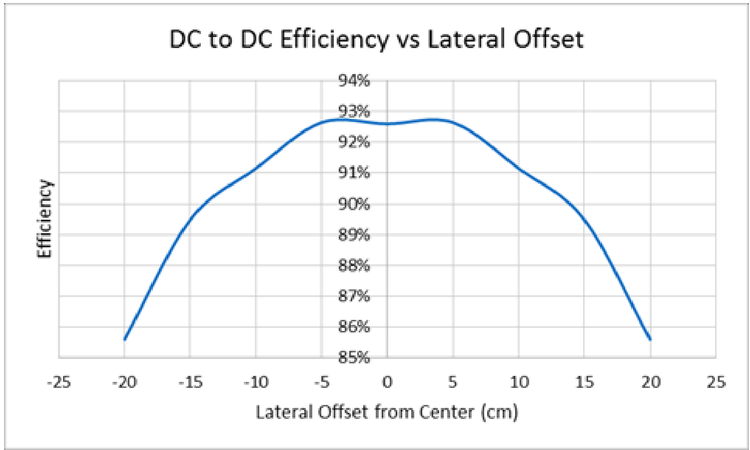
Comments:

Even if frequency is not optimized for efficiency, expected variability in operating range of interest is <1% (if still between two resonant peaks)

Phase 1 Development

Efficiency Data - Misalignment - Symmetric Coils

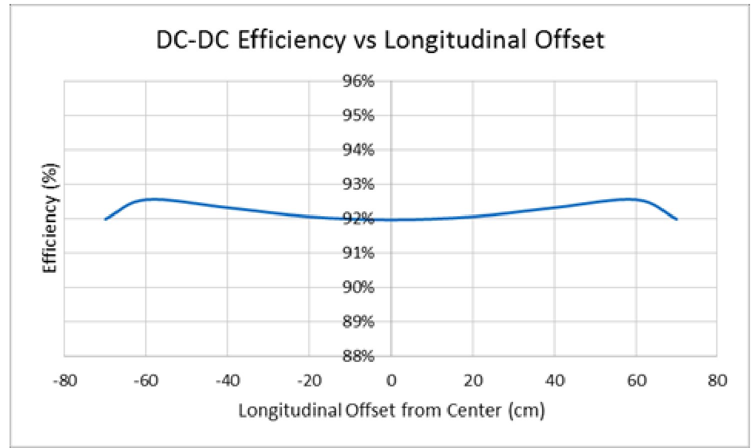
Lateral Misalignment



Conditions:

- 87kHz switching frequency
- Adjustable DC volts in
- 19.75cm coil to coil separation
- 360V output load voltage
- Coil design allows large lateral offset while maintaining high efficiency.

Longitudinal Misalignment



Conditions:

- 87kHz switching frequency
- >20cm coil to coil separation
- 360V output load voltage
- Coil design allows very large longitudinal offset while maintaining high system efficiency – important for quasi-dynamic and dynamic charging

Phase 1 Achievements

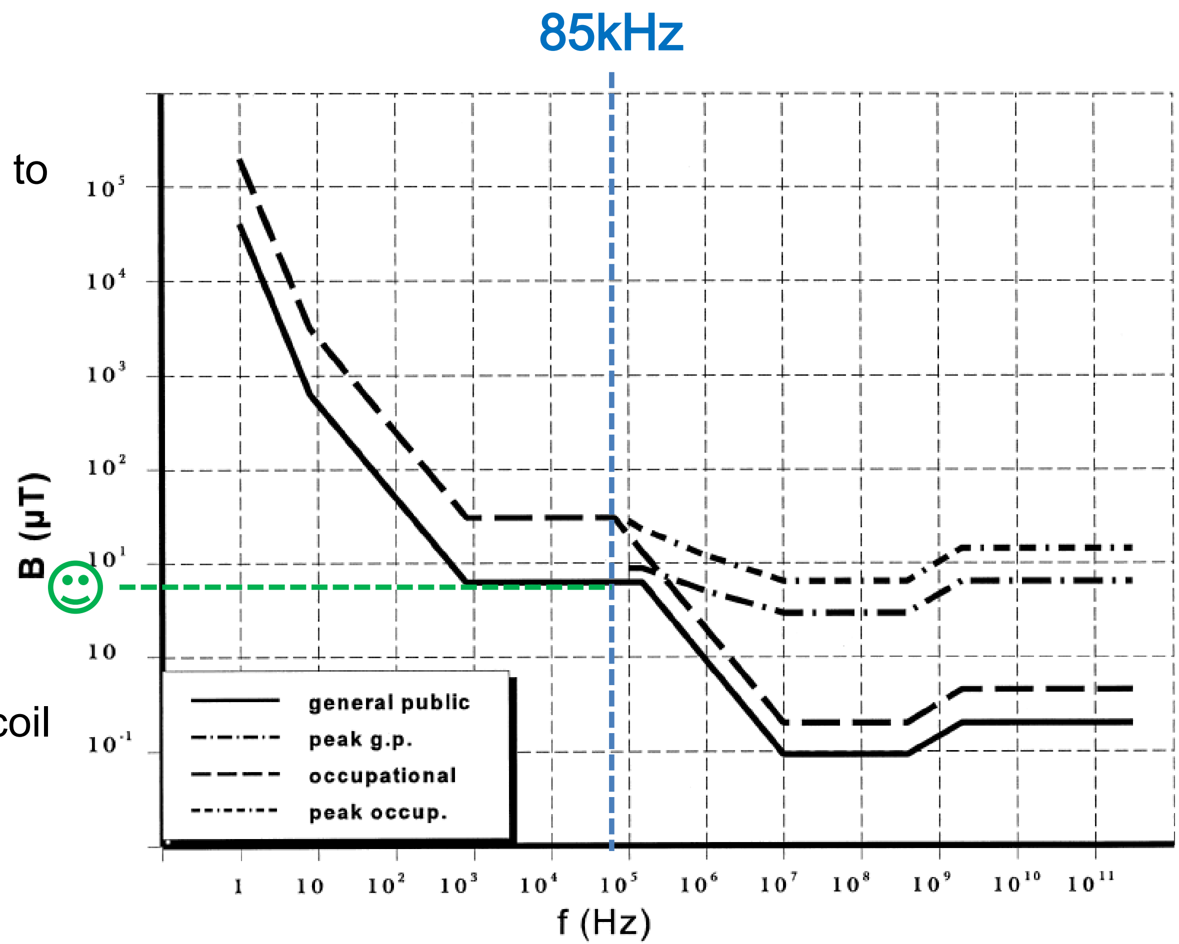
Electromagnetic Emission Safety Guidelines

ICNIRP Guidelines for Safe Exposure to Magnetic Fields in Frequency Range of 80kHz to 90kHz:

- 20uT for Occupational Exposure
- 6.25uT for General Exposure

System Performance (at 6.6kW)

- 6.0uT at 1m lateral distance from coil



Phase 1 Achievements

Efficiency Comparison with Wired Charging

	Average Level 2 Wired Charging	Symmetric Coils Wireless Charging	Asymmetric Coils Wireless Charging
High Energy Charge (>2kWh)	**86.5%**	**88.8%**	**86.2%**

- Level 2 standard wired chargers have average AC to Battery efficiencies of 86.5%
- Wireless charging provides comparable efficiencies and better user experience

Source:

Vermont Energy Investment Corporation: An Assessment of Level 1 and Level 2 Electric Vehicle Charging Efficiency, 2013

Responses to Previous Year Reviewers' Comments

Reviewer Comment	Response
6.6kW is a conservative power transfer goal.	6.6kW is Go/No-Go Criteria. The project goal is up to 19.2kW.
Technical barriers may not exist for this project.	It is expected that significant technical barriers exist is the area of electromagnetic emission reduction and containment at high power transfer rates.
Why is the alignment tolerance that this system is capable of required when many cars can parallel park themselves?	Alignment tolerance is desirable for “real world” implementation of this customer convenience technology. This capability also supports future goals of quasi-dynamic and dynamic charging.

Collaborations and Coordination with Other Institutions

- Mojo Mobility
  - Sub-recipient of award no. DE-EE0005963.
  - Responsible for design, development of wireless charging system.
  - Currently developing wireless charging systems for consumer electronics, and automotive applications.

- Society of Automotive Engineers (SAE)
  - J2954 Wireless Charging Task Force (Voting Member)
  - J2836/6 Wireless Charging Specific Use Cases (Voting Member)
  - J2847/6 Wireless Charging Specific Messages (Voting Member)
  - J2931/6 Wireless Charging Specific Protocols (Voting Member)

- Next Energy
  - Advising on commercialization strategies and opportunities.
  - Market intelligence support.
  - Vehicle level functional validation support.

Proposed Future Work

- FY14
  - Design of Third Generation WPT Prototype System
    - The primary coil X-axis dimension is expected to be reduced
      - Coil size is directly proportional to misalignment tolerance
      - Y-axis misalignment tolerance is unchanged (lateral)
      - X-axis misalignment tolerance is reduced (longitudinal)
      - Size reduction will make system less expensive
      - Misalignment tolerance remains very high
      - Drivers naturally align better in X-axis
      - Foreign object detection becomes easier
    - Develop Gen. 3 system for higher power transfer
      - Gen. 3 goal is a minimum of 6.6kW and up to 19.2kW power transfer rate
    - Reduce size, weight, and cost of current design
      - Retain design strengths while mitigating negative trade-offs
  - Vehicle Integration and Test
  - Complete Go/No-Go Milestone

Proposed Future Work

- FY15
  - Fleet Build-Up
    - Build five (5) WPT-enabled EVs based on the Gen. 3 system specifications
      - Vehicle retrofitting will be performed at HATCI HQ in Ann Arbor, MI
  - Validation
    - Deliver one (1) WPT-enabled EV and charging system to DOE
      - National Laboratory Testing
    - Perform vehicle and product validation
      - Component level EMC/EMI
      - Vehicle level EMC/EMI
      - Electrical parametric
      - Ingress protection
      - Thermal
      - Durability

Summary

The benefits provided by wirelessly charging Grid Connected Electric Drive Vehicles (GCEDV) are motivating innovation in the area to address technical challenges. The early design work by HATCI and Mojo Mobility is leading towards the ability to present new state of the art performance capabilities in the areas of:

- Low spurious unwanted emissions into the environment.
- High power transfer efficiencies.
- High power transfer
- Large coil to coil misalignment and vertical gap separation.

The cooperation of HATCI and Mojo Mobility provides an opportunity to develop a next generation GCEDV wireless charging system that can be quickly integrated into production ready vehicles for vehicle level testing that will provide proof of concept systems for evaluation for commercial potential.

- Commercial Viability Study performed in FY14 will provide and understanding of the following considerations:
  - Commercial viability and cost benefits.
  - Comparison with SAE 1772 compliant conductive charging system.
  - Expected market penetration.
  - Potential petroleum reduction.