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3DEXPERIENCE®

Simulations for drivetrain electrification

Dr Tamara Monti

SIMULIA – the simulation brand of Dassault Systemes

TRANSPORTATION & MOBILITY | **Industry trends**

Electric, Connected and Autonomous Vehicles

New Customer Experience

Quality, Costs, Regulations

Mass Production to Mass Customization

TRANSPORTATION & MOBILITY | **Industry trends**

Electric, Connected and Autonomous Vehicles

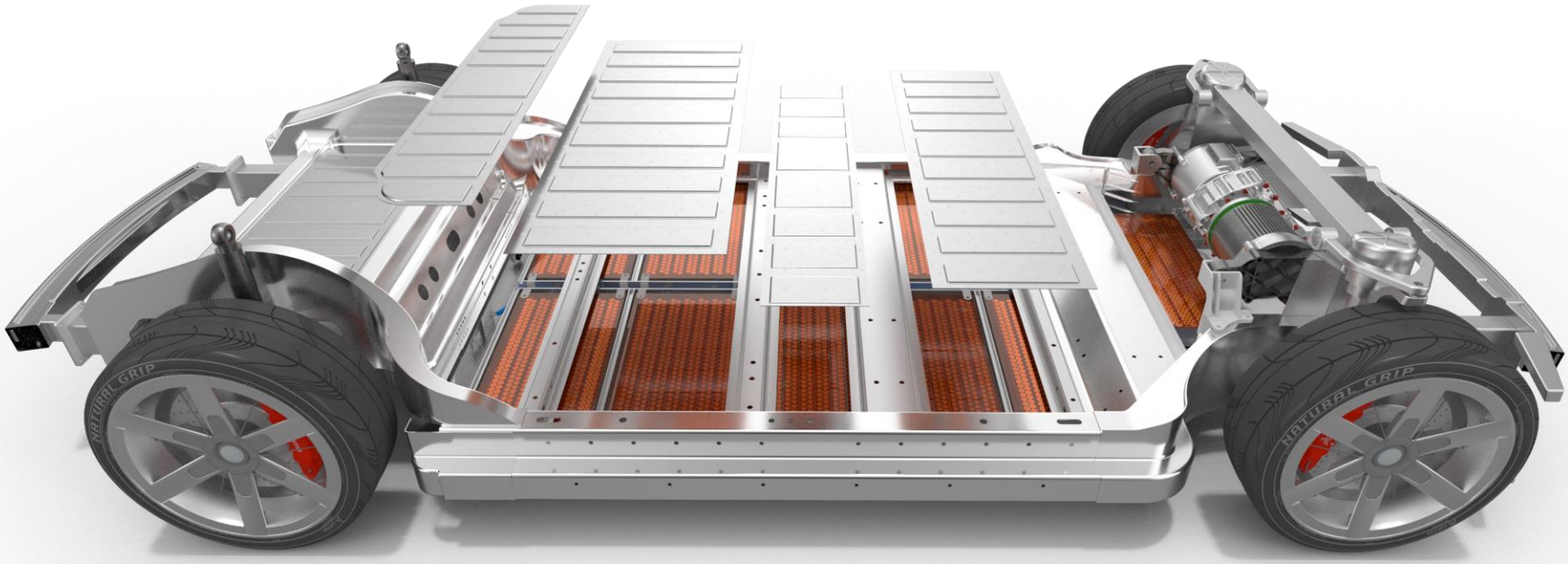
New Customer Experience

Quality, Costs, Regulations

Mass Production to Mass Customization

DASSAULT SYSTEMES

Focus on electric powertrain



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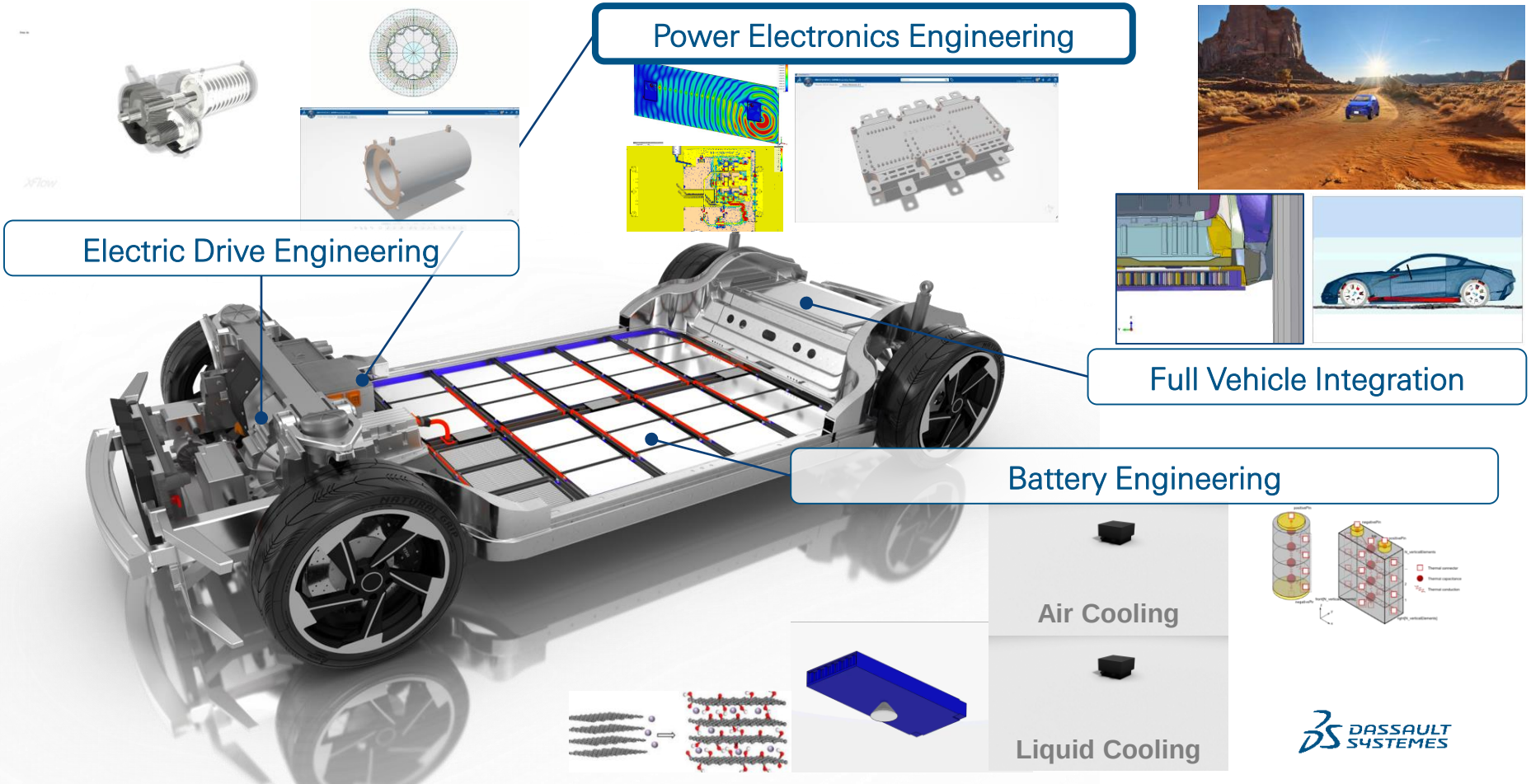
DASSAULT SYSTEMES

VEHICLE ELECTRIFICATION | **Electric powertrain processes overview**



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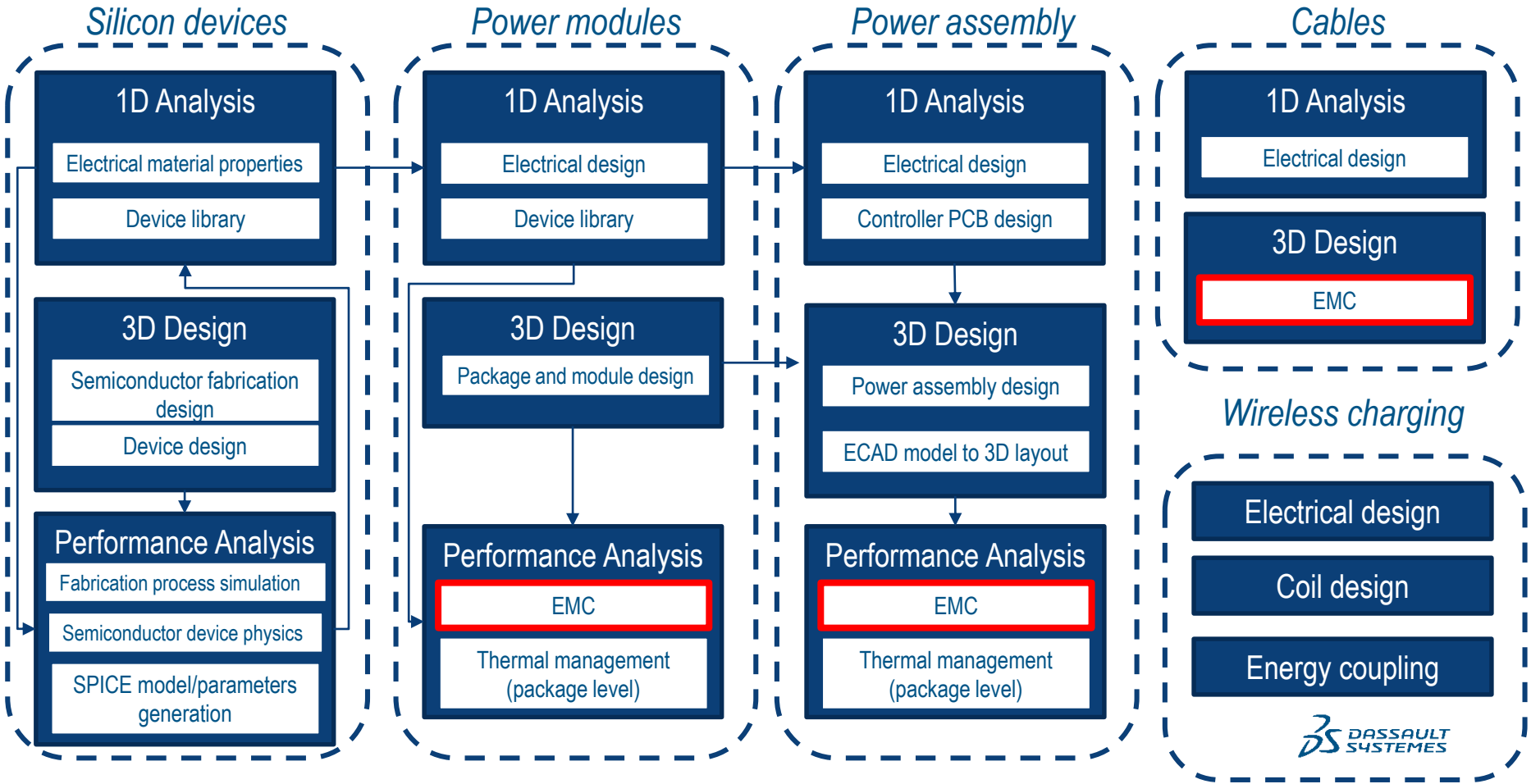
Vehicle Electrification | **Power electronics – DS solutions coverage**



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Scope of EMC/EMI

- The ability of an electrical system to work
  - In its electromagnetic environment
  - Without influencing the surrounding devices (emissions)
  - Or being influenced by surrounding equipment (immunity susceptibility)
- EMC compliance is crucial to all products!
  - Emissions and Immunity is a well regulated area
  - Automotive OEMs impose strict standards on components

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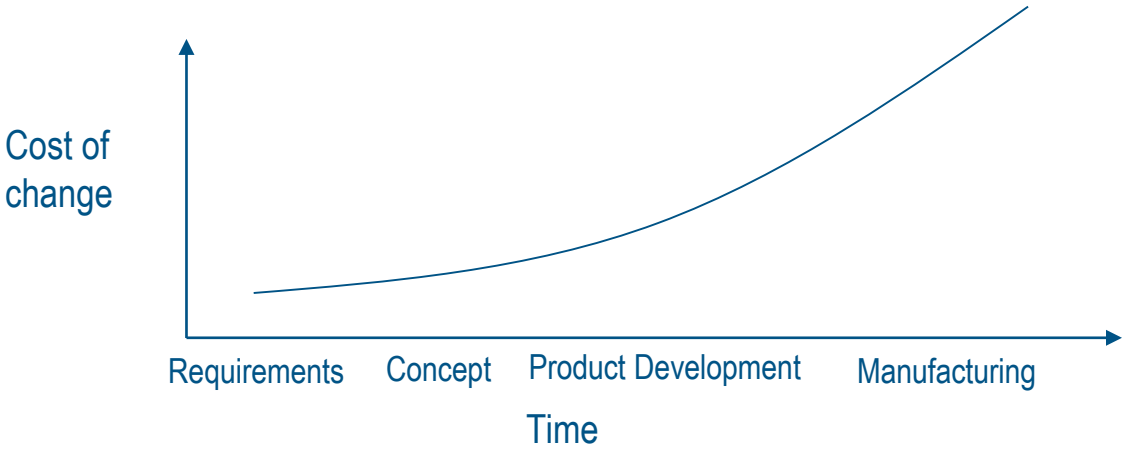
Motivation for simulations

- EMC as part of the Design Process, helping to avoid:
  - multiple troubleshooting iterations
  - high effort and costs to correct
  - delayed time to market



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EMC/EMI from inverters and cables

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POWER ELECTRONICS| **Functional components**

DC-AC Inverter

Converts the direct current coming from the battery to a three phase alternating current in order to drive an electrical machine.

DC-DC Converter

Converts the voltage level of the battery to other voltage levels for different electrical subsystems.

Plugin Charging System

Charges the battery from an electrical outlet or a charging stations (also when regenerative braking is employed).

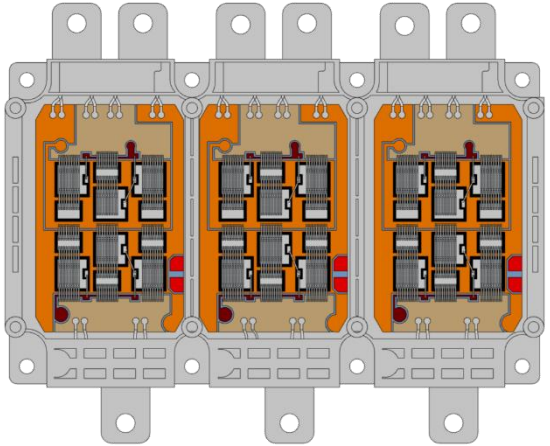
Wireless Charging System

Transfer electrical energy from a wireless charging pad to the battery (the charging pad itself is connected to an outlet).

Challenges

- Thermal management
- EMC compliance
- Weight and space reduction

Three Phase Inverter Power Module



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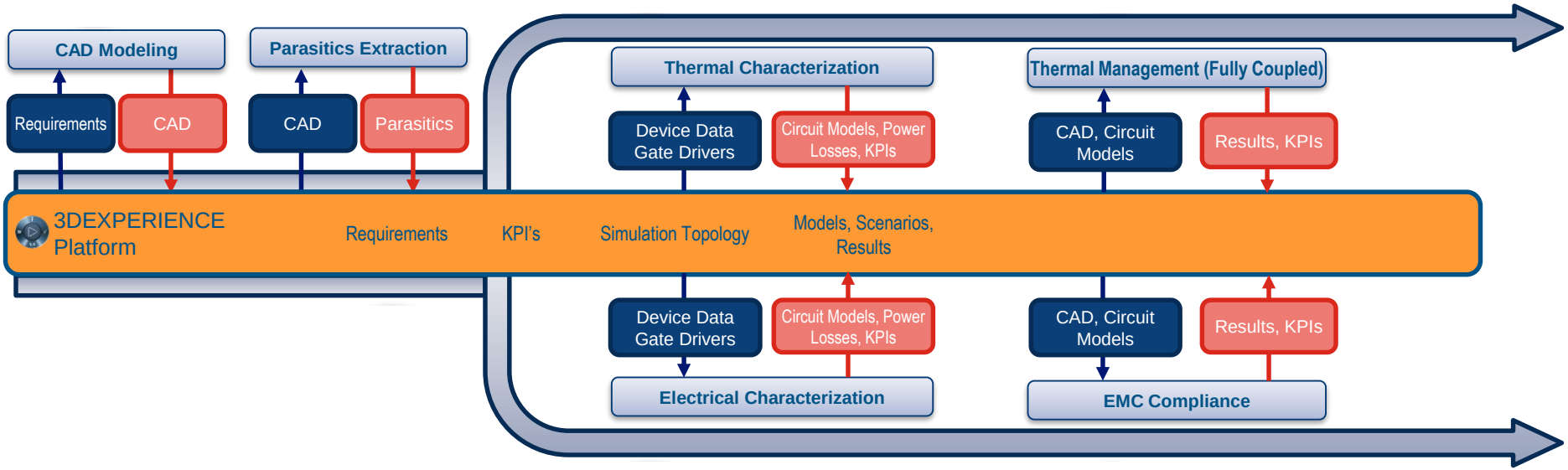
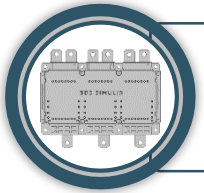
INVERTER POWER MODULE | **Workflow**



INVERTER POWER MODULE | **Workflow – CAD modeling**



- CAD model shared across all scenarios and workflows.
- Easy to maintain multiple designs and design changes.

CAD Modeling

Requirements

CAD

Parasitics Extraction

CAD

Parasitics

3DEXPERIENCE Platform

Requirements

KPI's

Simulation Topology

Models, Scenarios, Results

Thermal Characterization

Device Data Gate Drivers

Circuit Models, Power Losses, KPIs

Thermal Management (Fully Coupled)

CAD, Circuit Models

Results, KPIs

Device Data Gate Drivers

Circuit Models, Power Losses, KPIs

Electrical Characterization

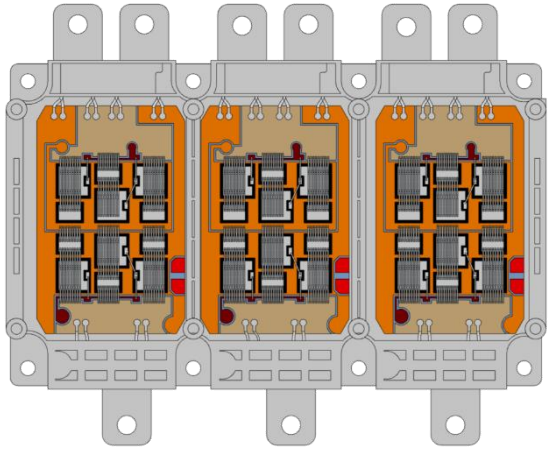
CAD, Circuit Models

Results, KPIs

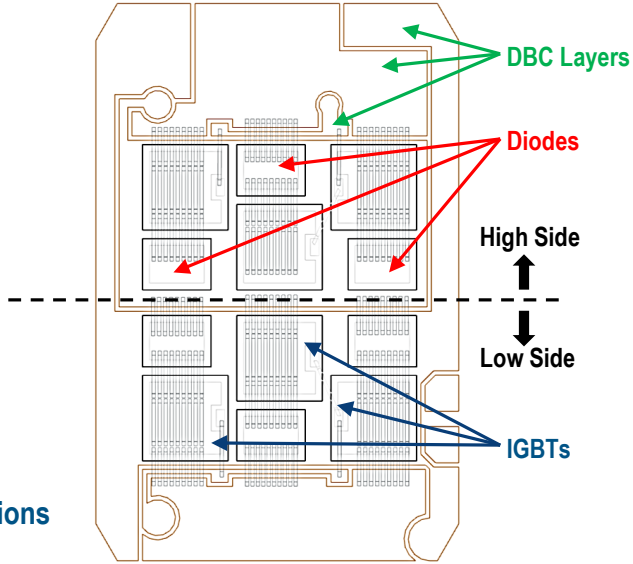
EMC Compliance

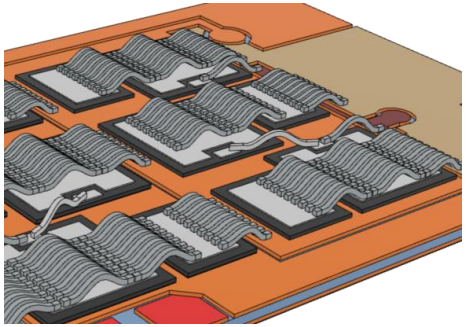
DASSAULT SYSTEMES

INVERTER POWER MODULE | **CAD design - electrical**



Three independently controllable H-bridge sections





Wirebonds connecting
IGBTs, Diodes and DBC Layers

- Three independently controllable H-bridge sections (one per each phase).
- Three parallel legs in each phase allow load sharing.
- Wirebonds are used for connecting IGBTs, Diodes and DBC layers.

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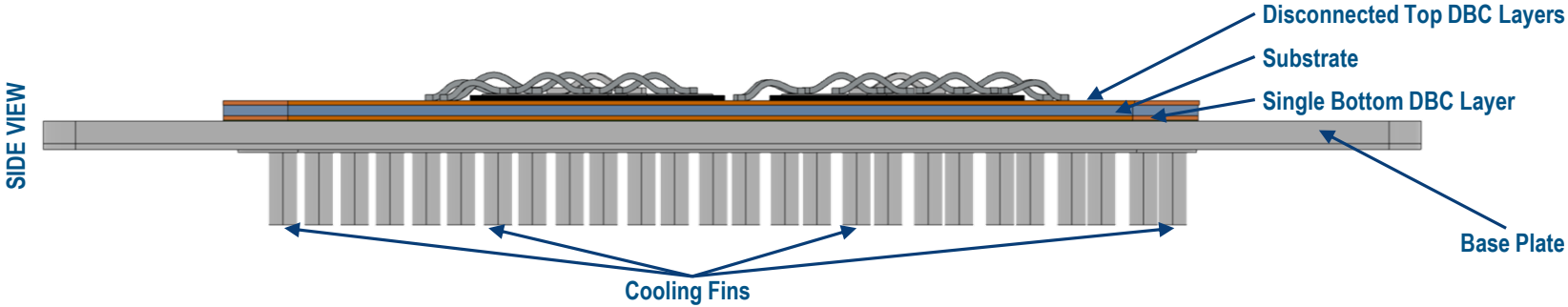
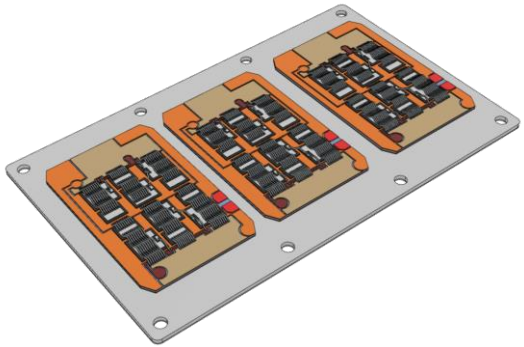
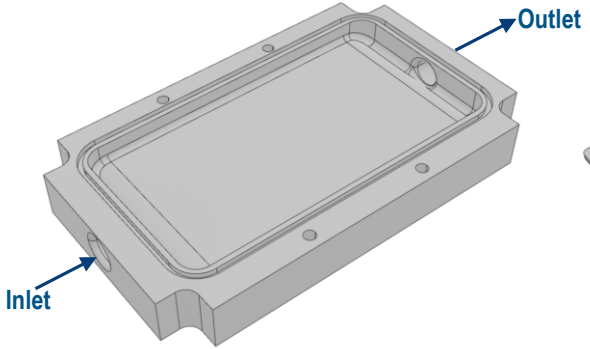
INVERTER POWER MODULE | **CAD design - thermal**

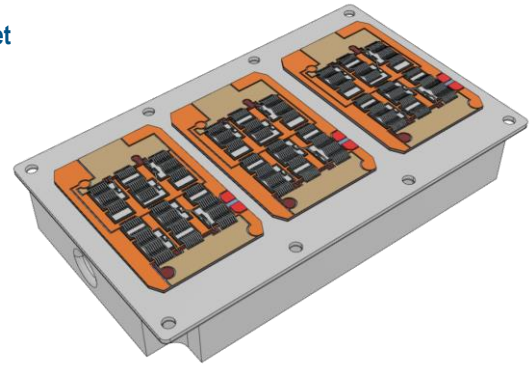




Inverter Module



Cooling System



Inverter Module + Cooling System

INVERTER POWER MODULE | **Extraction of parasitics**

- CAD model shared across all scenarios and workflows.
- Easy to maintain multiple designs and design changes.

CAD Modeling

Requirements

CAD

Parasitics Extraction

CAD

Parasitics

3DEXPERIENCE Platform

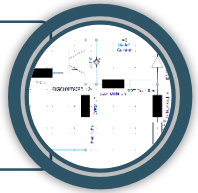
Requirements

KPI's

Simulation Topology

Models, Scenarios, Results

- A dedicated partial inductance solver.
- Pick and choose wirebonds of interest.



Thermal Characterization

Device Data Gate Drivers

Circuit Models, Power Losses, KPIs

Electrical Characterization

Thermal Management (Fully Coupled)

CAD, Circuit Models

Results, KPIs

EMC Compliance

Device Data Gate Drivers

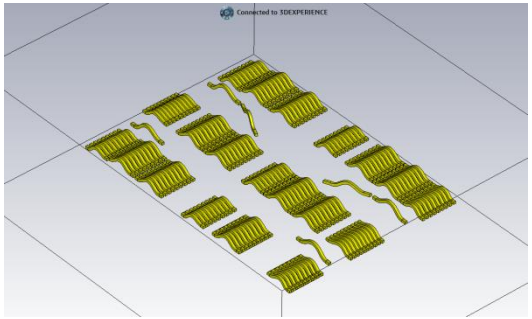
Circuit Models, Power Losses, KPIs

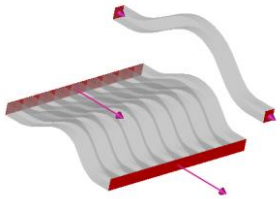
CAD, Circuit Models

Results, KPIs

DASSAULT SYSTEMES

INVERTER POWER MODULE | **Extraction of parasitics**





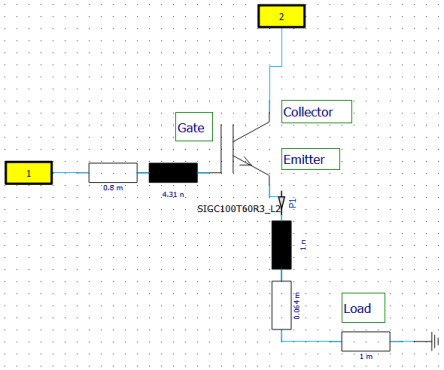
Gate Inductance	4.31 nH
Gate Resistance	0.8 mΩ
Emitter Inductance	1 nH
Emitter Resistance	0.46 mΩ
Diode-Diode Inductance	2.99 nH
Diode-Diode Resistance	0.88 mΩ
IGBT-Diode Inductance	3.35 nH
IGBT-Diode Resistance	1.07 mΩ

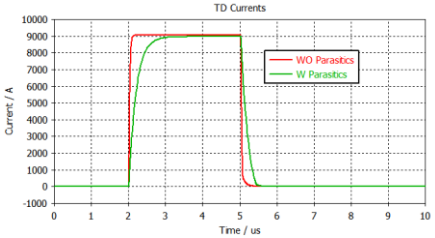
Import the Model from 3DEXPERIENCE Platform

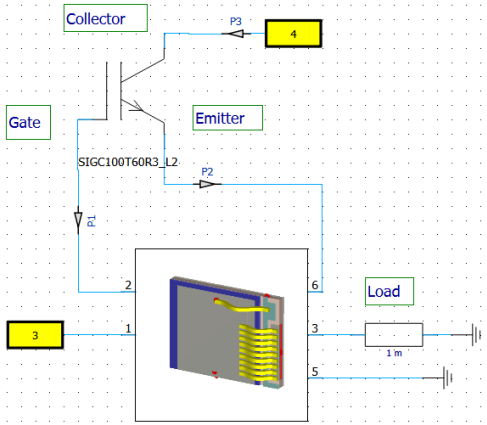
- Inductance is largely a property of geometry.
- Select unique wirebonds of interest.
- Use a dedicated partial inductance solver to compute parasitcs.

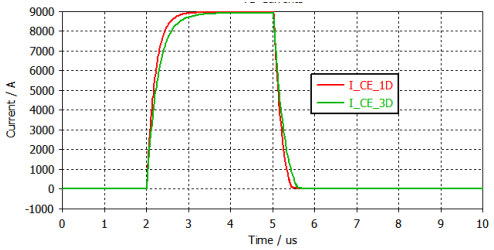
DASSAULT SYSTEMES

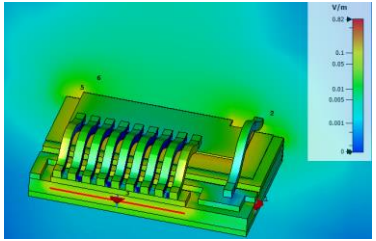
INVERTER POWER MODULE | **Extraction of parasitics**



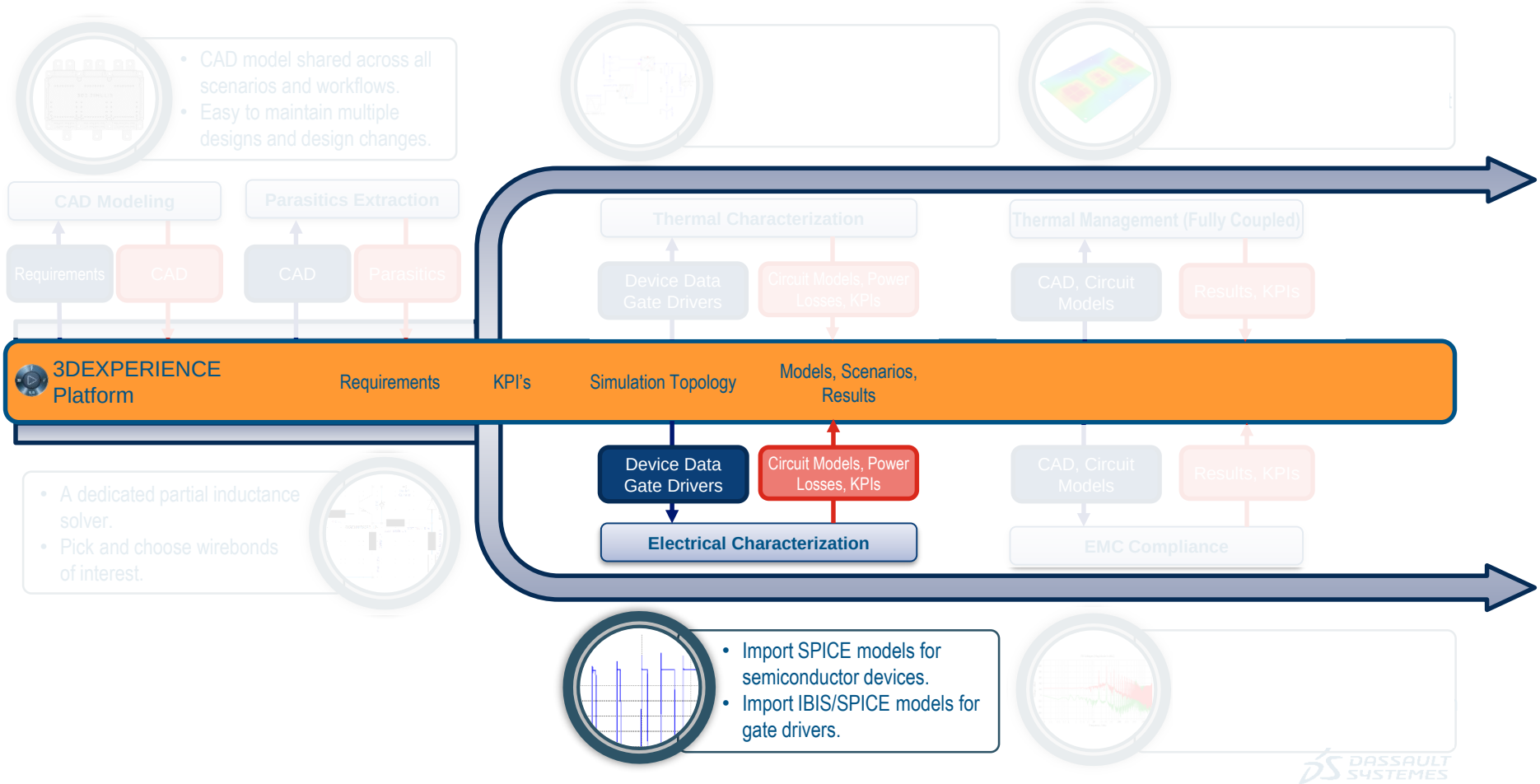




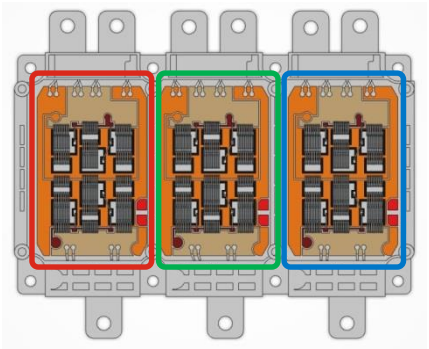




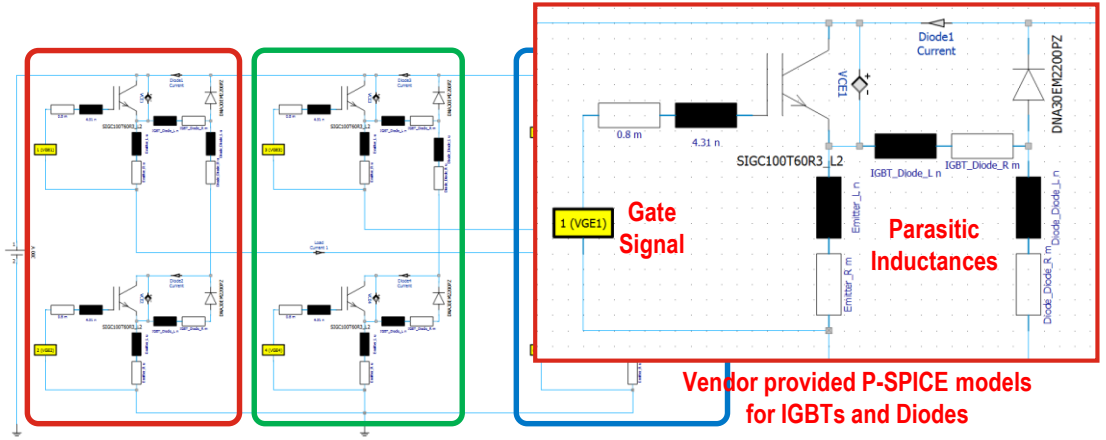
INVERTER POWER MODULE | **Workflow – electrical characterization**



INVERTER POWER MODULE | **Electrical characterization**



3D Model

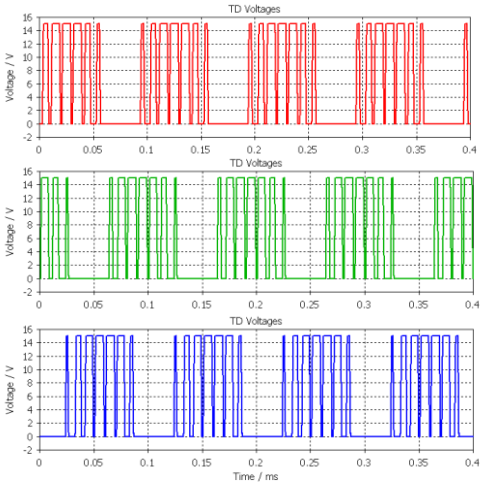


1D Equivalent Circuit

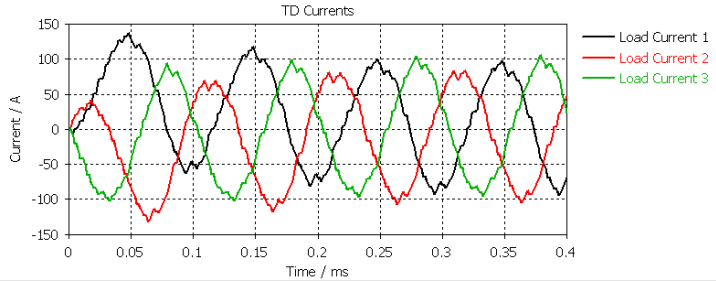
- Import SPICE models for semiconductor devices.
- Specify sine-triangular PWM gate driver signals.
- Analyze inverter output, back-EMF and evaluate dead times.

DASSAULT SYSTEMES

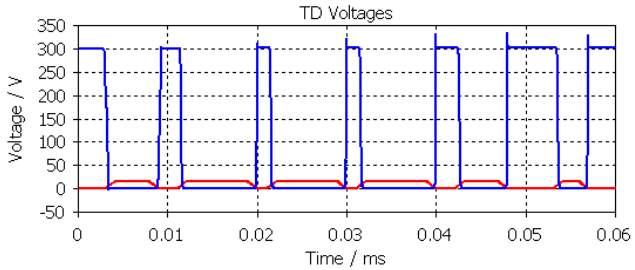
INVERTER POWER MODULE | **Electrical characterization**



PWM Gate Signals at 10 kHz

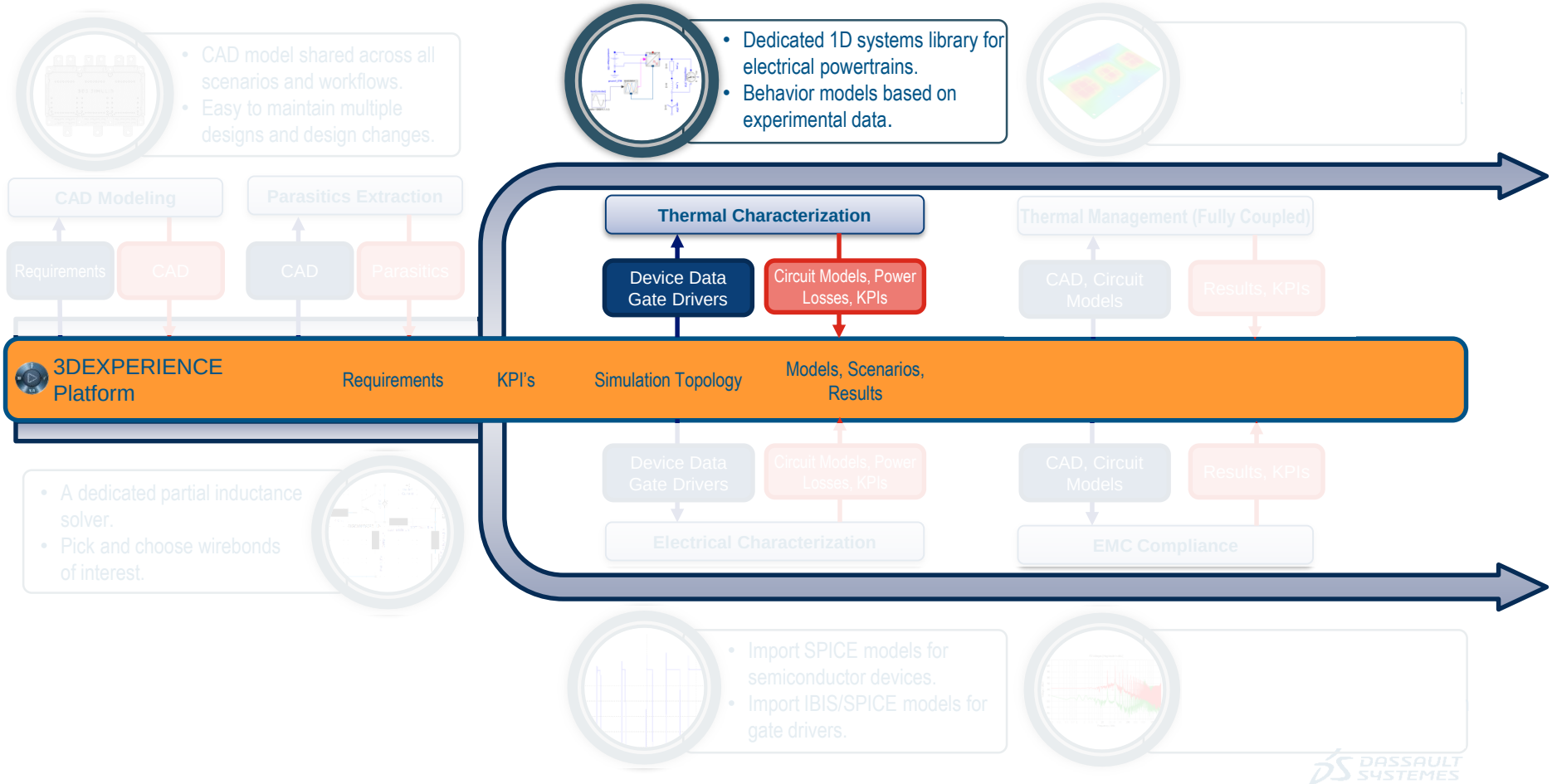


Inverter Output

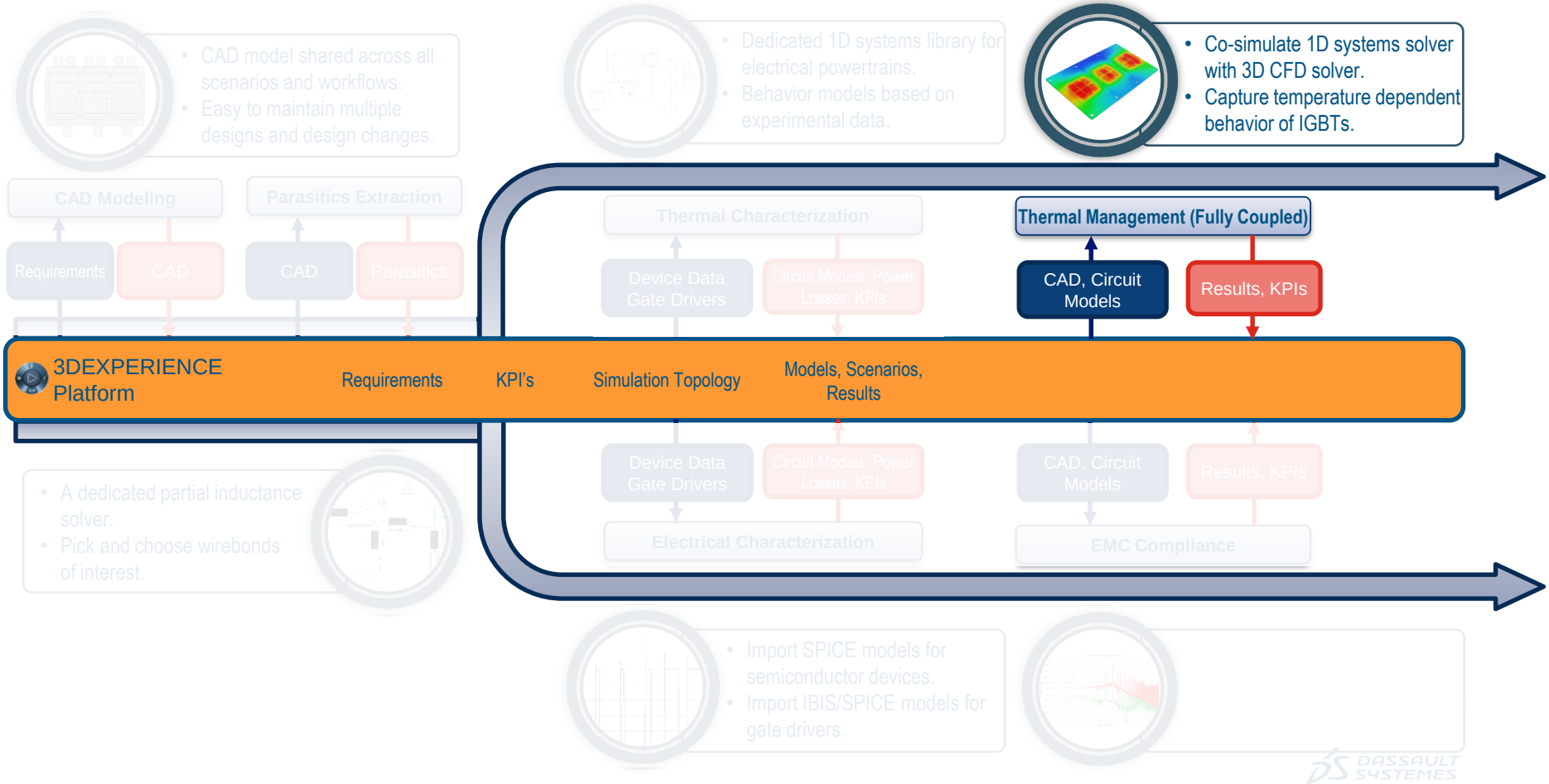


Voltage spikes in V_{CE}

INVERTER POWER MODULE | **Workflow - Thermal characterization**

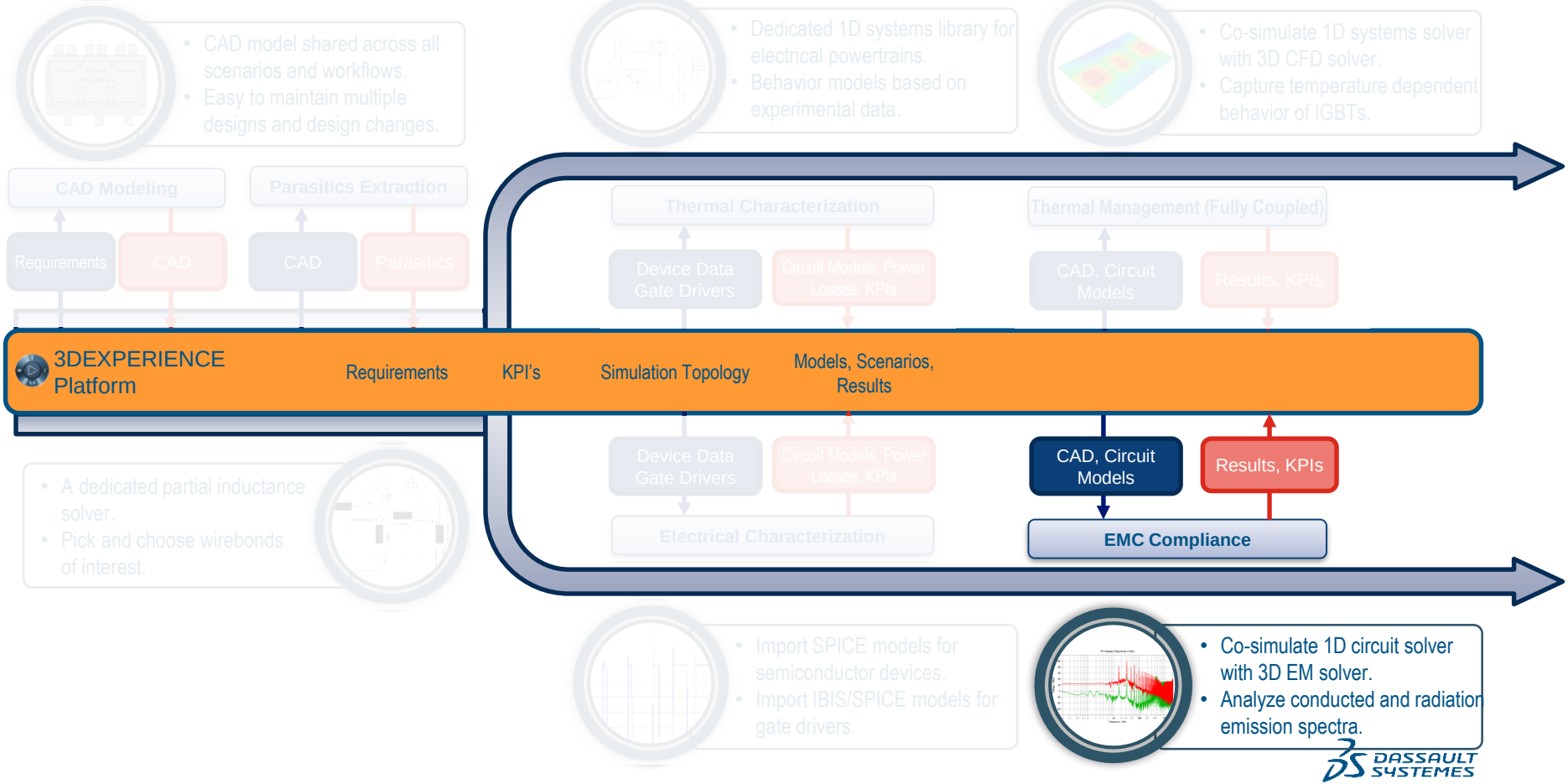


INVERTER POWER MODULE | **Workflow - Thermal management**



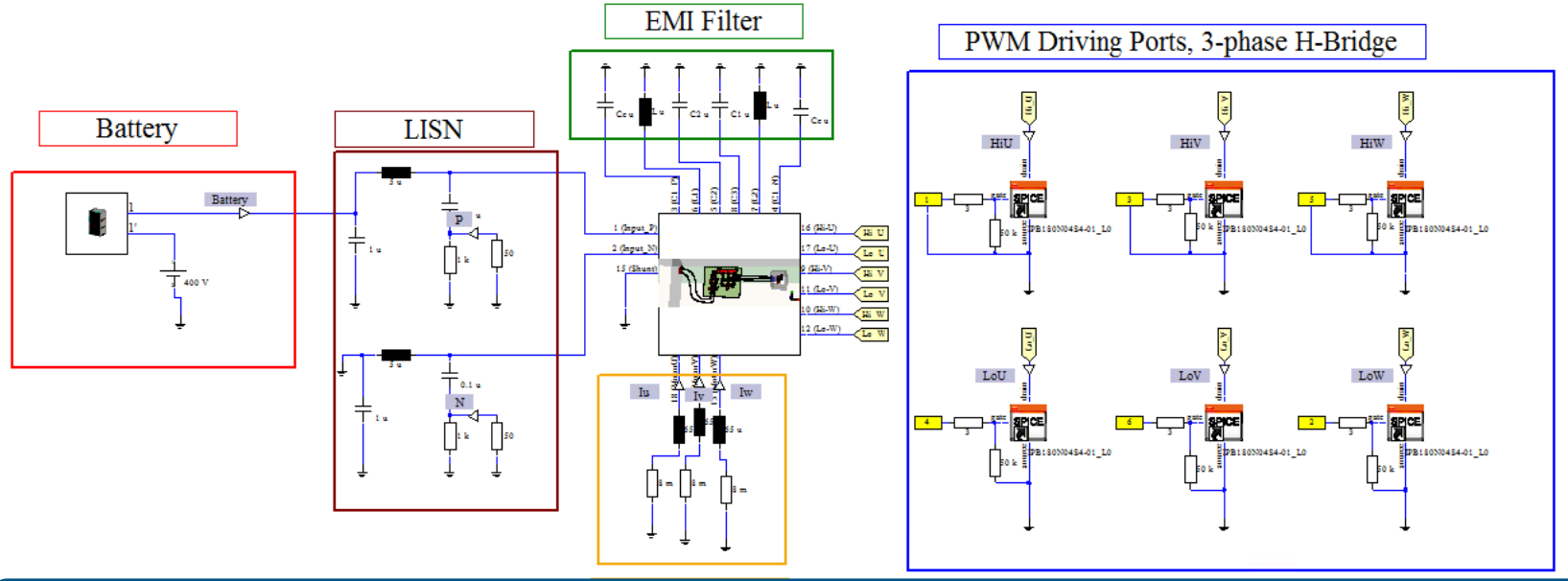
DASSAULT SYSTEMES

INVERTER POWER MODULE | **Workflow – EMC compliance**



DASSAULT SYSTEMES

INVERTER POWER MODULE | **EMC compliance**

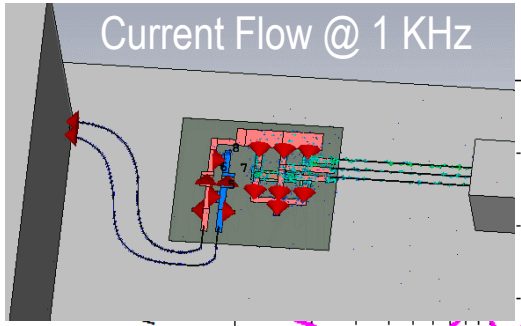


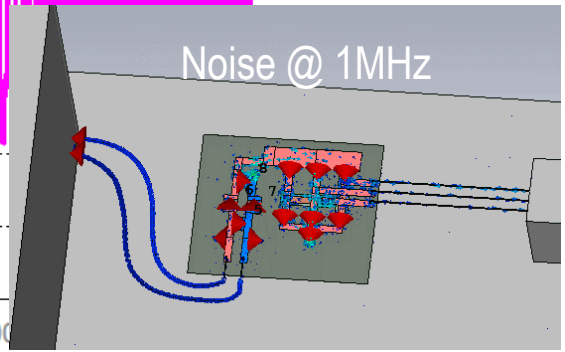
- Co-simulation between 1D circuit solver and 3D EM solver.
- Analyze conducted and radiated emissions.
- Design EMI filters to meet the compliance requirements.

DASSAULT SYSTEMES

INVERTER POWER MODULE | **EMC compliance**

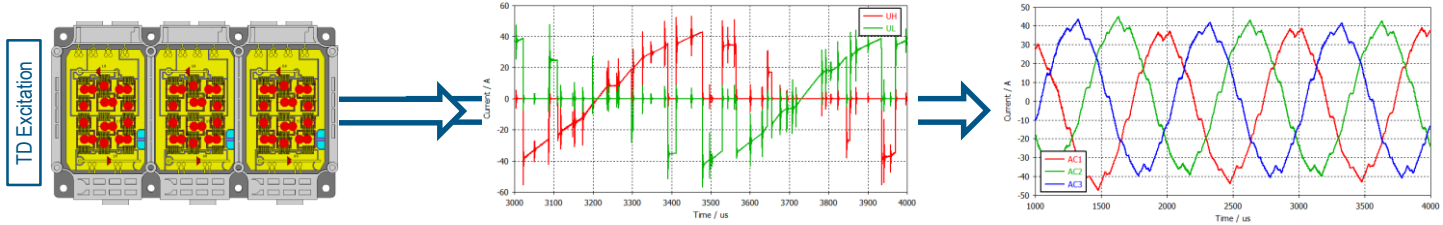
CISPR 25: <76 dBuV for frequency lower than 300 kHz

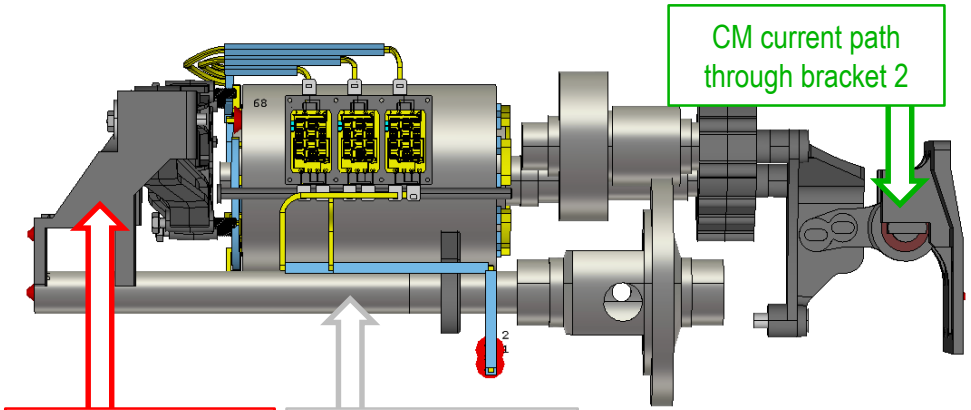


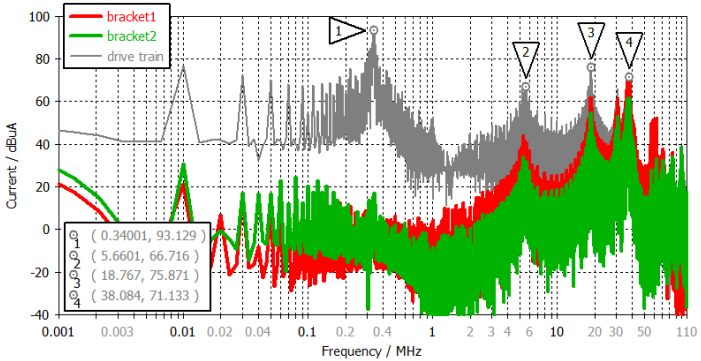


INVERTER POWER MODULE | **EMC compliance**

Time domain simulation. Setup transferred from IGBT module.

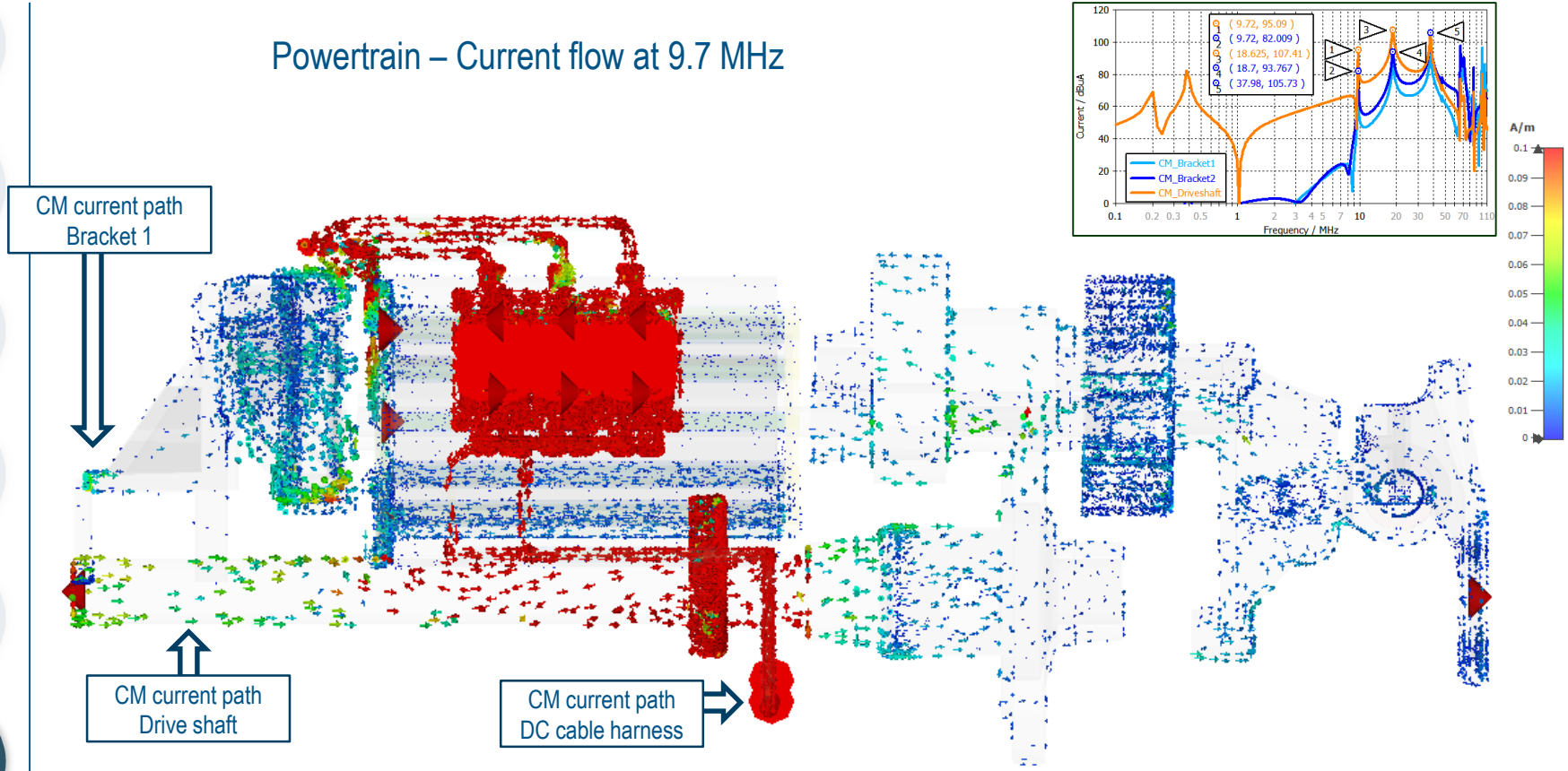






INVERTER POWER MODULE | **EMC compliance**

Powertrain – Current flow at 9.7 MHz

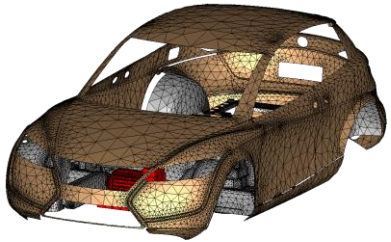


Vehicle level simulation

Common mode analysis

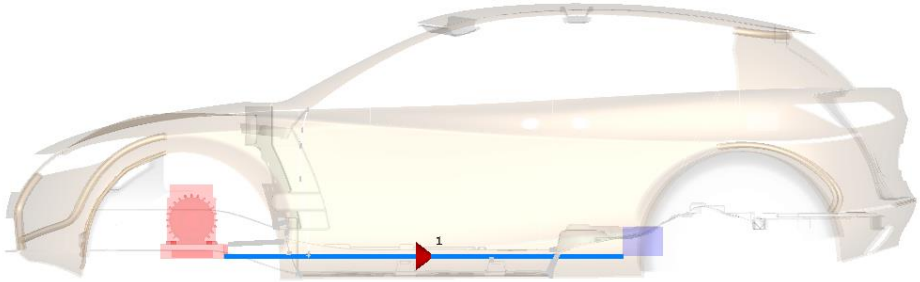
DASSAULT SYSTEMES

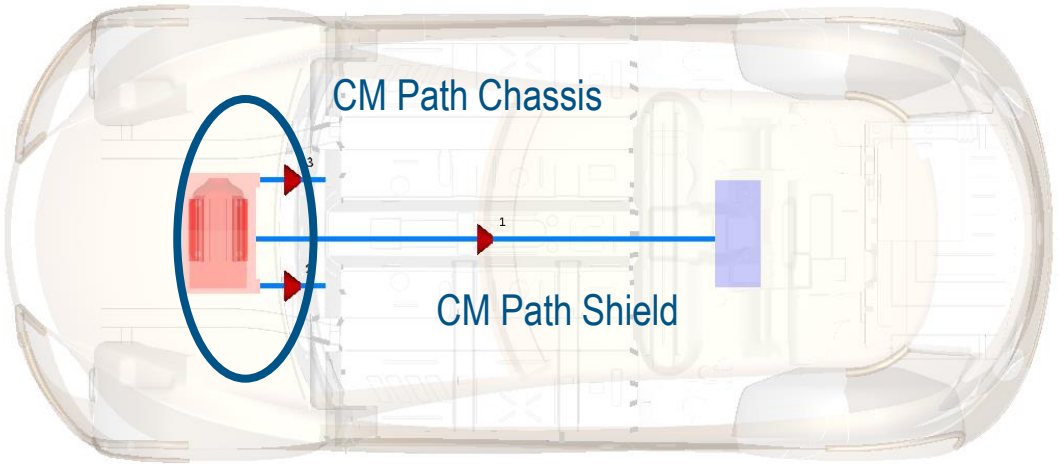
Common mode current path in e-vehicles



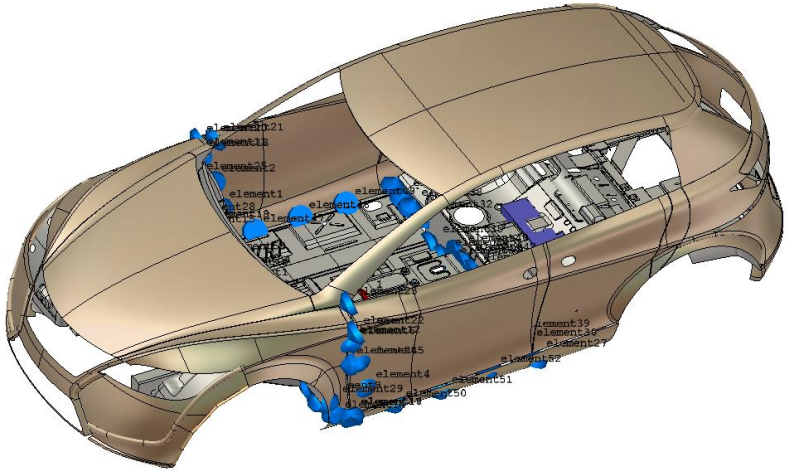
DASSAULT SYSTEMES

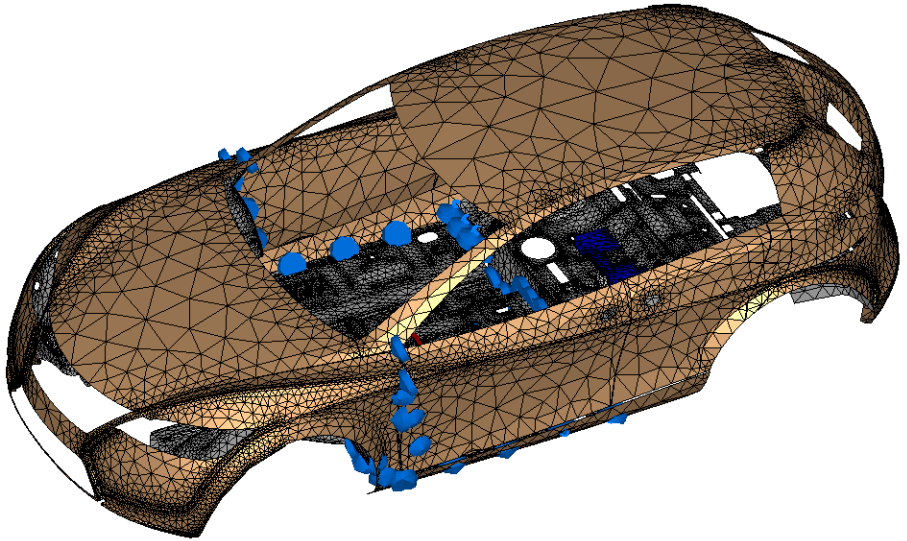
Common mode current path in e-vehicles





Model preparation

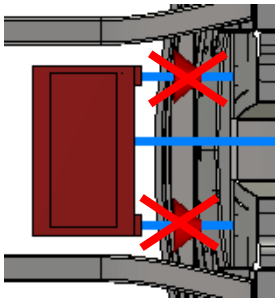




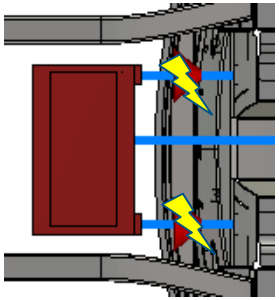
DASSAULT SYSTEMES

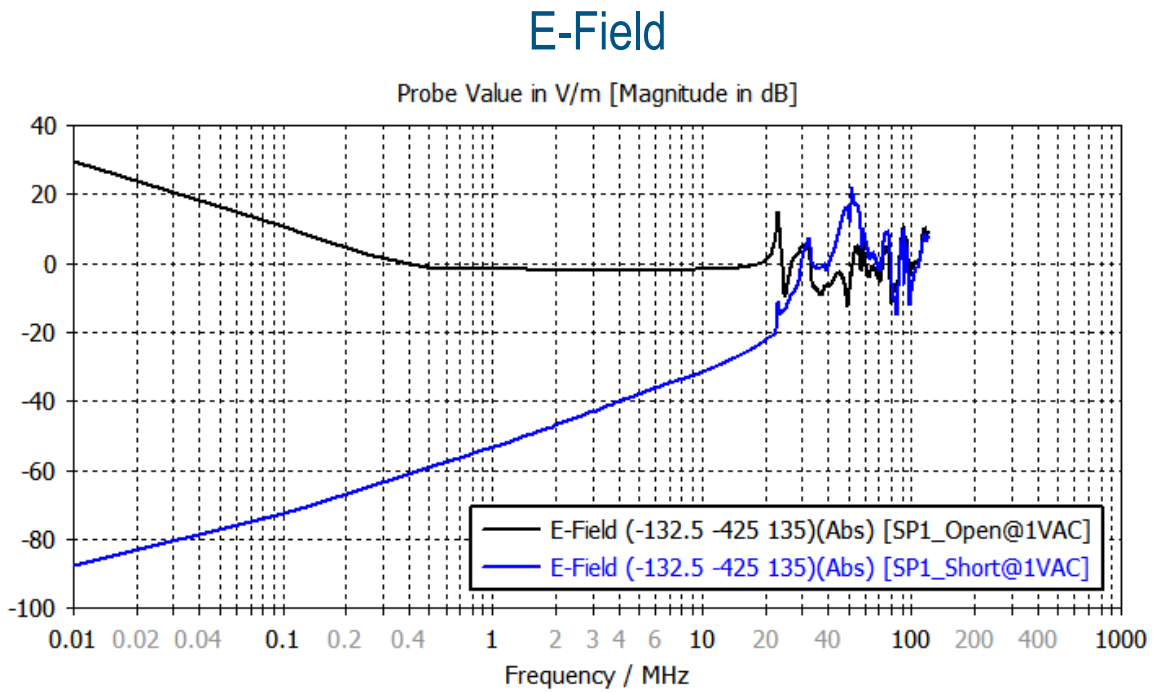
Radiated electric field

Open



Short



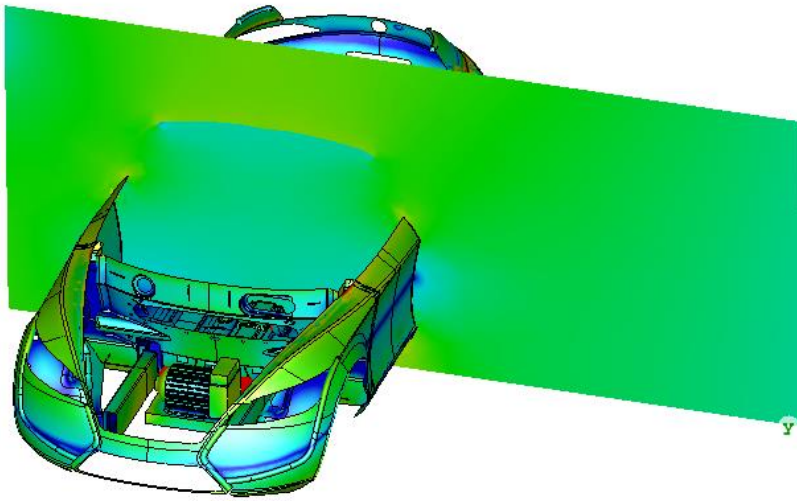


DASSAULT SYSTEMES

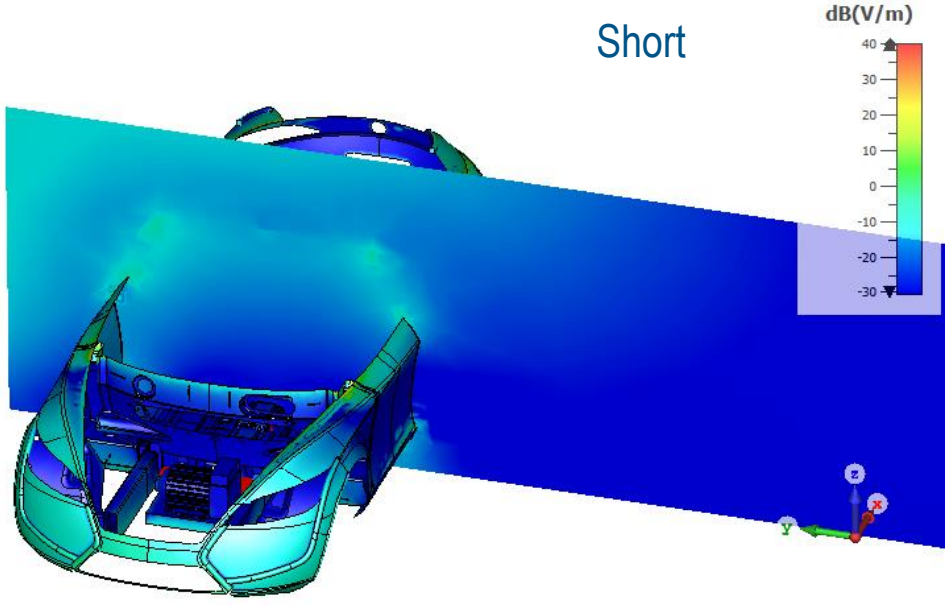
Electric field distribution

- 12 MHz

Open



Short

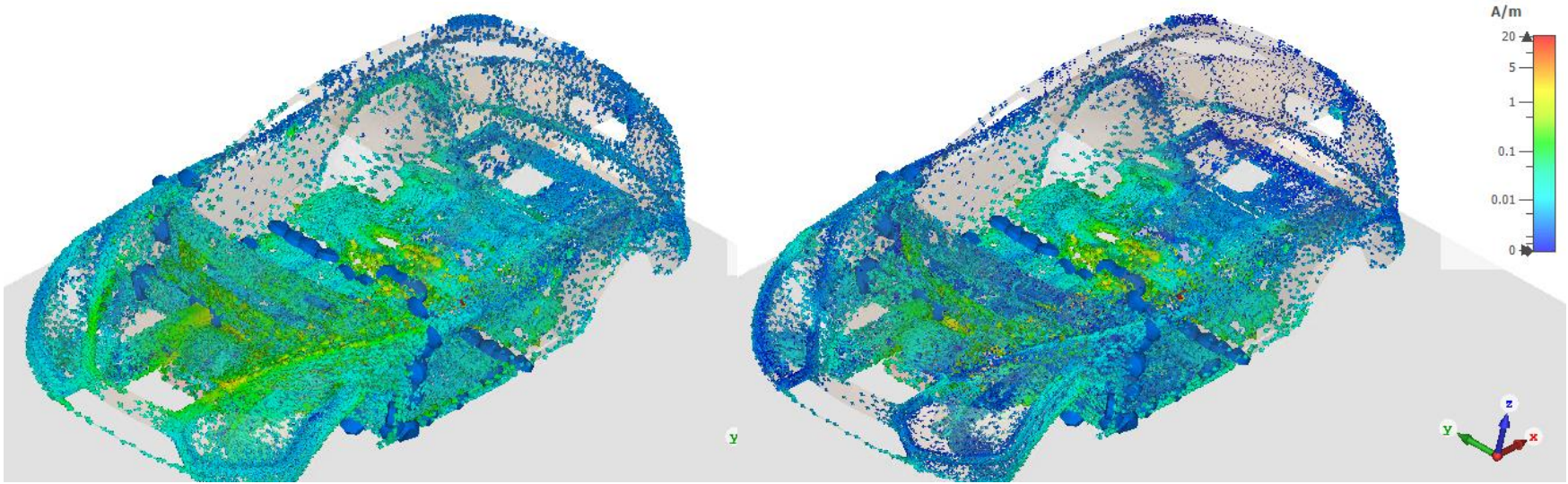


Current distribution

- 12 MHz

Open

Short



DASSAULT SYSTEMES

Wire Harness Simulation

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WIRE HARNESS SIMULATION | **Applications**

1D Simulation

- Crosstalk
- Signal/Power Integrity
- Shielding Effectiveness
- Scattering Parameters
- Characteristic Impedance
- Transient Simulation
- Conducted Emission
- Conducted Susceptibility

3D Simulation

- Radiated Emissions
- Radiated Susceptibility
- Far-Field/Near-Field
- Surface Currents
- EMI/EMC

BIO EM Simulation

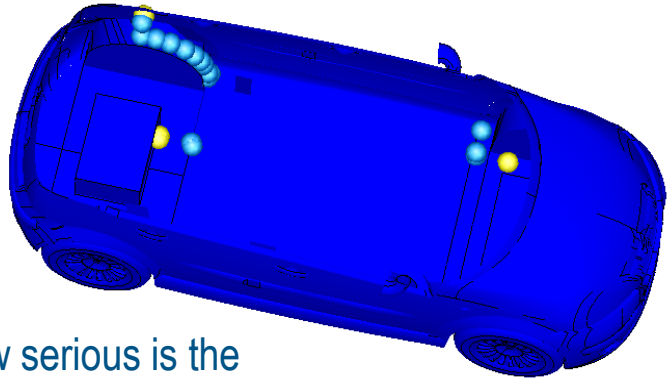
- Human Exposure Simulation
- Specific Absorption Rate
- Radiation Hazards

System Simulation

- Component
- Circuit Simulation
- Connectors
- ECU

DASSAULT SYSTEMES

QUESTIONS RELATED TO WIRING AND CABLE HARNESS



"How serious is the electromagnetic emission?"

"Do we need shielded cables?"

"How can we reduce vehicle weight and labor cost?"

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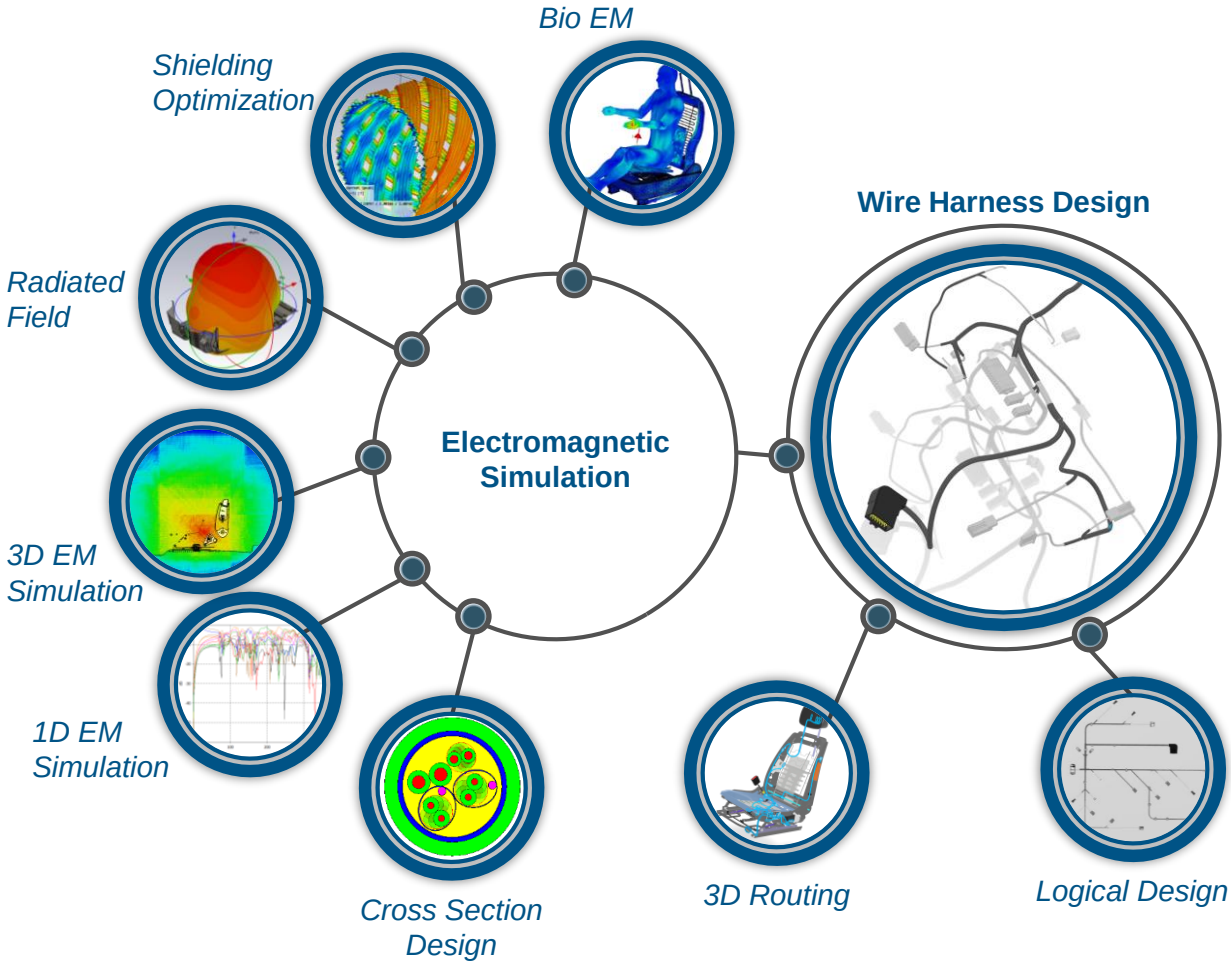
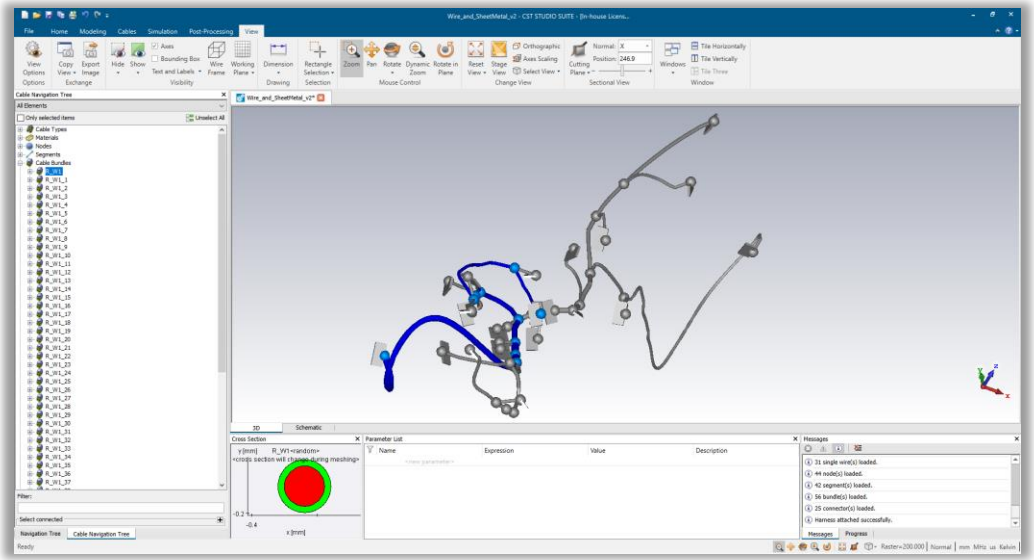
WIRE HARNESS SIMULATION | **Industry process**



WIRE HARNESS SIMULATION | **Cross section design**



- Imported wire harness data can be used (*.kbl)
- Full 3D routing
- Complex cross section definition
- Material & cable-type libraries

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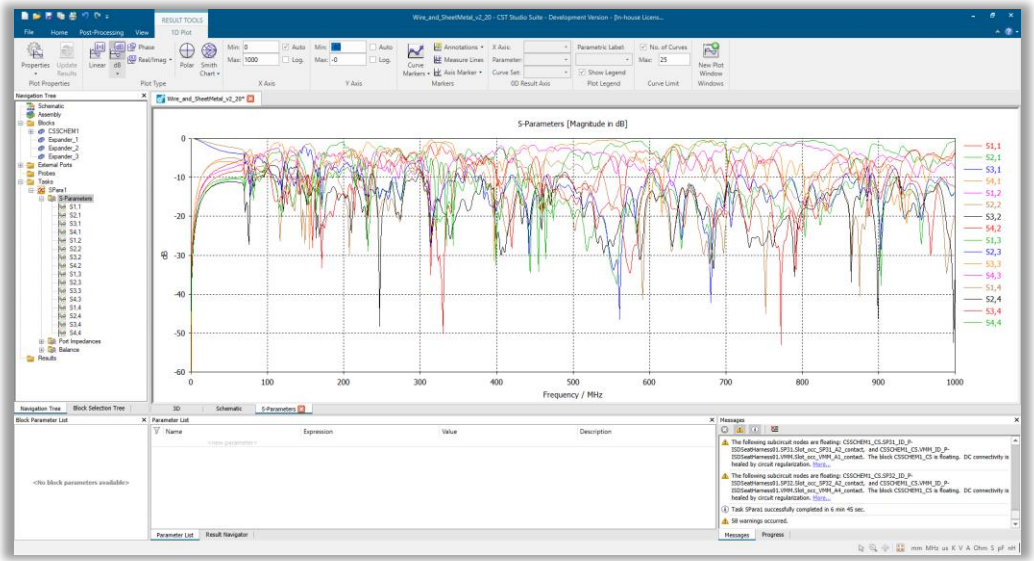
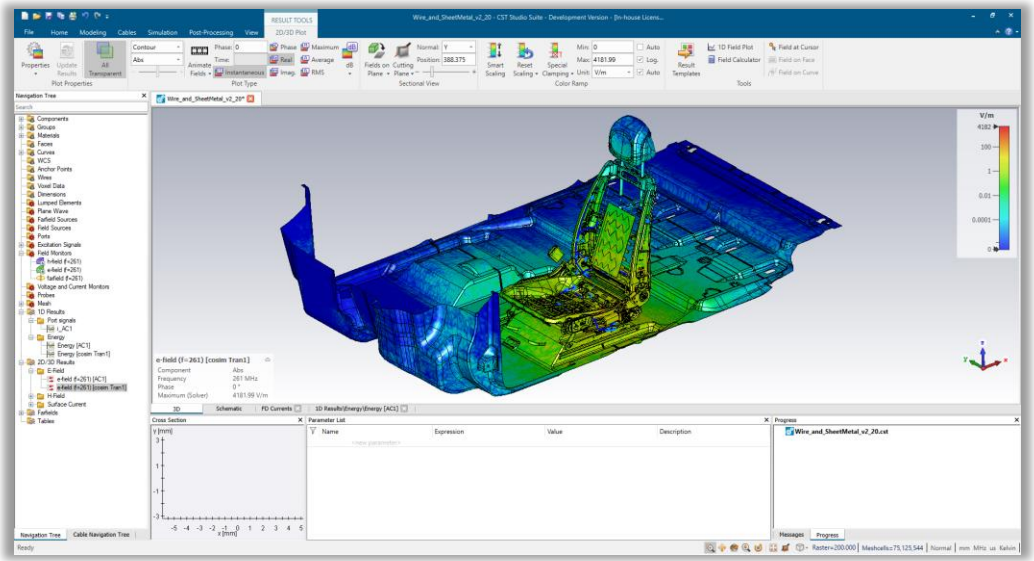
WIRE HARNESS SIMULATION | **1D EM simulation**



- Scattering parameters
- Transmission loss
- Induced pin voltage & current
- Transient simulation
- Propagation delay
- Cross talk
- Signal & power integrity
- Transfer impedance

DASSAULT SYSTEMES

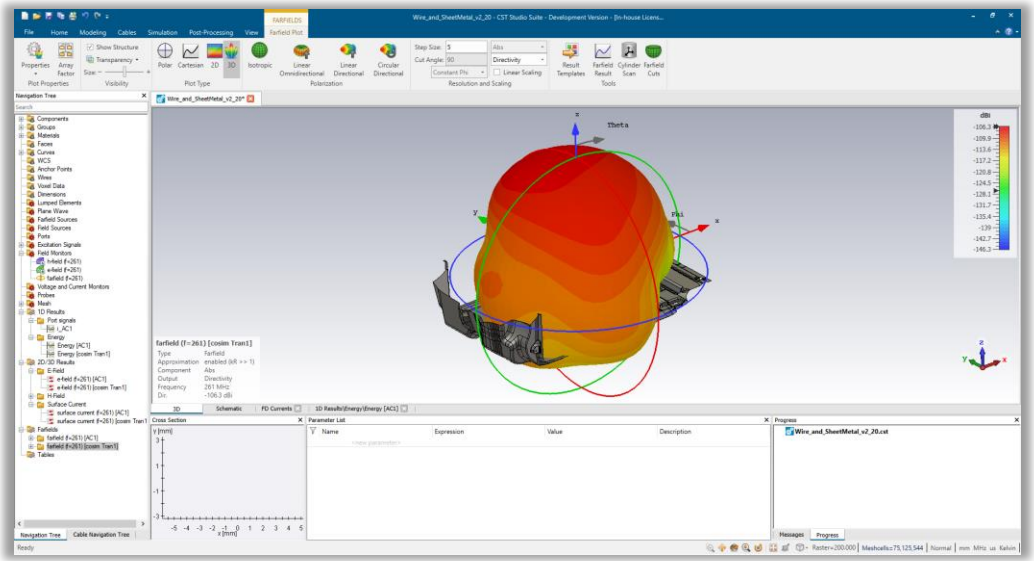
WIRE HARNESS SIMULATION | **3D EM simulation**



- Electromagnetic near field
- Electromagnetic flux density
- Surface current
- Radiated susceptibility

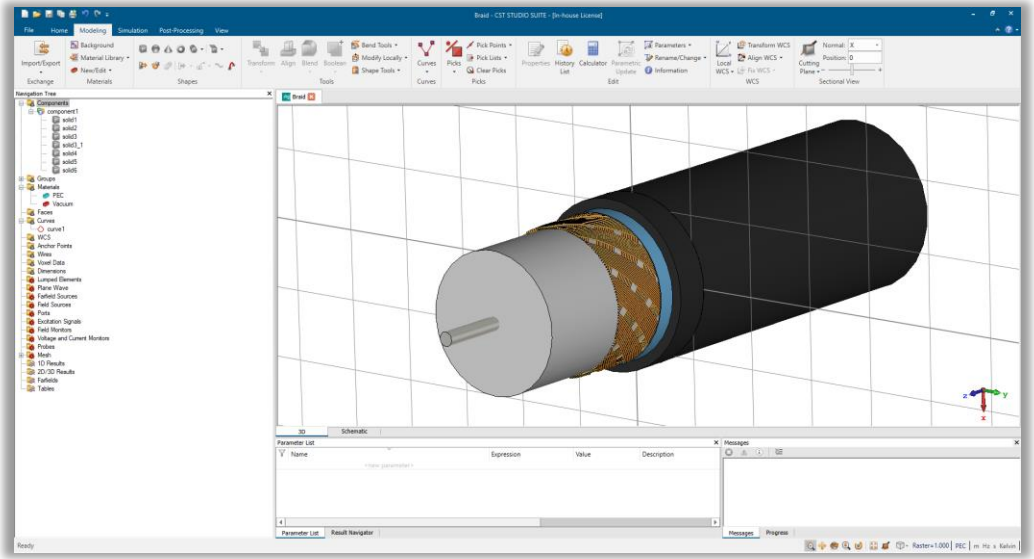
DASSAULT SYSTEMES

WIRE HARNESS SIMULATION | **Radiated field**



- Radiated Far-field characteristics
- Radiated emissions
- Electromagnetic Interference

WIRE HARNESS SIMULATION | **Shielding optimization**



- Full 3D shield modelling
- Library of shield types
  - Braid, solid, foil, etc.
- Fully parameterized
  - Optimize for optimal system performance

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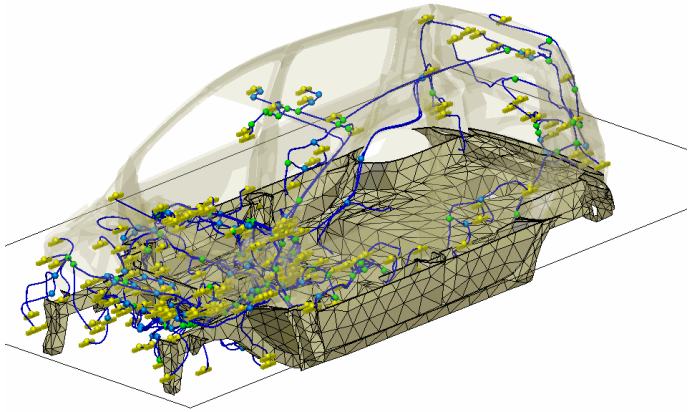
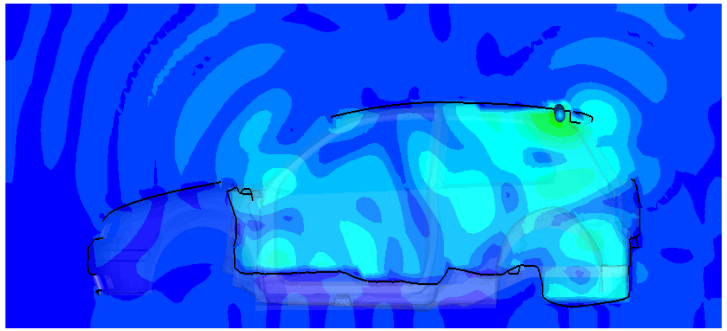
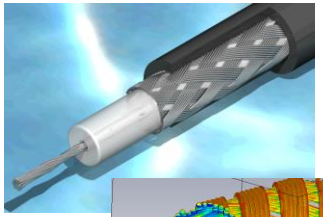
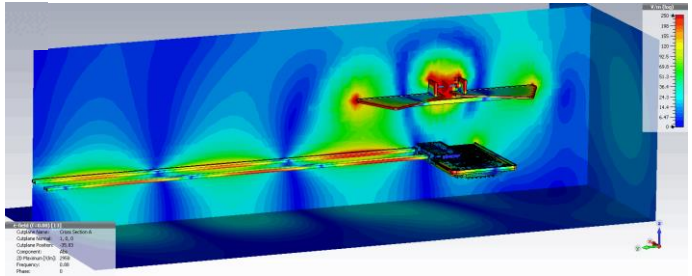
RADIATED EMISSION / IMMUNITY

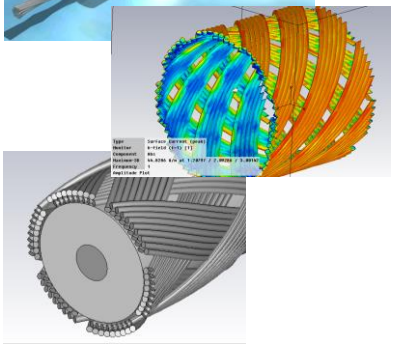


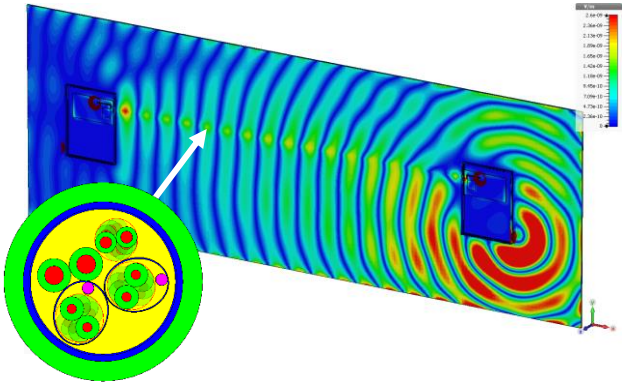
Component level &
System level
analysis











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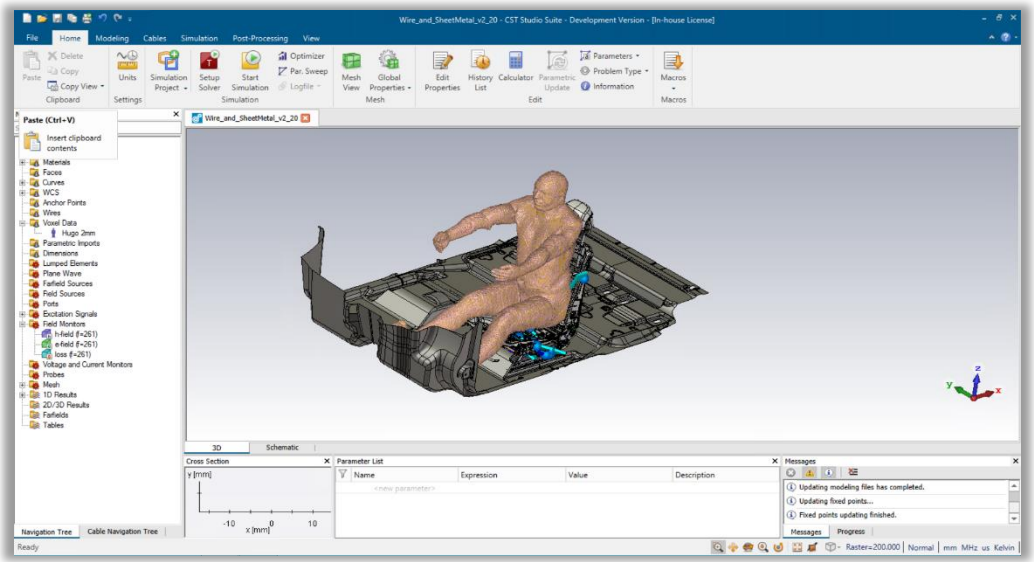
WIRE HARNESS SIMULATION | **BioEM simulation**



- Fully posable human body model
- Voxel based with different resolutions
- Human Exposure Simulation
- Specific Absorption Rate
- Radiation Hazards

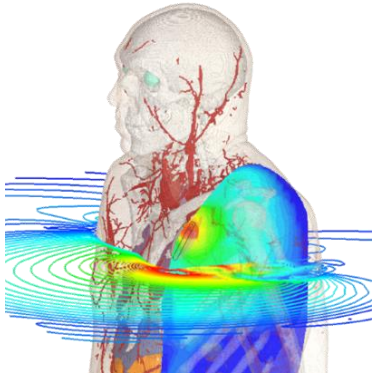
SAFETY | **Risk potential associated with HV**

Various organizations are involved in standardization and regulation providing guidelines for measurement and simulation setup as well as defining limits

International Commission on Non-Ionizing Radiation Protection (ICNIRP)

IEC, IEEE, local standardization authorities

Local legislation, e.g. *European Directive 2013-35 EU for "the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)"*

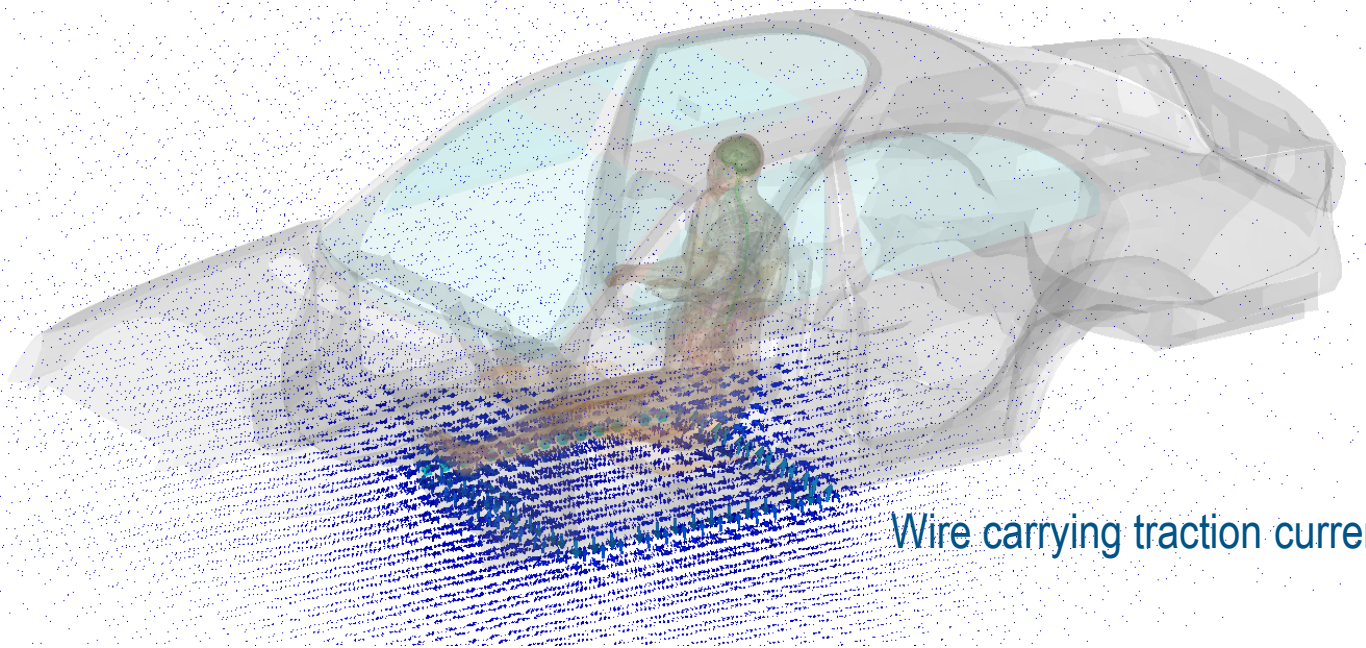


Potential risks are:

- Electric energy
- Accidental arcs
- Electric current flowing through the body (electric shock)
- Electromagnetic fields affecting e.g. pacemakers
- Interactions between electric energy and other media

DRIVER SAFETY IN PRESENCE OF HIGH TRACTION CURRENTS

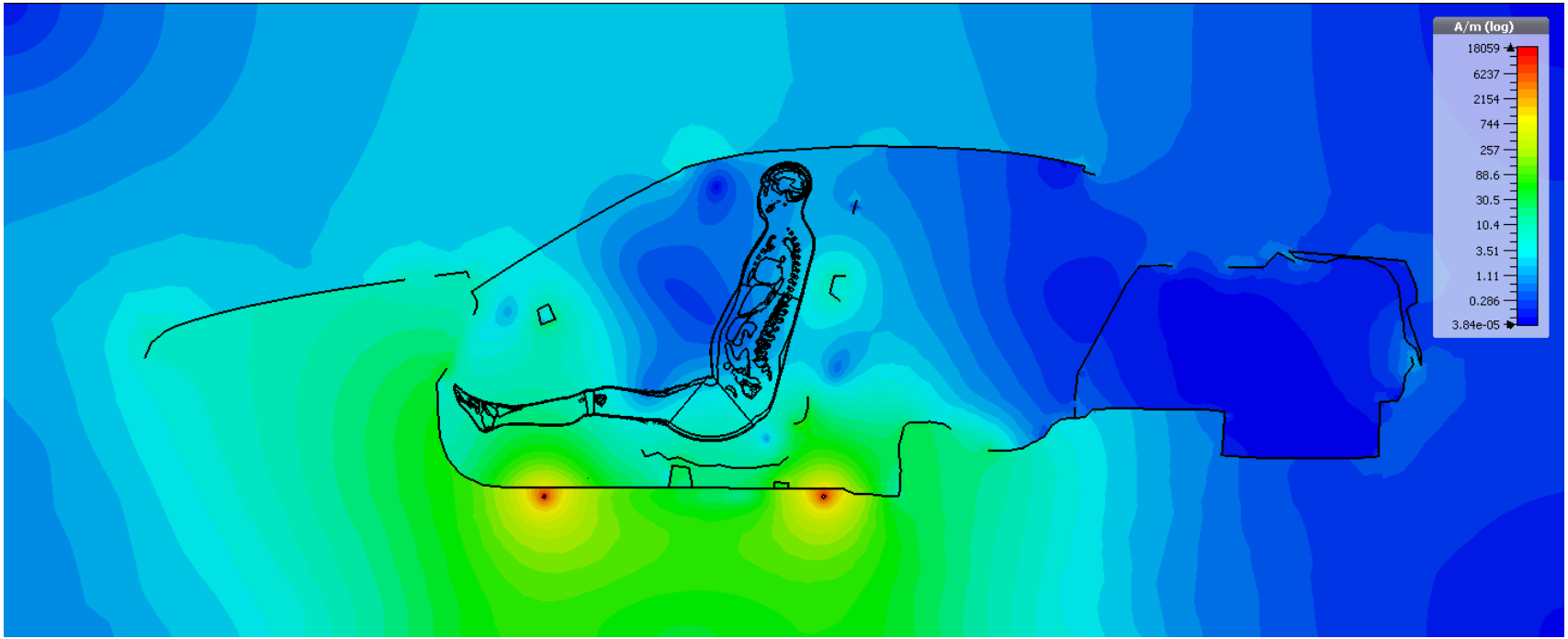
Car chassis modeled as transparent impedance sheet



Wire carrying traction current of 480 A at 2 kHz

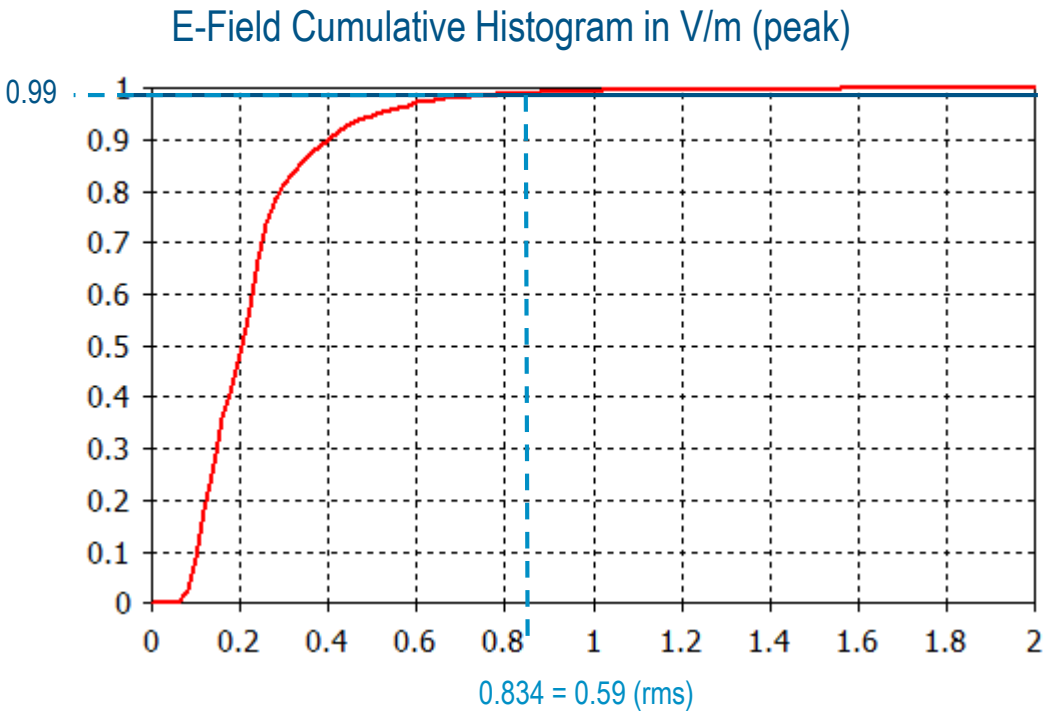
DASSAULT SYSTEMES

DRIVER SAFETY IN PRESENCE OF HIGH TRACTION CURRENTS



DASSAULT SYSTEMES

COMPLIANCE OF TRACTION CURRENT



Human exposure basic restriction at 2 kHz (ICNIRP)

- Occupational exposure: 0.8 V/m
- General public exposure: 0.4 V/m

99th percentile is 0.59 V/m (rms), above general public exposure limit. But: peak current high, average needs to be considered!

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Summary

- Simulation plays an essential role for the innovation of electric vehicles.
- Simulation can be done at different levels
  - Components, motor design, batteries and inverter
  - EMC/EMI Bench test
  - Full vehicle simulation
- Simulation provides insights into the problems associated with emissions.

- SIMULIA provides standard solutions and customized engineering services

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