SELECT Annual Meeting and Technology Showcase – Logan, Utah – September 27-28, 2016

University of Colorado Boulder

Capacitive Wireless Power Transfer System for Electric Vehicles

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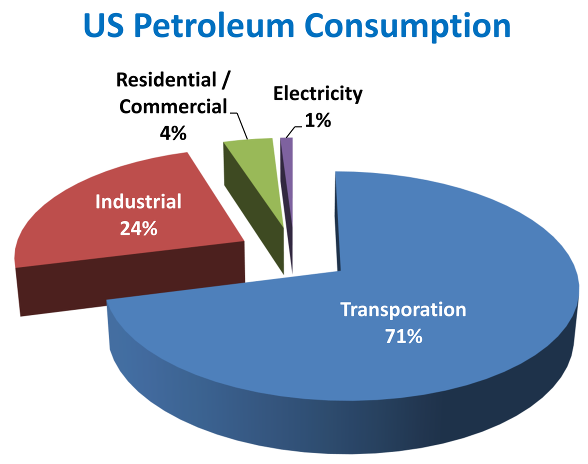
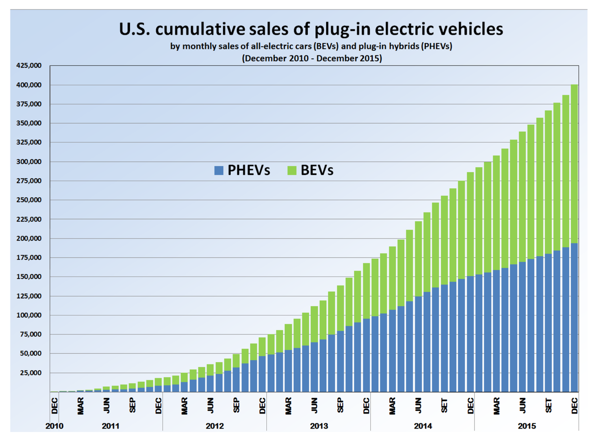
Introduction

- Transportation accounts for 71% of petroleum consumption, 27% of total energy consumption, and 33% of total greenhouse gas emissions in the US
- Electric vehicles (EVs) have much higher well-to-wheel efficiency compared to gasoline vehicles
- Penetration of EVs remains low – main hurdles are:
  - High cost
  - Limited range
  - Long charging times

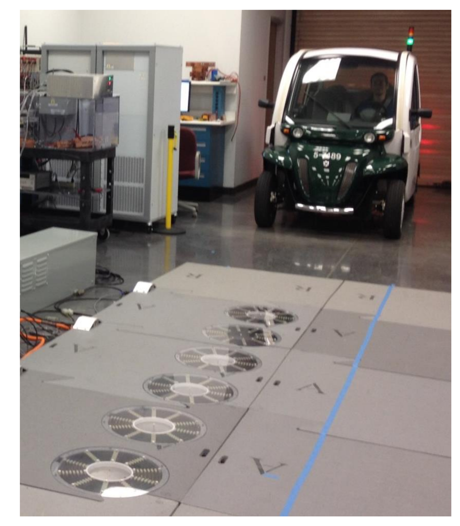
  all due to limitations in battery technology
- Cost effective, high power transfer density and safe dynamic wireless power transfer (WPT) can drastically reduce the need for batteries

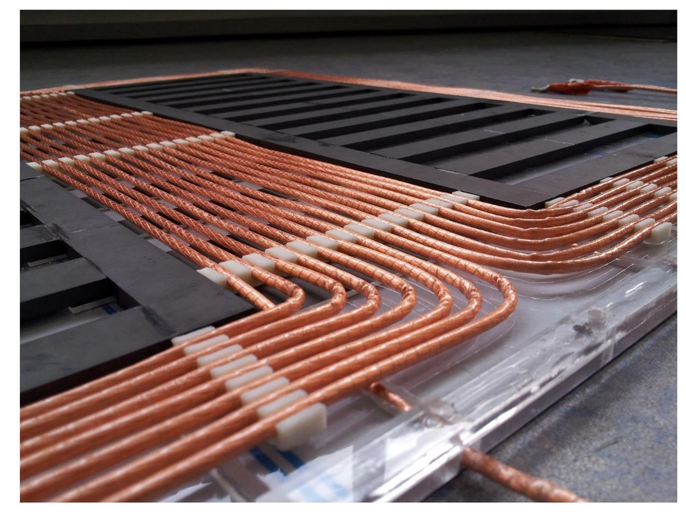




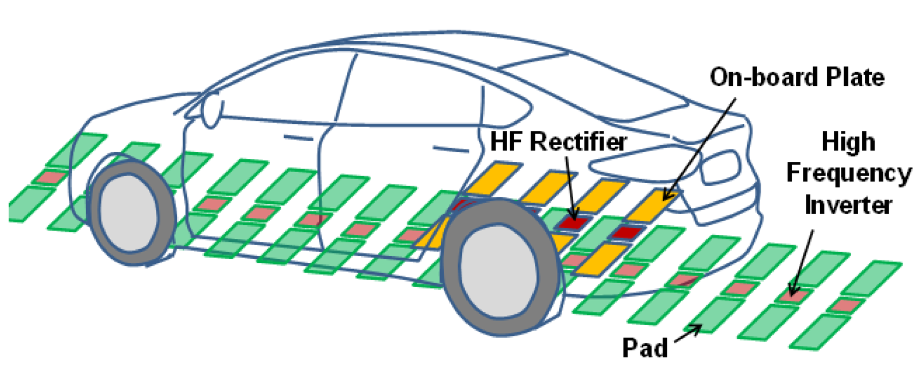
Opportunity

- Current approaches to stationary and dynamic WPT for EVs mostly rely on inductive coupling
- Inductive systems have limitations:
  - Require expensive and fragile ferrite cores for magnetic flux guidance and shielding
  - Relatively low operating frequencies to limit losses, resulting in large size
- Capacitive charging of EVs through tires has been tried
  - Low efficiency due to carbon black filler
  - Inadequate power transfer due to limited area
- Appropriately designed high frequency capacitive WPT systems can be less expensive, more efficient and smaller than inductive WPT systems

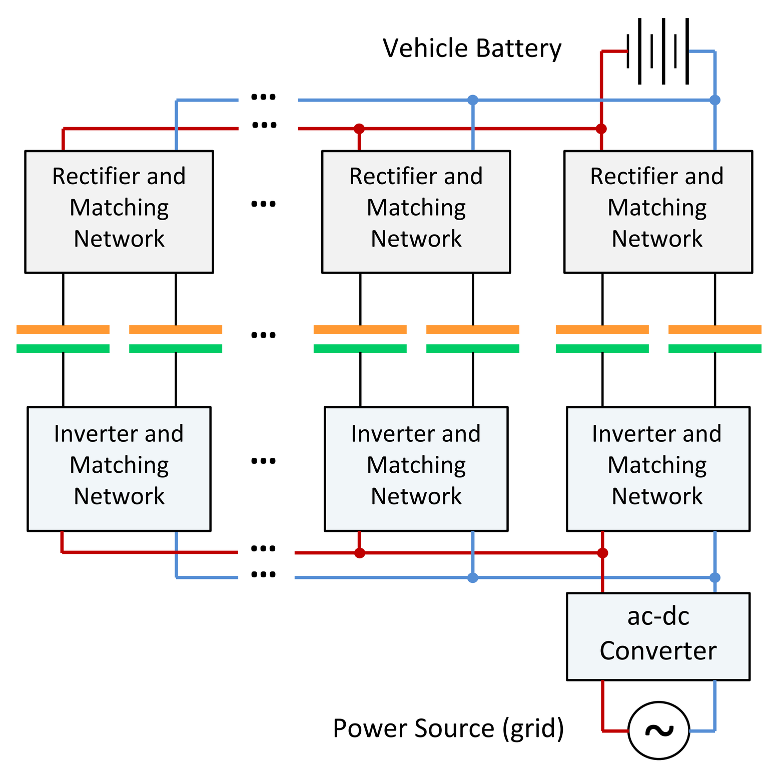




Modular Capacitive Wireless Power Transfer System

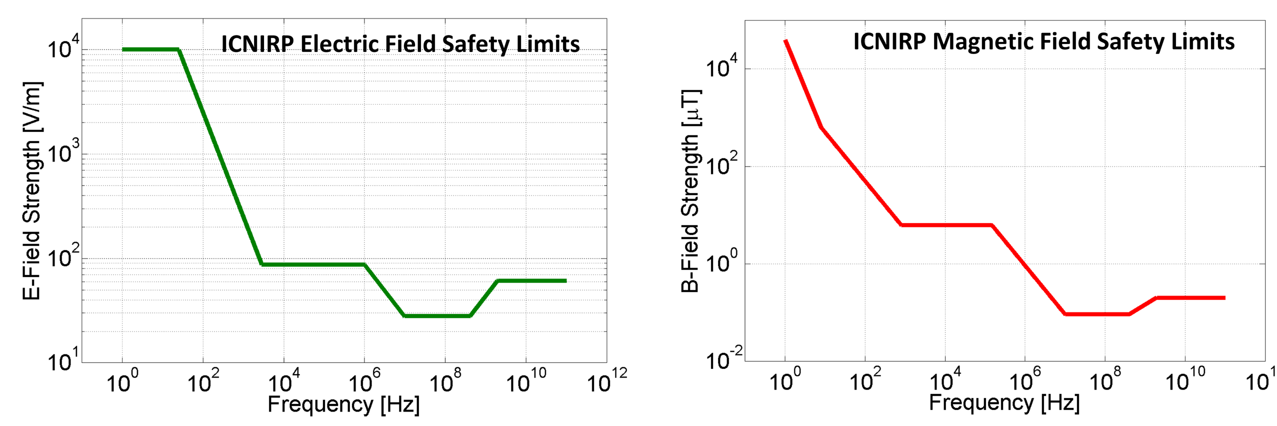


- Array of metal pads in road and metal plates on-board vehicle
- Adjacent plate-pairs can be phase-shifted with respect to one another using modular power electronics
- Phase-shifting reduces electric field strength in safety critical regions by canceling fringing fields generated by adjacent modules

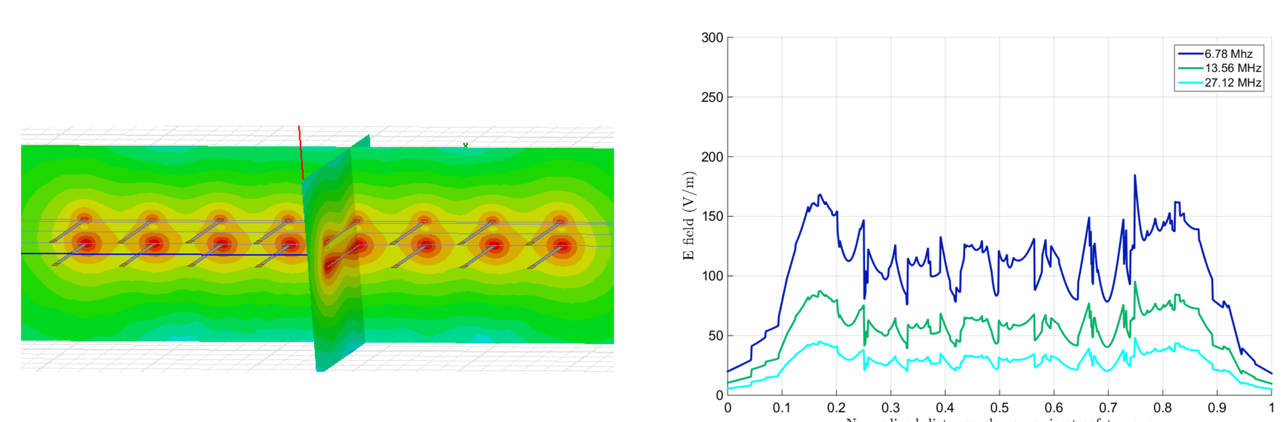


Architecture of a modular capacitive WPT system

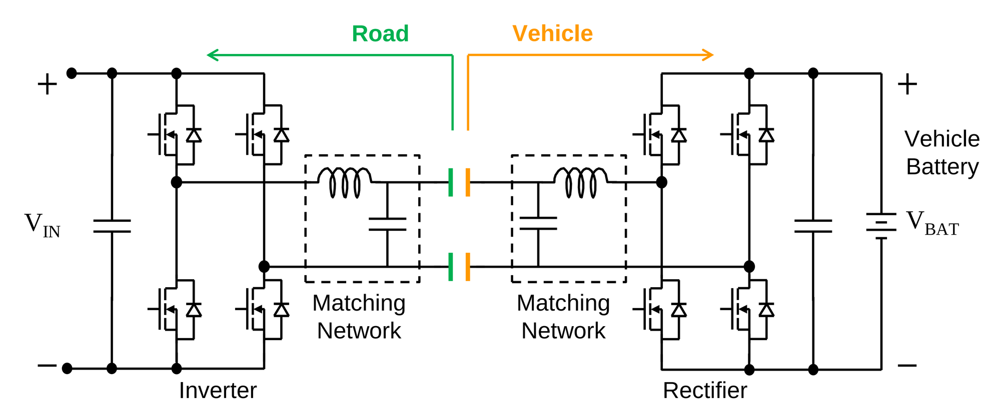
Target: 12 cm air-gap, 50 kW/m^2, 90% efficiency



Electromagnetic field safety requirements



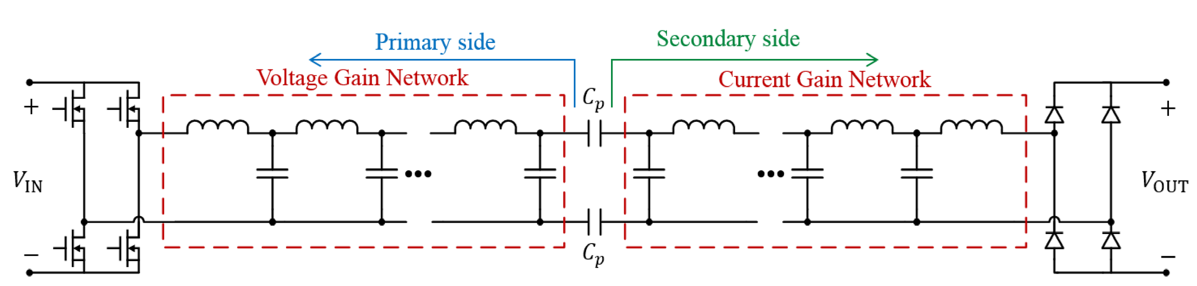
Electromagnetic fields of a modular capacitive WPT system in powering and safety critical zone



Example implementation of a single capacitive WPT module

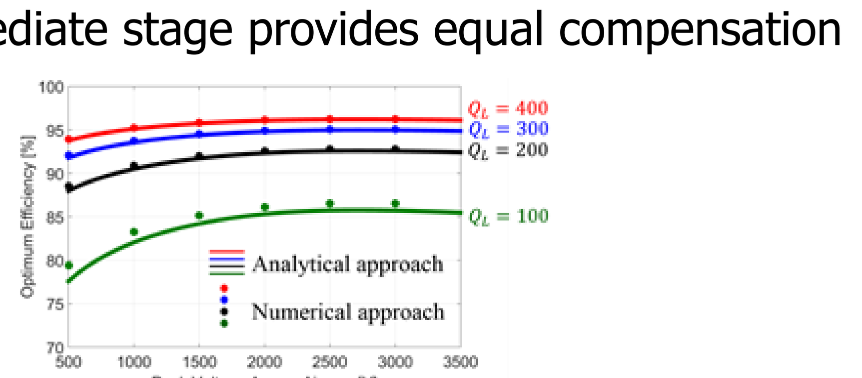
- Each module has a high-frequency inverter, two matching networks that provide voltage/current gain and reactive compensation, and a high-frequency rectifier
- Appropriate design of matching networks and soft-switching of inverter and rectifier transistors enable high efficiency operation

Matching Network Optimization



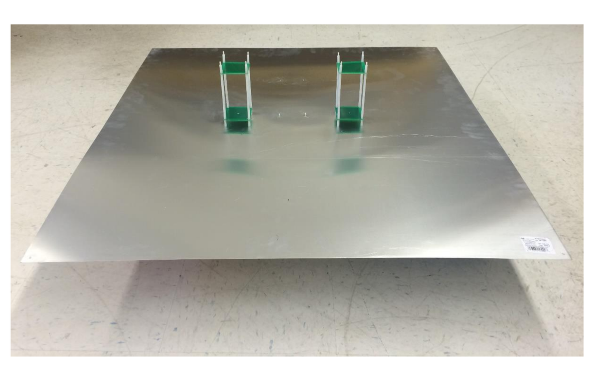
A capacitive WPT system with multistage L-section matching networks

- Each matching network stage provides gain and compensation for the capacitive reactance of the coupling plates, enabling effective power transfer
- Individual stages are optimally designed to maximize overall efficiency of the system
- In the optimal design:
  - Each stage on the primary side except the last stage provides equal gain
  - Each stage on the secondary side except the first stage provides equal gain
  - Each intermediate stage provides equal compensation

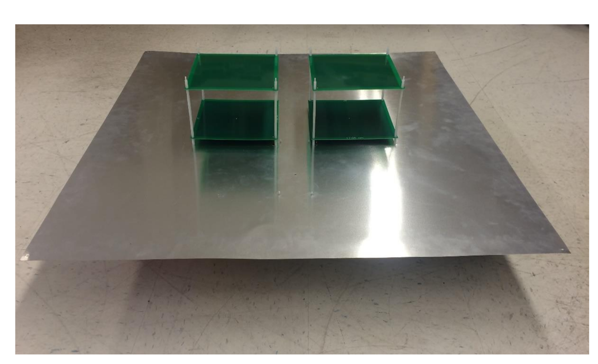


Efficiency of optimized matching network

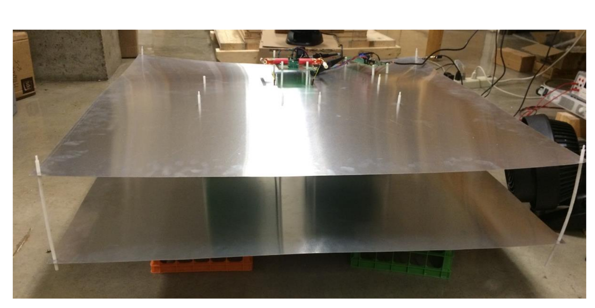
Capacitive WPT Prototypes



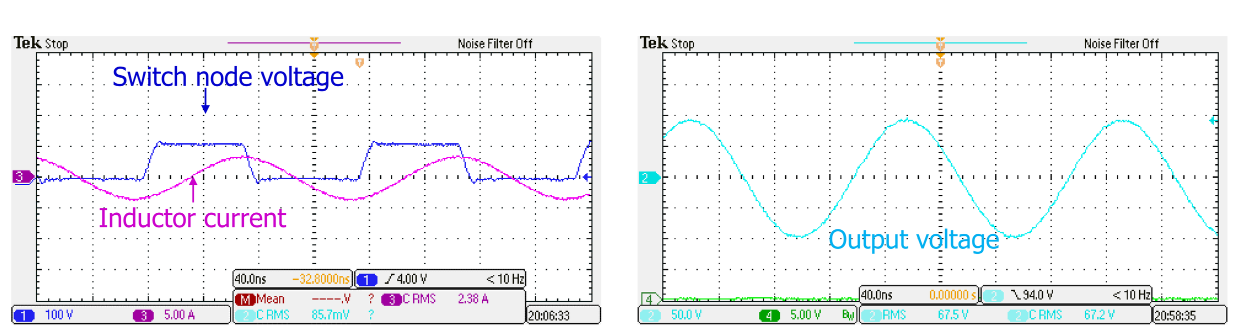
250 W 12-cm air-gap capacitive WPT system (under development)



3 kW 12-cm air-gap capacitive WPT system (under development)



Testing under realistic vehicle environment – metal shields emulate the vehicle chassis and road



Experimental waveforms of capacitive WPT system transferring 110 W power across a 12 cm air-gap at 90% efficiency

Summary and Conclusions

- Capacitive wireless power transfer systems can enable efficient, high power transfer density and cost effective dynamic and stationary WPT for electric vehicles
- Modular approach can significantly enhance power transfer density in large air-gap applications while meeting safety requirements
- Ongoing work validates effective large air-gap capacitive wireless power transfer at high efficiency

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