Wireless Charging Testing to Support Code & Standards Development

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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

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

Test Setup

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Bench sub-system testing

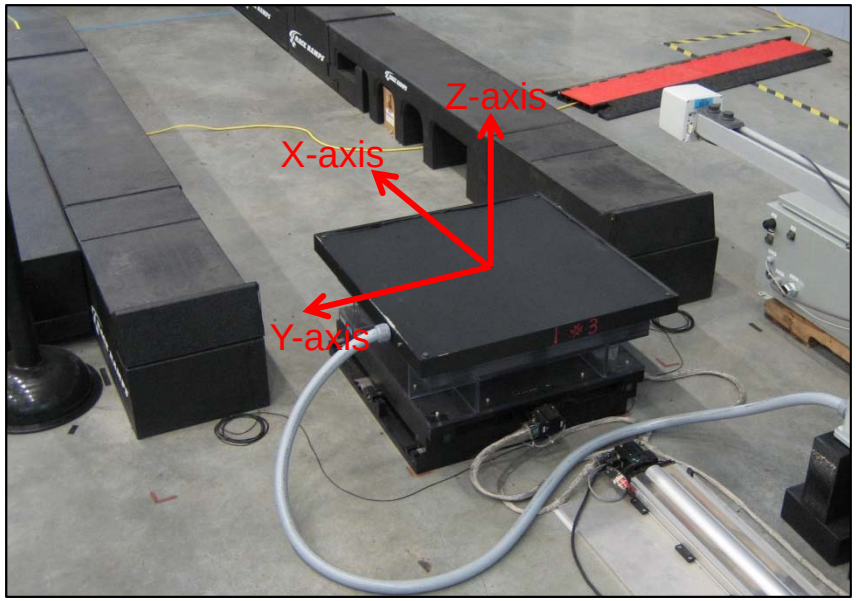
- Standardized testing for technology evaluation
- Fiberglass frame and fasteners supports the vehicle side coil and power electronics
- Vehicle emulation modules
  - Battery emulator
    - DC load w/ variable resistance
  - Communications

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

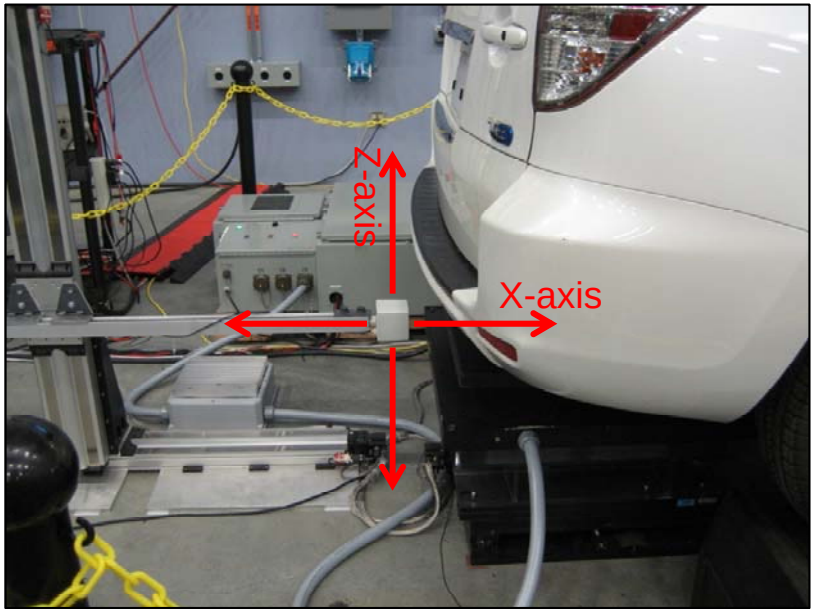
Coil positioning system

- Servo-motor driven positioning system for primary coil (ground assembly)
  - Enables accurate coil misalignment
    - Move primary coil with respect to vehicle coil
- Vehicle is stationary
  - Non-metallic vehicle ramps used to elevate vehicle to provide necessary space for the coil positioning system



Magnetic and Electric Field scan at rear bumper

- 2-axis positioning device used to position Narda EM-field meter
  - Precise positioning
  - Quasi-static scan of region



INL Scope of Testing and Evaluation

Evaluate the ORNL Wireless Charging System (FOA-667)

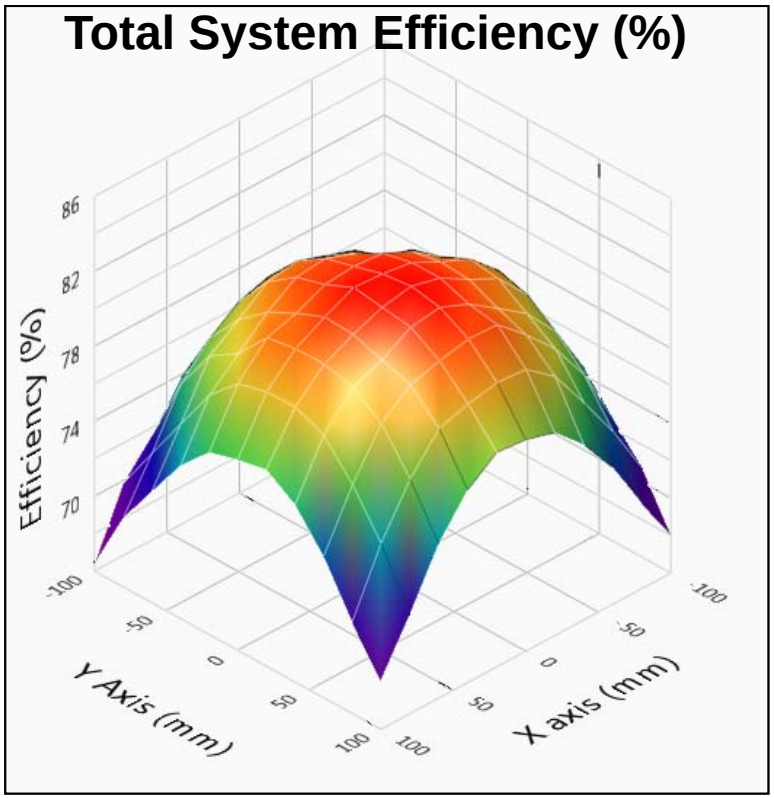
- Characterize the performance:
  - Charging Efficiency
  - EM-field
  - Power Quality

- Characterize impact from:
  - X and Y misalignment
  - Z gap (coil to coil gap)
  - Input voltage
    - 208 vs. 220 vs. 240 V
  - Output voltage
  - Charge Power level
  - EM-field in and around all parts of the vehicle

ORNL Wireless Charger Performance Results

As of January 2016:

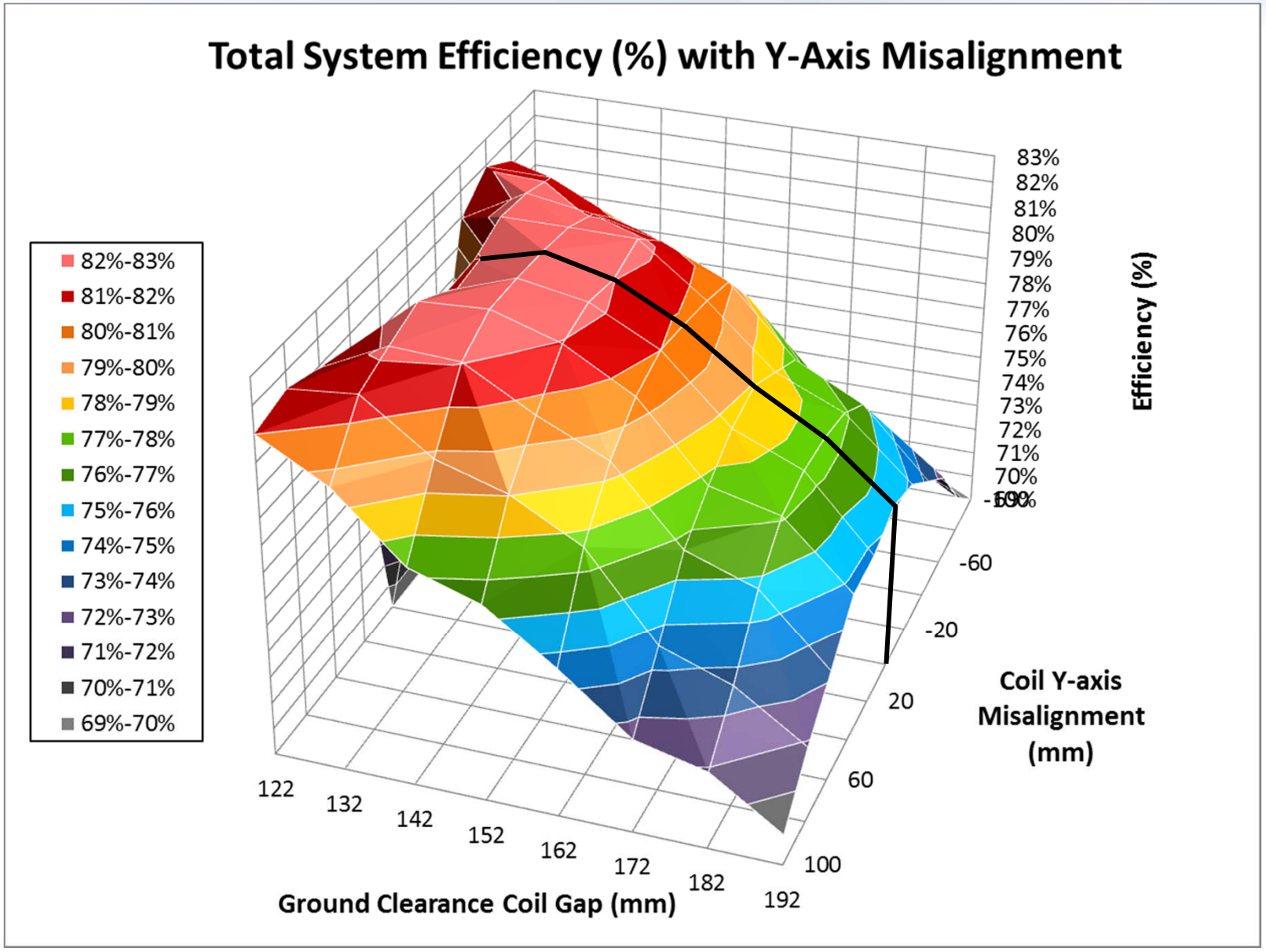
- ORNL Wireless charging system (FOA-667):
  - Total System Efficiency: 82.2%
  - Power capability: up to 7.0kW output
  - Operating Frequency: 25 kHz
  - Ground clearance: 152mm
  - Power quality:
    - Power Factor: 0.94
    - Harmonic Distortion: 60%
  - Electromagnetic field at vehicle bumper
    - Mag. field: 132 A/m
    - Elec. field: 105 V/m



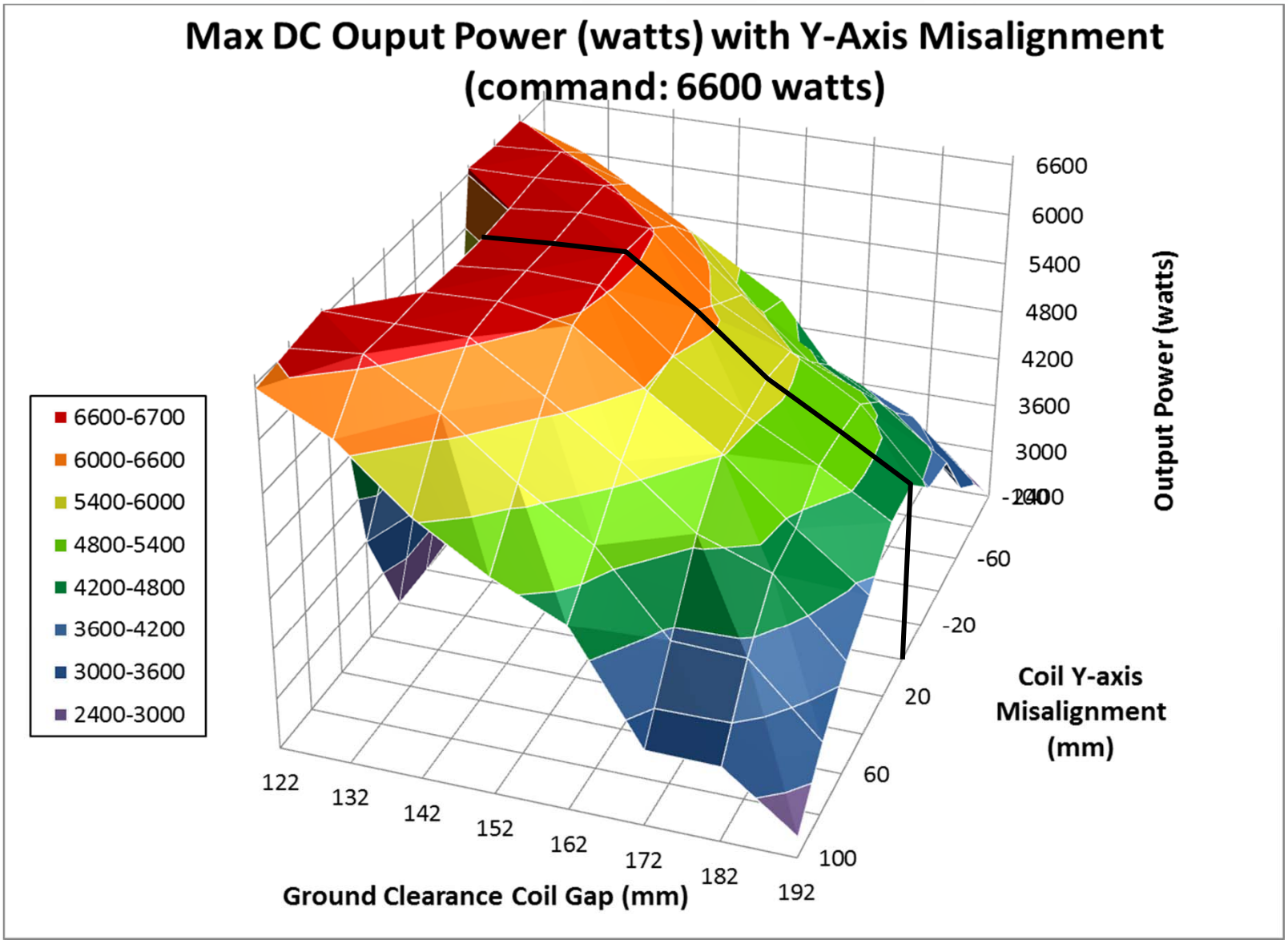
Max. = 82.2 %

- **Note**: After INL testing, ORNL made significant changes to topology, controls, and other aspects
- As of April 2016
  - System efficiency: >90%
  - Power capability: 20 kW

Total System Efficiency

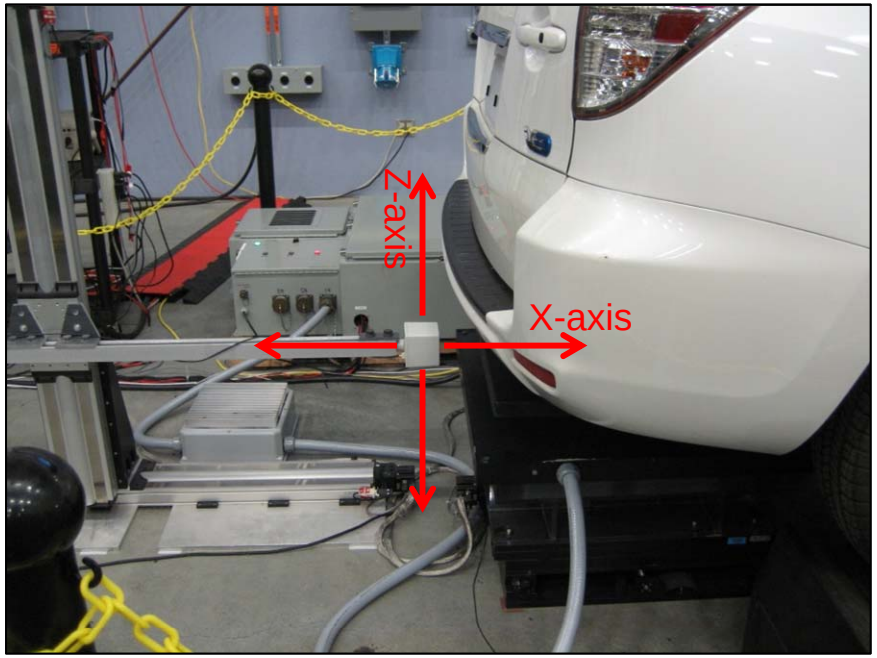


Maximum Output Power (watts)



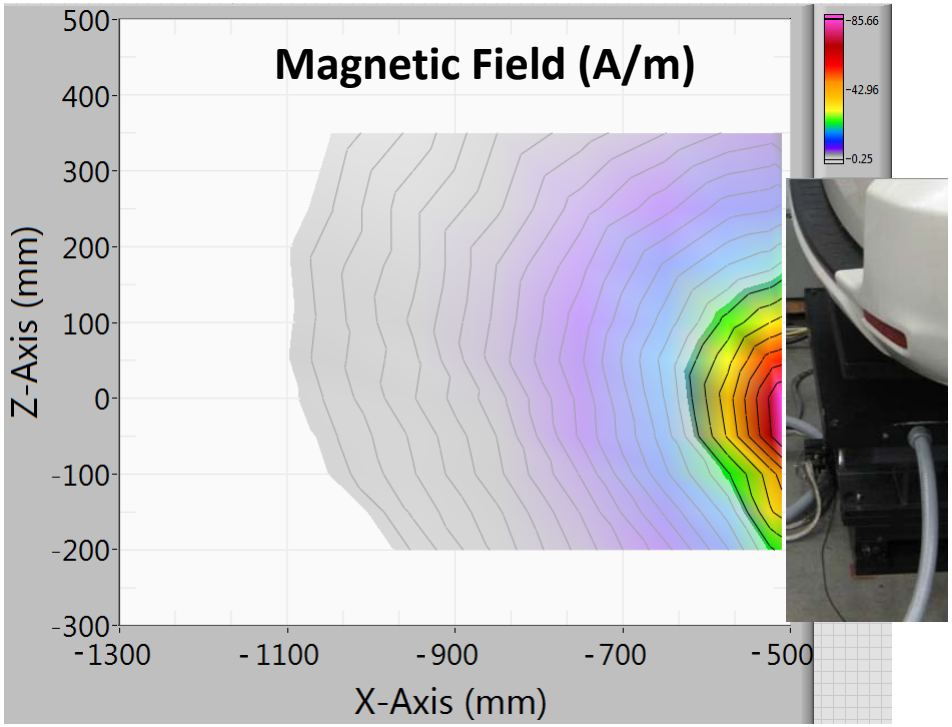
EM-field Scan in X, Z plane near rear bumper

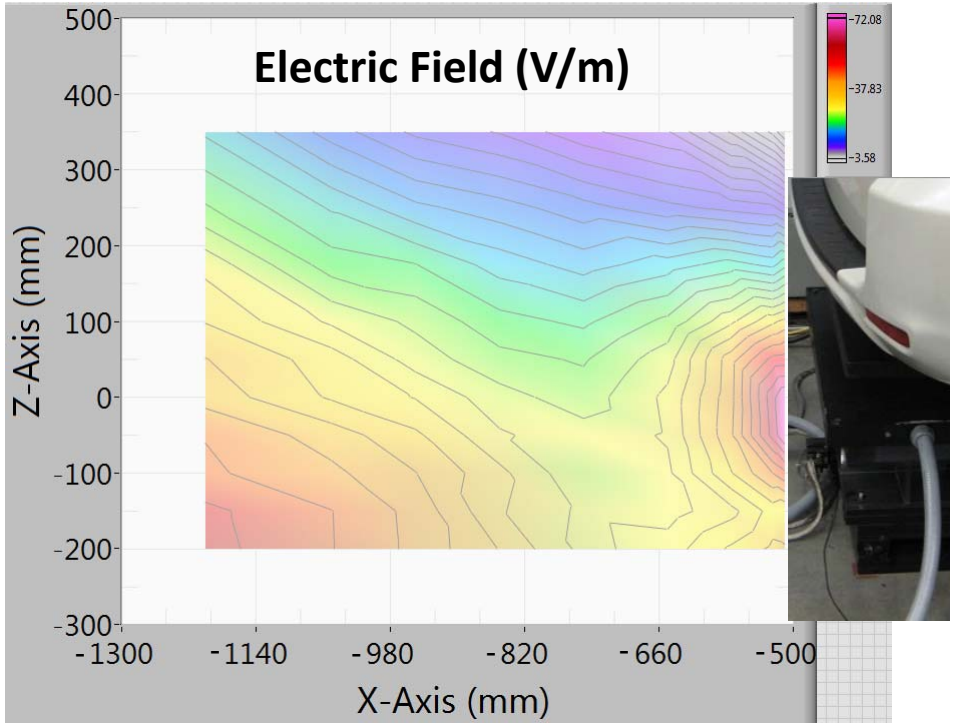
- Coils Aligned (0,0)
- Output power: 6.6 kW
- Input voltage: 240 V RMS
- Output Voltage: 366 VDC



Magnetic and Electric Field at 132mm coil gap

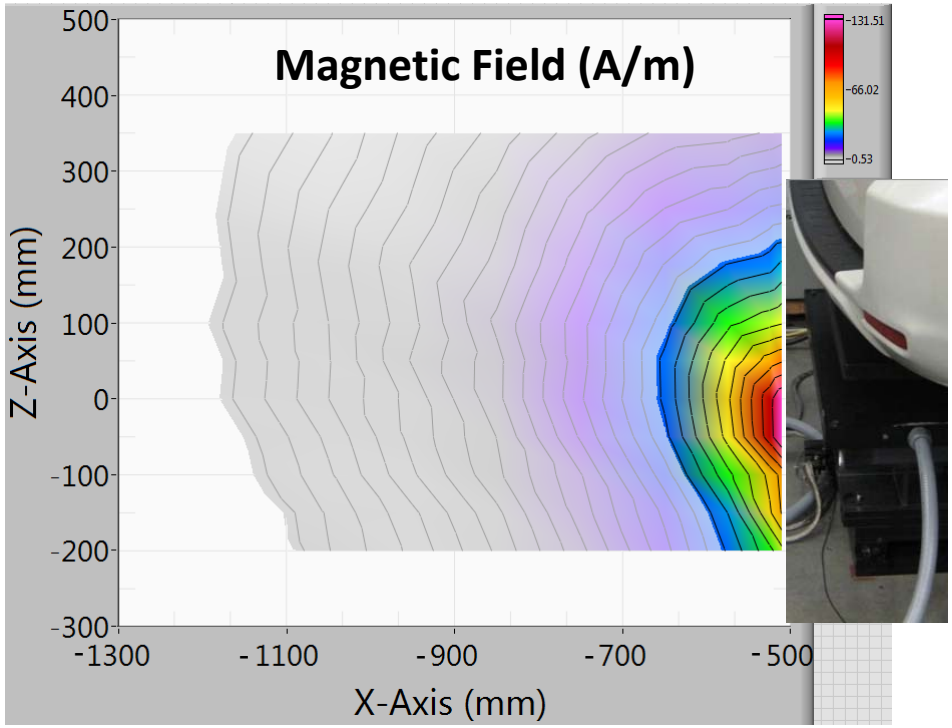
- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Large area near bumper at ankle height shows peak of 85.7 A/m
- Electric field (V/m)
  - All areas measured around rear bumper are below ICNIRP 2010

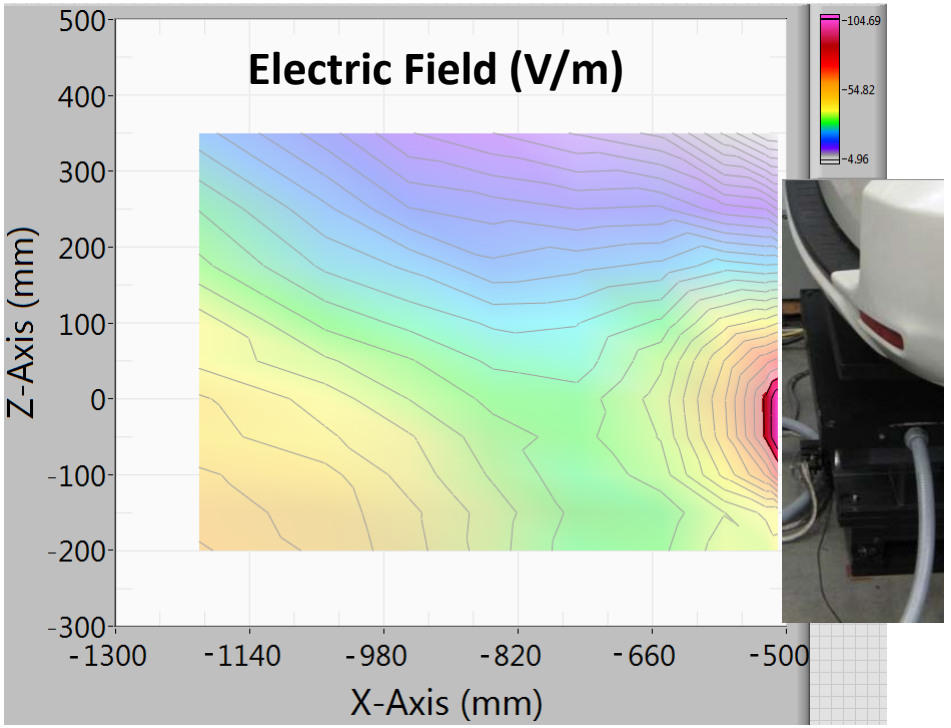




Magnetic and Electric Field at 152mm coil gap

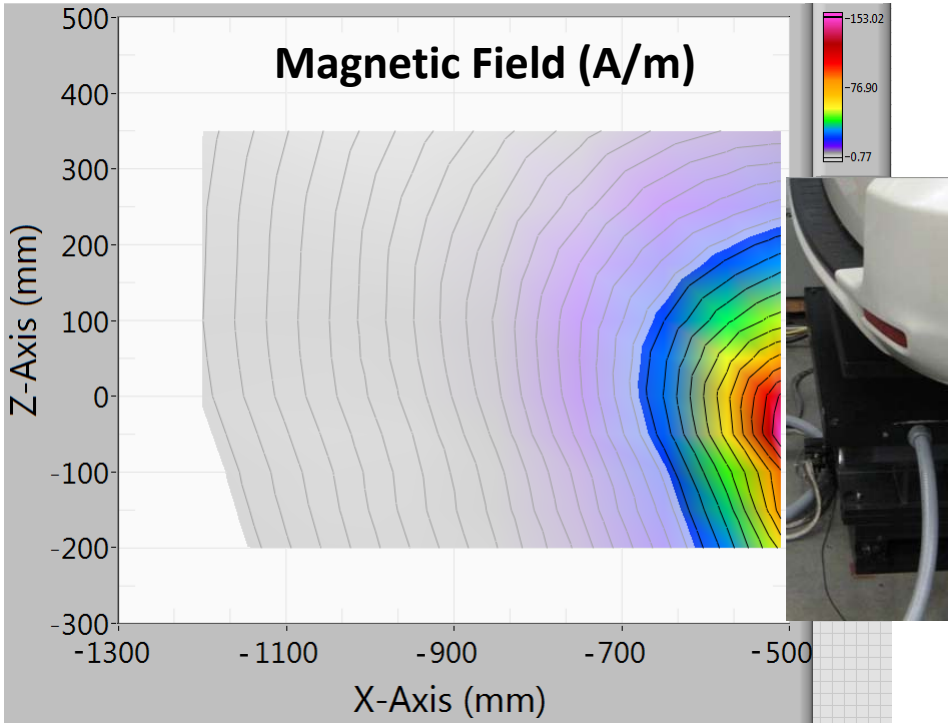
- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Large area near bumper at ankle height shows peak of 132 A/m
- Electric field (V/m)
  - Small area near bumper at ankle height shows peak of 105 V/m

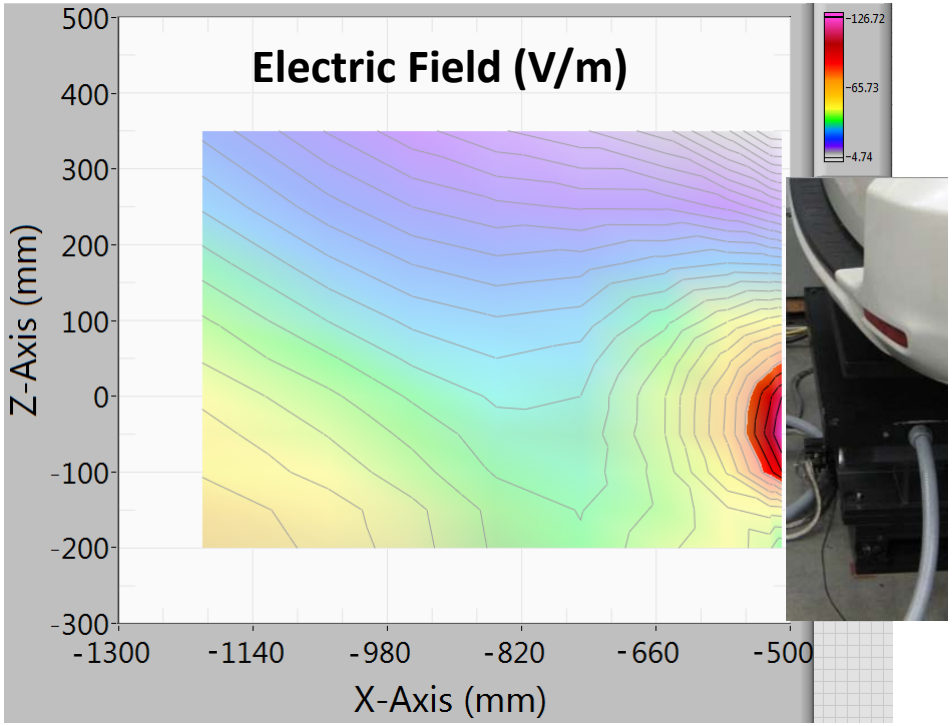




Magnetic and Electric Field at 172mm coil gap

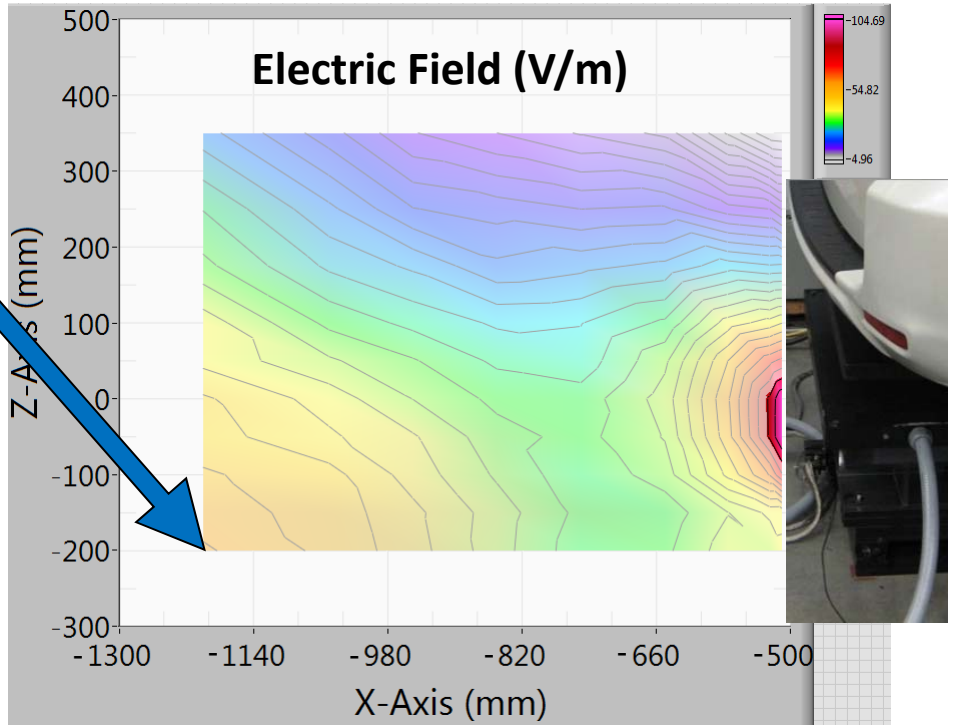
- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Large area near bumper at ankle height shows peak of 153 A/m
- Electric field (V/m)
  - Small area near bumper at ankle height shows peak of 127 V/m



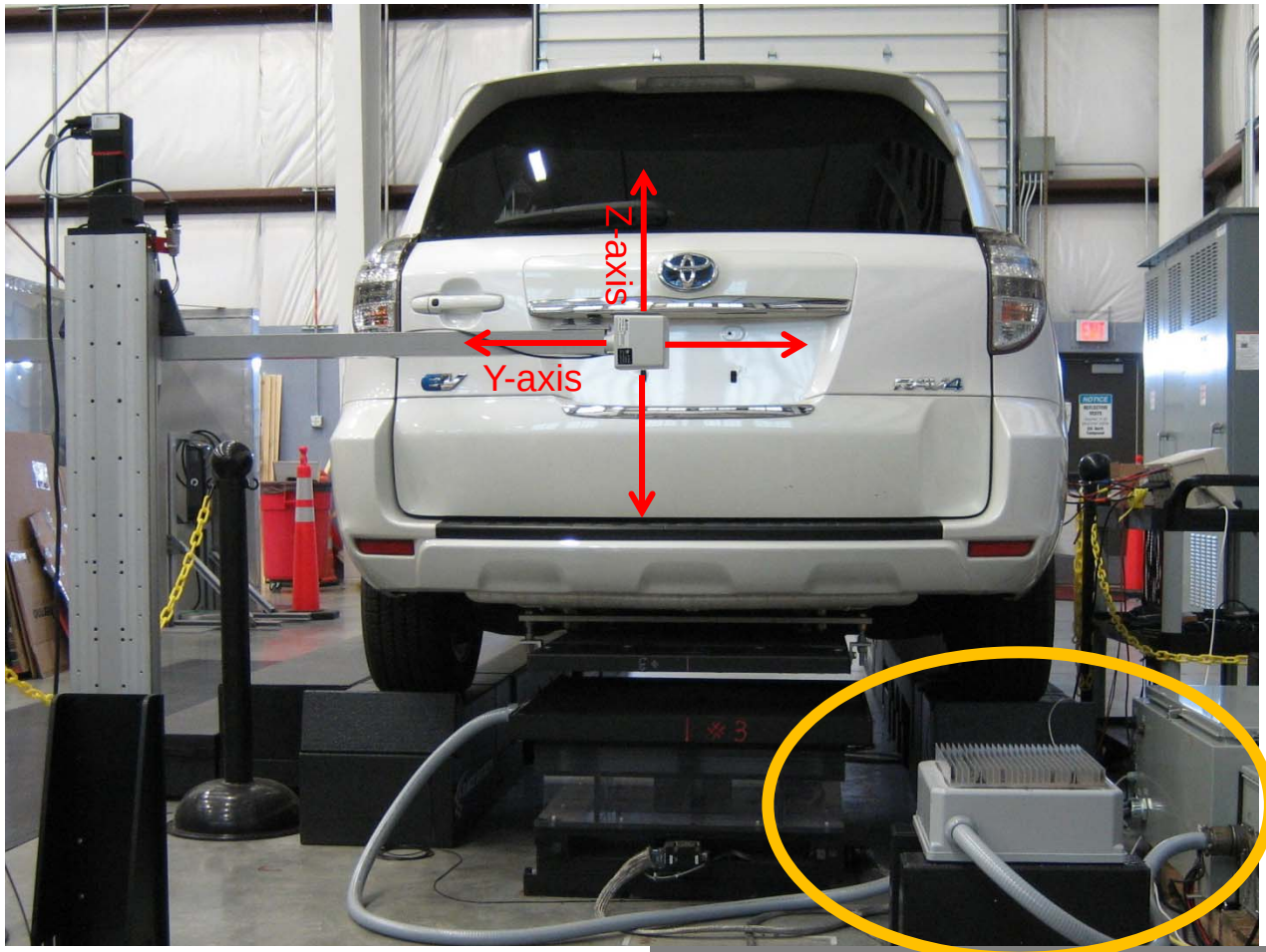


Magnetic and Electric Field at 152mm coil gap

- 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

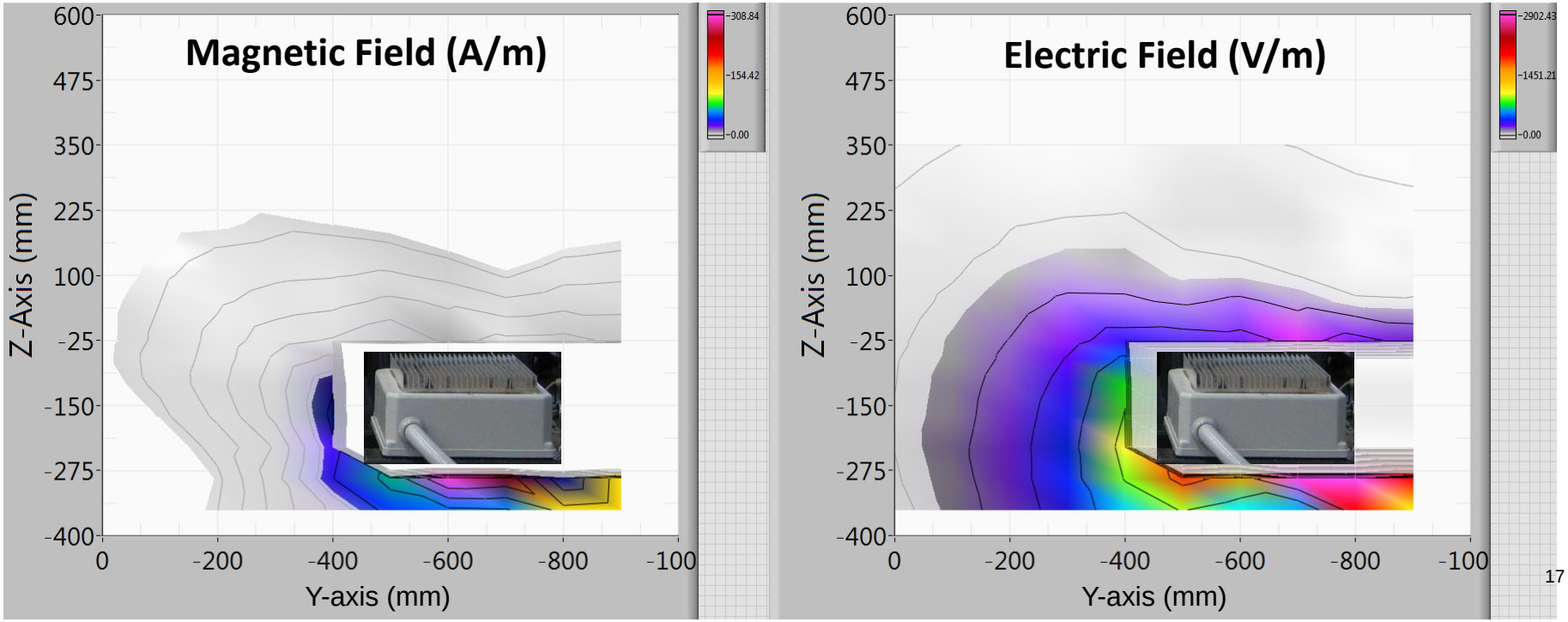


EM-Field near Tuning Capacitor Enclosure
at 152mm ground clearance coil gap



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



Summary

- INL test results supports codes and standards development
  - Refining and validating test procedures
  - Identifying gaps
  - Results enable robust decisions for
    - Test procedures
    - Setup requirements
    - System design requirements for interoperability

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

Acknowledgement

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More Information

http://avt.inl.gov

http://at.inl.gov

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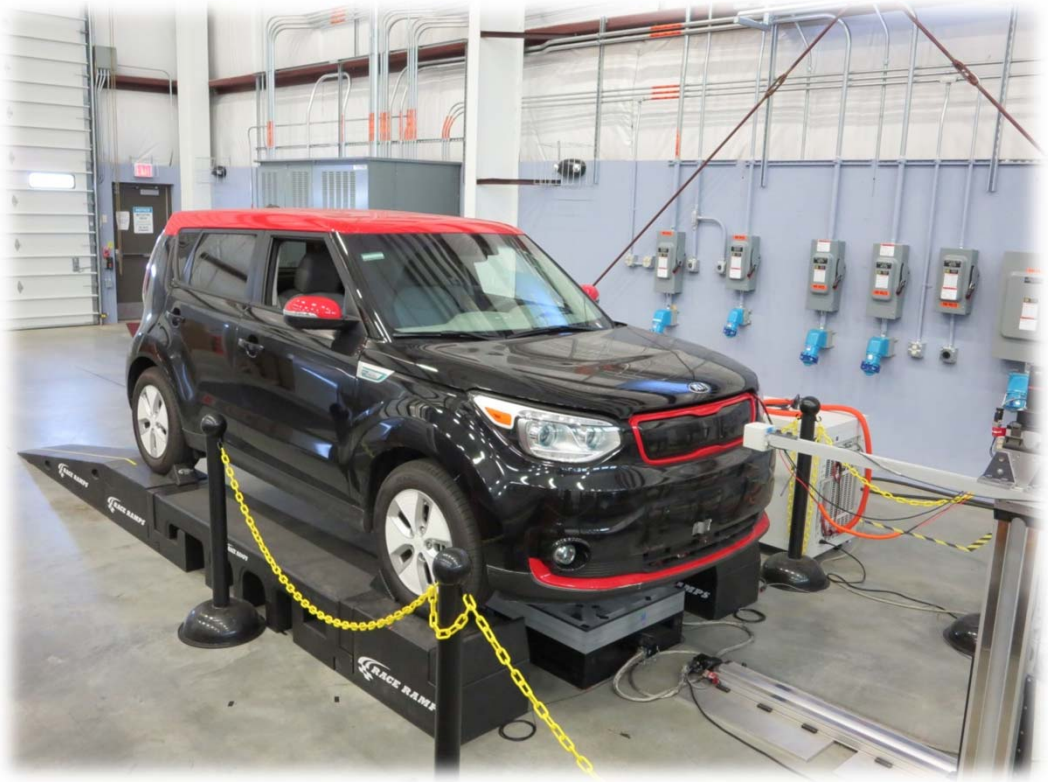

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