FREEDM SYSTEMS CENTER

Wireless Charging Systems for Electrified Transportation

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September 24th, 2020

Introduction

- Welcome
- FREEDM Overview
- Zoom Functionality

freedm.ncsu.edu

Outline

- Introduction
- WPT Concept
- FAQ on WPT
- DWPT Research projects
  - Sensorless/Seamless Transition
  - Misalignment Estimation
- Current work at NC State

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Introduction

2015-2020:

Grad. Researcher/PhD Student

Utah State University

SELECT Research Center

Since Feb. 2020:

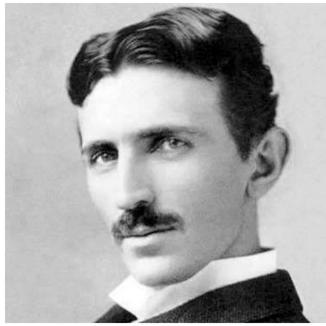
Post Doctoral Researcher

NC State University

FREEDM Systems Center

Photo taken at 2016 SELECT Showcase

WPT is not NEW

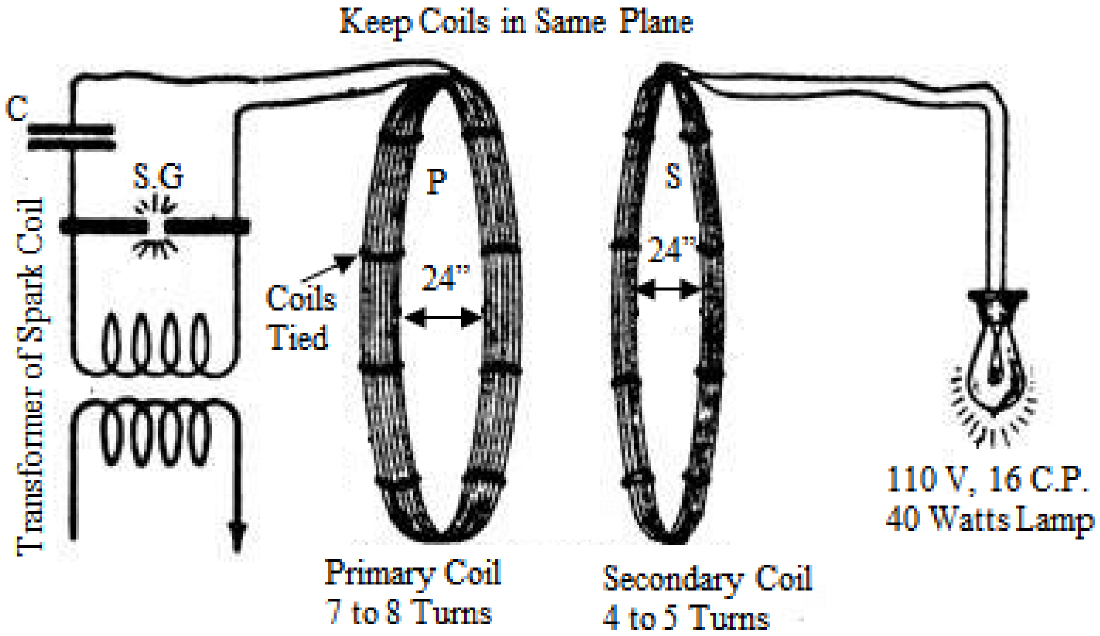


Nikola Tesla published a paper on November 17, **1898**

Ampere's Law $\oint \overline{B}\bullet\overline{dl} = \mu_0 NI$

Faraday's Law $\oint \overline{E}\bullet\overline{dl} = -\frac{d\Phi_B}{dt}$

One-foot Separation



"Tesla Apparatus and Experiments—How to Build Both Large and Small Tesla and Oudin Coils and How to Carry On Spectacular Experiments With Them," by H. Winfield Secor, Practical Electrics, November 1921

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WPT Applications

NC STATE UNIVERSITY

Electric vehicles

carbuzz.com

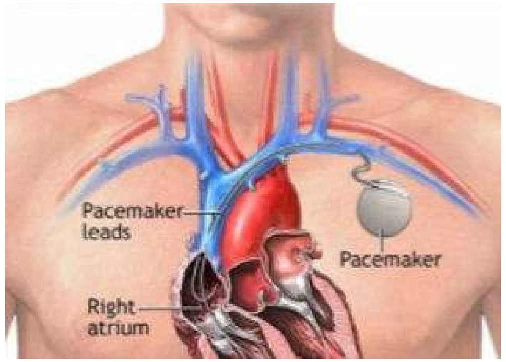
AGV

alibaba.com

Personal Transportation

www.thesuperboo.com

Bio implants



www.alansonsample.com

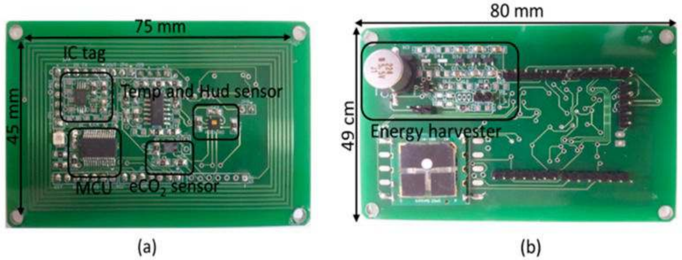
Robotics

docs.mistyrobotics.com

Cell Phone

www.cellphonecover.com

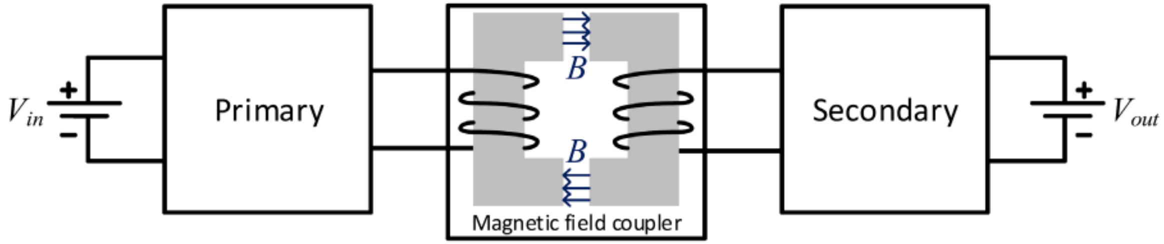
Energy Harvesting



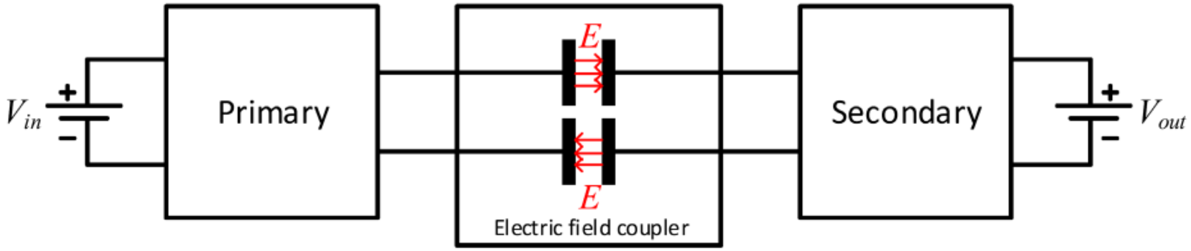
An Enhanced Multiplication of RF Energy Harvesting Efficiency Using Relay Resonator for Food Monitoring.

WPT for EV

Inductive



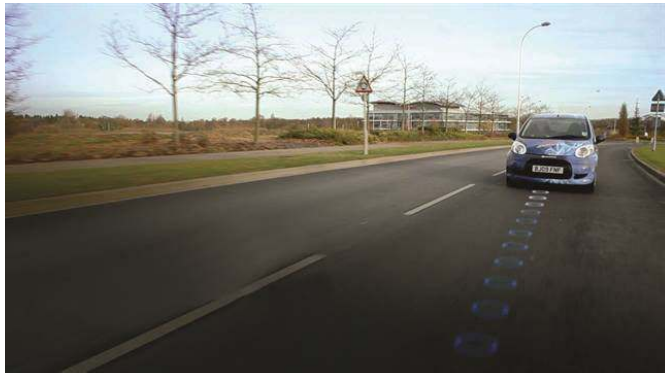
Capacitive



Hybrid = Inductive + Capacitive

Stationary

Dynamic



Dai, Jiejian, and Daniel C. Ludois. "Single active switch power electronics for kilowatt scale capacitive power transfer." *IEEE Journal of Emerging and Selected Topics in Power Electronics* 3.1 (2014): 315-323.

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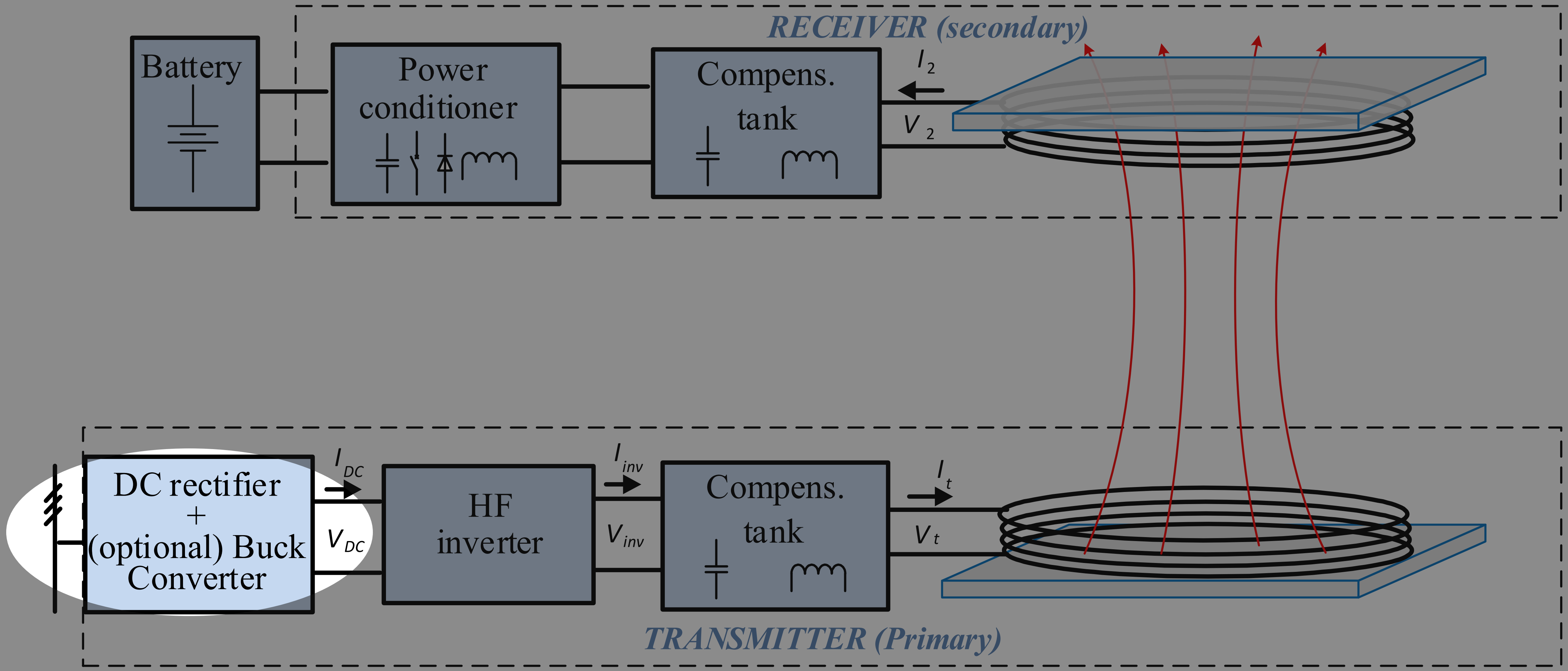
Basic Structure

NC STATE UNIVERSITY



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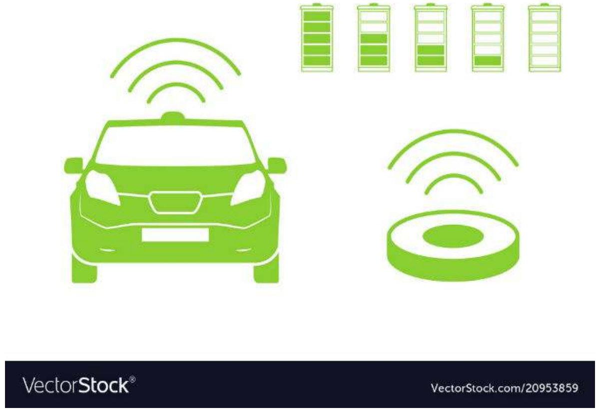
50 kW is 50 kW

https://new.abb.com/news/detail/58193/e-mobility-for-the-masses-with-abb-home-ev-charging-solution

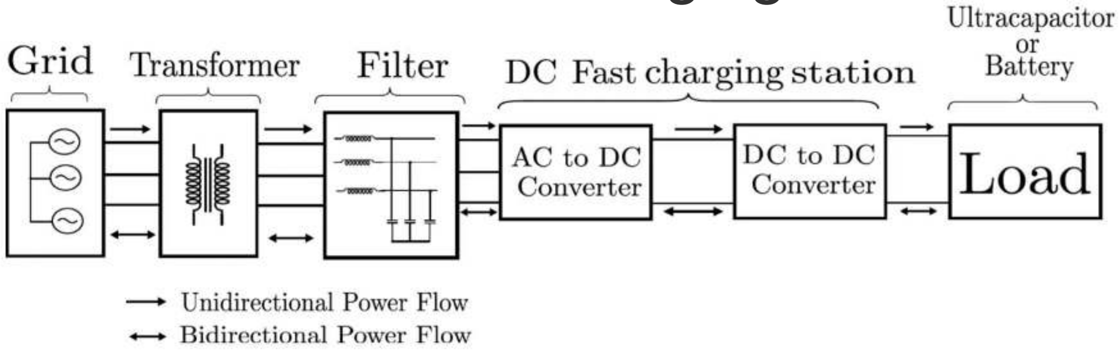
https://www.cnbc.com/2020/06/08/researchers-work-on-the-next-generation-of-wireless-charging-for-evs.html

Good for Battery?

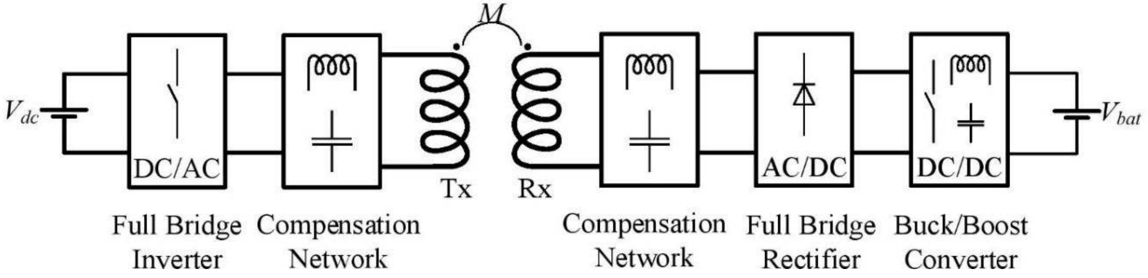


Is it efficient?

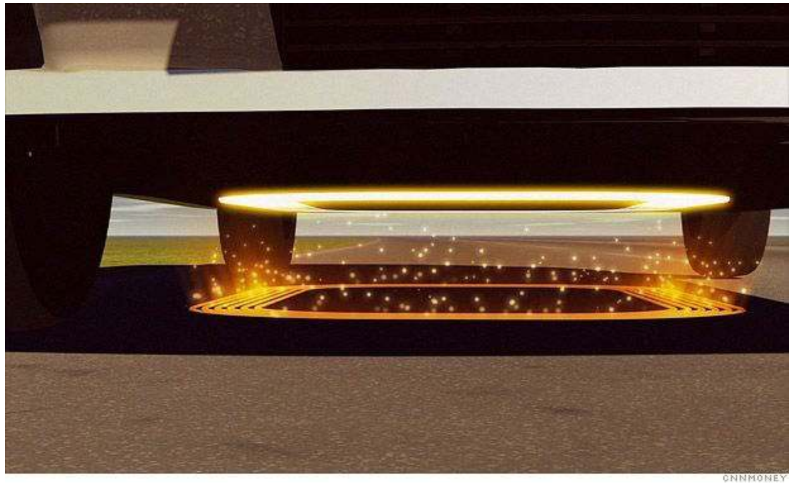
Conductive charging



Inductive charging



Losses do not occur in the airgap



https://www.theautochannel.com

Channegowda *et al*. "Comprehensive review and comparison of DC fast charging converter topologies: Improving electric vehicle plug-to-wheels efficiency." *IEEE 24th ISIE*, 2015.

Is it Safe?

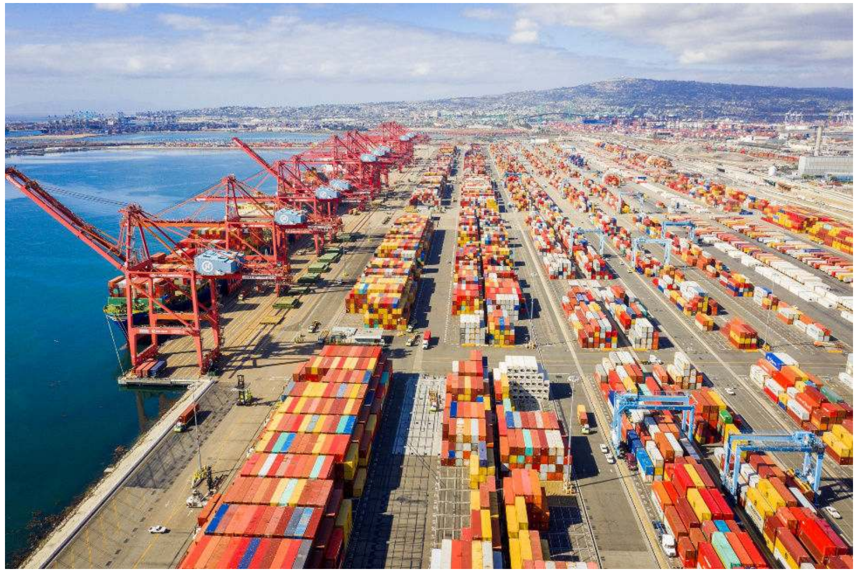
Pad is not energized unless there is a vehicle

IEEE C95 standard:
Tissue heating starts at 300kHz
Standards recommend 85 kHz

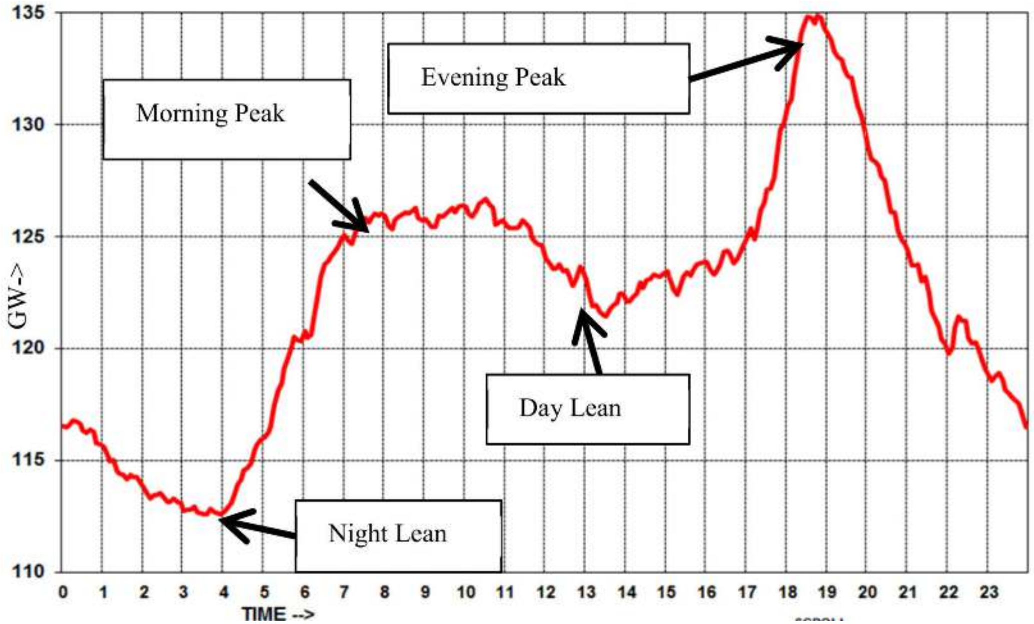
www.powerelectronics.com

Impact on Grid?

Intermittent charging vs fast charging



mohawkglobal.com



Gaur, Kajal, et al. "Analysing the electricity demand pattern." 2016 National Power Systems Conference (NPSC). IEEE, 2016.

Compatibility?

Conductive or inductive; we need two parts, one on the ground and another one on the vehicle

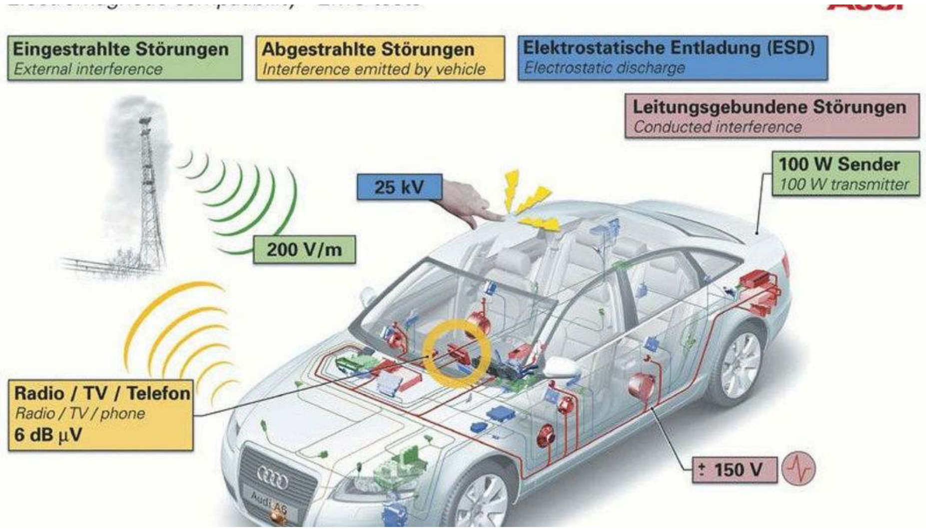
Nissan Leaf

Momentum Dynamics

Compatibility?

Electromagnetic interference:

- ADAS or any power electronics
- conducted or radiated emissions
- FCC parts 18 and 15



https://www.motor1.com/photo/161006/electromagnetic-compatibility-emc-tests/

Economic Incentive?

Autonomous driving is the future

But it needs autonomous fueling

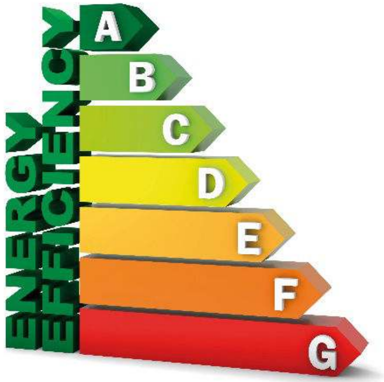
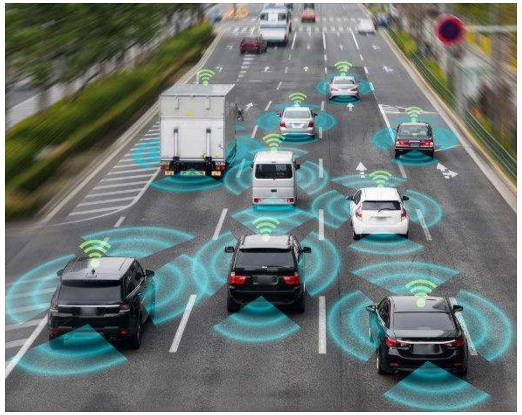
Automated parking + Automated charging

https://goodtimes.sc/santa-cruz-news/news/ucsc-self-driving-car/

Market:

- Fleet
- Port facilities
- Trucks and busses, taxis
- Last mile delivery vehicles, then
- Passenger vehicles
- Northern Europe, electrification is happening

Commercialized DWPT?

Higher Cost	Lower Efficiency	Misalignment/ Autonomy	Need for Standards
			

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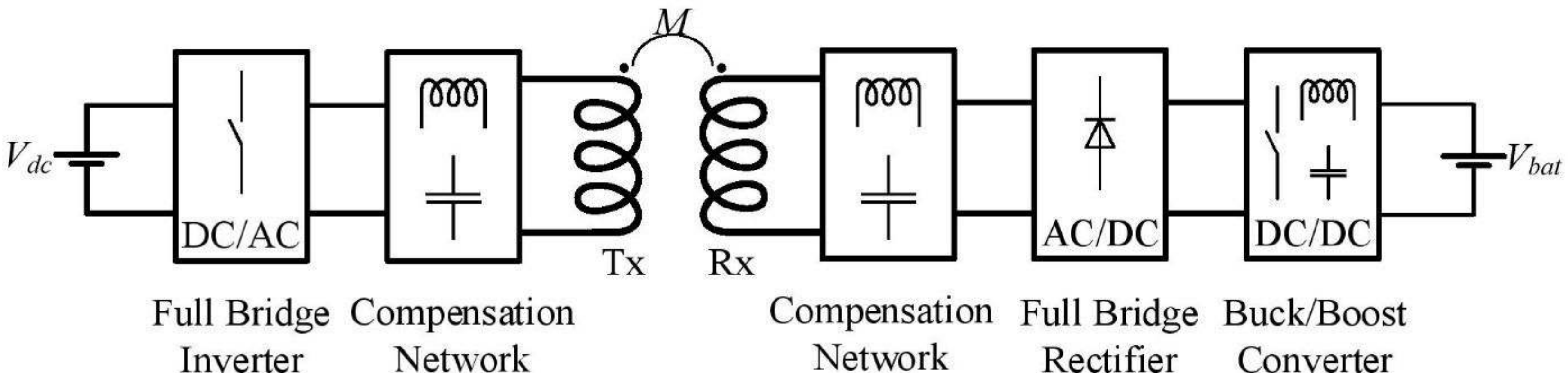
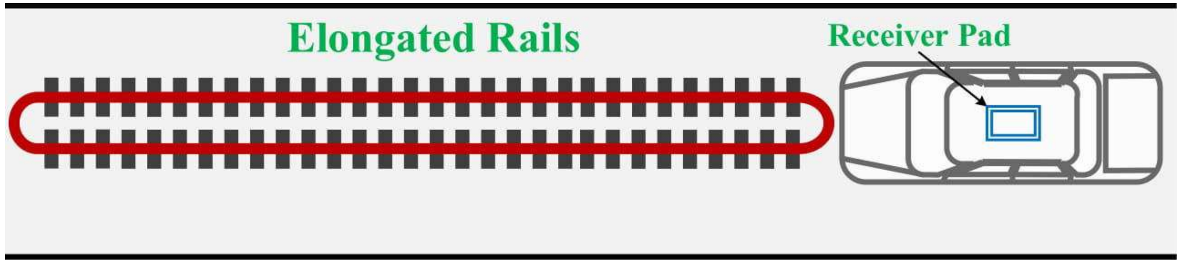
DWPT System



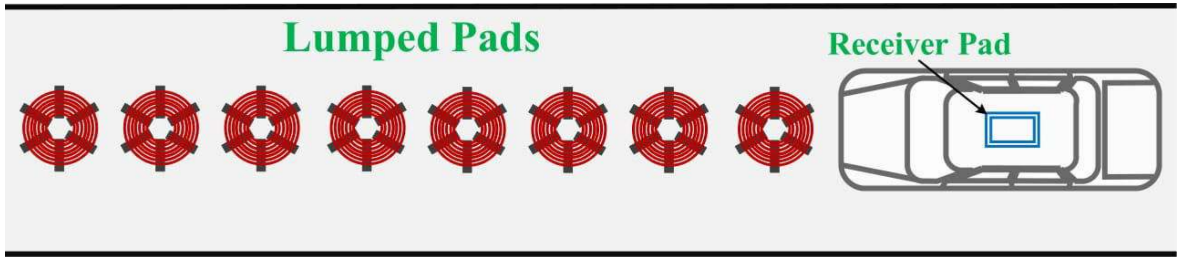
Research on DWPT:

i) coil/pad designs (Tx and Rx pads),
ii) compensation topologies and
iii) power converters and control methods

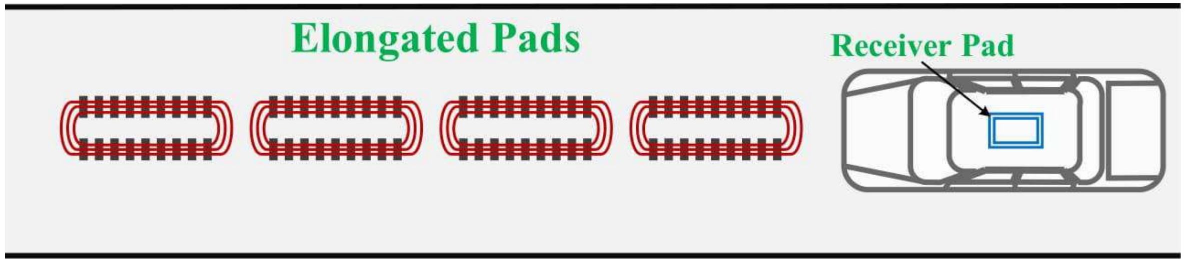
Transmitter (Tx) pad configuration for DWPT



- Stable power transfer
- Simple controller
- Low efficiency

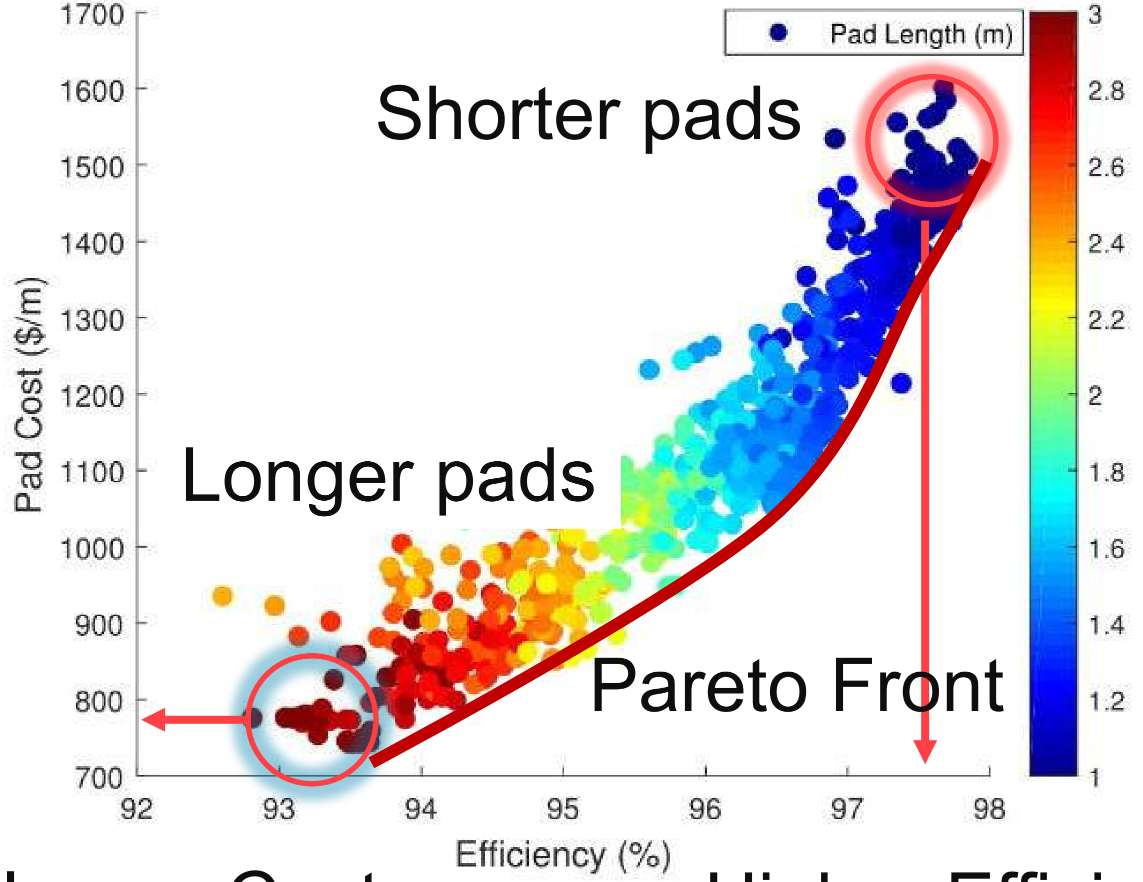


- Pulsating power transfer
- Complicated controller
- High efficiency



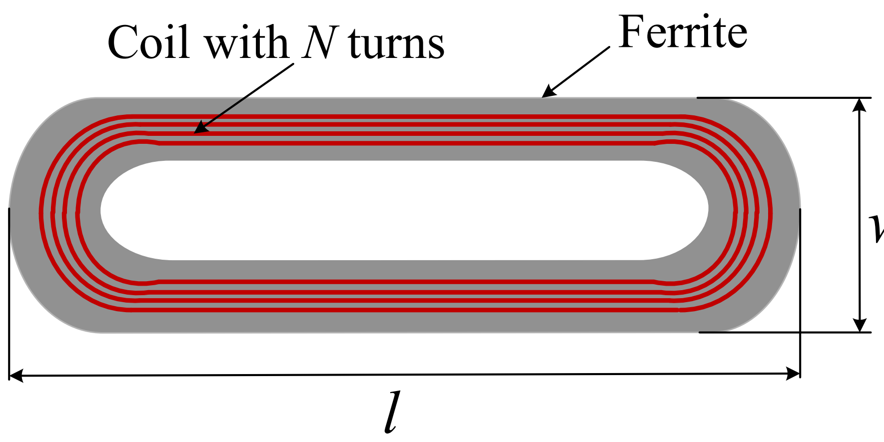
- A compromise between above options

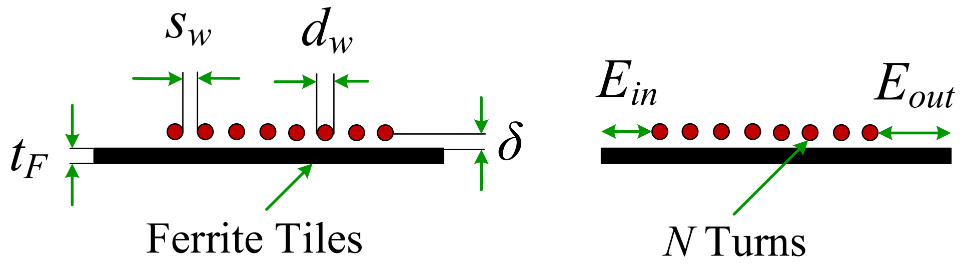
Tx pad Optimization



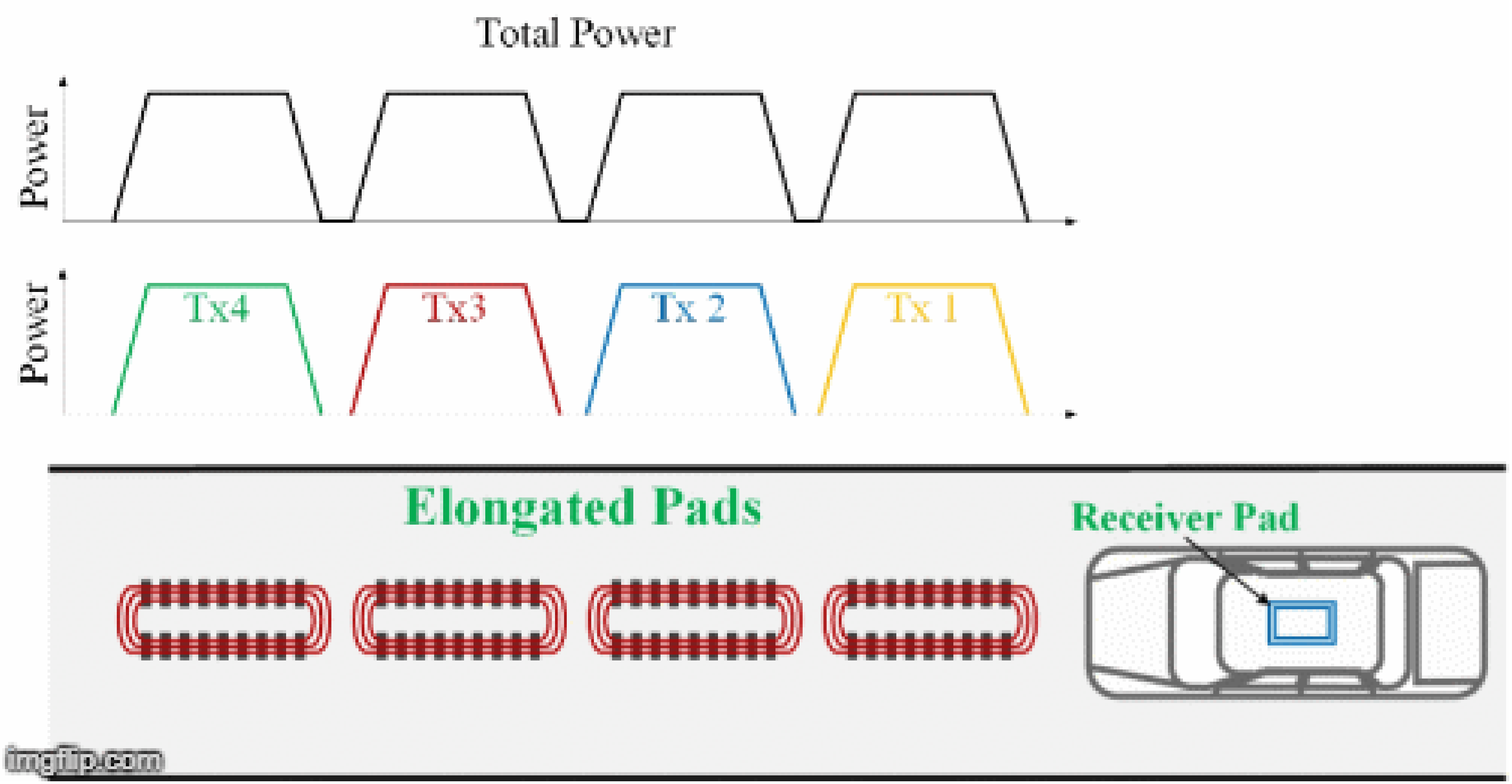
Lower Cost

Higher Efficiency

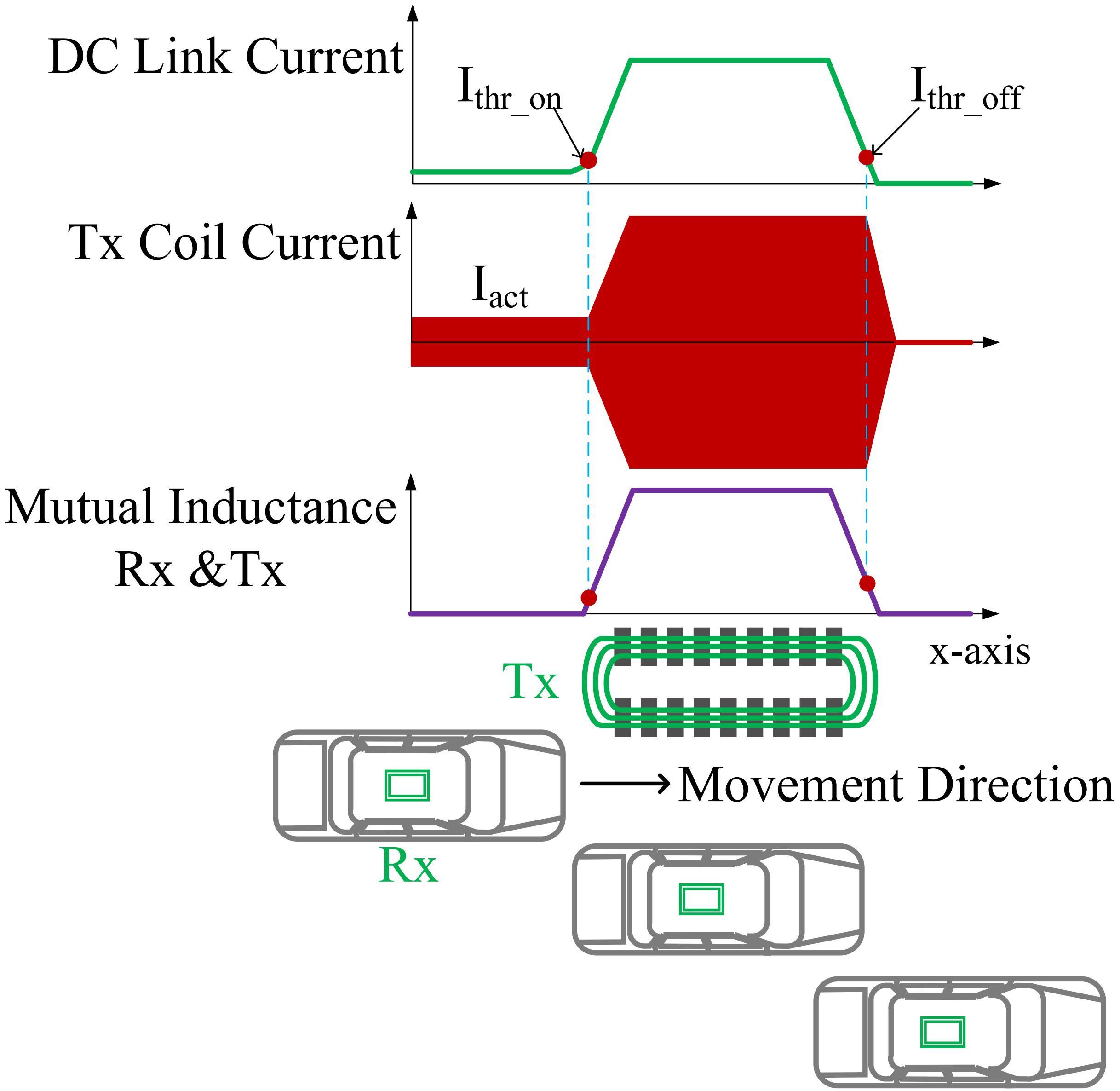




Gap between Tx pads

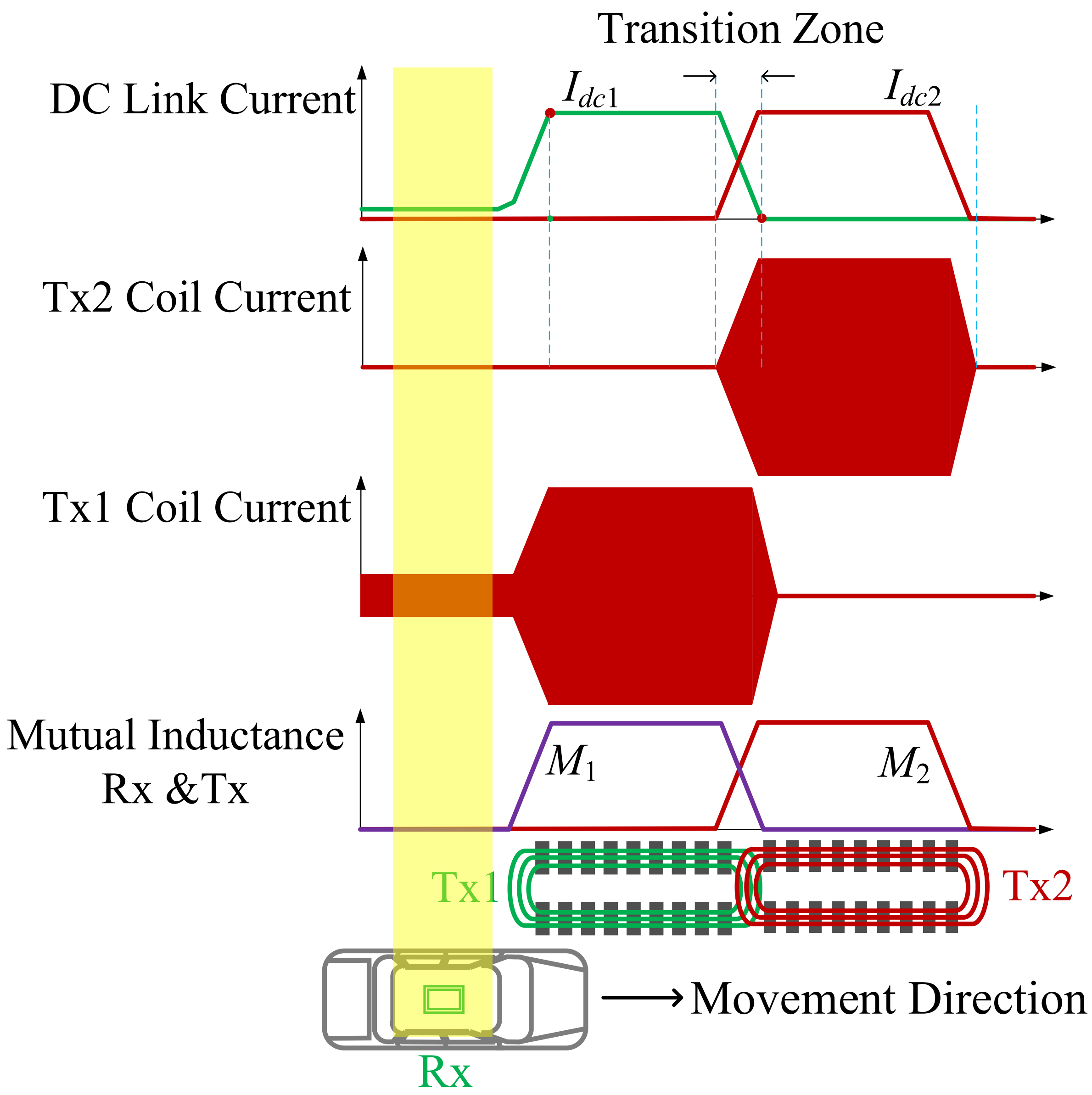


DWPT System



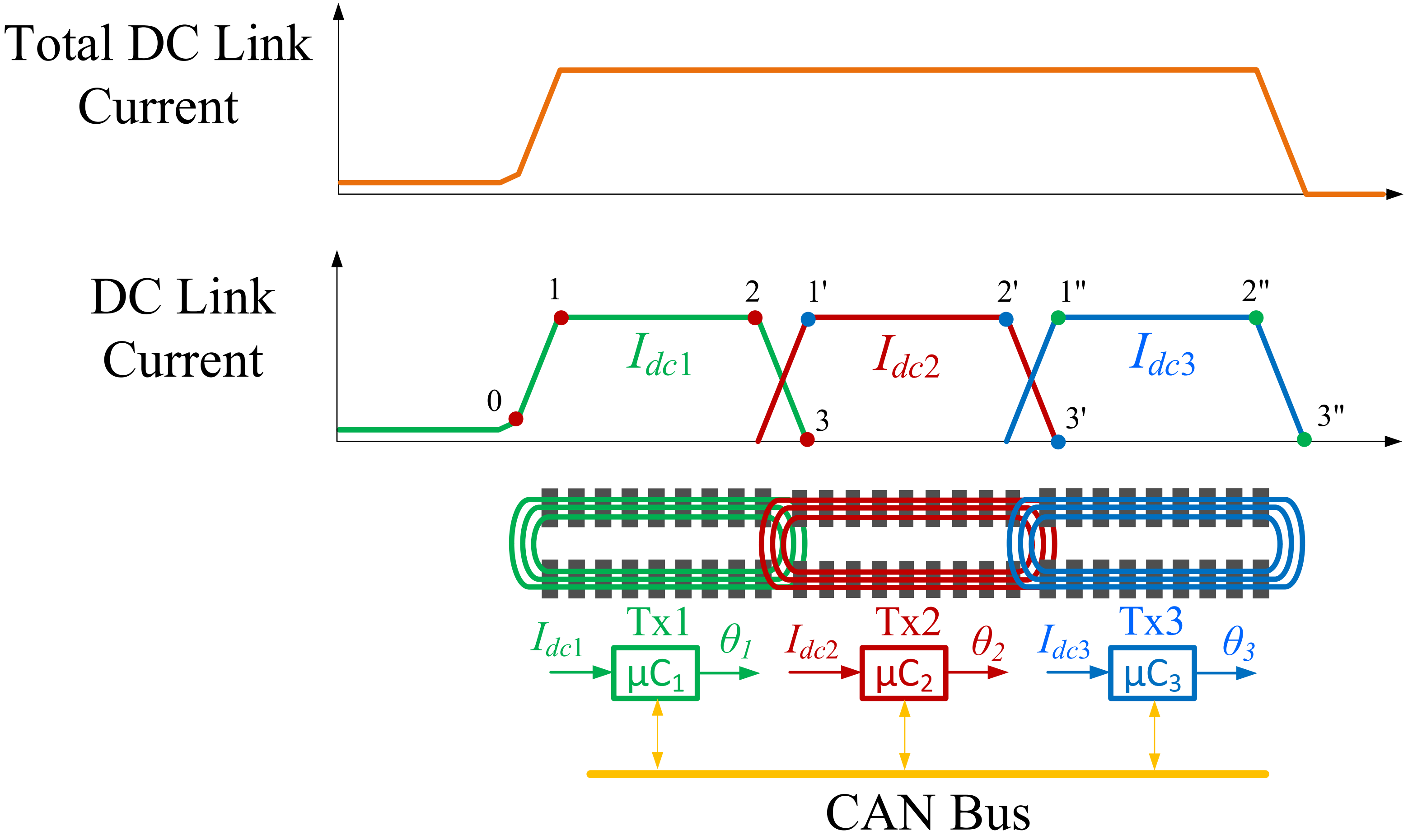
Sensorless
Activation
Deactivation

DWPT System

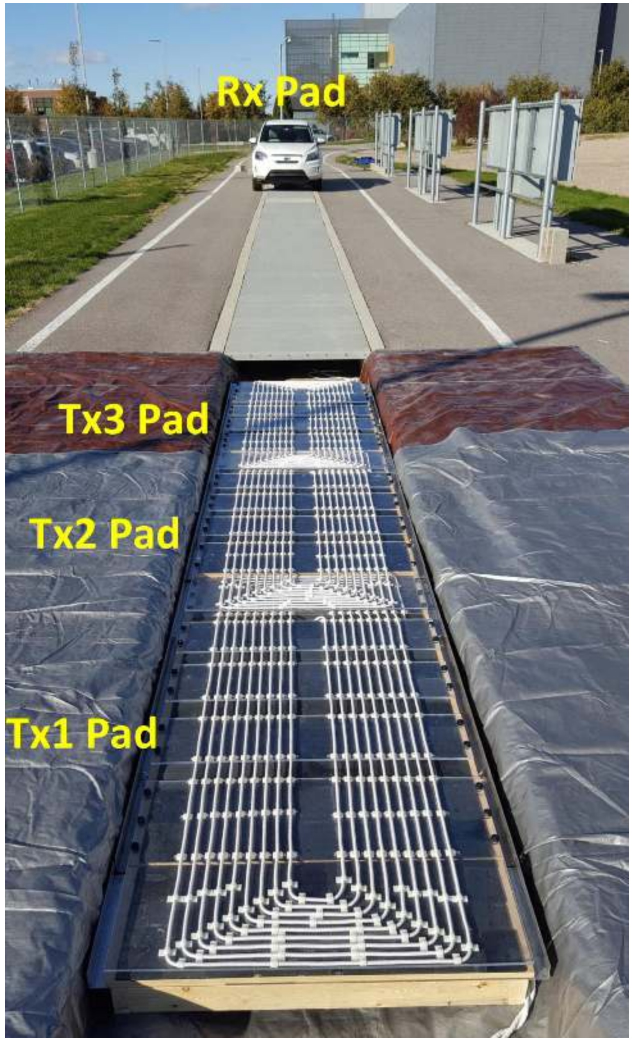


Seamless Transition

Comprehensive Controlling Scheme

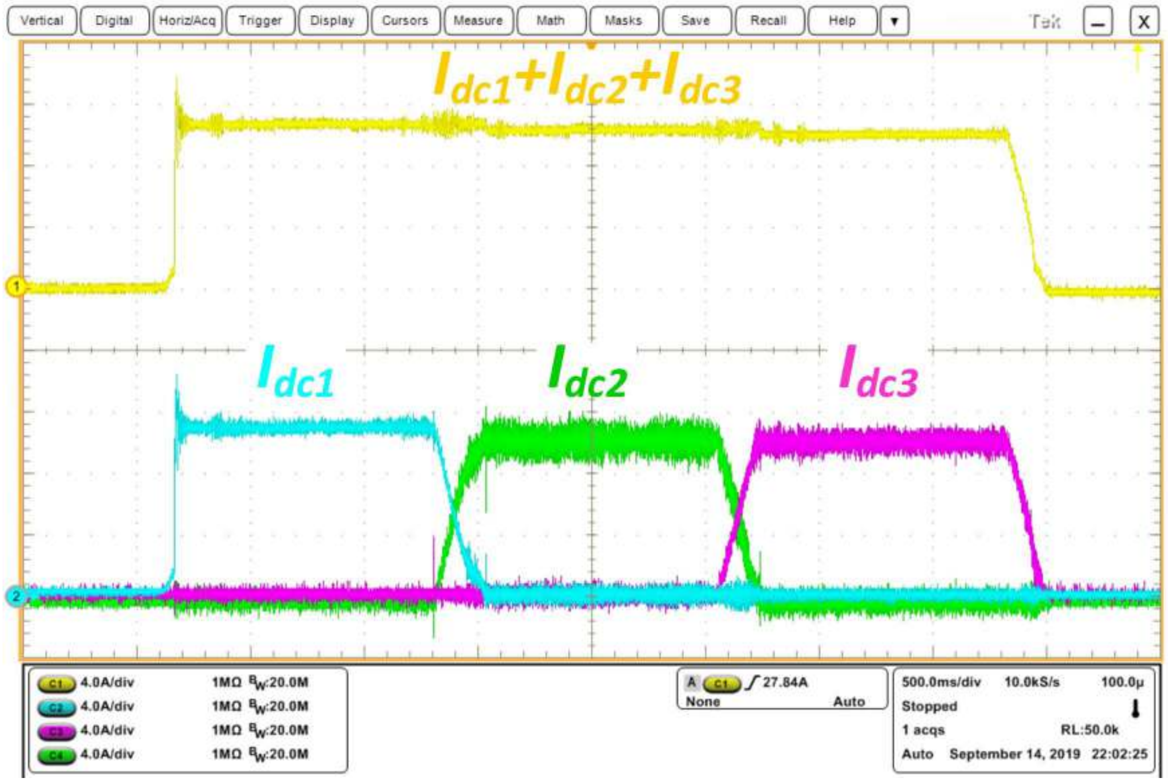


DWPT System



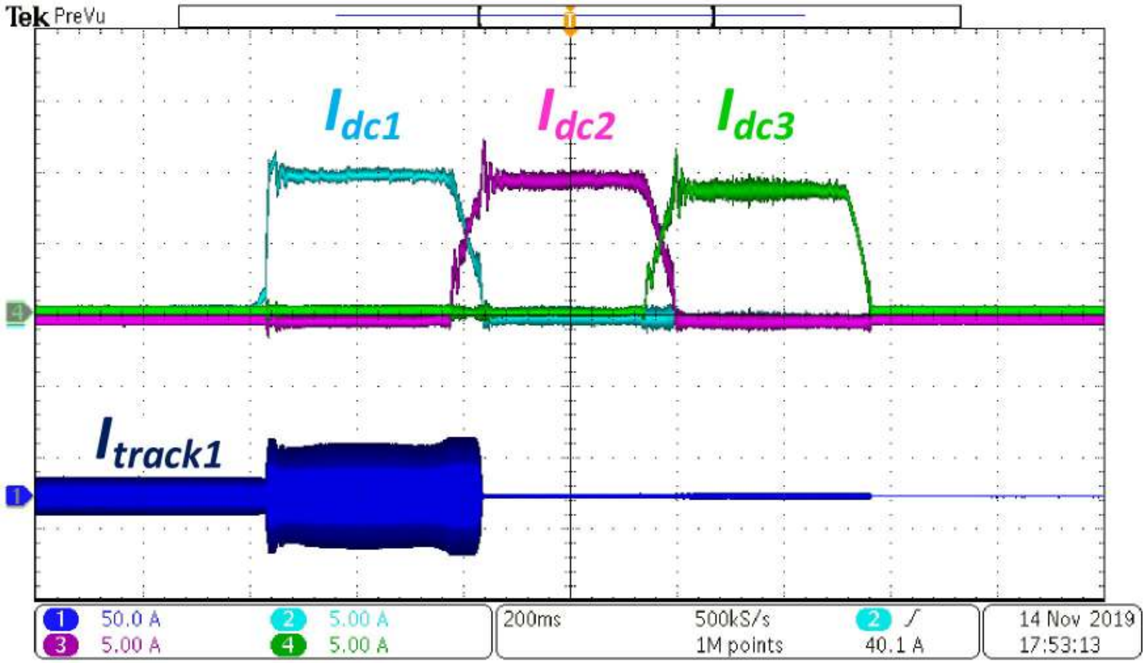
DWPT System


I_{inv}
V_{inv}
I_{dc}

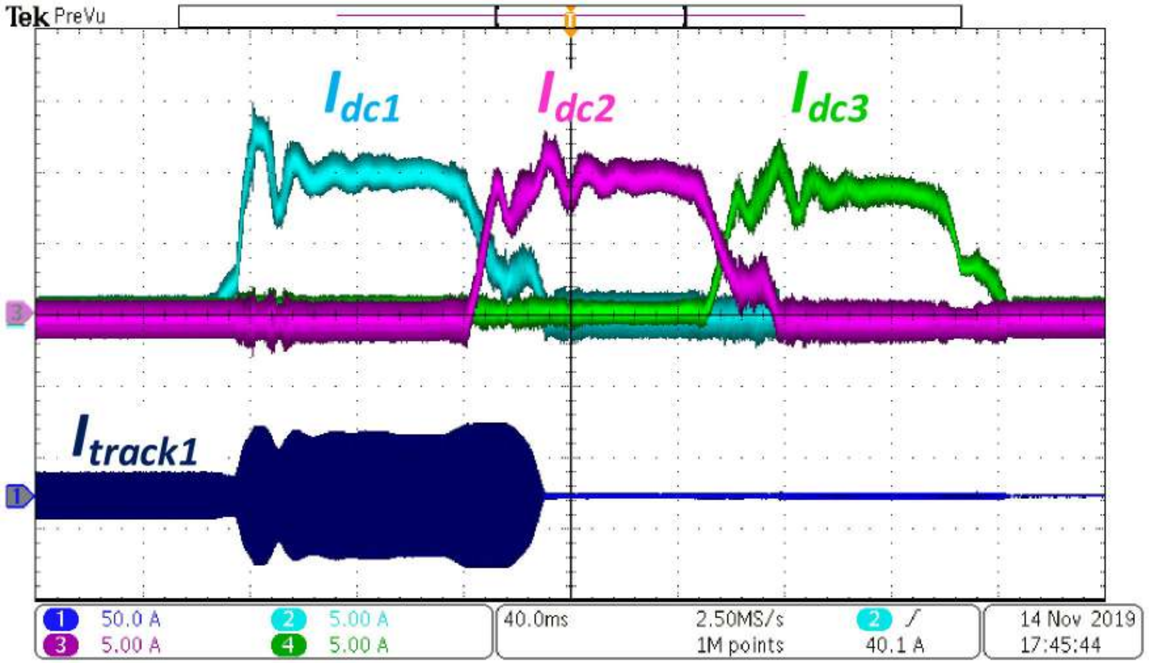

$I_{dc1}+I_{dc2}+I_{dc3}$
I_{dc1}
I_{dc2}
I_{dc3}
4.0A/div
500.0ms/div 10.0kS/s 100.0µ
Stopped
1 acqs RL:50.0k
Auto September 14, 2019 22:02:25

DWPT System

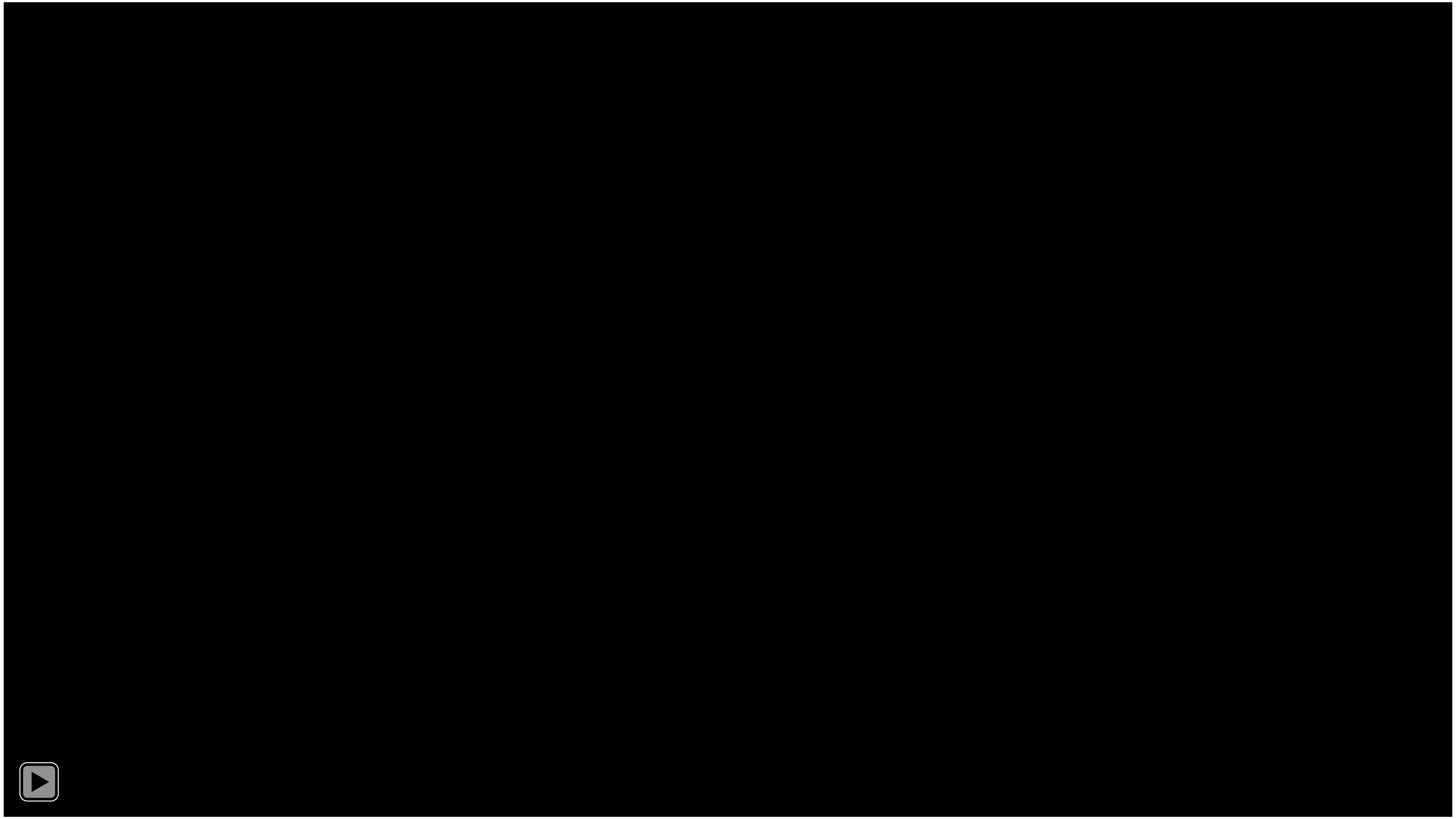
Vehicle Speed = 10 mph



Vehicle Speed = 40 mph

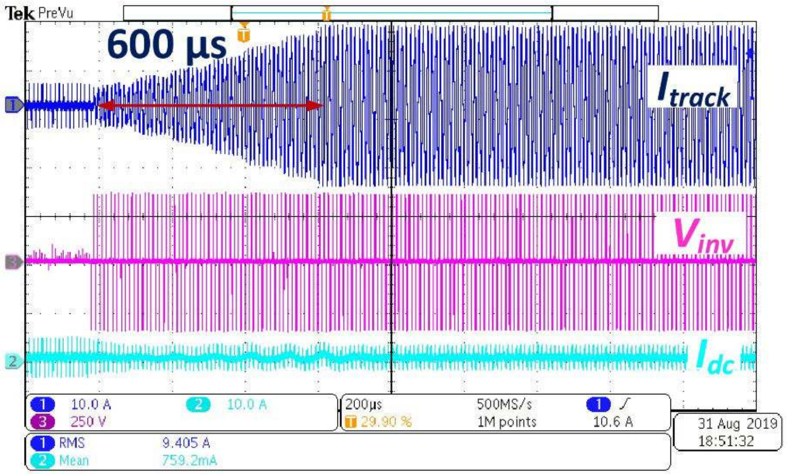


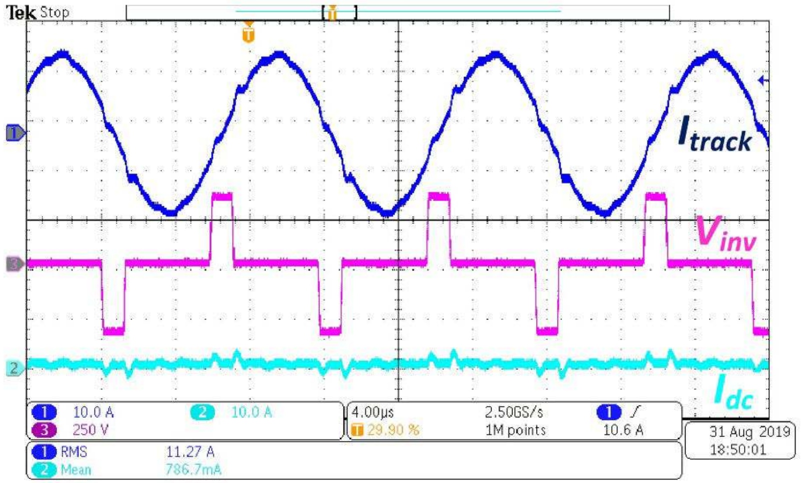
DWPT System



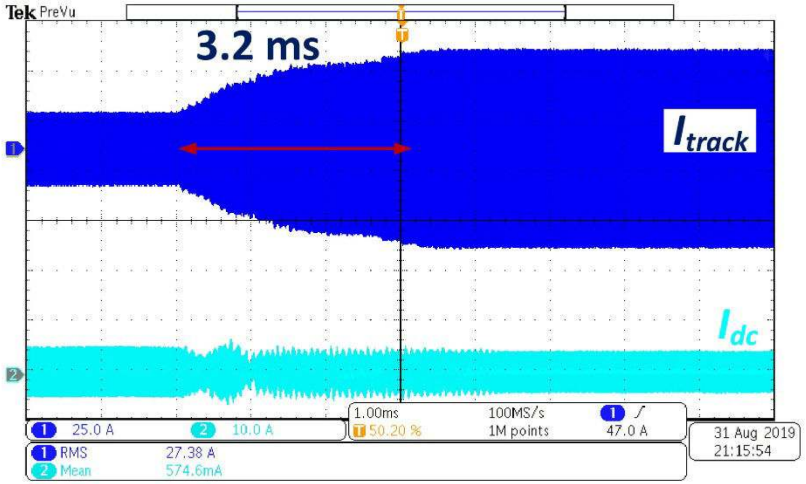
DWPT System

Initial Energizing





Full Energizing



In 600 μs:

- Inverter phase increase to 30˚
- I_{track} increases to 11 A
- EV moves 2 cm, at 80 mph

- In 3.2 ms, I_{track} reaches full current

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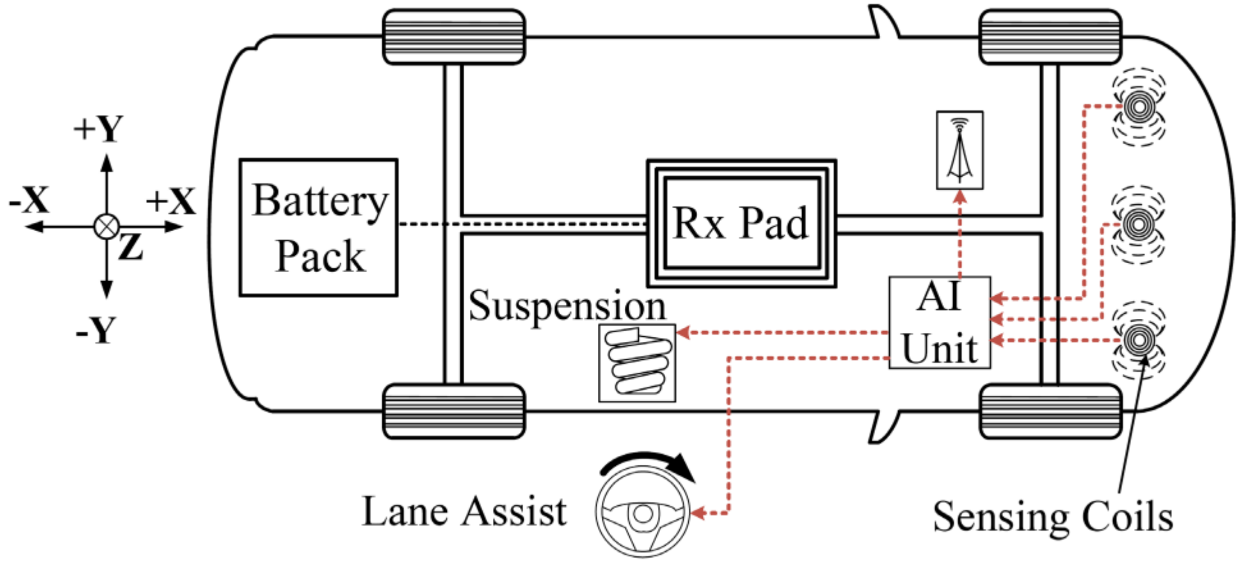
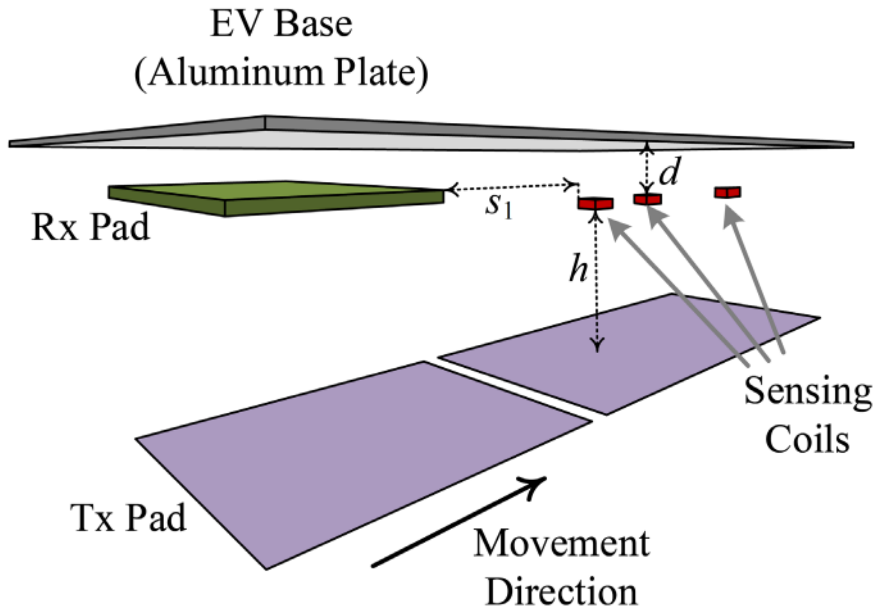
Misalignment Estimation

If Misalignment ↗ Power Transfer ↘ Efficiency ↘

System Structure

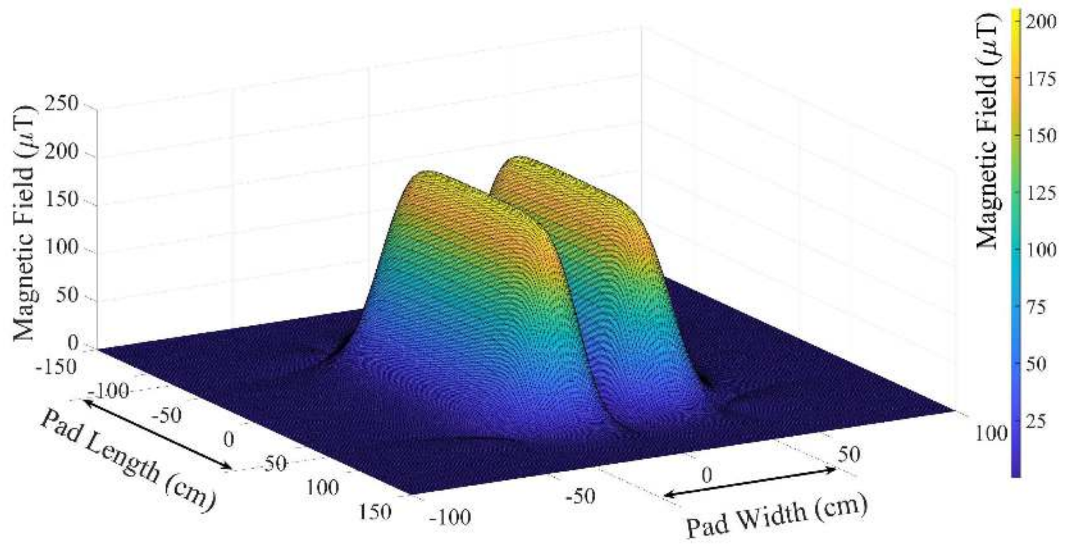


EV Bottom View

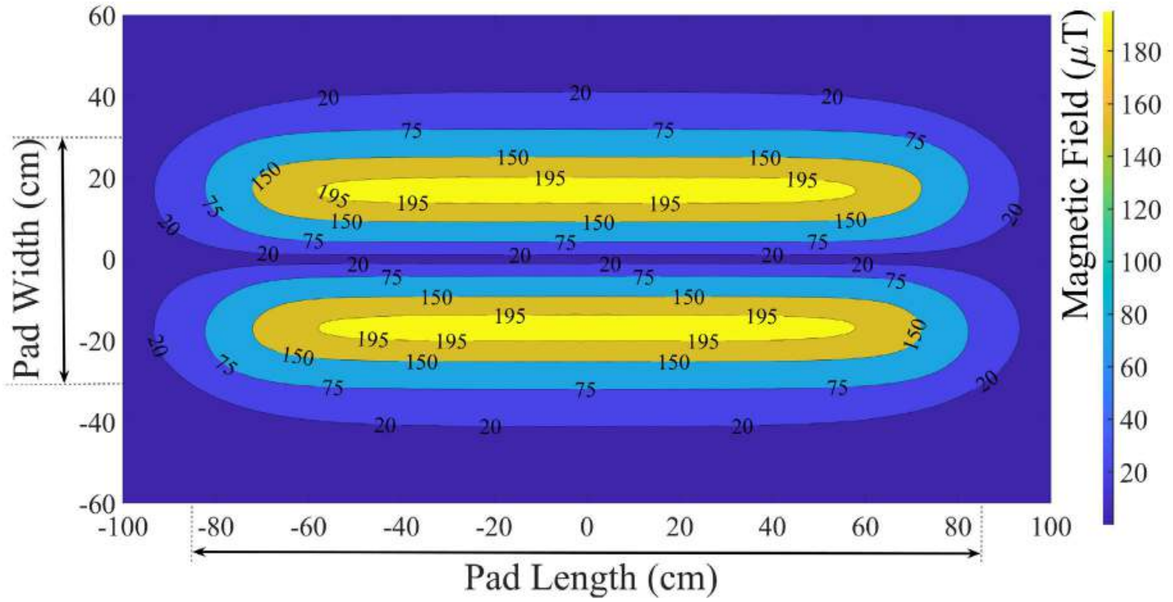


System 3D view

Magnetic field above Tx pads



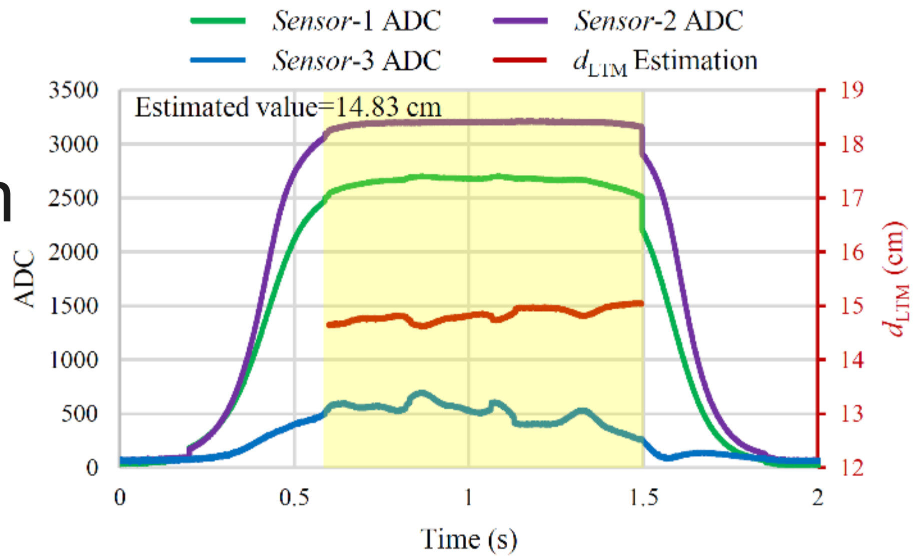
3D view B_y



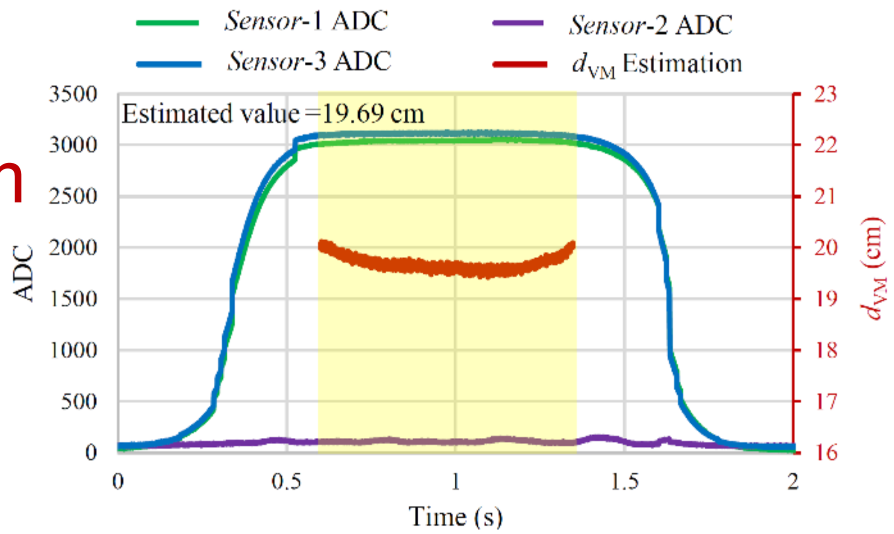
2D view B_y

Misalignment Estimation

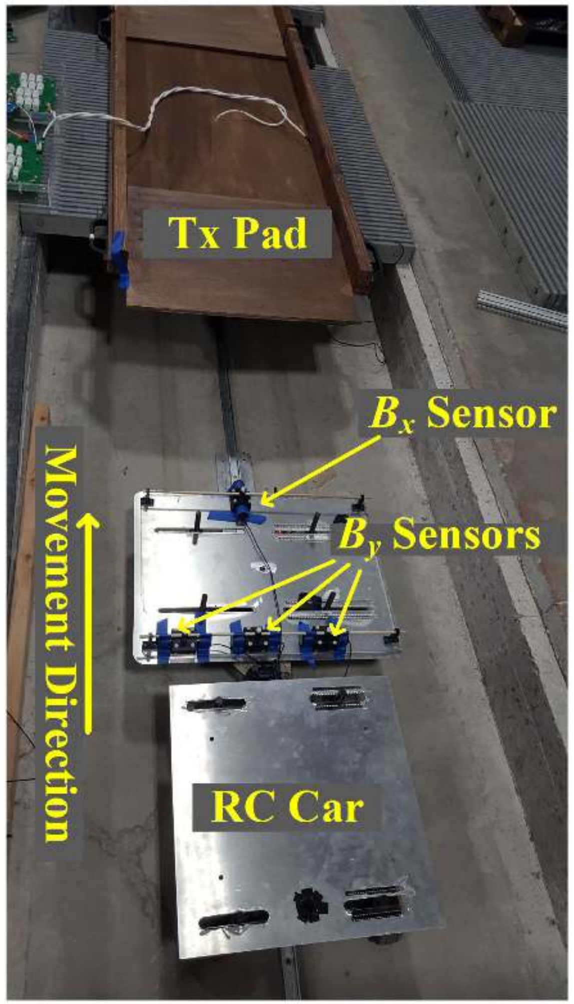
d_{LTM}=15 cm
d_{VM}=16.5 cm



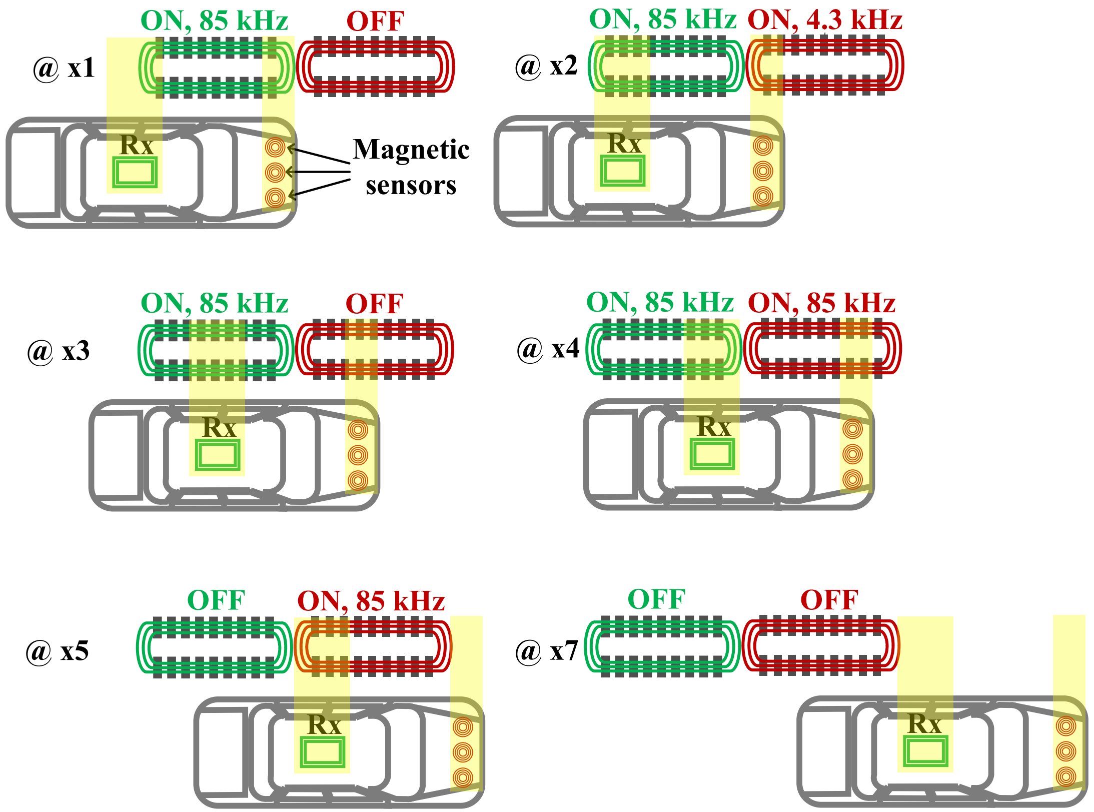
d_{LTM}=0 cm
d_{VM}=19.5 cm

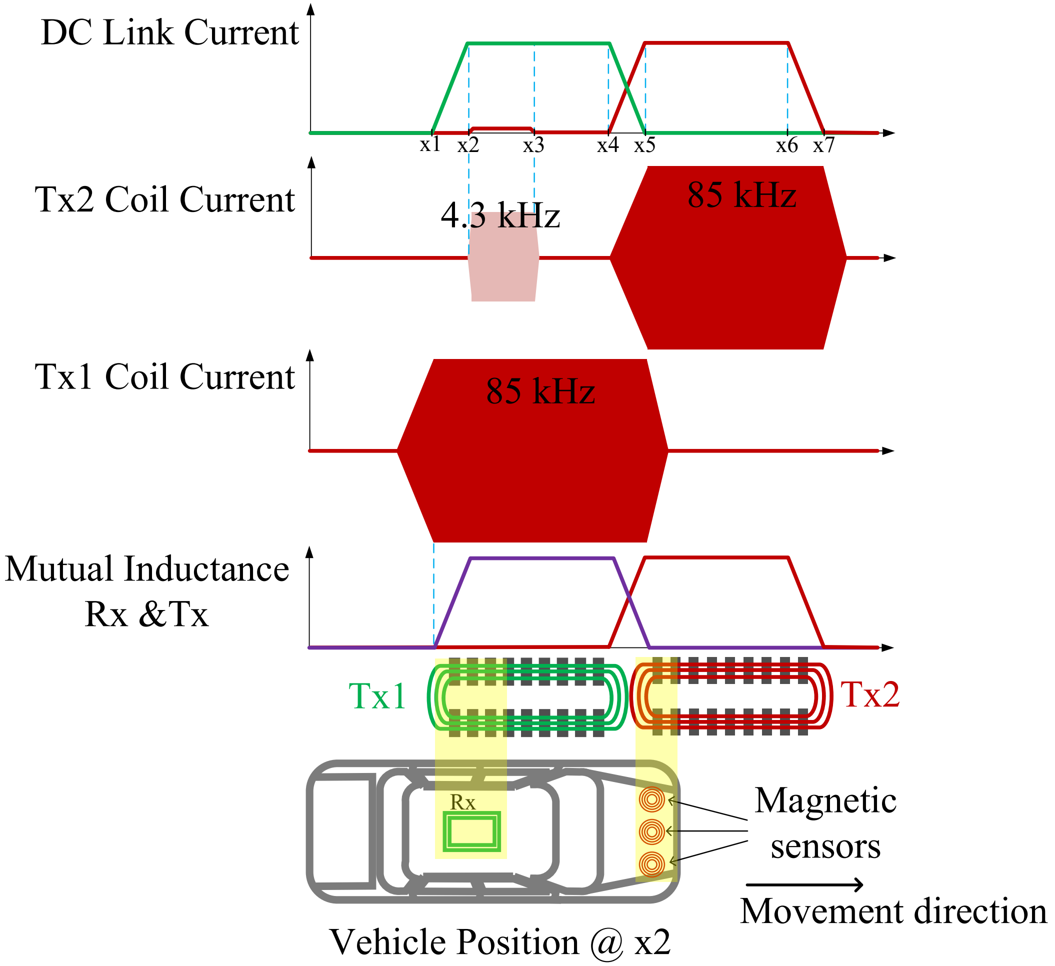


Experimental Setup



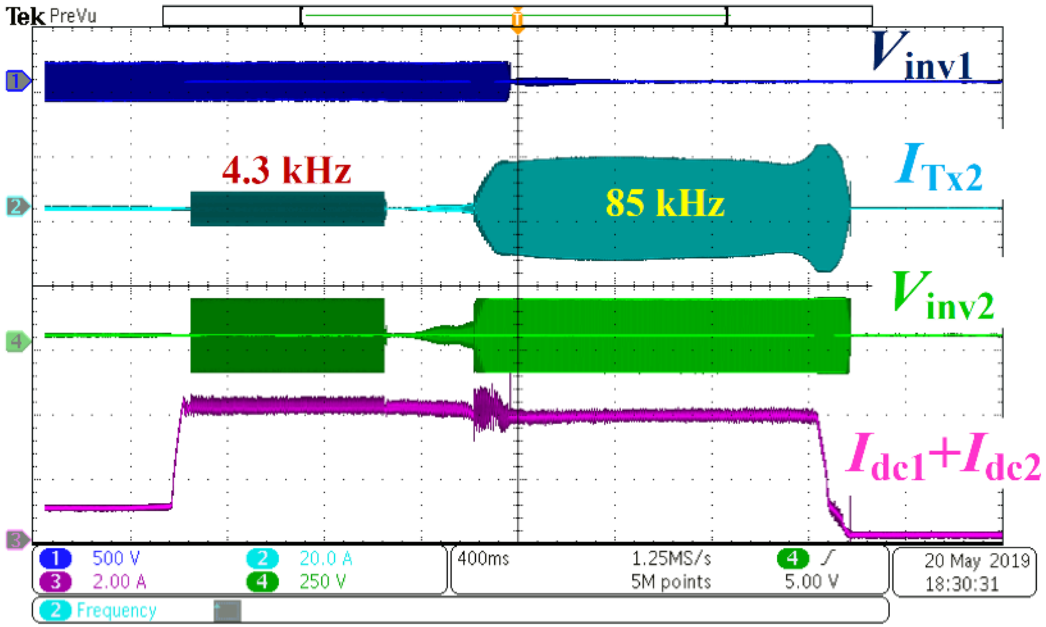
Integrating Misalignment Estimation & DWPT



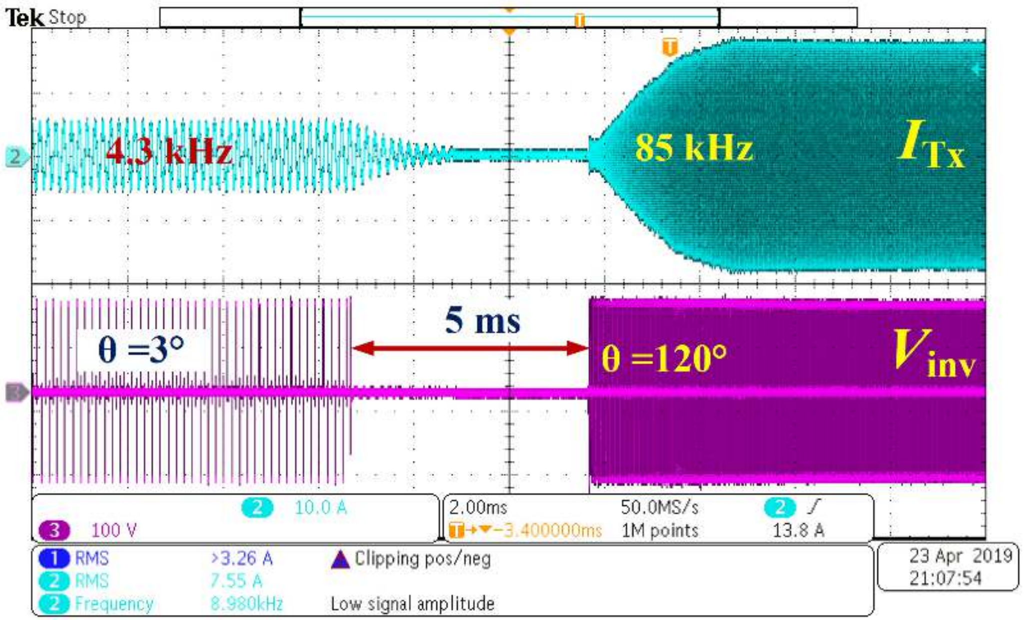


Misalignment Estimation

Transition between modes



Transition between modes



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WPT for Power Wheelchairs and Scooters

NC STATE UNIVERSITY

- Survey about futuristic transportation or mobility invention – winning proposition: New Energy Source (34%)

- Need for public charging ecosystem: 1.1 million EVs (US) - 22,000 public charging stations (Sept. 2018)

- 1.7 million PMDs (US) only 17 public charging spots

- The Next-Generation Public Charging Infrastructure and Cyber-Information Network for Power Mobility Devices (DHHS funded)
  - Development of the charging infrastructure
  - Chapel Hill (NC) as the testing site
  - NCSU-UNC collaboration

Photo credit: (E.J. Harris) eastoregonian.com

Underwater Charging System

- Wet-mate connectors for underwater power delivery - weakest part of an underwater energy system
- Deployment of divers or sophisticated ROVs to establish underwater connection
- Recharging AUVs: passive latching techniques and docking stations with a tapered cone and capture tube
- Wave energy harvesting and delivery - flexible underwater grid
- Loosely coupled coils and near-field resonance (DOD):
  - Water layer causes power loss
  - Alignment issue due to water currents

Photo credit: http://www.teledynemarine.com/

Photo credit: https://www.youtube.com/watch?v=IMfnwZiPp2s

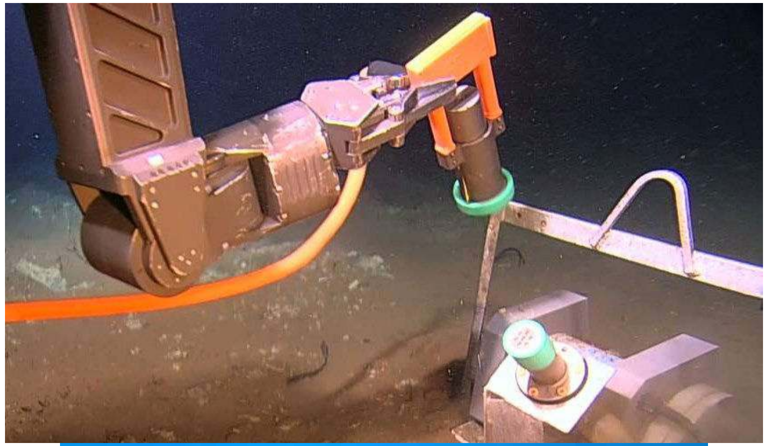


Photo credit: https://www.eenewspower.com/news/wireless-charging-underwater-vehicles

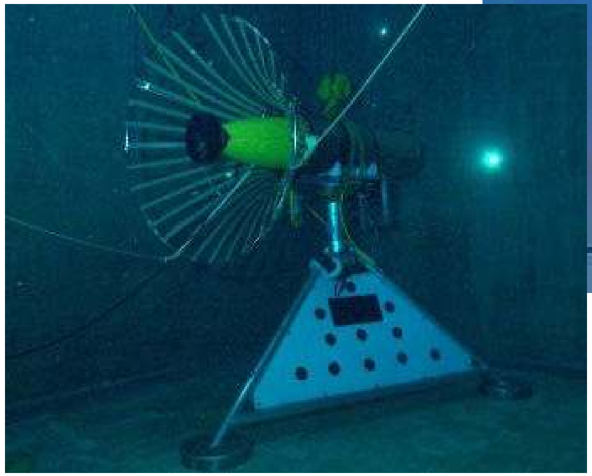


Photo credit: https://www.kongsberg.com/

DWPT Test Station

Bridging gap between DWPT bench and macro-scale outdoor testing/implementation

Challenges of prototype testing

- Laboratory prototype reaching $4,000 per meter or $7,000 per pad
- 50-m test track allows around 5 seconds of testing
- Thermal characteristic
- Limited repeatability
- Limited speed range
- Testing of accidental and fault conditions

Photo credit: ORNL's EVWPT experimental facility

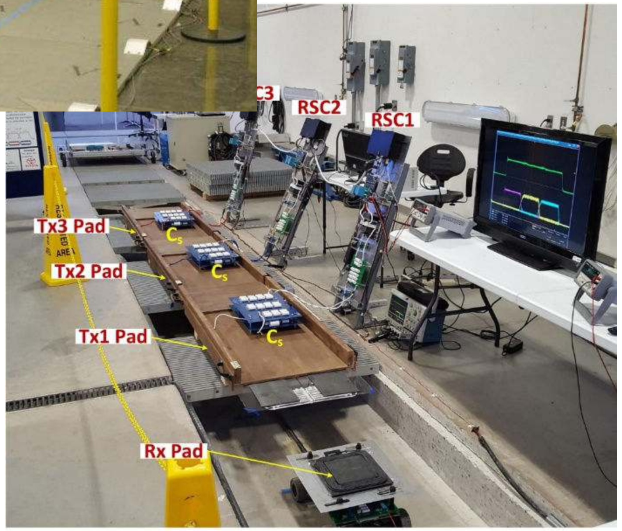


Photo credit: https://chargedevs.com/

Photo credit: https://www.ise.ncsu.edu/driving-simulation/

Class E Inverters for Wireless Charging

- Variable inverter load impedance - varying output power and reduced efficiency
- Passive and active compensation methods, new topologies, new tuning techniques, new components
- Challenges: complex design, tuning sensitivity, no closed-form tuning algorithm problem to incorporate parasitic capacitance
- PowerAmerica funded project

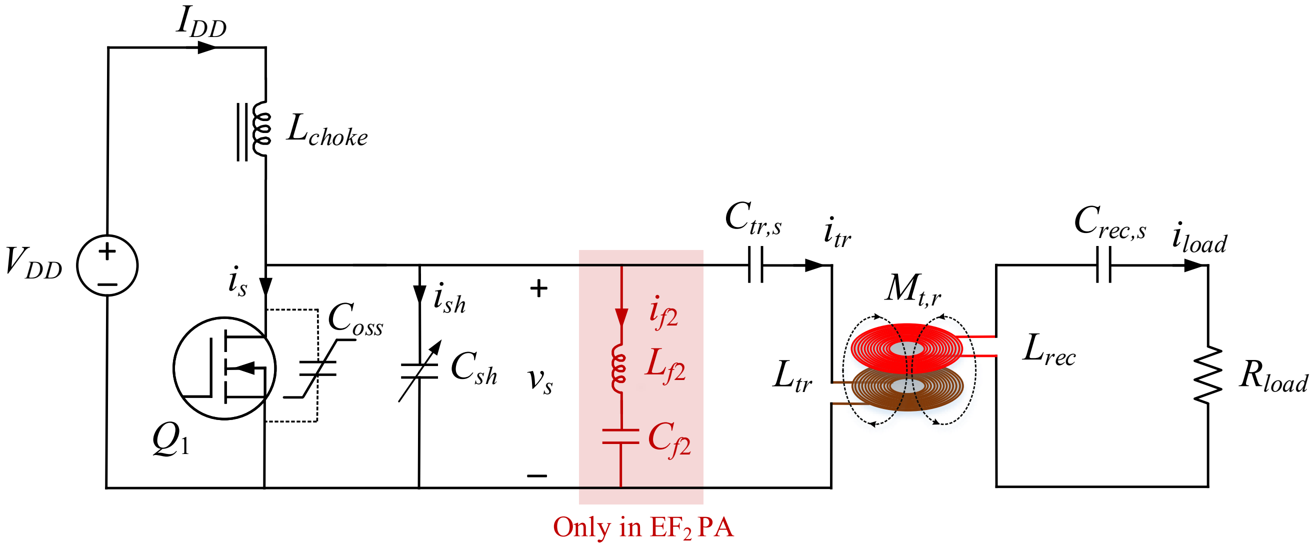


Photo credit: Powermat Technologies

WPT applications

Key Enabling Technology

Key technology that defines space and scope of the application

- Biomedical electronic implant
- Mobile factory automation
- Underwater charging

Autonomy Enabling Technology

Key enabler for full autonomy due to energy storage constraints

- Unmanned Arial Vehicles
- Personal transpiration (micromobility)
- Dynamic EV Charging

Technology for Convenience Improvement

Customer-centric business (convenience, predictability, and efficiency)

- Cellphone chargers
- Consumer electronics
- Static EV charging

Design Objectives

WPT optimization

WPT to support autonomy; WPT uses the device autonomy and intelligence

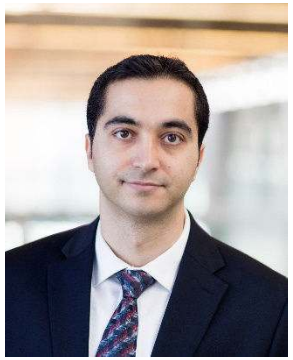
Effective time utilization, portability, and avoidance of unpleasantness

WPT – Challenges and Directions

- Standardizations (J2954, Qi, AFA)
- Modular design for high power operation
- Integrated intelligence and automation (alignment, FOD and LOD, EM measurements and safety, cybersecurity)
- Grid integration
- Power metering
- Advanced materials (new switching devices, magnetic materials, wire)
- Testing procedures and testbeds
- System construction and installation
- Economic evaluation

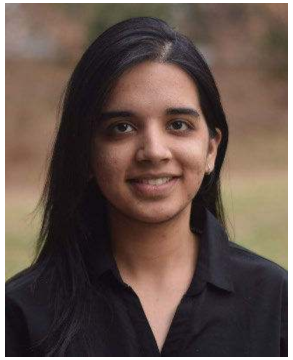
Group Members

Dr. Zeljko Pantic
Associate Professor
Power electronics, WPT,
Micromobility Electrification



Dr. Reza Tavakoli
Postdoc Researcher
High-frequency WPT
Inductive WPT

Ujjwal Pratik
Graduate Researcher
High-frequency WPT
Capacitive WPT



Urvi Ahluwalia
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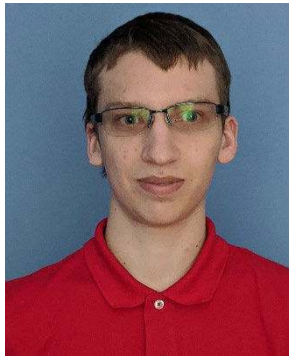

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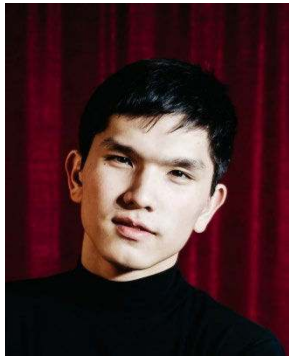

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Thank you