WIRELESS POWER TRANSFER FOR ELECTRIC VEHICLES

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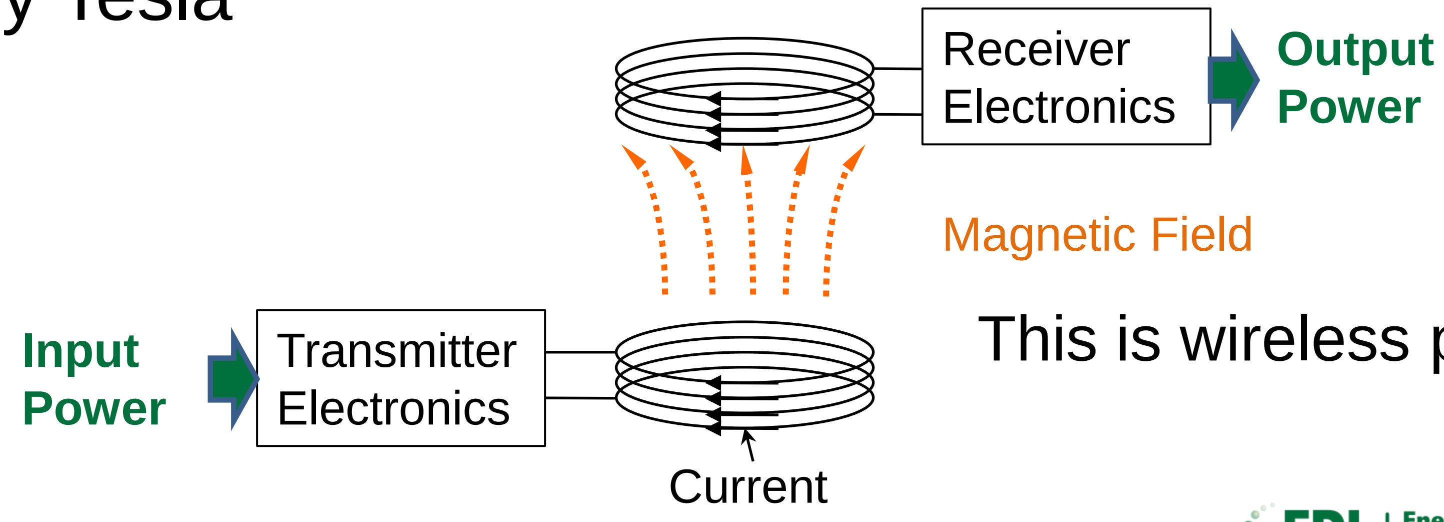
What Is Wireless (Inductive) Power Transfer?

- IPT transfers electric power over an air gap
- Uses ampere's and faraday's law
  - Ampere: current in transmitter coil produces magnetic field
  - Faraday: magnetic field induces a voltage in receiver coil
- IPT concept not new – proposed over 100 years ago by Tesla



This is wireless power!

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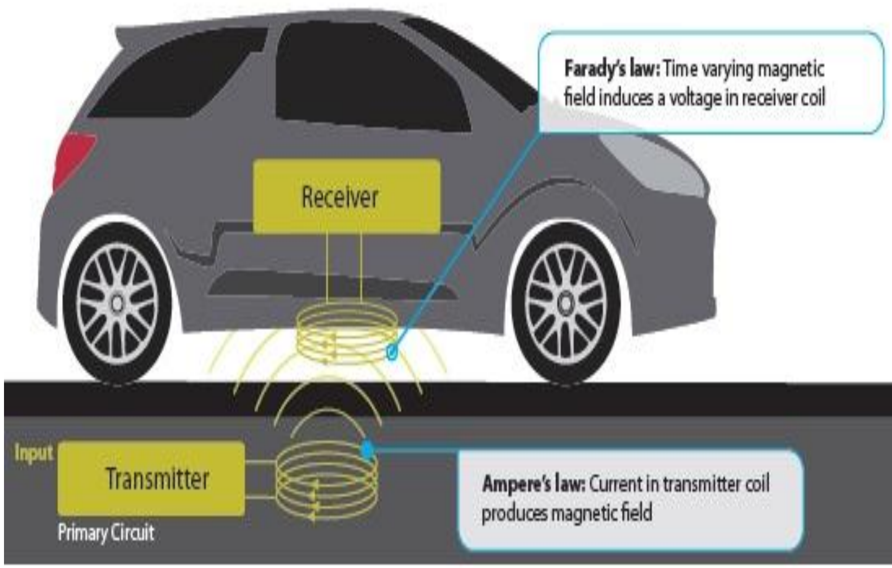
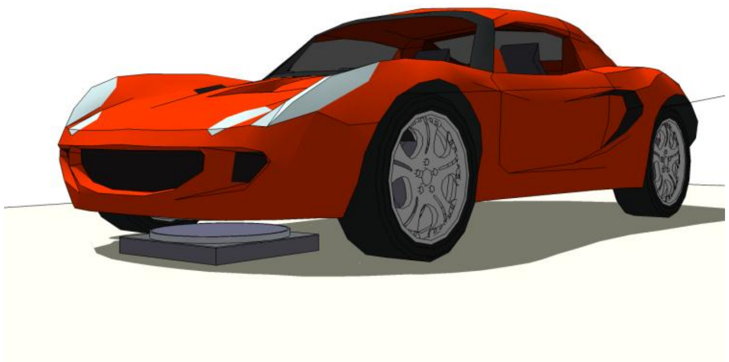
Proposed Approaches

- High power stationary charging
- In-motion power transfer



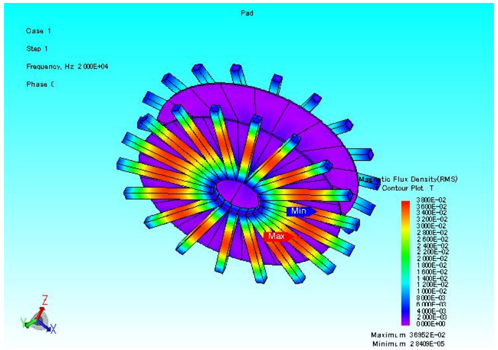
High Power Stationary Charging

- High power levels
  - Achieve 30miles/min goal using 450kW
- Convenience – no user input
  - No wasted time to mate plug
- Maintenance free – solid state
- Weather proof
- Less efficient than conductive (>93%)
- Relative costs (?)



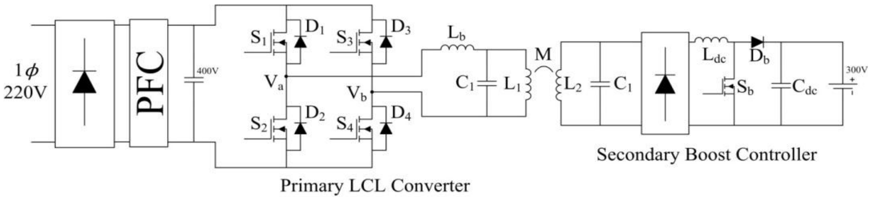
Current Stationary Charging System

Parameters	Value	Notes
Power Level	5kW	Pad sized for 20kW
Frequency	20kHz	20 – 100kHz capabilities
Air gap	6 – 10.5 in	With maintained efficiency across range
Efficiency	> 90%	> 98% magnetic transfer
Voltage	300VDC	Output
Pad dimension	32-in diameter	
Pad weight	~ 45 lbs	Expect 2X reduction in future designs
Misalignment	8 in @ 6 in gap	With maintained efficiency (conical region)
EMF exposure	ICNIRP	Meets latest ICNIRP standards
Modularity	Scalable	Rapid design deployment



Pad simulation

- 5kW
- High efficiency
- Wide gap tolerance
- Meets safety standards



IPT System Topology

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High Power Charging Technology

- Power module development
  - 1200V power high wideband gap devices
  - Gate driver development

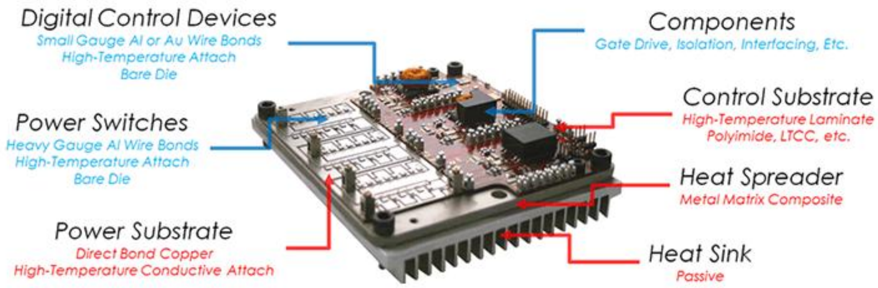


Photo credit: APEI

- IPT development
  - Fixed frequency soft-switching
  - New concepts for field shaping
  - Active EMF cancellation
  - Wide range coupling operation
  - Paralleling inverters

In-motion Power Transfer Benefits

- **Economic Security:** reduces dependence on:
  - Foreign oil (currently $300B per year)
  - Rare Materials (lithium: 80% battery size reduction)

Reserves	U.S.	Our Allies	Other Nations
Lithium	0.4%	8.1%	92%
Copper	7.5%	14%	86%
Iron	4.5%	20%	80%
Manganese	-	19%	81%
Zinc	20%	44%	56%

Battery (Lithium)

WPT (Copper, Iron, Manganese, Zinc)

Ferrite (Iron, Manganese, Zinc)

- **Relieves range anxiety, adds convenience, reduces battery size and increases battery life**
- **Cost [1,2]:** comparable with ICE and cheaper than battery EV
  - The region around I-5 in Seattle, 80% electrification, 30 mile battery range and cost of $2.7M per lane mile results in rough cost competitiveness with ICE vehicles

1. F. Risch, "Electrified roadway activities at the Bavarian technology center for electric drives", Transportation Research Board, 26th January 2011, Washington DC
2. A. Brooker, M. Thorton and J. Rugh, "Technology improvement pathways to cost-effective vehicle electrification", SAE 2010 World Congress and Exhibition, 12th April 2010, Detroit

Challenges to In-Motion IPT

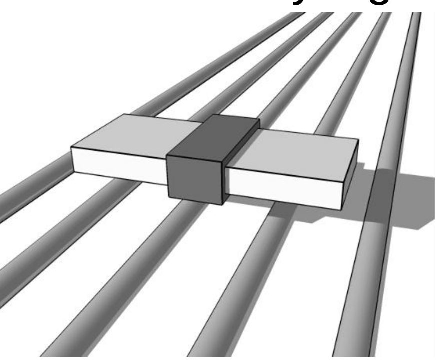
- **Challenge:** Achieve > 90% grid-to-vehicle transfer efficiency @ 75mph, 40kW and wide tolerance
- **Challenge:** Reduce cost of roadway electrification to ~$2M/ lane mile

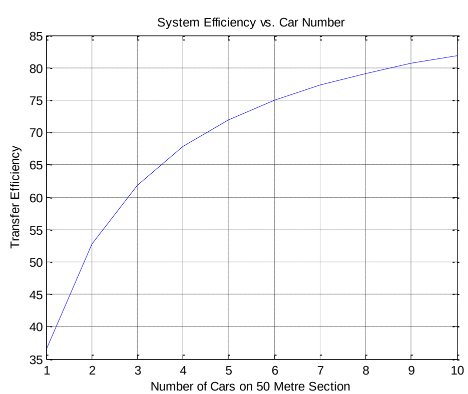
Conventional Distributed IPT

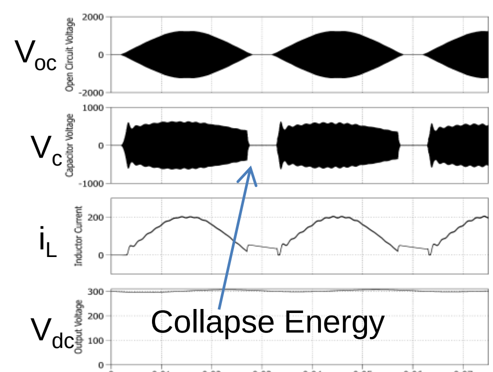
- From [1], $P=\omega I_1^2 Q_2 M^2/L_2$
- I_1=~400-600A
- Very high track losses (230-520W/m)
- Fields too high for humans
- Efficiency high only with10 vehicles

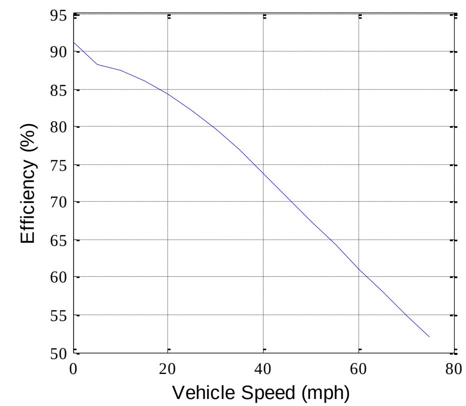
Stationary IPT

- Circular pad has power null at 80% of pad radius [2], only 46% usable
- Collapse of magnetic energy around power null causes losses









1. J. T. Boys, G. A. Covic and A. W. Green, "Stability and control of inductively coupled power transfer systems," *IEE Proceedings - Electric Power Applications*, vol. 147, no. 1, pp. 37-43, 2000.
2. M. Budhia, G. A. Covic and J. T. Boys, "Design and optimisation of magnetic structures for lumped Inductive Power Transfer systems," in *IEEE Energy Conversion Congress and Exposition, 2009. ECCE 2009.*, 2009, pp. 2081-2088.

In-motion Technology

- Key Outcomes
  - Eliminate range anxiety
  - 40kW @ 75 mph, $\eta > 90\%$
  - <$2M per lane mile
- Proposed Approach
  - Magnetic field shaping
  - Fast dynamic controllers
  - Reactive VAR compensators
  - Soft switching topologies
  - High speed rotating test approach

Parameters	State of Art	Proposed System
Operation Speed	Stationary	>75mph
Power Level	Up to 6.6kW	30kW-50kW
Frequency	20kHz	20-140kHz
Air gap	Up to 10”	Up to 15”
Efficiency	> 90% (System)	> 90% (System)
Pad weight	~ 45 lbs	< 80 lbs
Misalignment	8”at 6” gap	10” at 15” gap
EMF exposure	ICNIRP	ICNIRP