Wireless Charging for Electric Vehicles: INL's Testing Supports Code & Standards Development

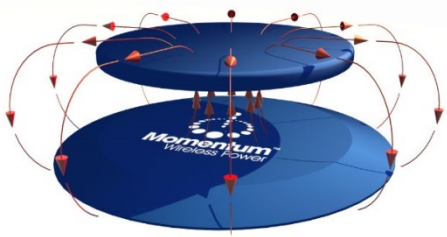
www.inl.gov

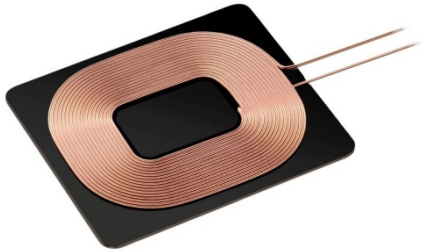
Barney Carlson
Idaho National Laboratory
Energy Storage & Transportation Systems

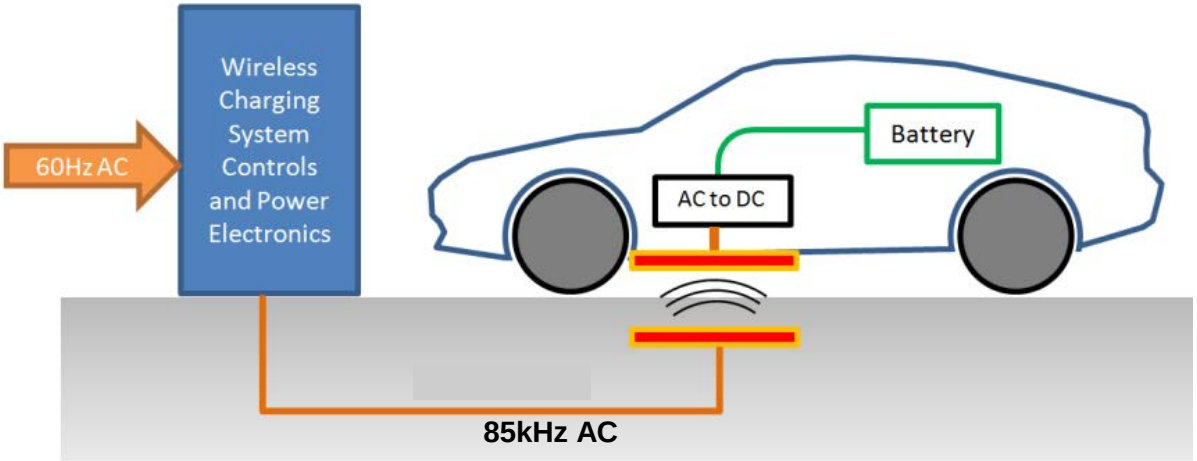
INL/MIS-16-39664

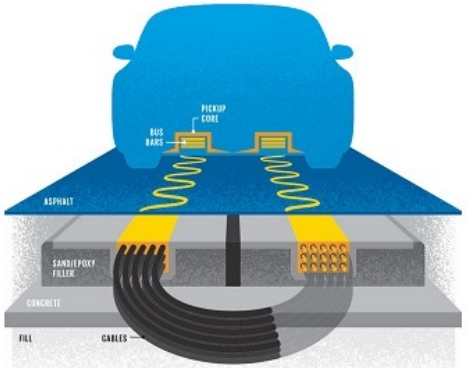
What is Wireless Charging?

- Similar to cell phone wireless charging <u>BUT</u> larger gap and higher power
  - Gap: typically 100 mm to 250 mm
  - Power (standardized levels):
    - 3kW, 7kW, 11kW, 22kW, 50kW
  - Operating Frequency:
    - 85 kHz (automotive)
    - 20 kHz or higher (medium duty)



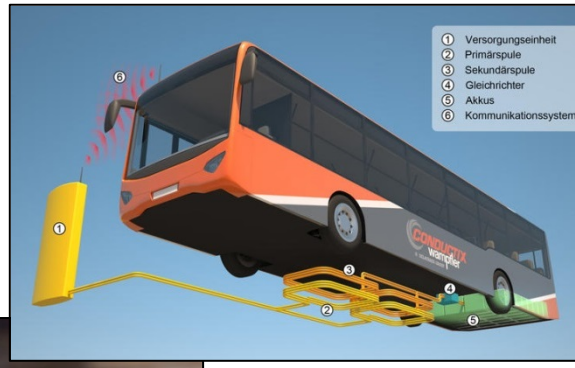


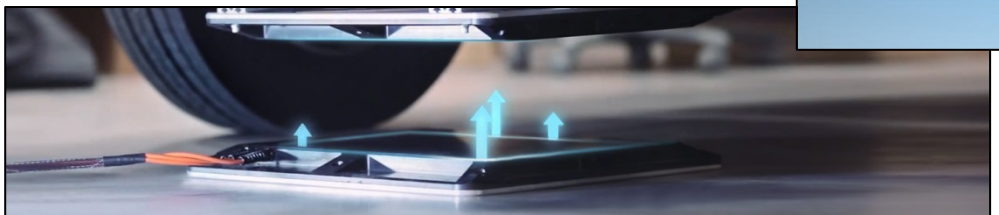




Wireless Charging: State of the Industry

- Very few production systems available
  - 3kW - 7kW for passenger vehicles
  - 20kW - 50kW for bus / Med. Duty vehicles
- Many vehicle manufacturers have announced production wireless charging systems for the near horizon (starting in 2019 or 2020)
- Standardization is needed before significant production volume
  - Interoperability, efficiency, electromagnetic field (EM-field)
    - Safety, interference, compliance
- Impact on EV market / adoption
  - Ease of use (hands-free and automated)
  - Enabling technology for autonomous vehicles





Wireless Charging: Benefits and Challenges

- Benefits
  - Hands-free / Automated
  - Nearly the same efficiency as conductive charging (tested at INL)
    - Conductive charging (level 2): **89% - 95%** (varies by vehicle)
      - https://avt.inl.gov/project-type/vehicle-charging-system-testing
    - Wireless charging (3 - 7 kW): **70% - 93%** (varies by manufacturer)
      - https://avt.inl.gov/evse-type/wireless
- Challenges
  - Performance is dependent upon coil to coil alignment (vehicle parking)
    - Efficiency
    - EM-field
  - Safety: EM-field interaction with nearby objects
    - Metallic objects, implanted medical devices, etc.
  - EMC / EMI compliance (FCC regulations)
  - Interoperability
    - ground coil and vehicle coil are from different manufacturers
  - Cost? (as compared to conductive charging)

INL's Electric Vehicle Infrastructure (EVI) Lab

- Support codes and standards development and harmonization
  - Test results of state of the art charging systems

- Measure performance metrics
  - System efficiency
  - EM-field emissions
  - Power quality
  - Response to dynamic grid events
  - Cyber security vulnerability assessment

- Wide range of input power
  - 120 VAC to 480 VAC 3ϕ
  - 400 kVA total capability

- Bench and vehicle testing capabilities

https://avt.inl.gov/panos/EVLTour/?startscene=pano5141

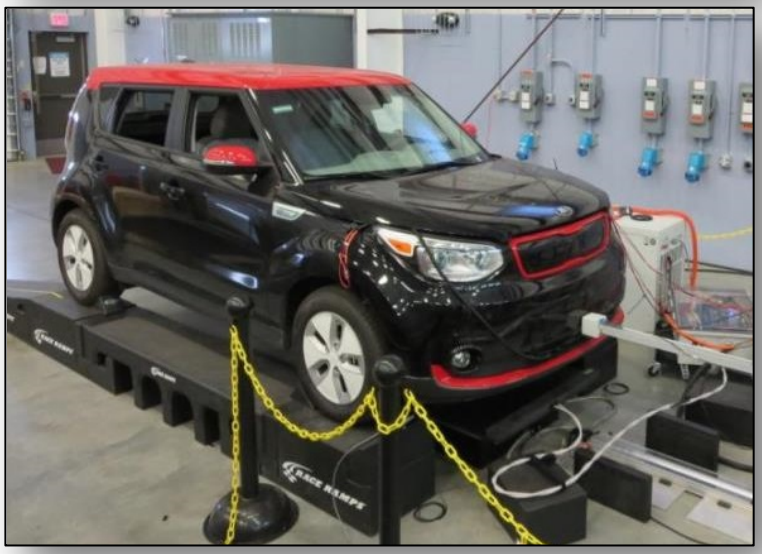
Wireless Charging: Testing and Evaluation

Bench sub-system testing

- Standardized testing for technology evaluation
- Fiberglass frame and fasteners supports the vehicle side coil and power electronics
- Coil positioning system
- Vehicle emulation modules
  - Battery emulator
  - Communications

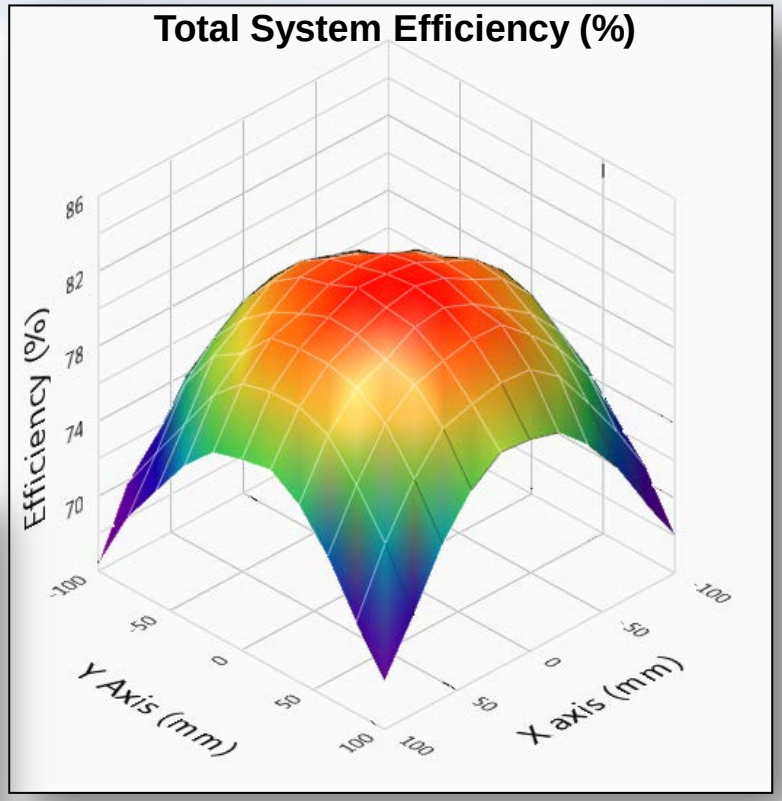
Vehicle testing

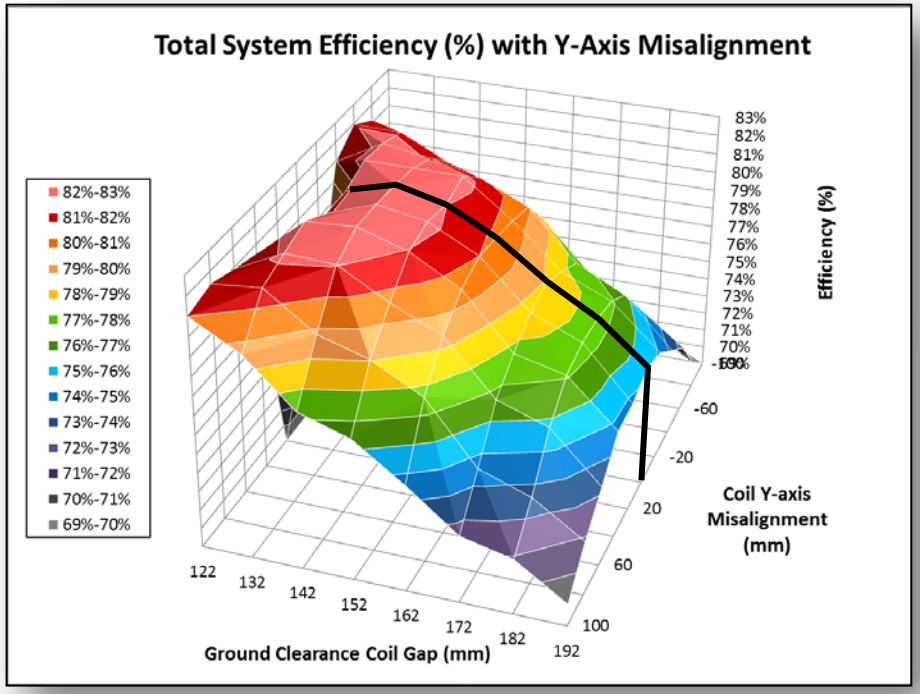
- Testing of specific system integration tuned and calibrated for the specific vehicle application
- Non-metallic vehicle ramps used to elevate vehicle to provide necessary space for the coil positioning system



Performance: Wireless Charging

- Performance is dependent upon:
  - Coil to coil alignment
  - Coil to coil gap
- System Efficiency
- Power transfer capability
- EM-field



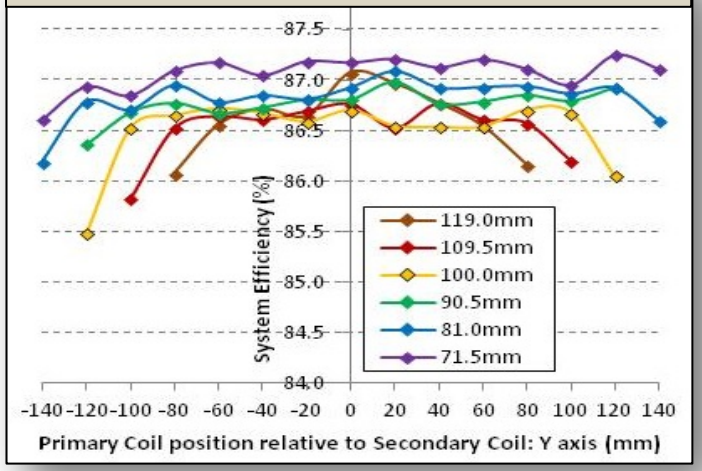


Efficiency: Impact of steel vehicle chassis

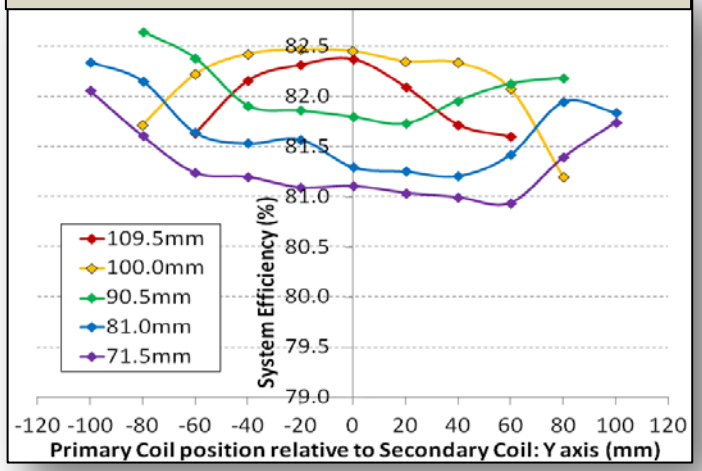
Evatran PLUGLESS wireless charger

- Efficiency varies with
  - Coil to coil gap
  - Coil to coil misalignment
- Significant differences between
  - on-vehicle performance
  - stand-alone performance
    - Due to EM-field interaction with steel vehicle chassis

Bench Test Efficiency

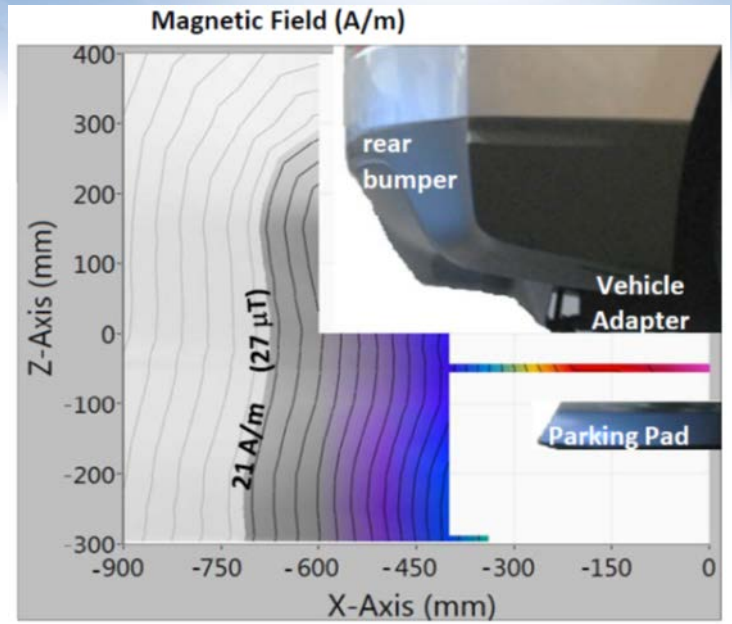


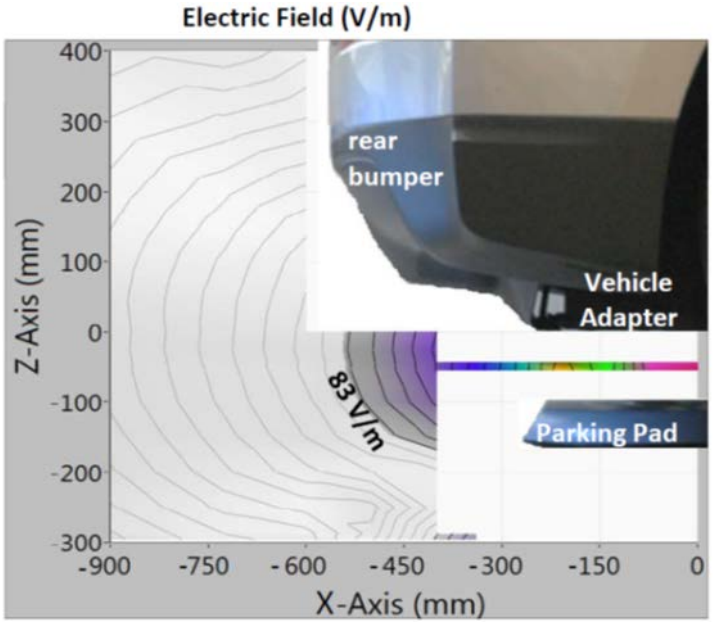
Vehicle Efficiency (Chevy Volt)



Safety: Wireless Charging

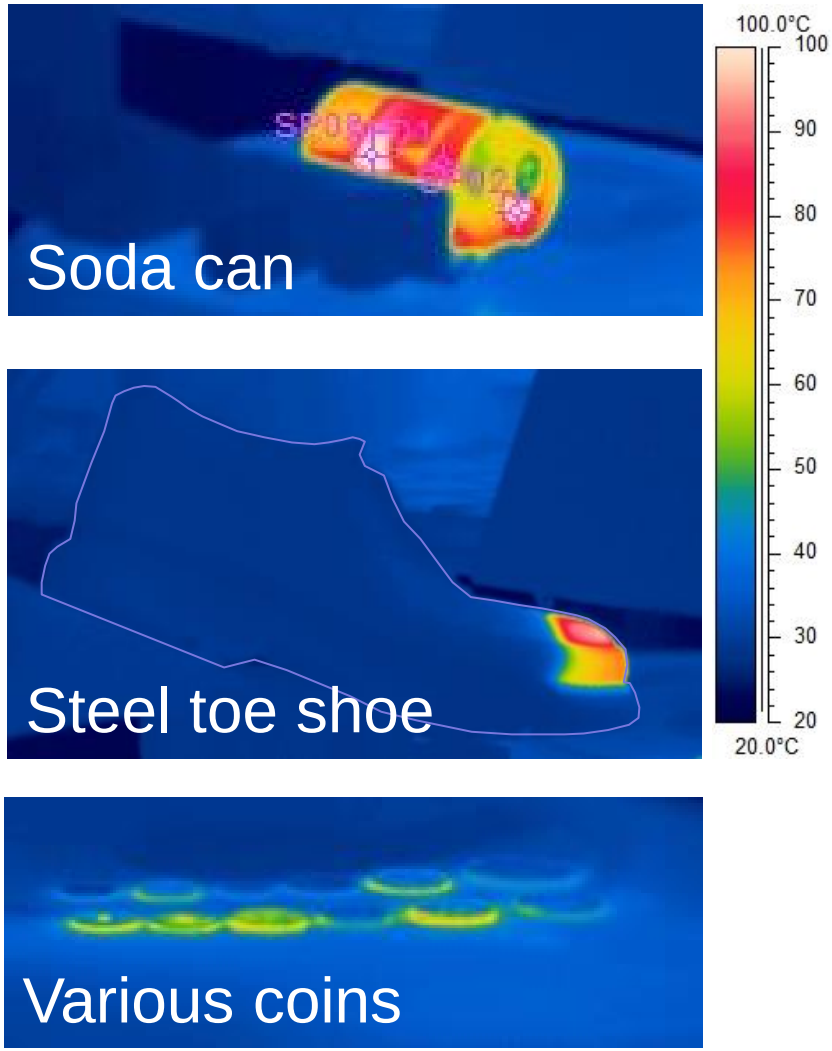
- EM-field
  - Human interaction
    - ICNIRP EM-field limits
      (International Committee Non-Ionizing Radiation Protection)
      - Public exposure limits
      - Occupational exposure limits
  - Interaction with metal objects
    - Heating of objects
      - Burn hazard
    - Interference / interaction
      - Implanted medical devices
      - Communication devices





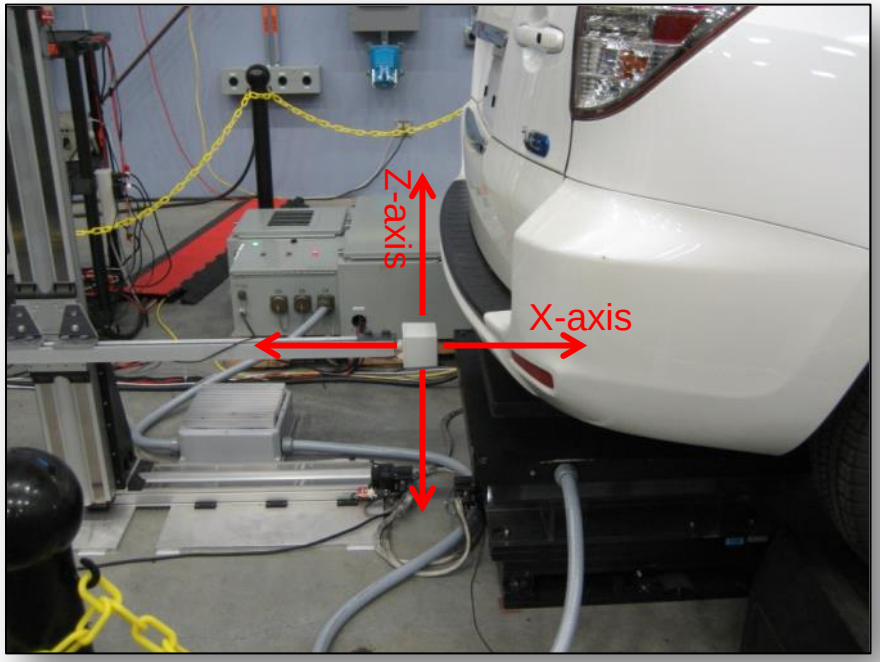
Object Interaction with EM-field

- Metallic object heating due to magnetic coupling with EM-field
- SAE J2954 TIR has a recommended list of Test Objects including:
  - Soda can, coins, paper clips, foil, many more….
- Photos show IR temperature of object in strong EM-field
- Implanted medical device interaction with EM-field is a serious potential issue
  - Pace maker
  - Insulin pump
- EM-field Interaction shows the need for Foreign Object Detection systems



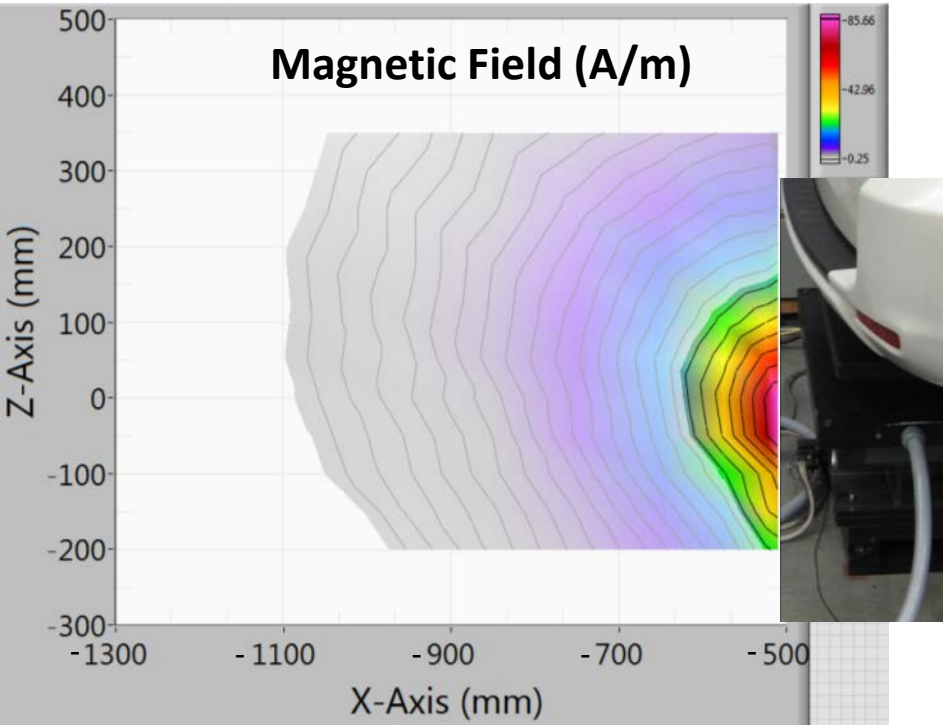
Test Results: EM-field of ORNL's Wireless Charger

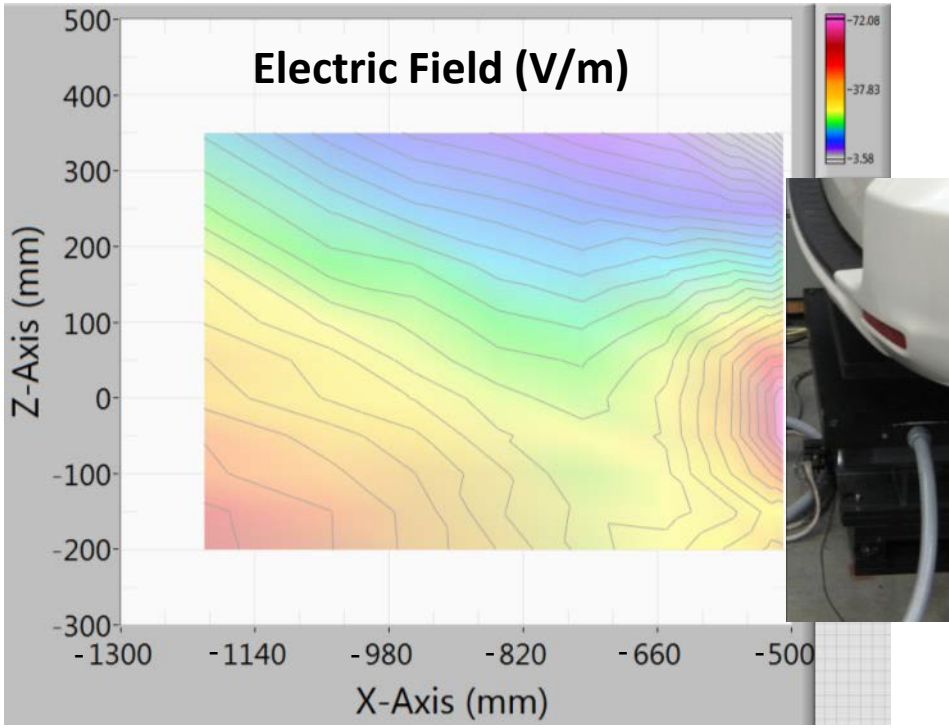
- Coils Aligned (0,0)
- Output power: 6.6 kW
- Input voltage: 240 V RMS
- Output Voltage: 366 VDC



Magnetic and Electric Field at 132mm coil gap

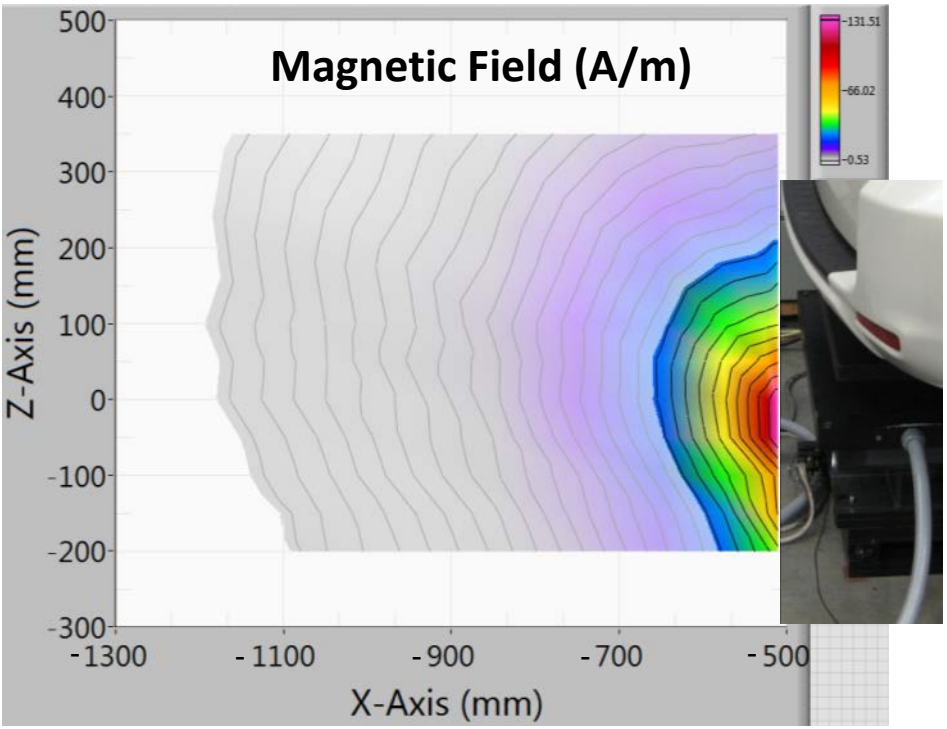
- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Large area near bumper at ankle height shows peak of 85.7 A/m
- Electric field (V/m)
  - All areas measured around rear bumper are below ICNIRP 2010

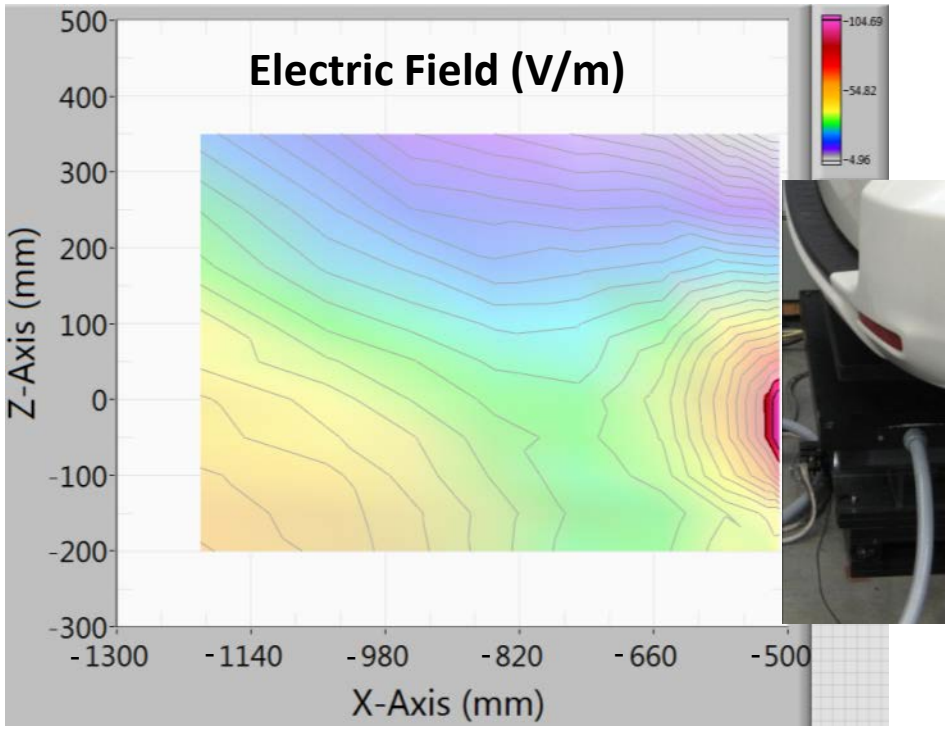




Magnetic and Electric Field at 152mm coil gap

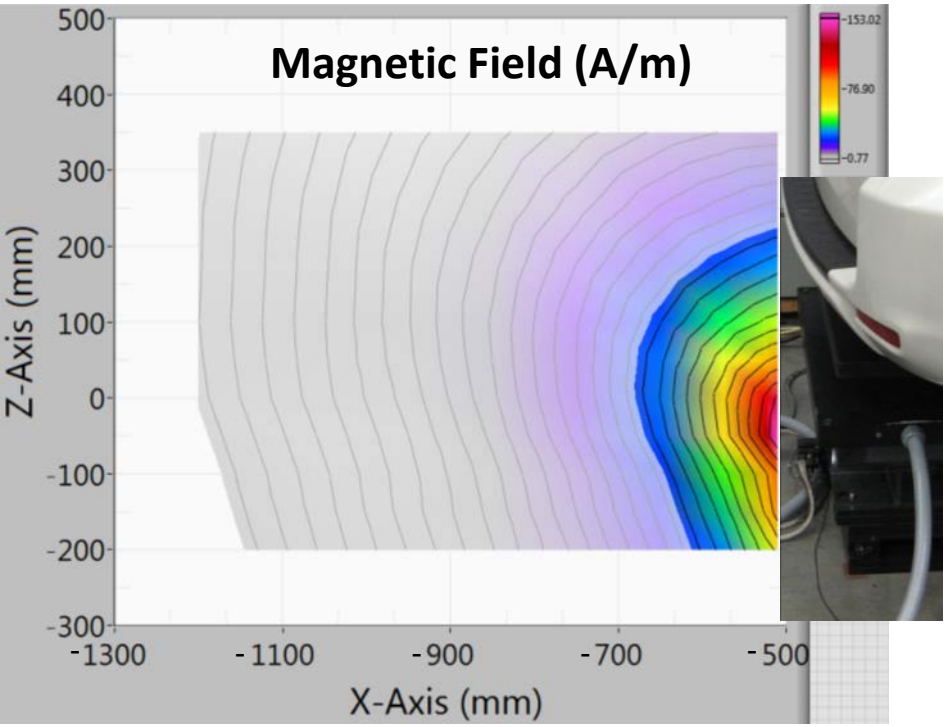
- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Large area near bumper at ankle height shows peak of 132 A/m
- Electric field (V/m)
  - Small area near bumper at ankle height shows peak of 105 V/m

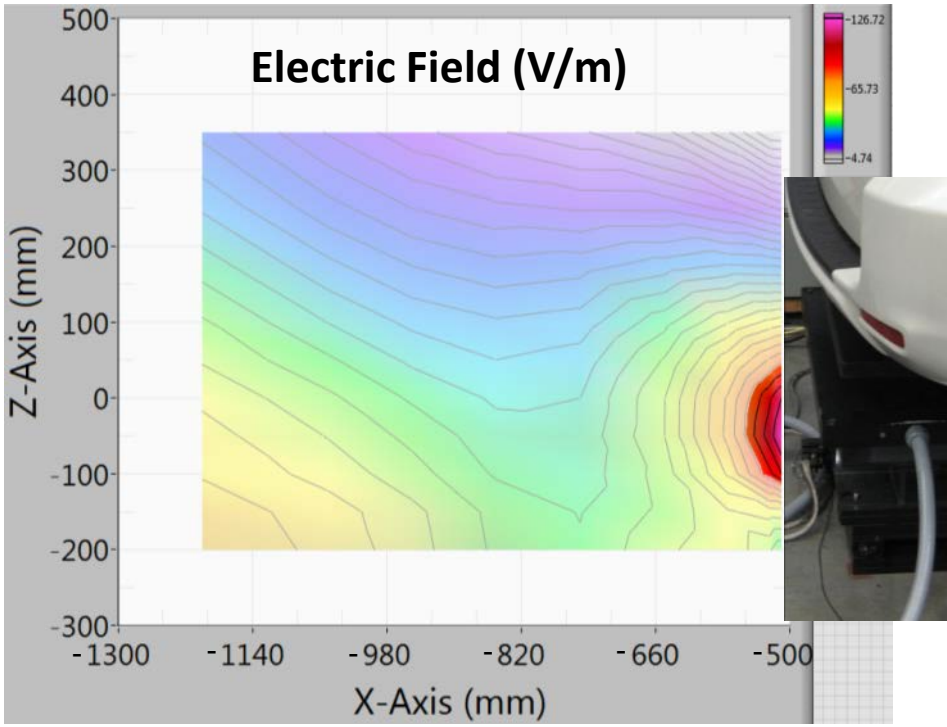




Magnetic and Electric Field at 172mm coil gap

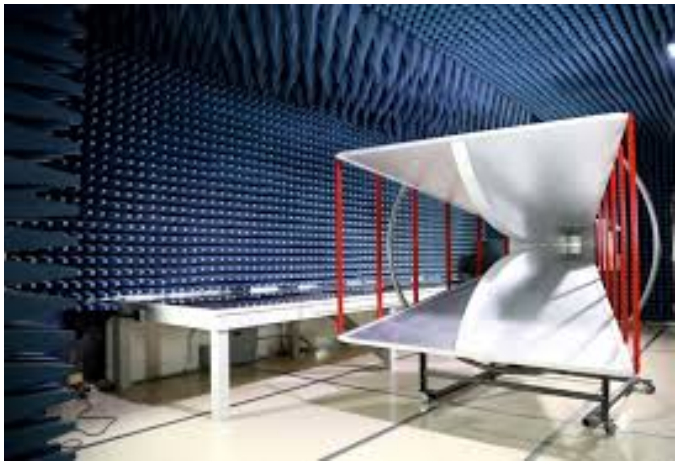
- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Large area near bumper at ankle height shows peak of 153 A/m
- Electric field (V/m)
  - Small area near bumper at ankle height shows peak of 127 V/m





Electromagnetic Compliance (EMC) and Interference (EMI)

- FCC regulations
  - FCC part 18: field strength limit (uV/m)
    - Rating based on power transfer capability
    - Limit at a distance of 300m
      - Typically tested at 10m to 30m
      - Results extrapolated to 300m
- Interference
  - Communication
  - Functionality



Interoperability Testing at INL: in Progress

- INL is currently testing eight wireless charging systems with SAE J2954:
  - Qualcomm, Daimler, Jaguar, Nissan, WiTricity, and Toyota
    - Various coil topologies, coil gap classes, and charge power range
  - Performance tested:
    - Efficiency
    - EM-field
    - Power Quality
  - Conditions tested:
    - X & Y coil misalignment
    - Z coil gap
    - Charge Power Level
    - Battery voltage
  - Steel vehicle floor pan mimic plate
  - Standardized aluminum shield plate
  - Test results will enable solid decisions for standards development

Summary

- Wireless Charging for Electric Vehicles in on the horizon
  - A few production system are currently available
  - Many manufacturers has announced production plans (~2019)

- INL testing supports codes and standards development
  - Refining and validating test procedures
  - Identifying EM-field safety requirements and test procedures
  - Results enable robust decisions for
    - System design requirements for interoperability
    - Test procedures and requirements

- Bench testing enables standardized technology comparison
- Vehicle testing characterizes actual system performance in vehicle

Acknowledgement

This work is supported by
the U.S. Department of Energy's
EERE Vehicle Technologies Office

More Information

http://avt.inl.gov

http://at.inl.gov

Back-up Slides

EVI Lab Measurement Equipment

- Efficiency and Electrical Power Quality
  - Hioki 3390 Power Meter
    - 0.15% accuracy
    - 4 channels
      - Voltage
      - Current Probes

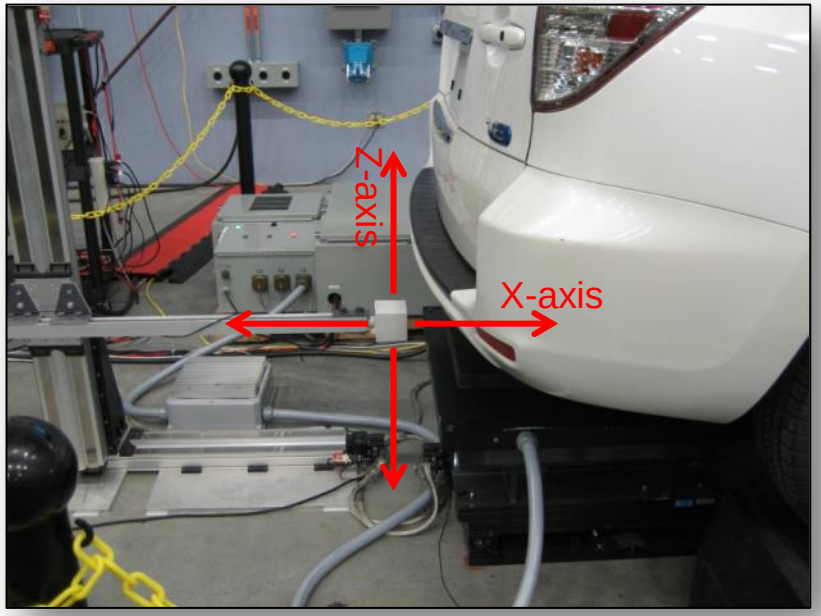
- Electro-magnetic field
  - Narda EHP-200a
    - 9 kHz – 30 MHz

- Surface Temperature
  - FLIR SC640 infrared camera connected to PC

- Custom LabVIEW host control and data acquisition

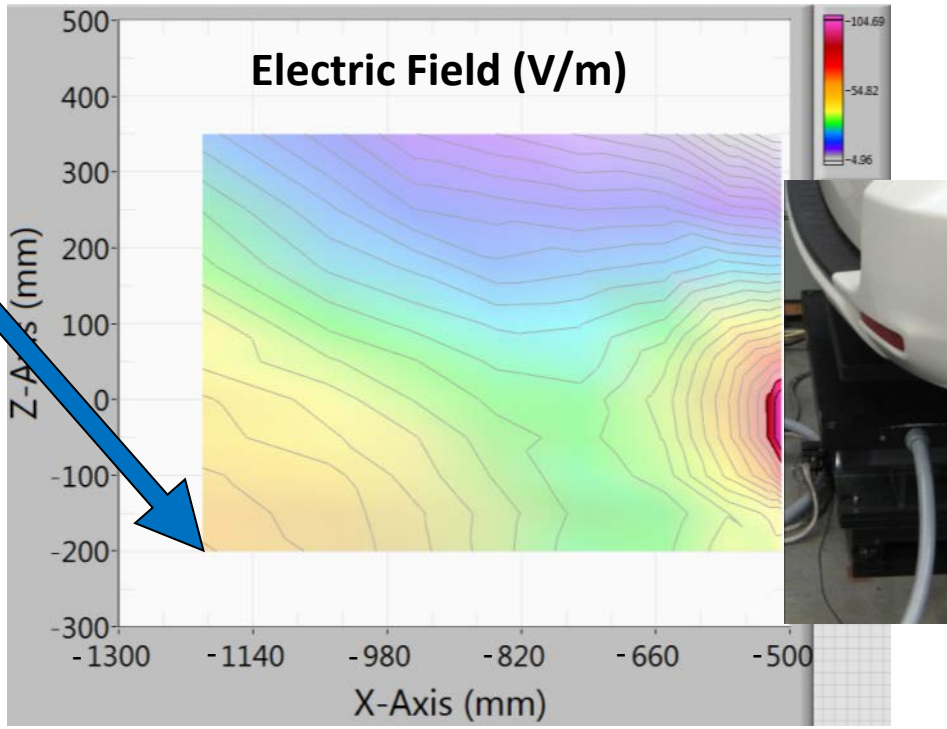
INL's Test Fixture: Magnetic and Electric Field scan near vehicle

- INL's 2-axis positioning device used to position NARDA EM-field meter
  - Precise positioning
  - Quasi-static scan of region

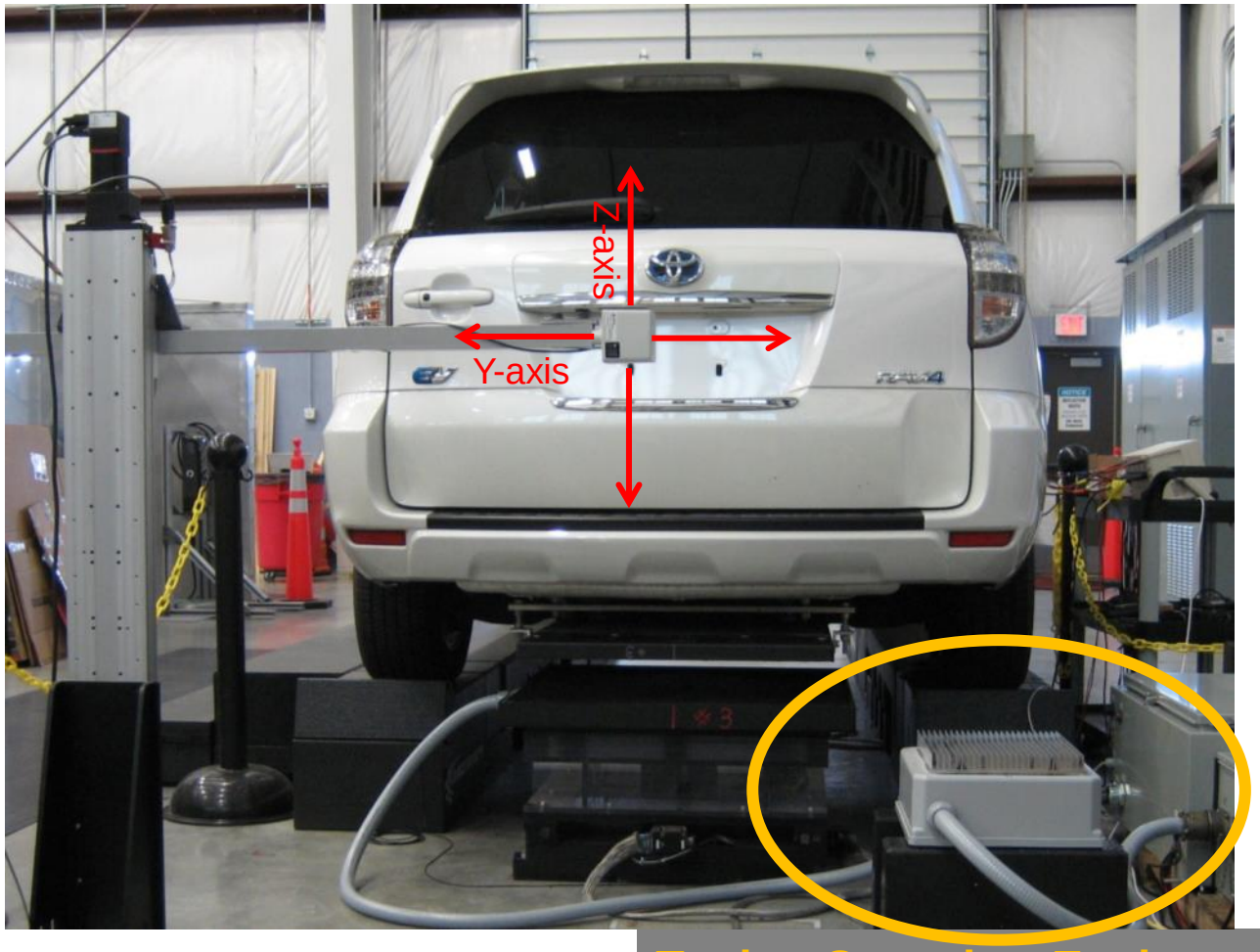


Magnetic and Electric Field at 152mm coil gap

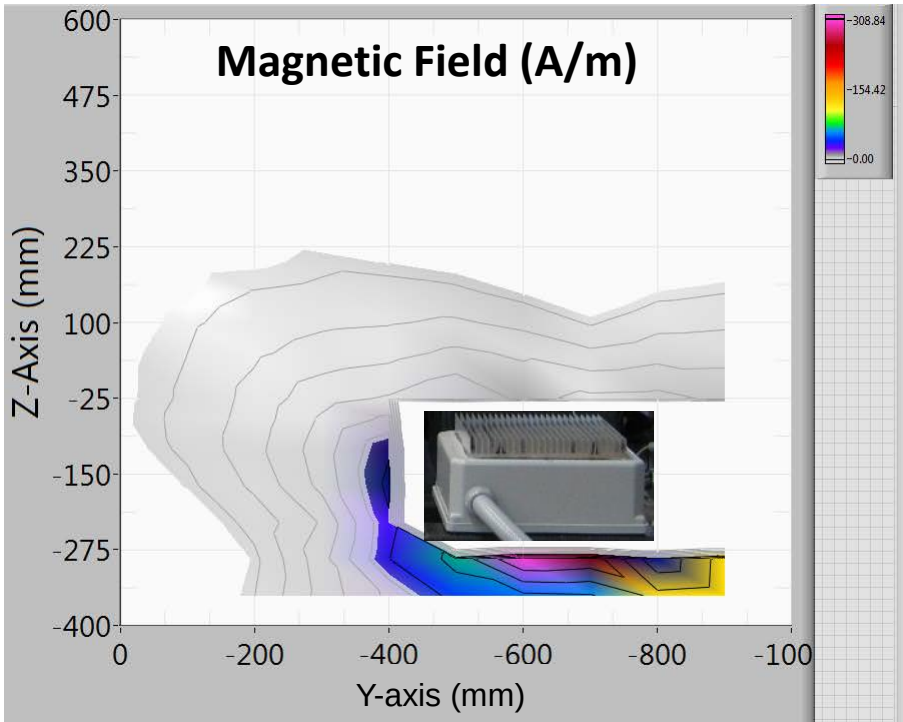
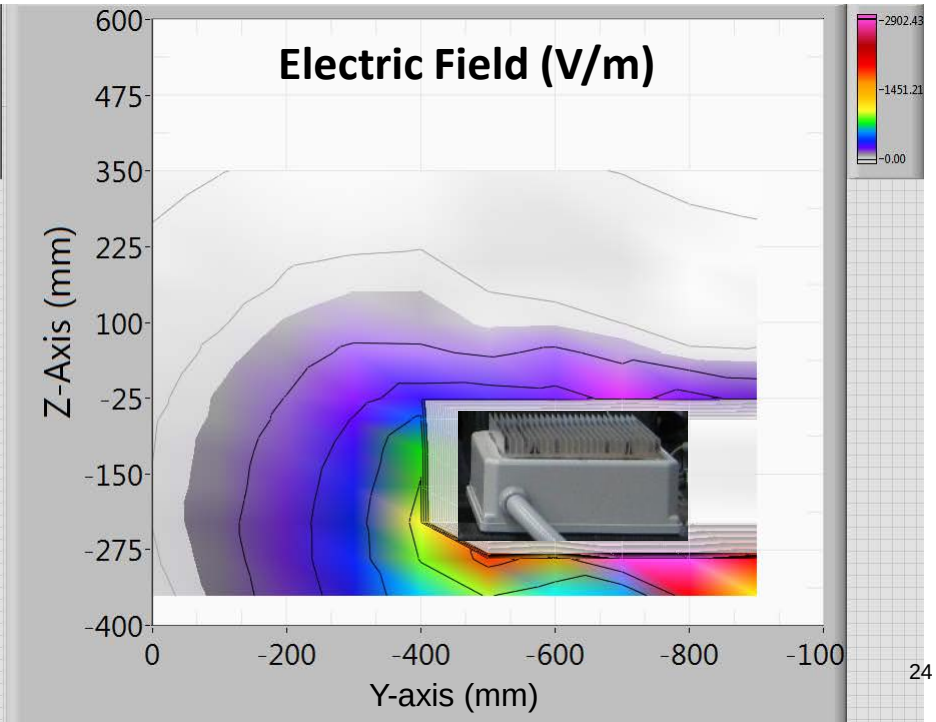
- What is the additional Electric field approximately 1.2m from the coil center?
- Approx. 60 V/m
- This is EM-field generated from the tuning capacitor enclosure between the GSU and the Primary coil



EM-Field near Tuning Capacitor Enclosure
at 152mm ground clearance coil gap



Tuning Capacitor Enclosure

EM-Field near Tuning Capacitor Enclosure
at 152mm ground clearance coil gap

- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Shows peak under the enclosure of 309 A/m
- Electric field (V/m)
  - Shows peak under the enclosure of 2,902 V/m