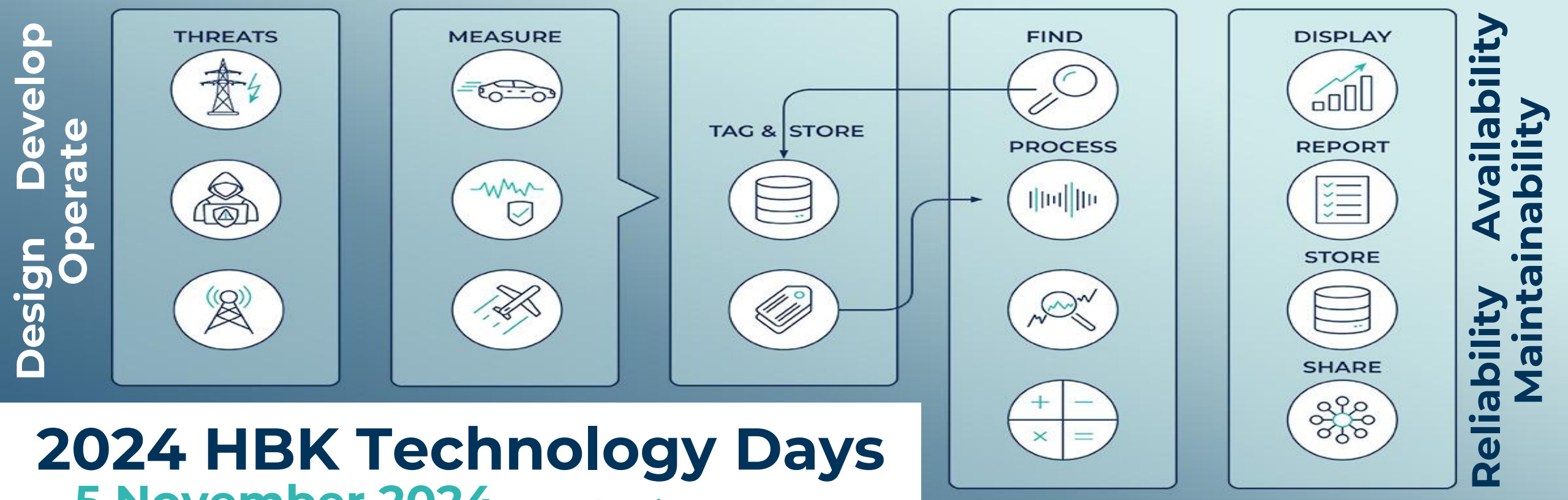


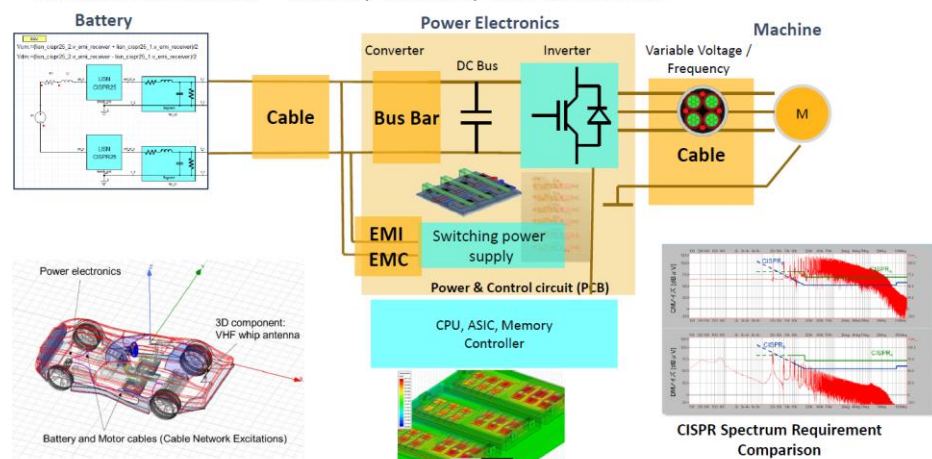


2024 HBK Technology Days

5 November 2024

Session 1: Minimising Electromagnetic Interference to Measurements

Problem Overview – Cables, Busbars, EMI & Thermal



- Electromagnetic simulation methods in automotive design to minimise interference and ensure electromagnetic compliance

Flavio Calvano,
ANSYS

Electromagnetic simulation methods in automotive design to minimise interference and ensure electromagnetic compliance

Abstract

- The world of power electronics is transitioning from silicon to wide-bandgap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) due to their superior performance in automotive and industrial applications. GaN and SiC enable smaller, faster, and more efficient design, but they produce high-level electromagnetic interference (EMI), which generates conducted and radiated emissions. The noise on the battery and motor cables or busbars can radiate and disturb the control units and antenna placed on the vehicle, and in addition, internal couplings can be dangerous for functional behaviour of the complete e-powertrain system.
- This presentation presents a complete simulation approach, formulated to be optimal in terms of accuracy and speed for each inverter main component. The virtual simulation approach is proposed at the design stage of each component, as well as at system level in the final validation and homologation to save time for EMI testing. The common mode chokes (CMC) and EMI filter designs are helping EMC engineers achieve lower emissions.

Electromagnetic simulation methods in automotive design to minimise interference and ensure electromagnetic compliance

▲ About the presenter, Flavio Calvano

Application Engineering Manager, EMI/EMC, ANSYS

- Flavio Calvano graduated in Electronic Engineering from the University of Naples "Federico II" with summa cum laude in 2007 and went on to obtain a PhD in Computational Electromagnetism in 2010. He is the author and co-author of numerous articles on electromagnetic simulation, applied to both low and high frequencies. Since 2011 he has held the position of Application Engineer at Ansys working on issues regarding Signal / Power Integrity, Power Electronics and Electromagnetic Compatibility; for the last three years he has been managing the Ansys EMI/EMC Application Engineering team in Europe.



Powering Innovation That Drives Human Advancement

Electromagnetic simulation methods in automotive design to minimize interference and ensure electromagnetic compliance

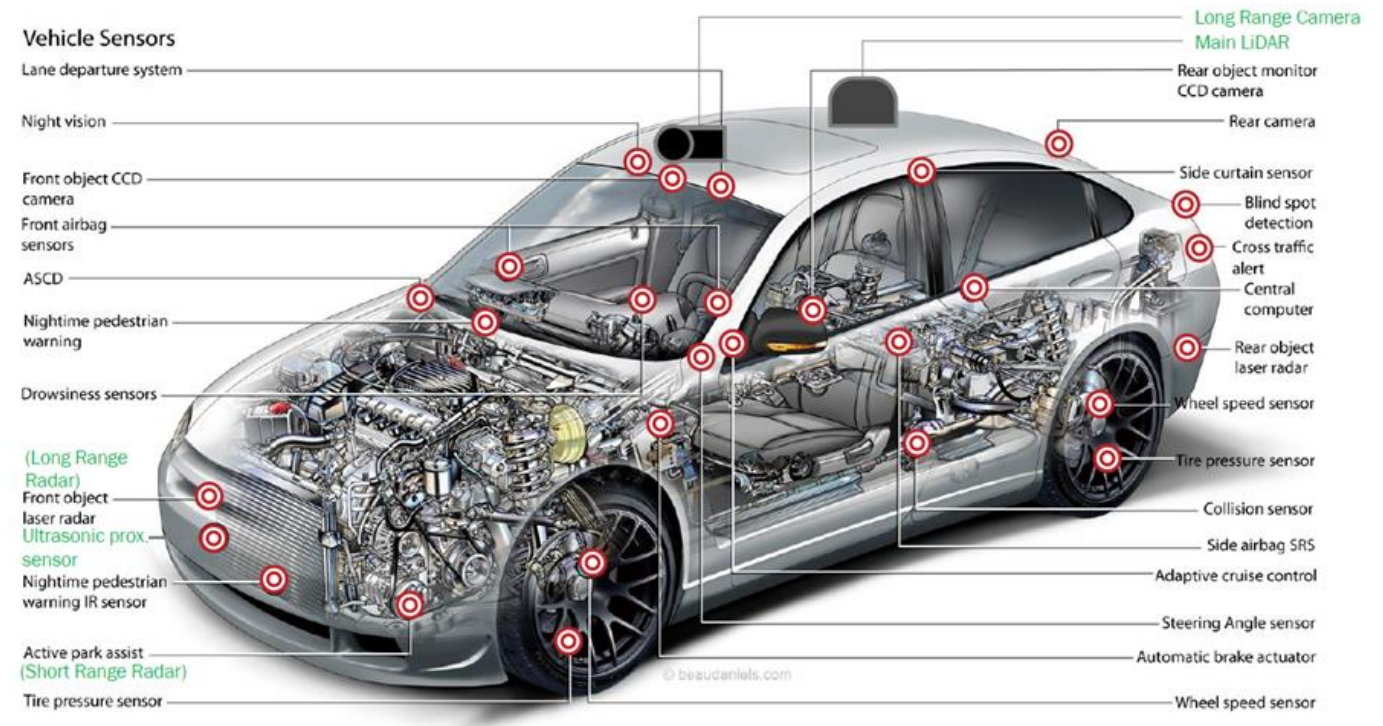
Flavio Calvano PhD

Application Engineering Manager EMI/EMC

flavio.calvano@ansys.com

Motivation: Vehicle Electronics

- Fully electric powertrains and the development of vehicle autonomy increases the need for:
 - Active electrical components
 - Complex interconnected systems
 - The use of RF systems.
- Both far and near-field sensors **require low-noise environments** to ensure adequate performance
- Real-time decision making for **safety-critical situations** requires high speed communication and processing
- **Power quality** from both on-board (powertrain) and off-board (utility grid) requires deliberate EMC analysis
- Safety requirements of **increasing autonomy** mean that more electronic system functions will be required to pass radiated immunity testing perfectly to meet regulatory requirements

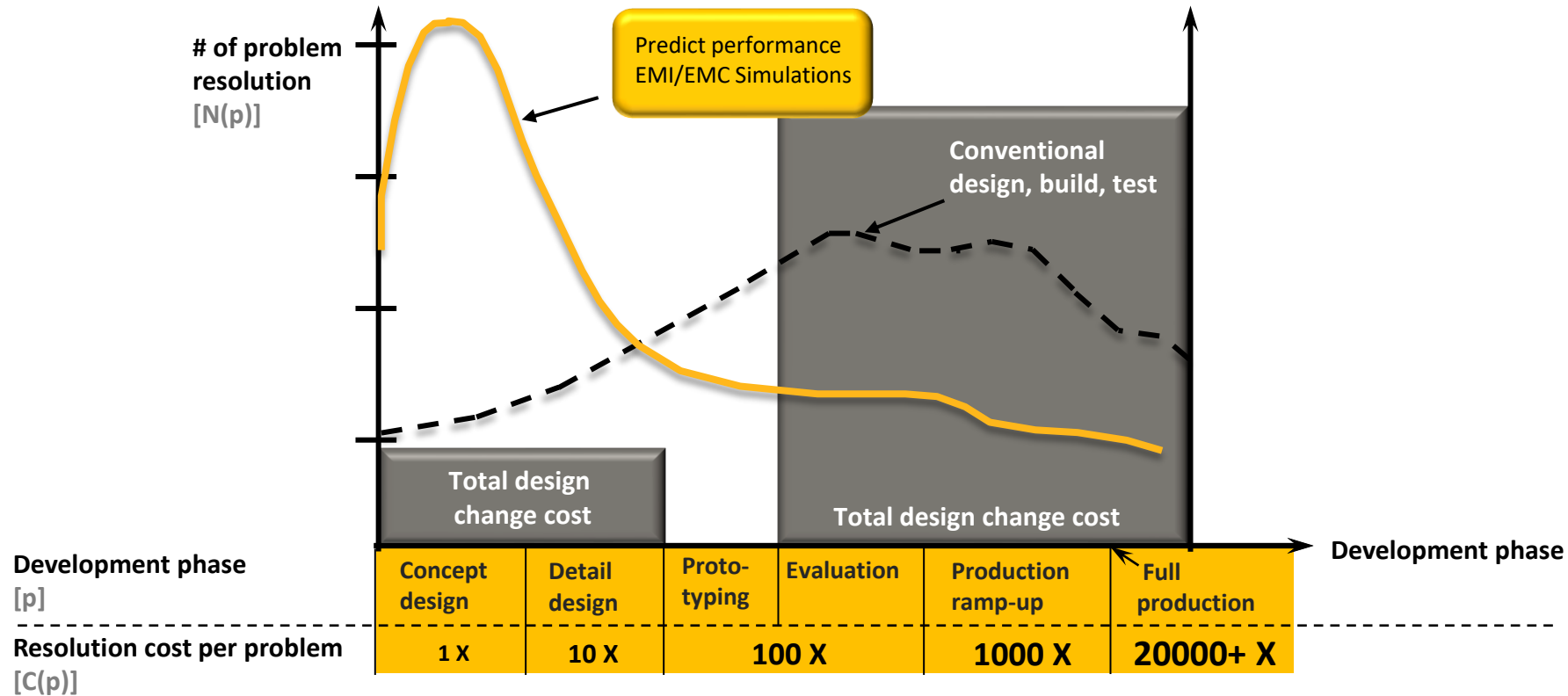


Motivation: EMC Testing

- Vehicles with increasingly complex electronic systems need to pass EMC tests, including:
 - CISPR 12, 25, and 36 for EVs
 - ISO 11451 and 452
 - ECE Reg 10.05/10.06 (Europe)
 - ISO 10605 (ESD)
 - ICNIRP 1998/2010/2020
 - OEM-specific vehicle and component requirements
- Failure to consider EMI/EMC in early design phases will result in dramatic schedule delays and additional cost.
- The existence of regulatory requirements creates the real possibility that vehicles coming off assembly lines **cannot be sold** until compatibility is retrofit on the vehicle.



Benefits of EMI / EMC Simulation

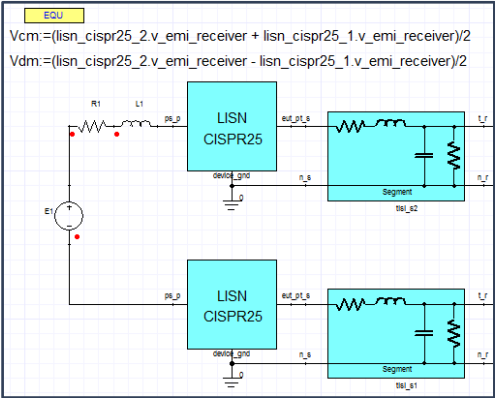


Agenda

- Introduction: Goals & Challenges in Power Electronics design
- Power Converter Design
- Electro-thermal Design
- EMI/EMC

Problem Overview – Cables, Busbars, EMI & Thermal

Battery



Power Electronics

Converter

DC Bus

Inverter

Cable

Bus Bar

Variable Voltage / Frequency

Cable

M

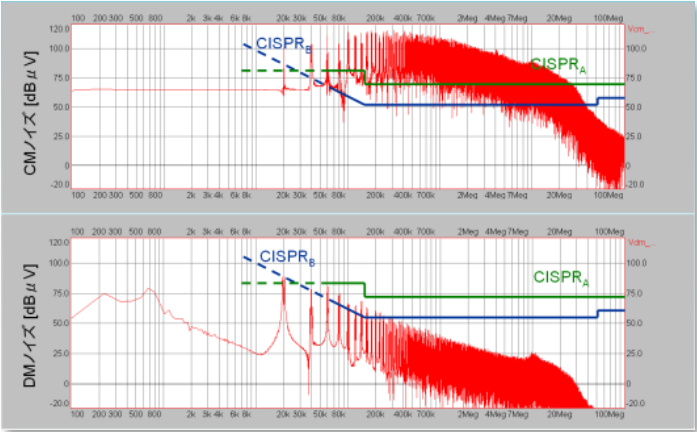
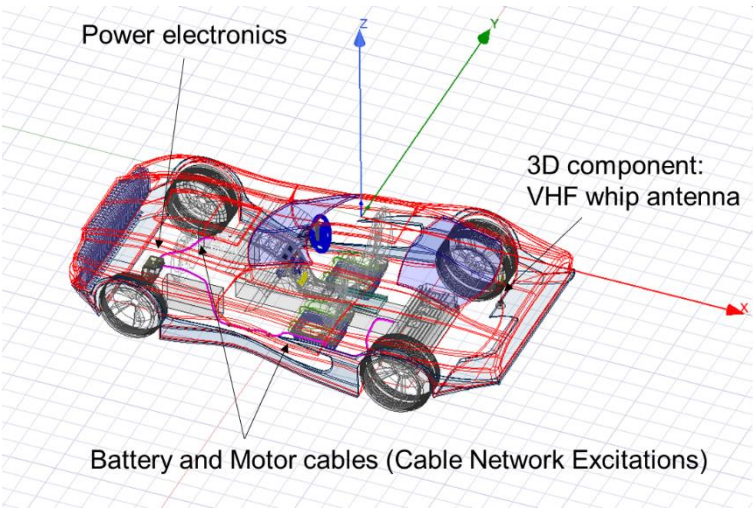
EMI
EMC

Switching power
supply

Power & Control circuit (PCB)

CPU, ASIC, Memory
Controller

Machine



CISPR Spectrum Requirement
Comparison

Power Electronics– Goals & Challenges

Engineering goals:

High Performance

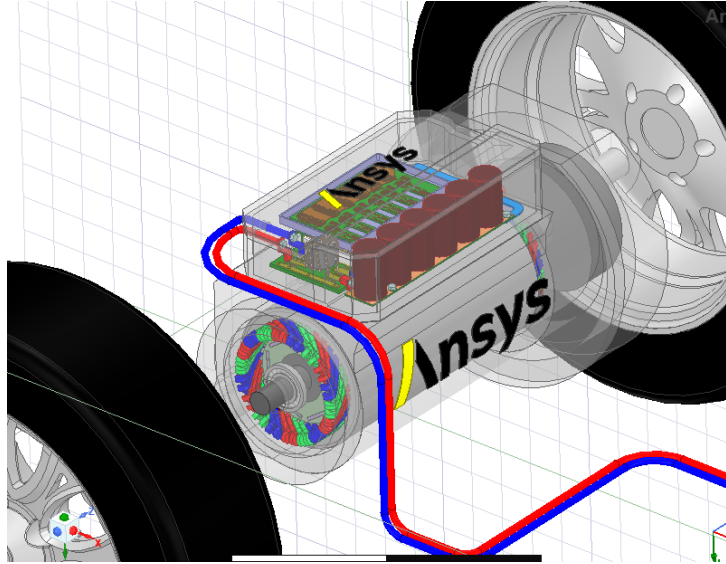
- Max. Power density
- High efficiency
- Long life time

Reliability

- Thermal reliability
- EMI/ EMC
- Structural reliability

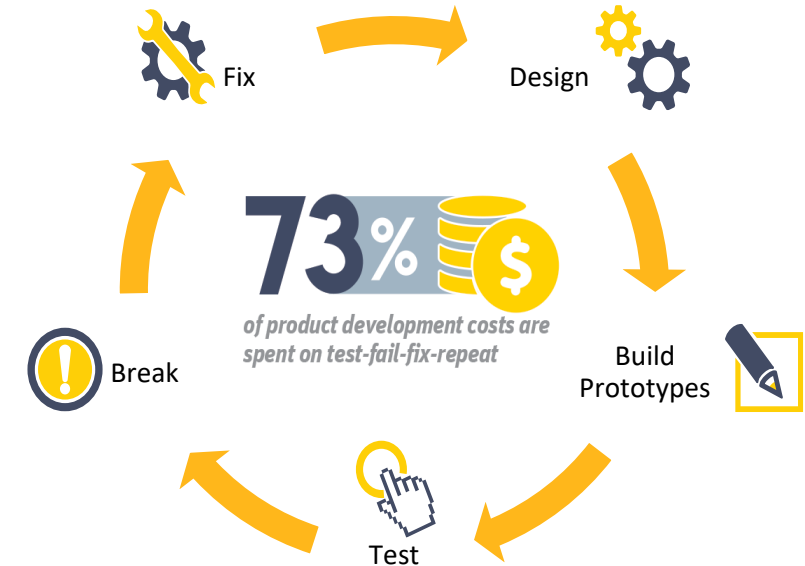
Low costs

- Miniaturization
- Failure detection
- Material/ components
- Manufacturing



Challenges:

- Increasing complex requirements
- Time and competitive pressure
- System integration/ component interaction

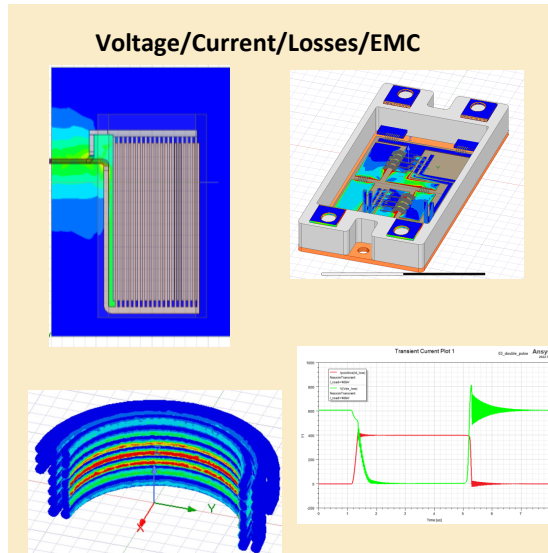


Simulation-led design can significantly reduce the number of physical prototypes
Reduction in overall development time, cost and risk

Ansys Multi-physics Solution

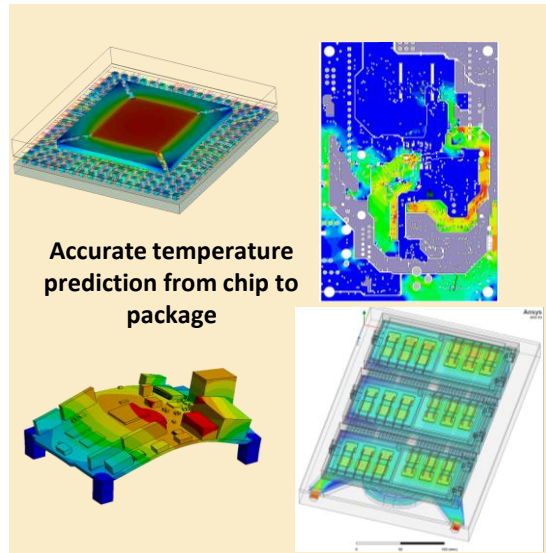
Component & Physics Interaction and System Integration

Electromagnetic



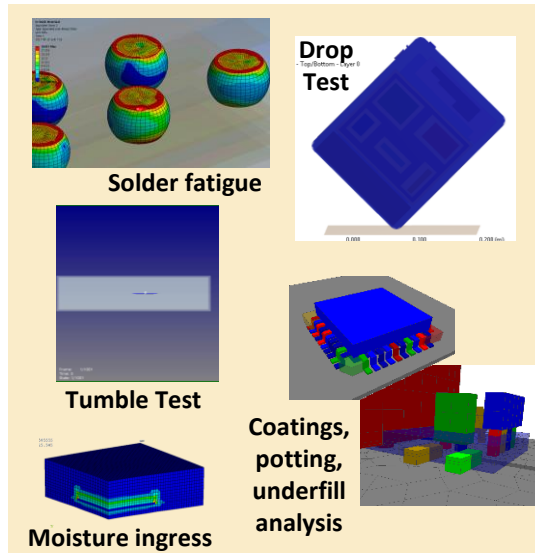
- **Optimized performance** by maintaining low losses and optimized design of components
- **Reduce cost** by early fault detection and mitigation of risks

Thermal reliability



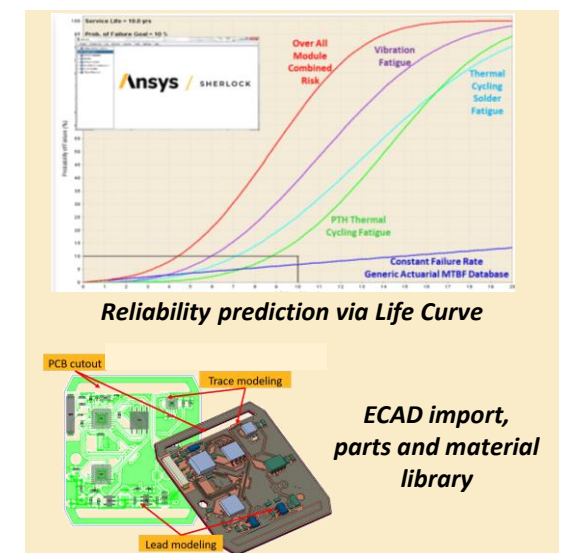
- **Optimized performance** by enhanced cooling strategy
- **Longer lifetime** through less failure
- **Reduced development costs and time** by early detection of cooling design weakness

Mechanical reliability



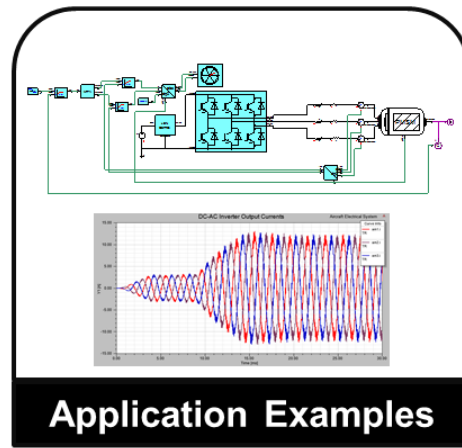
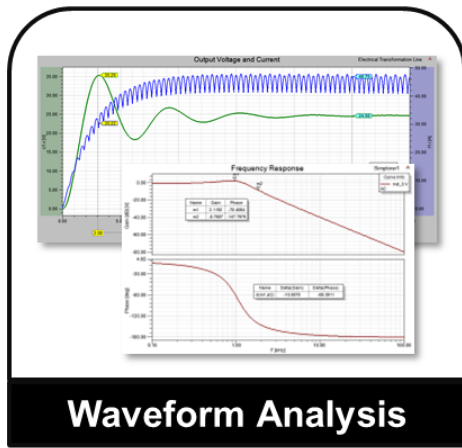
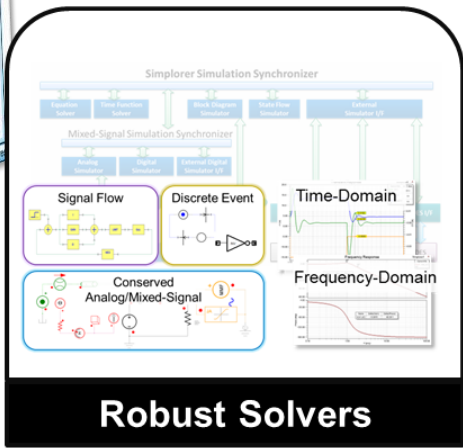
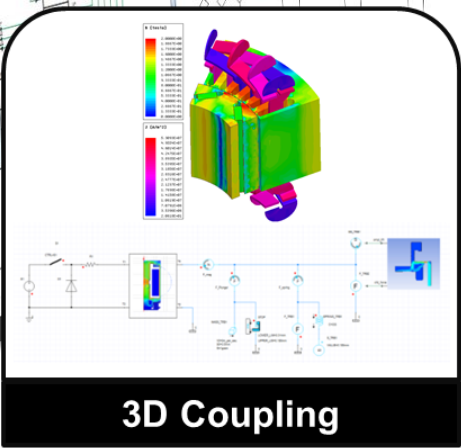
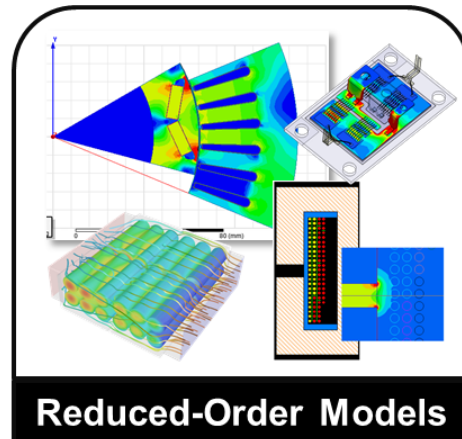
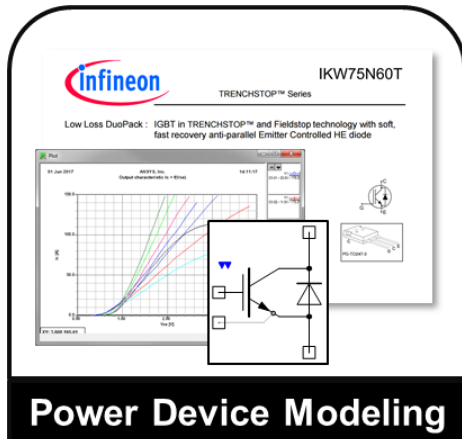
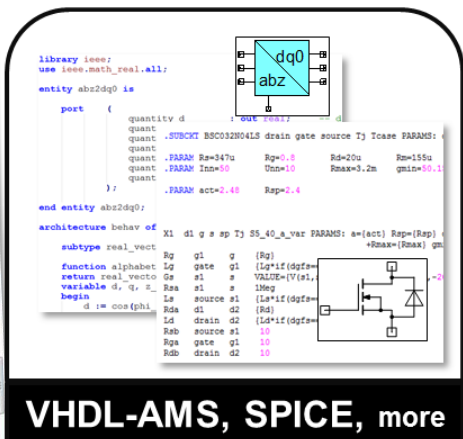
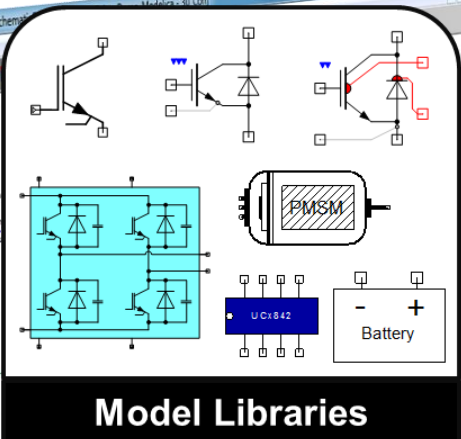
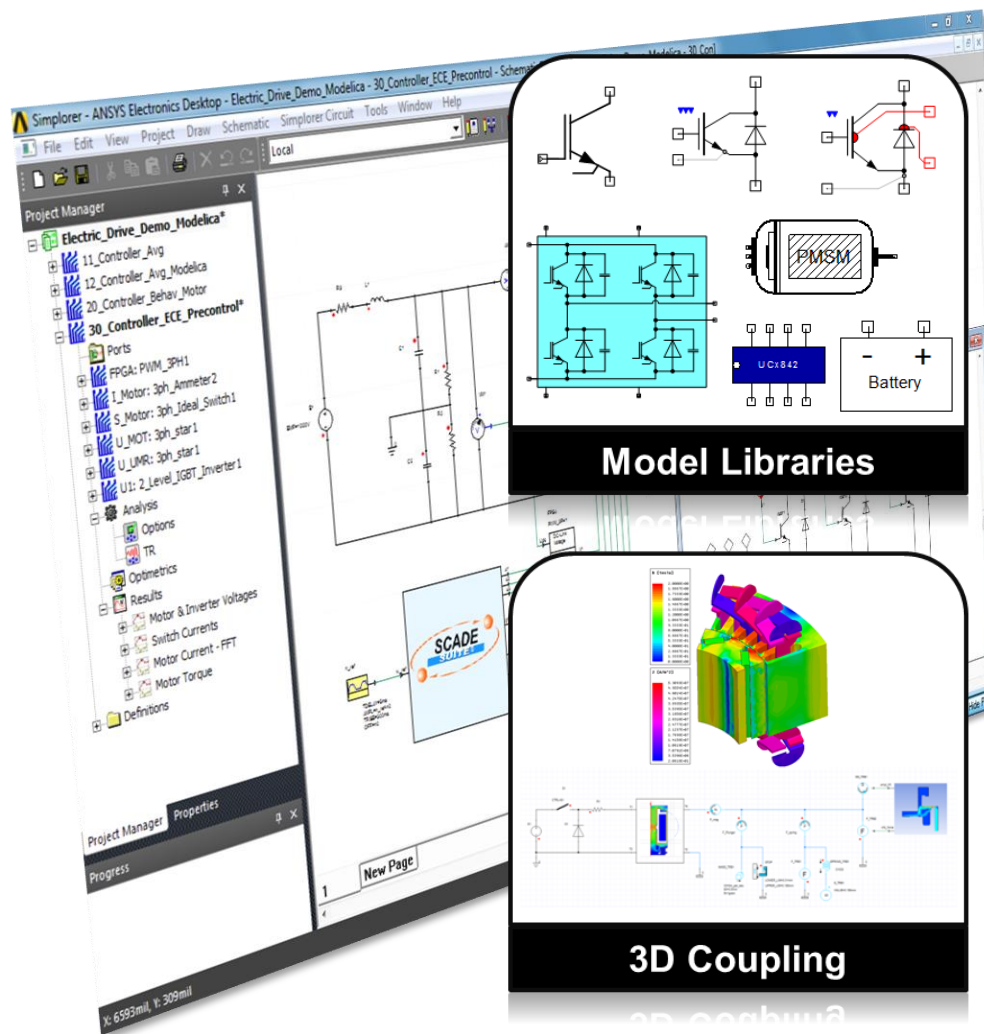
- **Optimized performance** by testing under real and extrem conditions and insight into physical behaviour
- **Reduced development costs and time** by early detection of failure
- **Reduced costs** by avoiding over-engineering

Lifetime prediction



- **20-50% time reduction** in PCB reliability prediction at all levels, **reduced program cycle time** (8 weeks/ test)
- **Reduced costs** by optimized component selection & placement, **~50% less physical prototypes**

Modeling, Simulation & Analysis for Power Electronics & Electrified System





Power Converter Design

Component Level Solutions

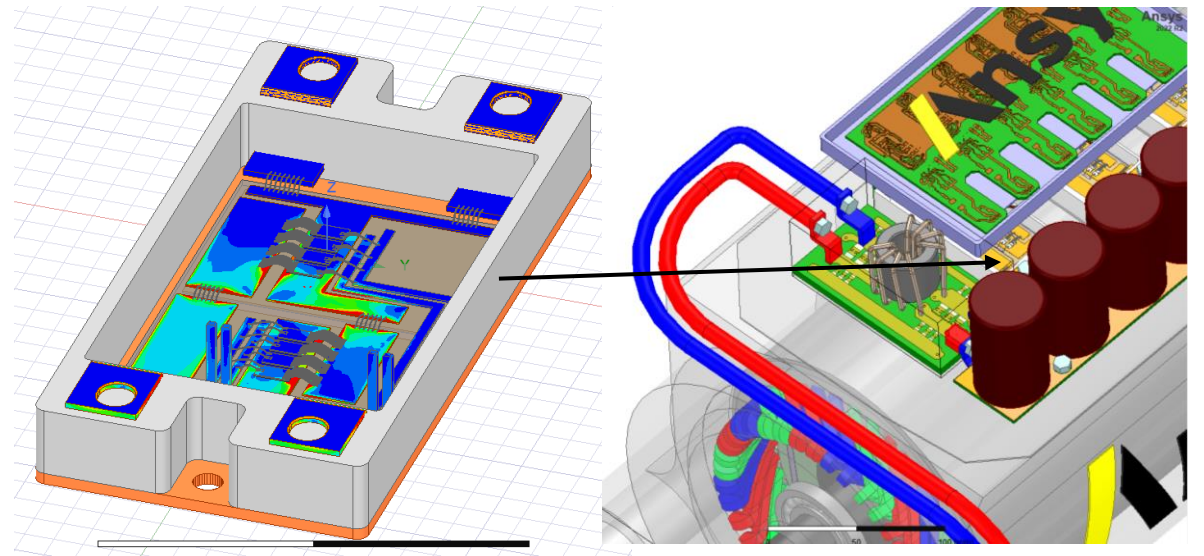
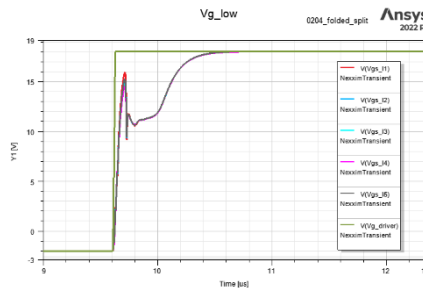
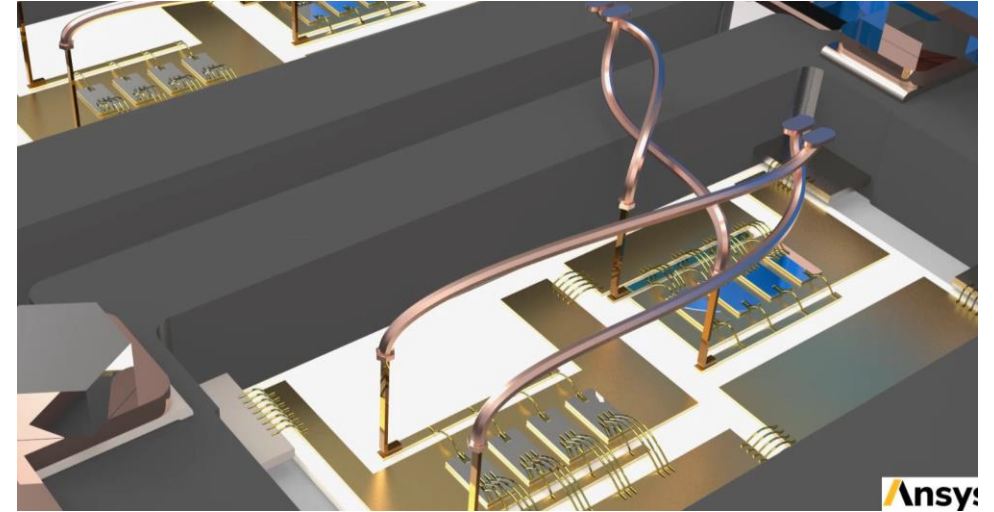
Power Modules Design

Critical within the electric drive system

- Most expensive component
- Highest failure rates
- Validation with prototype increases delivery time and cost

Technical challenges

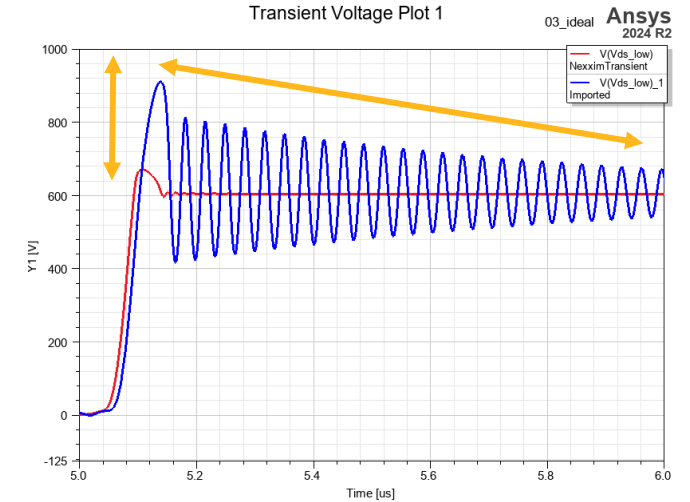
- Complicated electromagnetic environment in compact space
 - Multiple transistors in parallel
 - Parasitics and coupling of bond wires and circuiting traces
 - **turn-on/off -> High freq EMC issues**
- Fast turn-on and performance requirements
 - SOA (Safe Operating Area): over voltage, current and temperature
 - Low losses
 - Equal current sharing between transistors
 - Oscillation
- Interaction with externals
 - DC link inter connection
 - Gate Drive



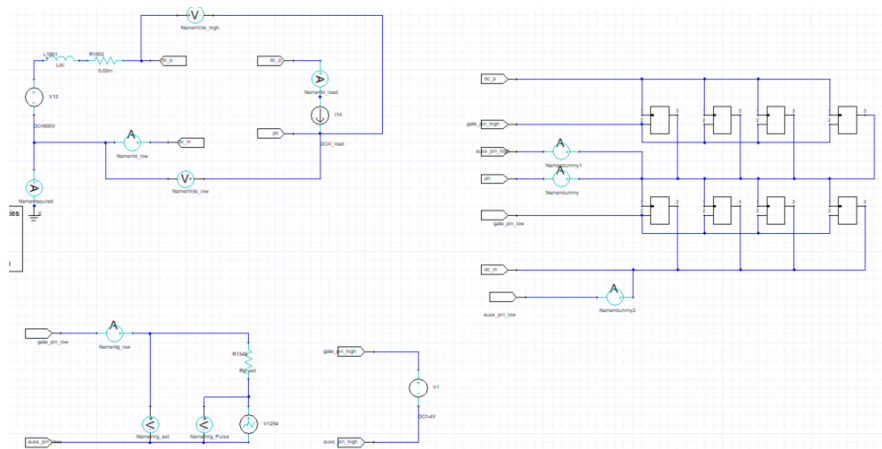
Comparison between ideal case and 3D simulation

Comparison between ideal case (red) and high fidelity Q3D model(blue)

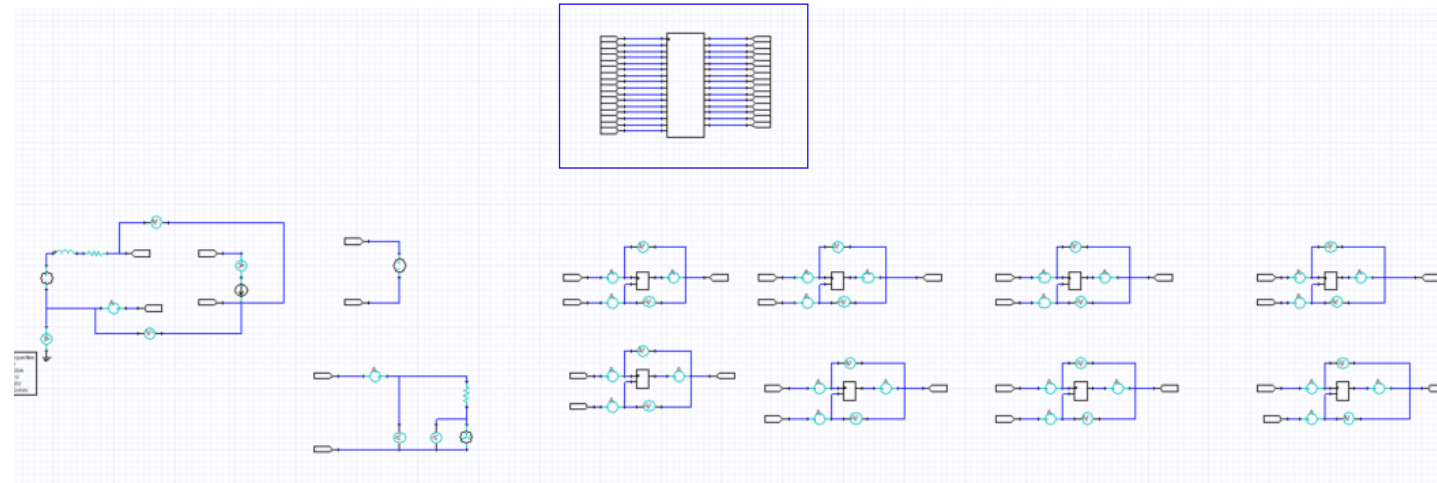
	Ideal case	Q3D model
Voltage overshoot	68V	300V
Oscillation	-	29MHz (EMI/EMC issue)



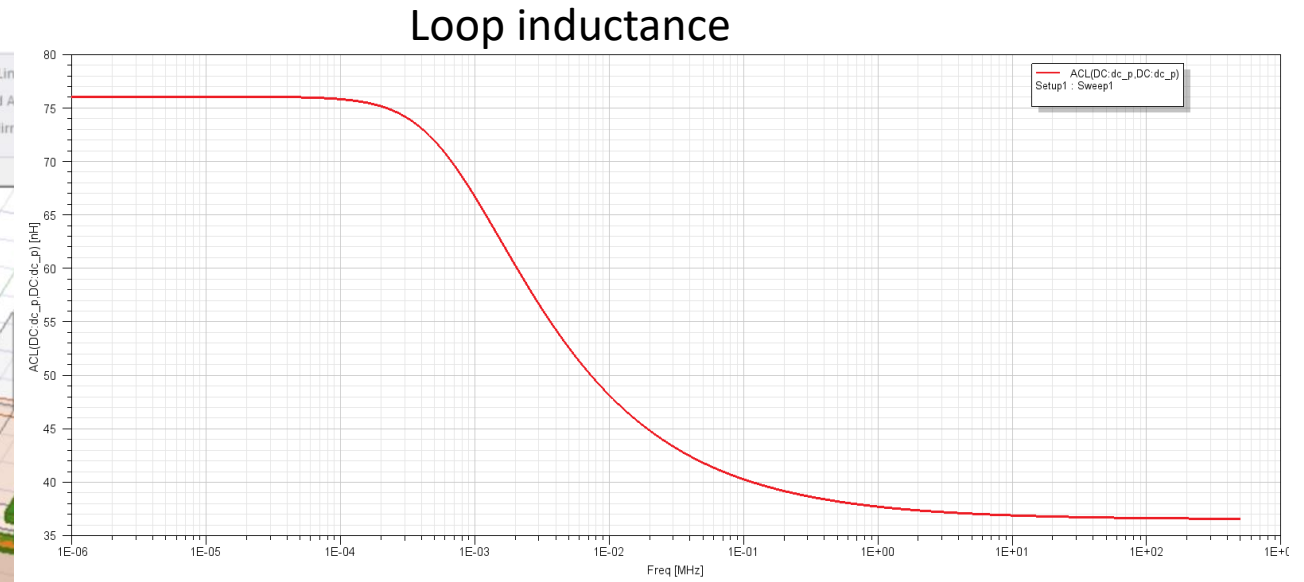
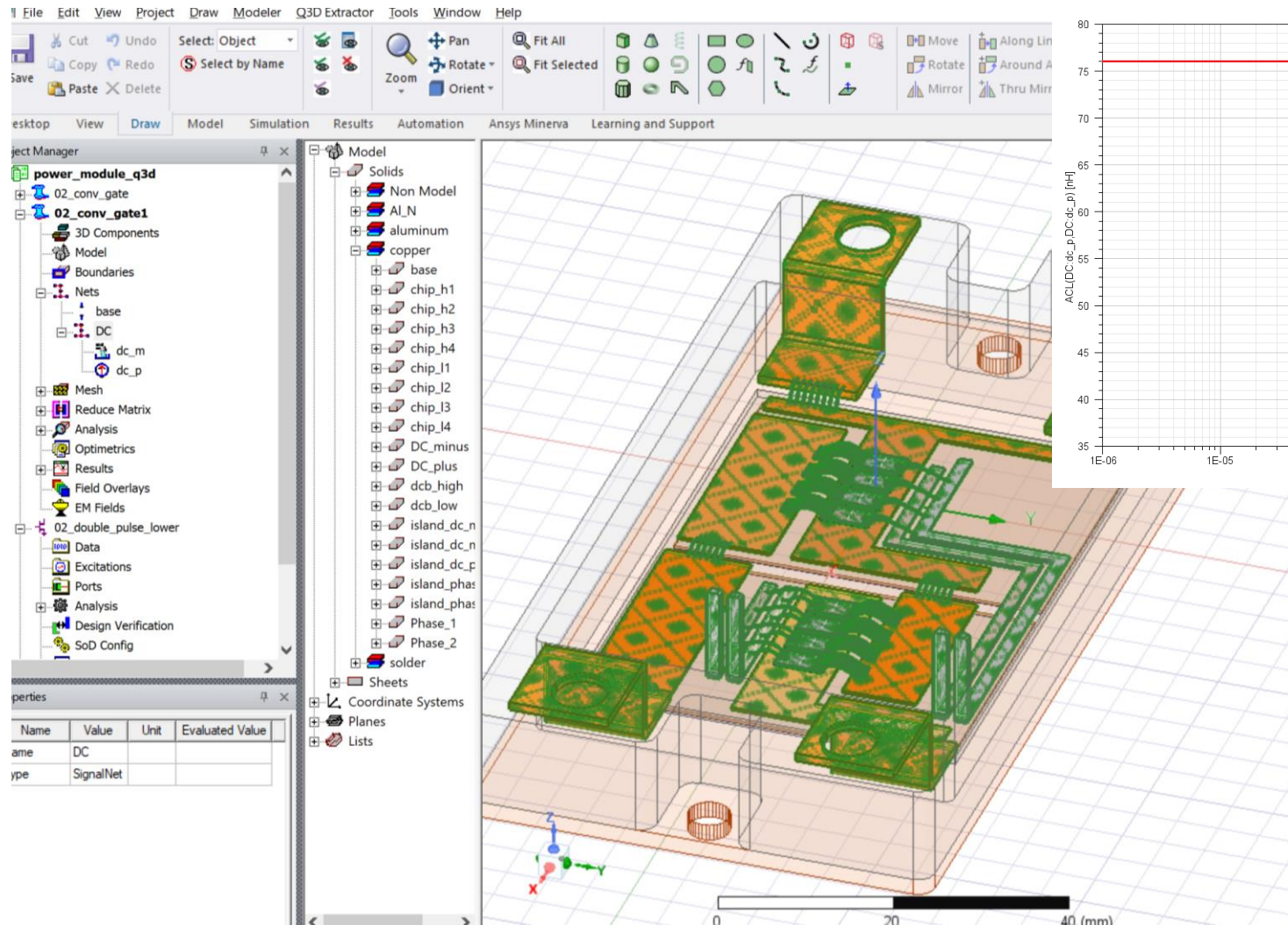
Ideal circuit



Circuit with Ansys Q3D model

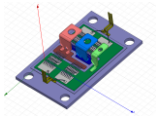


Loop inductance computation



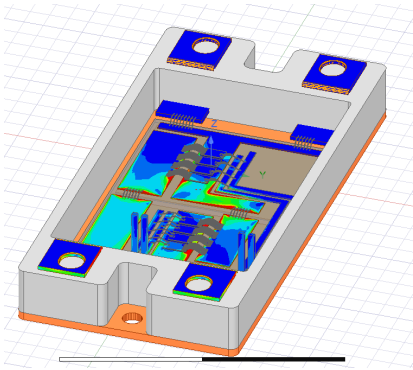
Power Devices Design

Power
Module

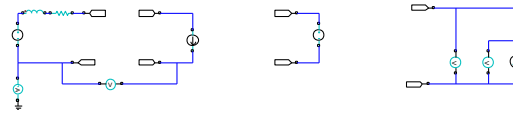
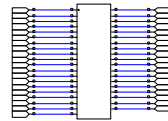


Analysis of device switching behavior

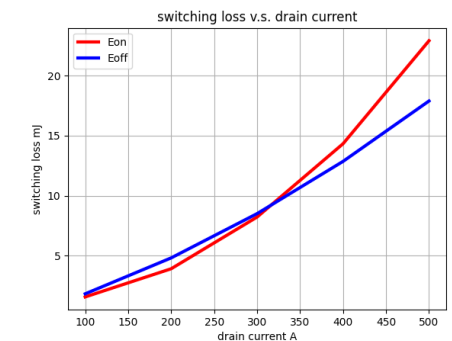
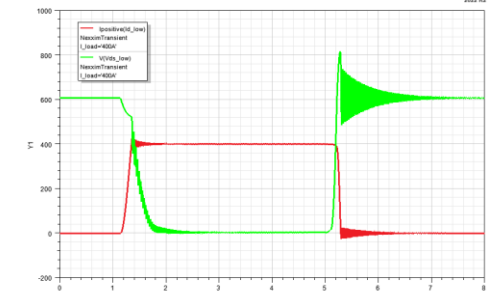
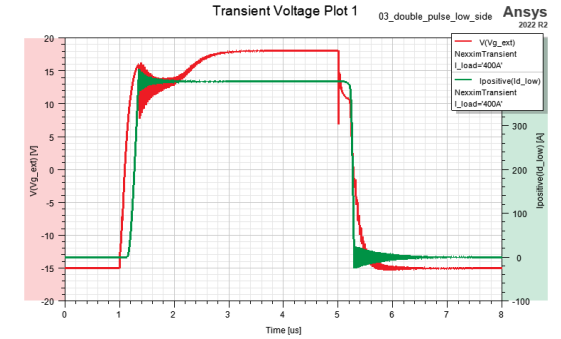
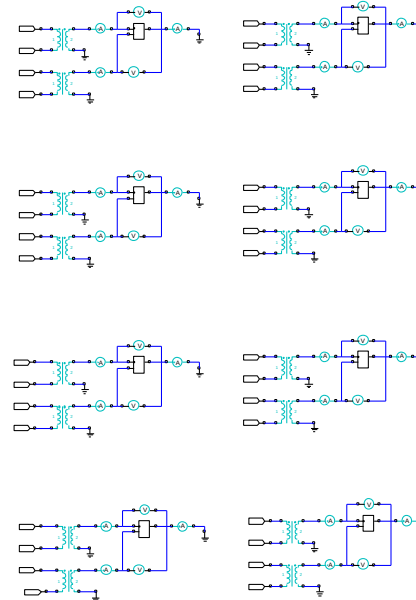
- Non-linear frequency dependent inductance and resistance
- Fast switching results in ringing
- Switching losses need to be kept to minimum



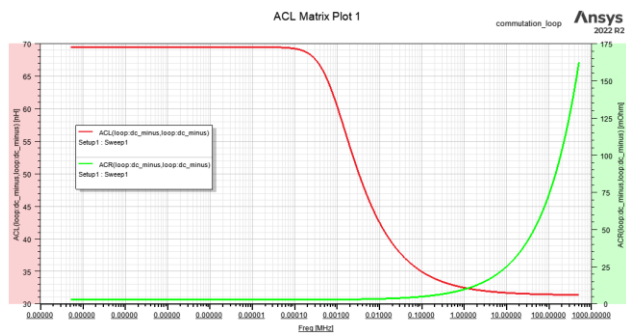
Power module parasitics ROM



Double Pulse Test setup

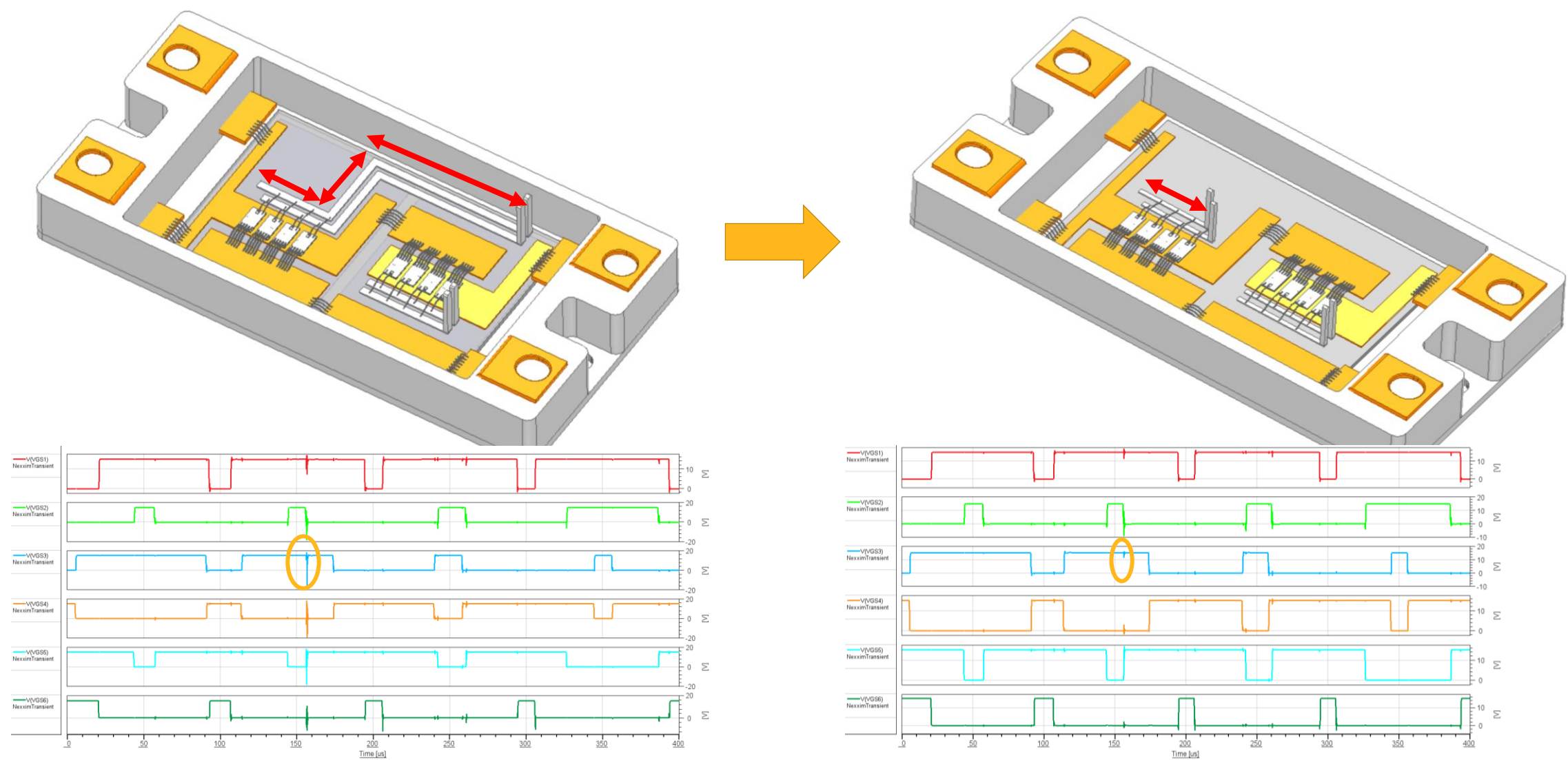


Frequency dependance of inductance and resistance



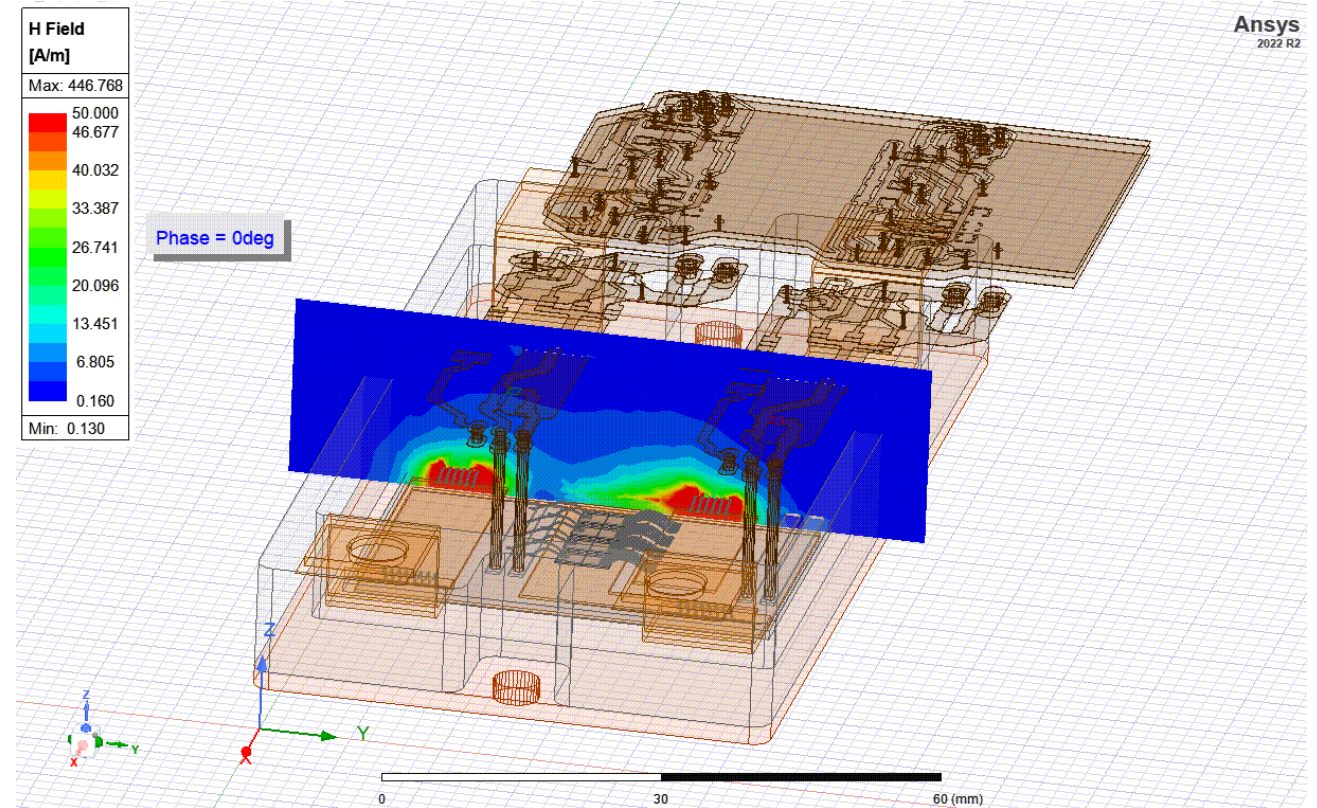
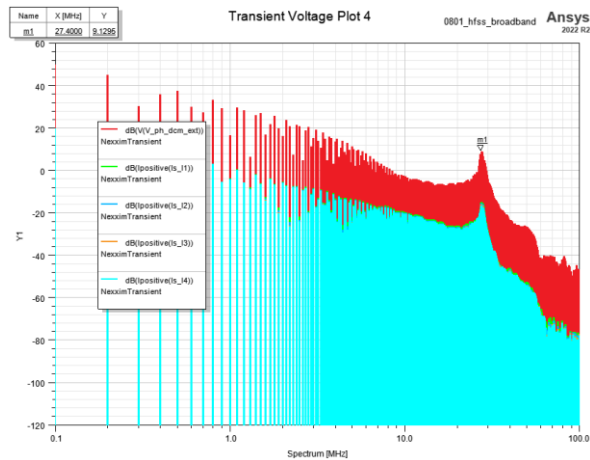
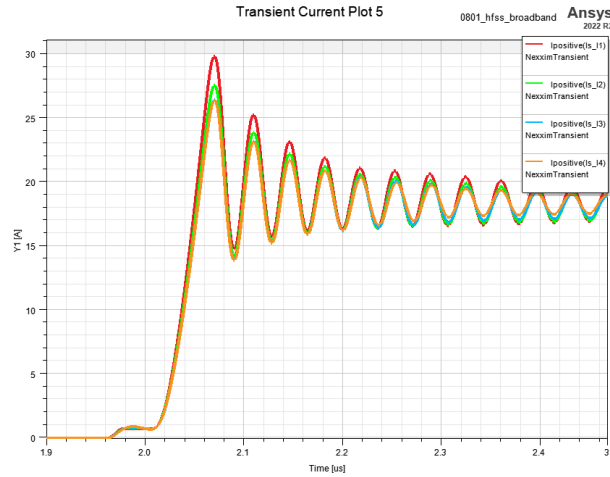
Gate Oscillation

Gate pin length reduced to mitigate oscillations



Power Devices Radiated Emissions

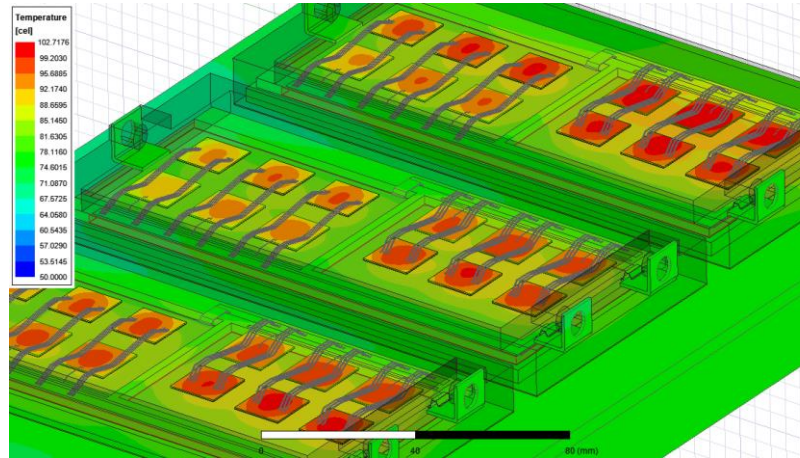
- Radiated Emission Workflow



Power Devices Design

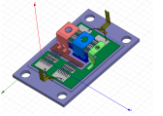
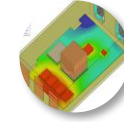
Power Module Thermal Management

- Assemblies are large and complex
- Liquid cooling
- Loss sources
 - SiC/IGBTs/Diodes
 - Circuit tracing
- Steady state and transient behavior
 - R_{th}/Z_{th}
- Reduced order models extraction

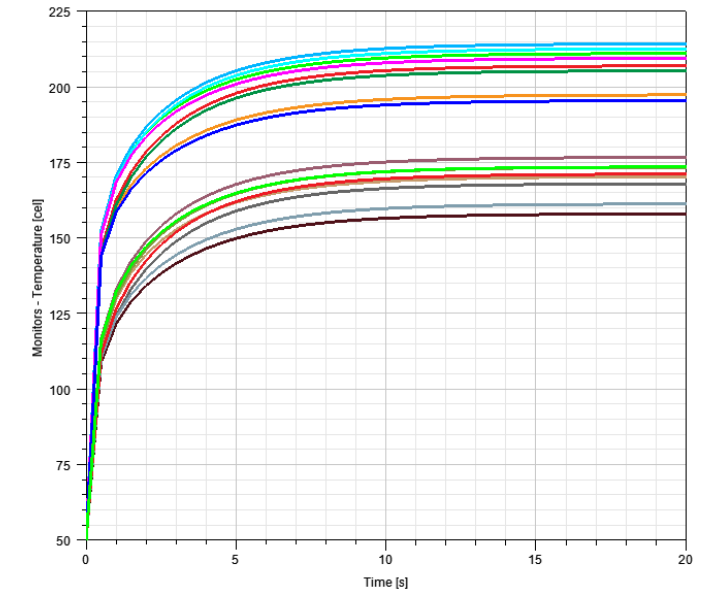
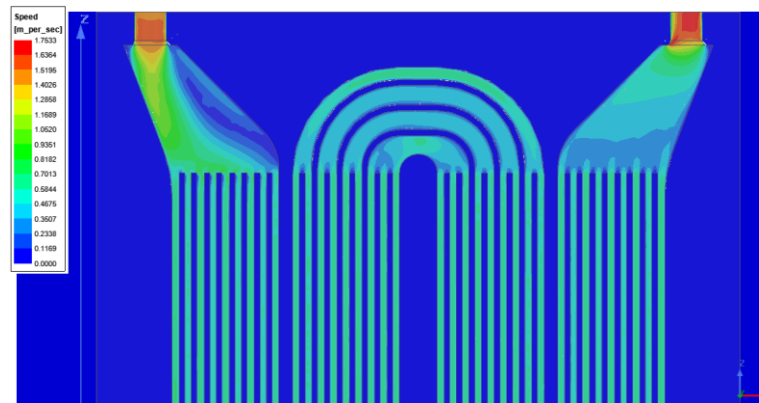


Thermal & Mechanical Integrity

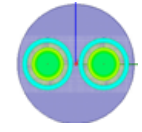
Power Module



SiC/IGBT junction temperature



Inter-Connection: Busbar and cables

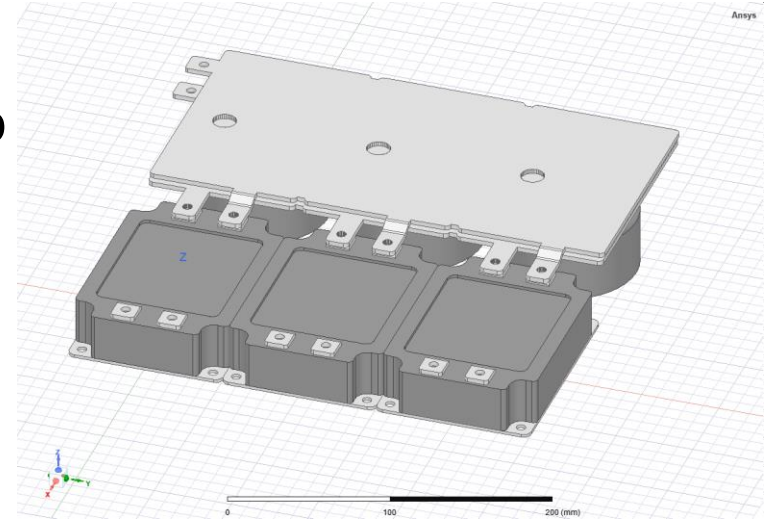


Busbar
Cables

Design of the inter connections needs care and sees several key challenges

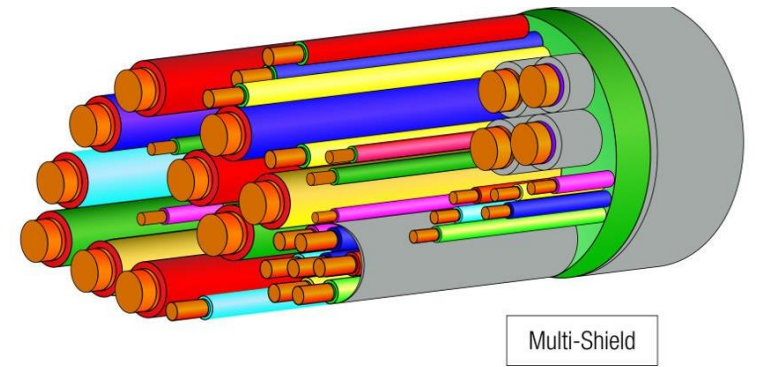
Busbar

- The parasitic inductance from DC-link busbar contributes to the commutation loop inductance
- Difficult to predict current and loss distribution



Cable

- Transmission line: voltage amplification
- Complex cable harness: mix of power and signal cables
- Source of disturbance: EMI/EMC issues

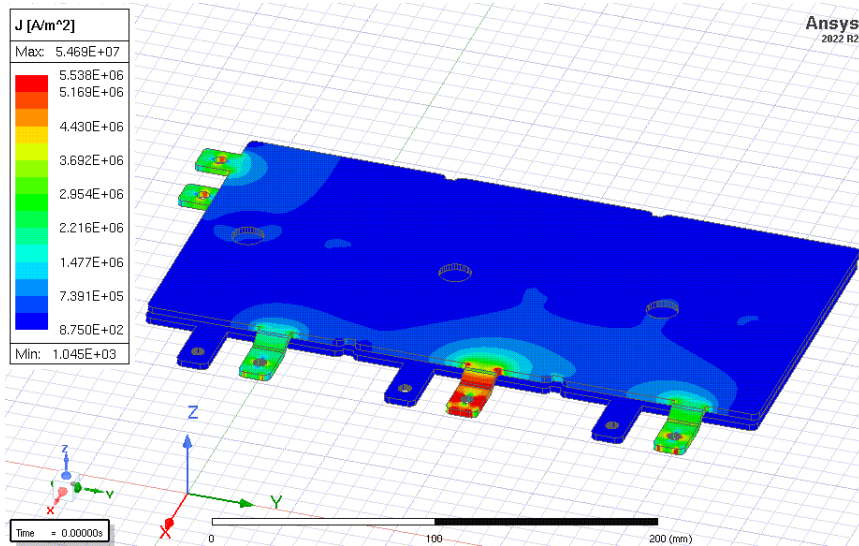


Inter-Connection: Busbar and cables

Simulation can capture impact of busbars and cables on the drive design

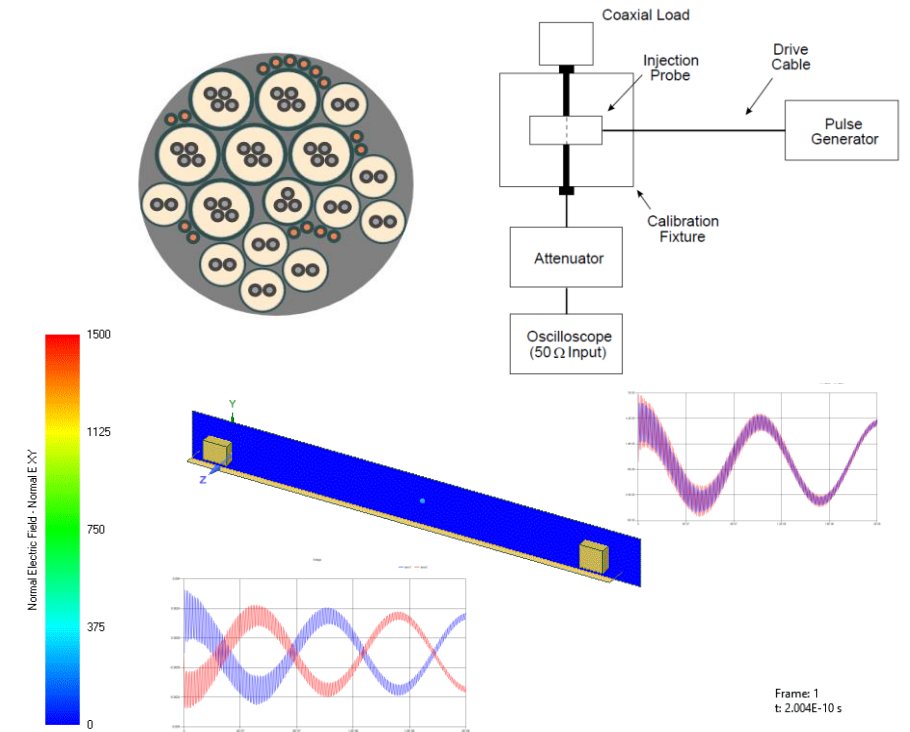
Busbar Solution

- Combined circuit and field solvers
- Accurate prediction of losses
- Thermal modelling allows for hot spot prediction



Cable Solution

- Platform Level Cable Modeling Solution



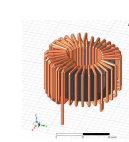
Magnetic Components

Design of Transformer/Inductor/Choke

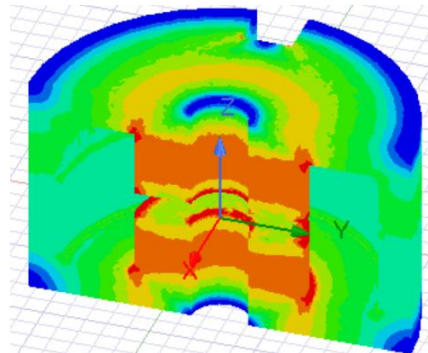
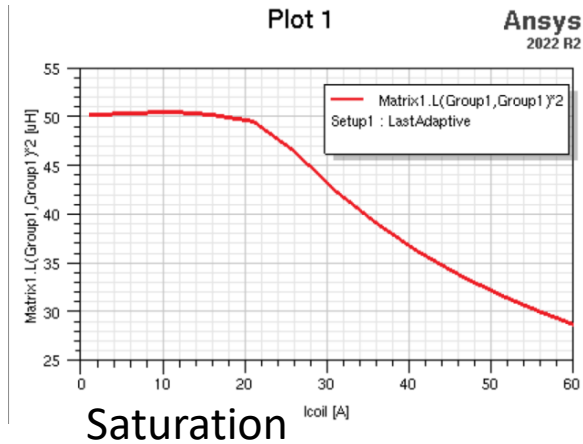
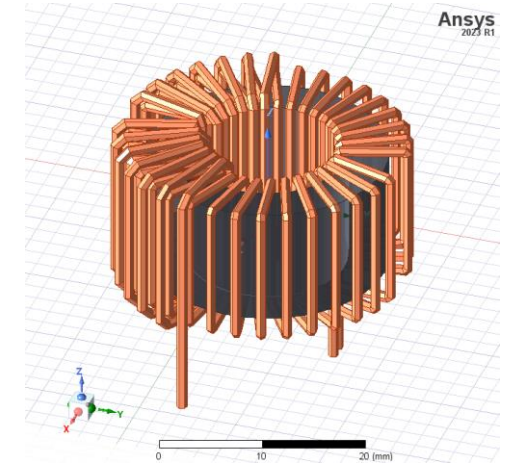
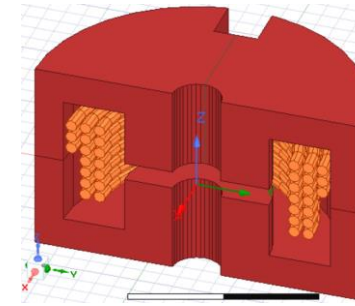
- Highly non-linear behavior
- Broad frequency spectrum DC-50Hz-kHz-MHz
- Losses and thermal stress

Ansys provides wide range of capabilities:

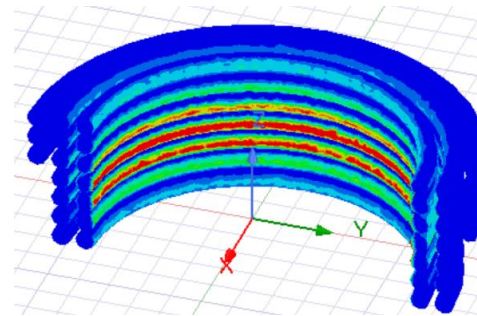
- Static, quasi-static, time transient and full-wave fields solutions
- linear and nonlinear materials
- Accurate prediction of non-linear and high frequency effects
- Reduced Order Model generation



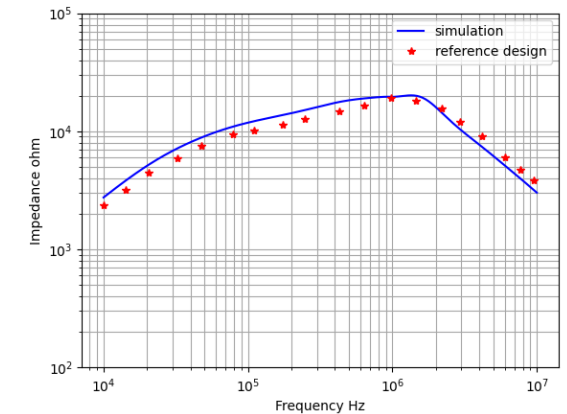
Magnetics,
E-motor



Core loss



Winding losses



Choke impedance

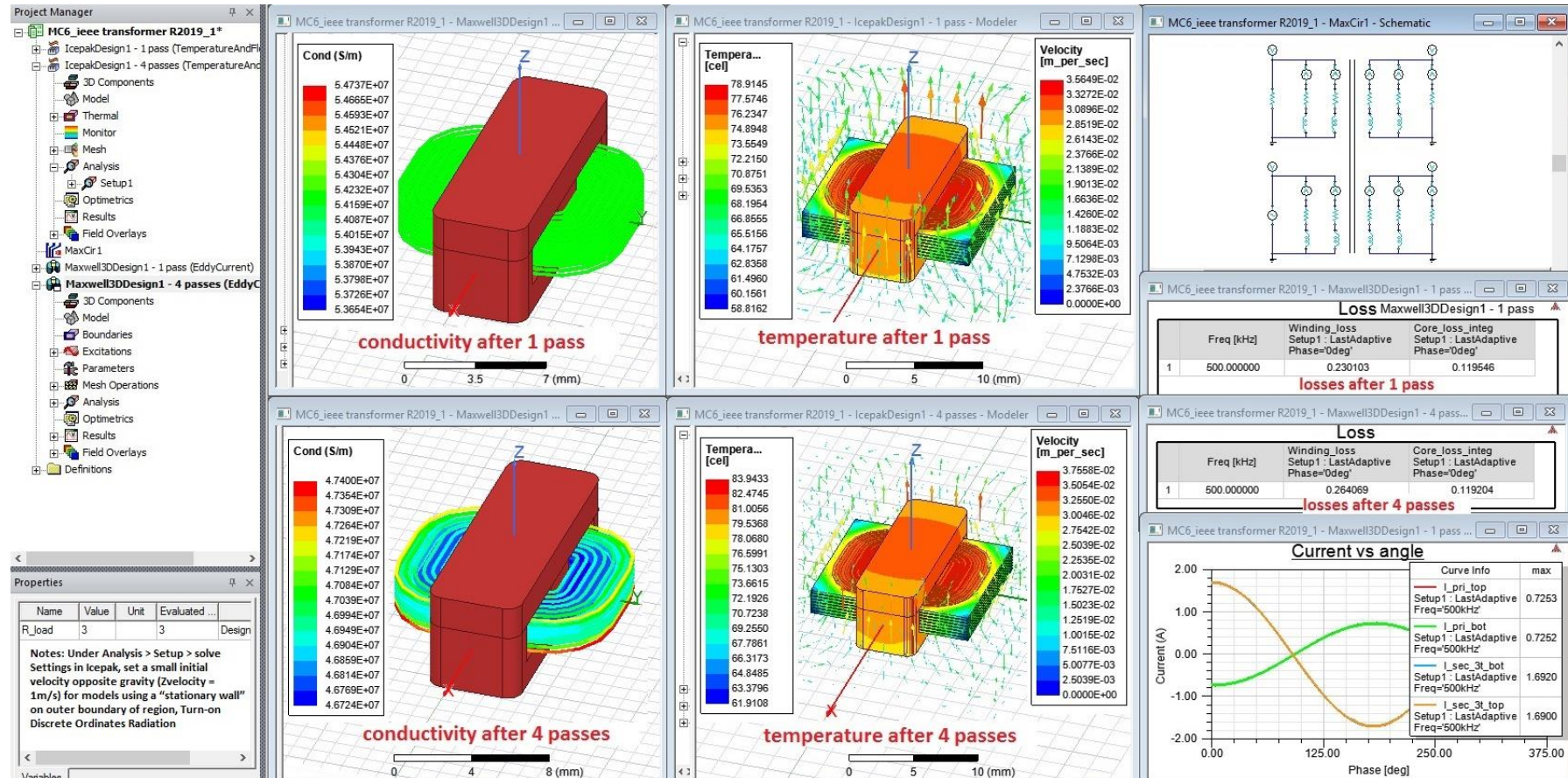
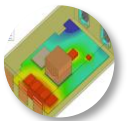
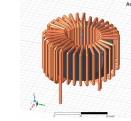
Magnetic Components

Magnetics,
E-motor

Thermal &
Mechanical Integrity

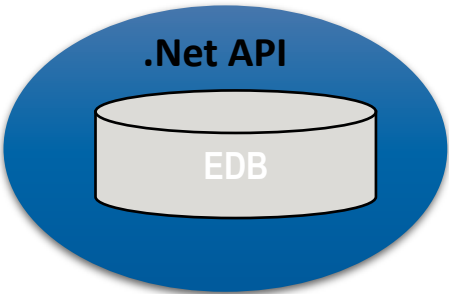
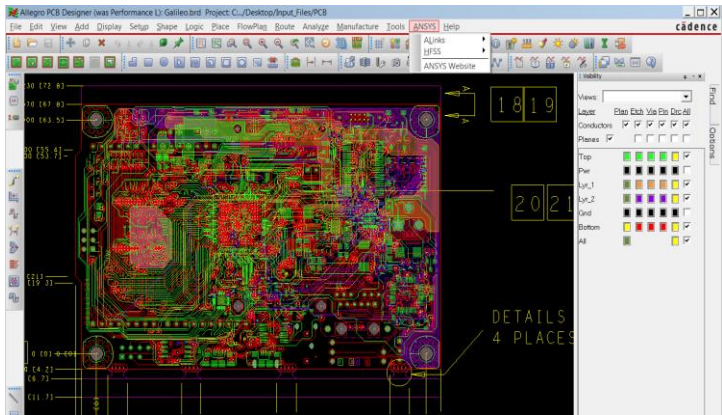
Thermal design

- Built-in integration for electromagnetic-thermal analysis with two-way coupling.



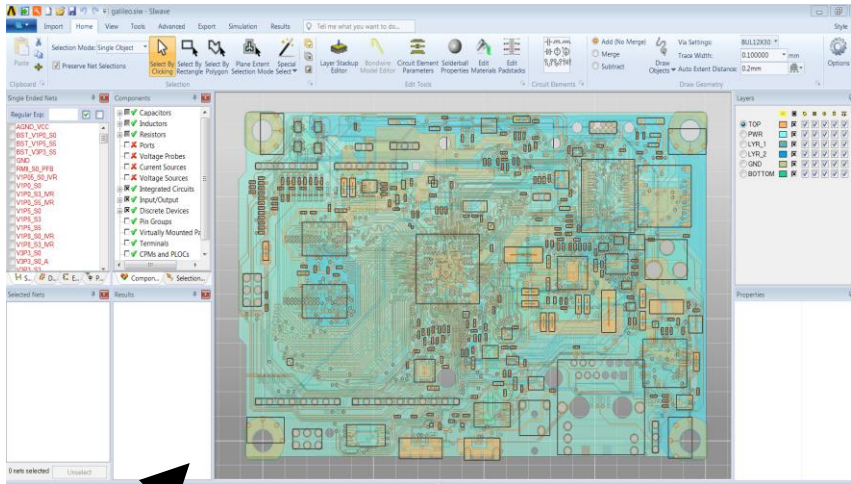
Printed Circuit Board (PCB)

Electronic Design Environment (Cadence, Mentor, Zuken, Altium ...)

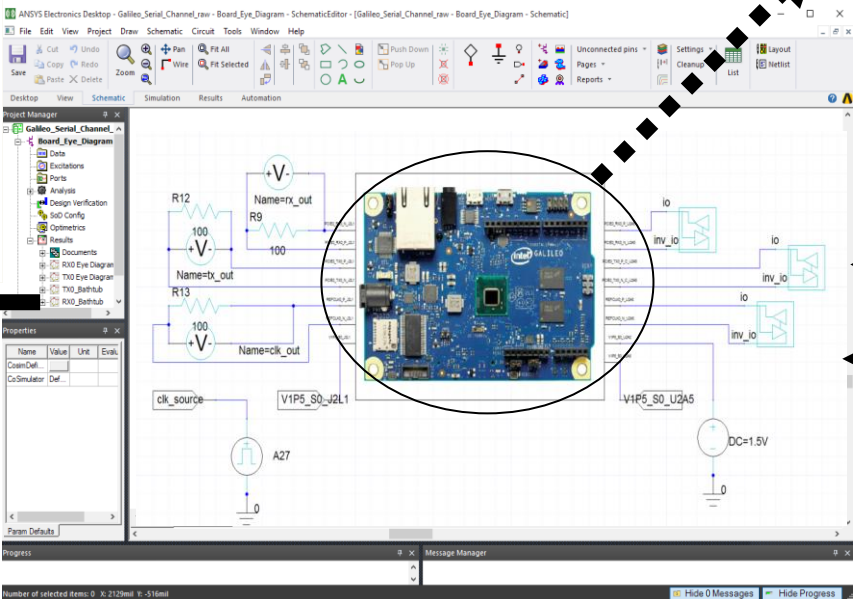


Database Import
Geometry, Stack up, Components

EM Simulation & Extract Parasitics



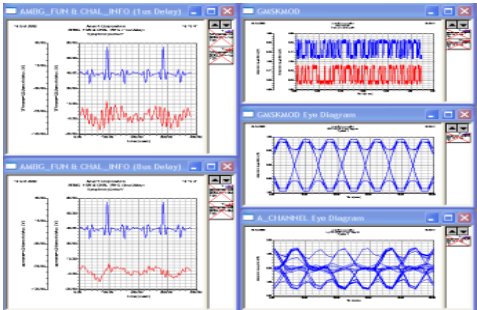
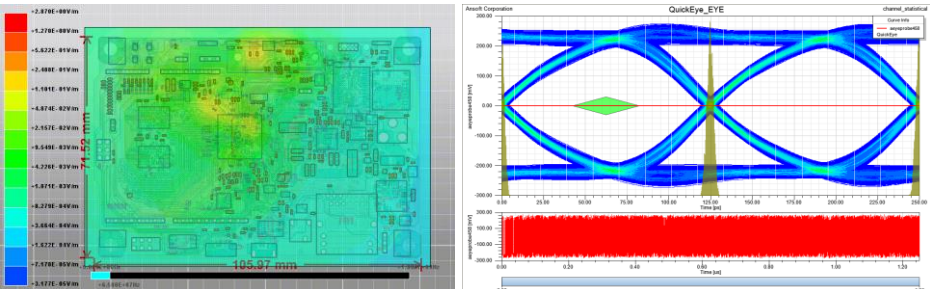
Circuit Simulation



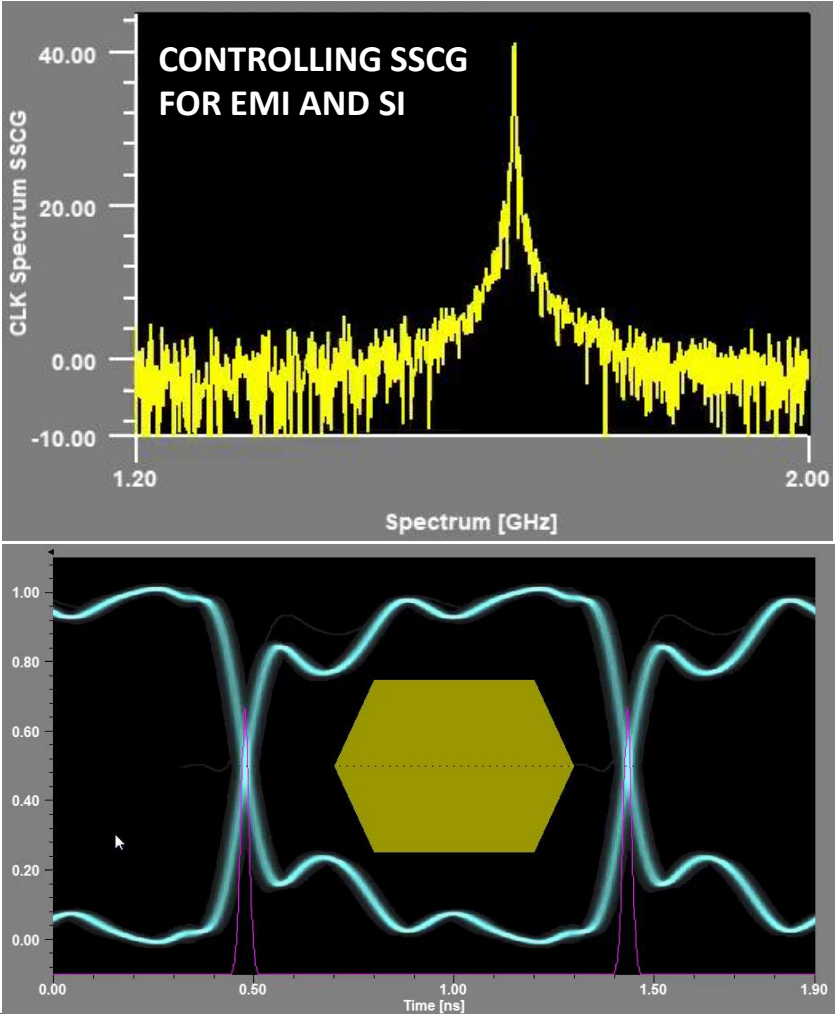
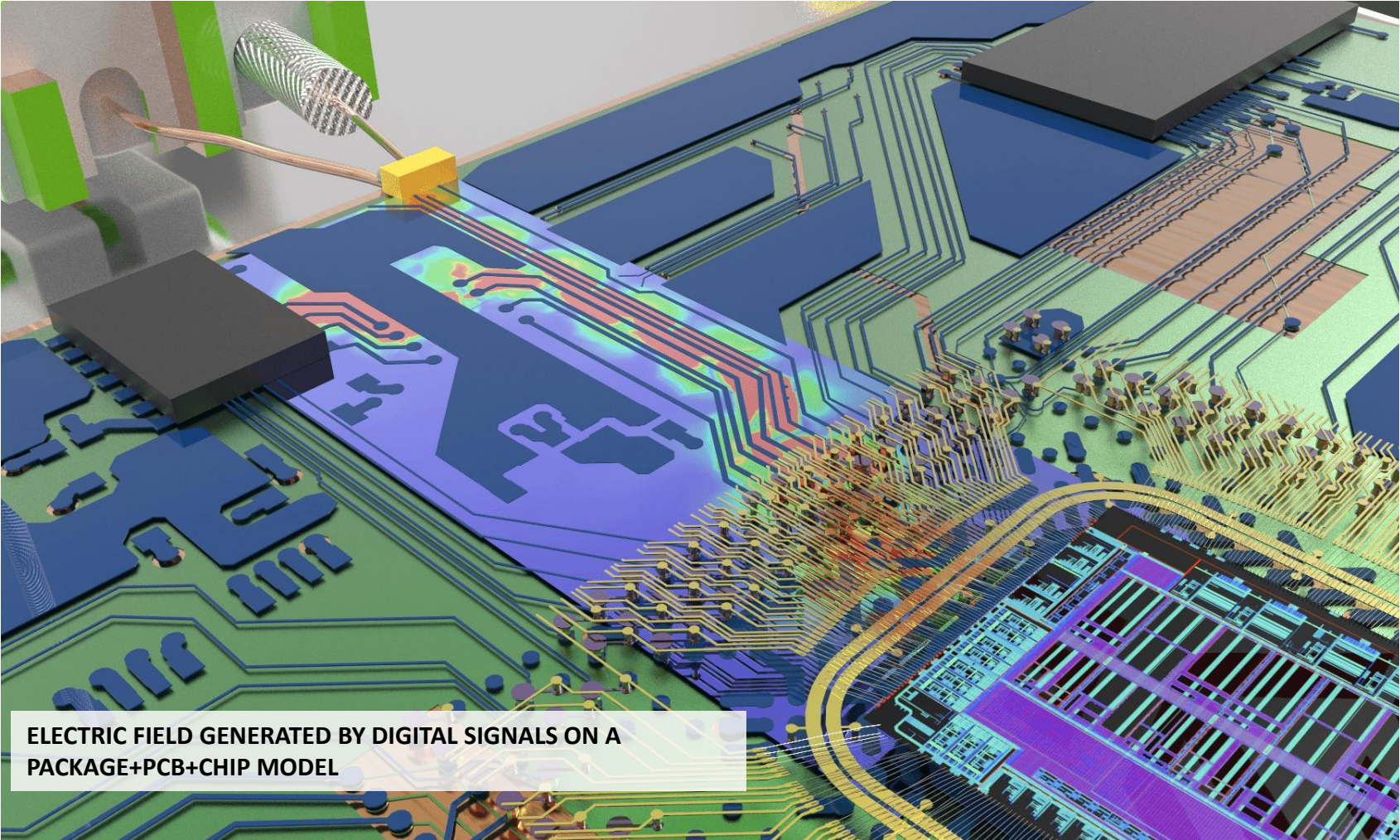
EM Model

Spice
S Parameter

Verilog-A
IBIS 5
IBIS AMI
CPM



Improve the design

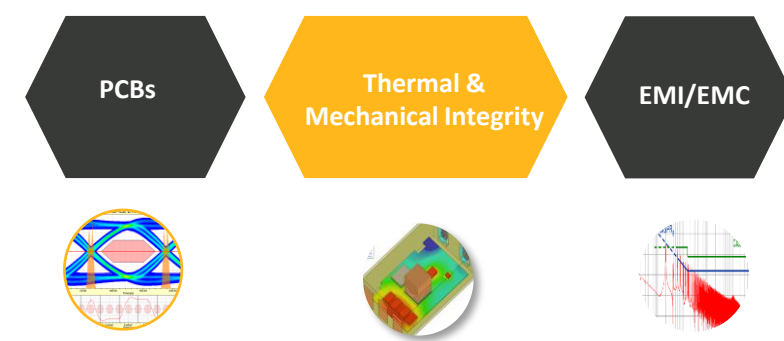
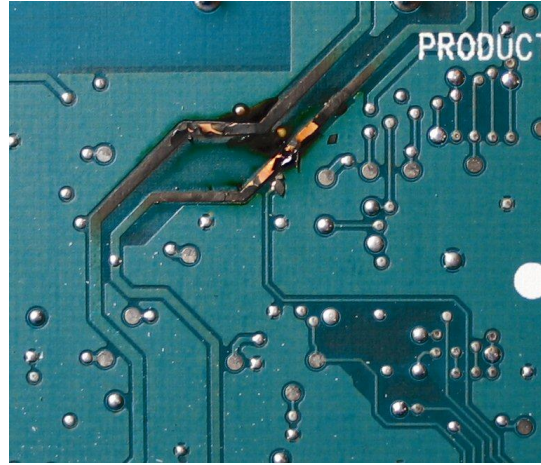


PCB

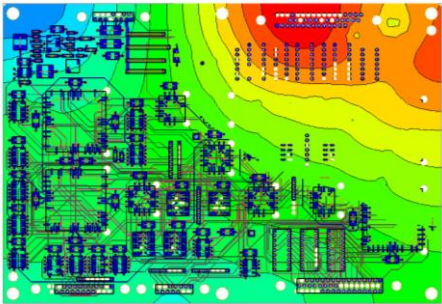
Key challenges:

- Mitigate failure of electronic components:
 - Power/Signal Integrity
 - Thermal integrity
 - EMI/EMC
 - Shock/Vibration
 - Influence of environmental
- Meet standard test criterion with minimum physical prototyping and testing

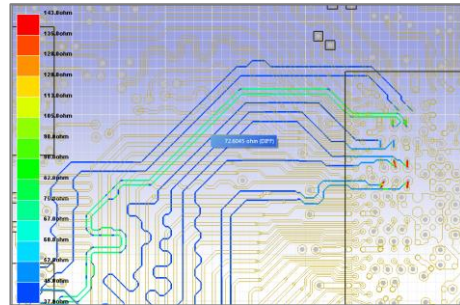
A set of solutions for printed circuit boards (PCB) – which allow characterization of “critical areas” within very short time – even for non experts



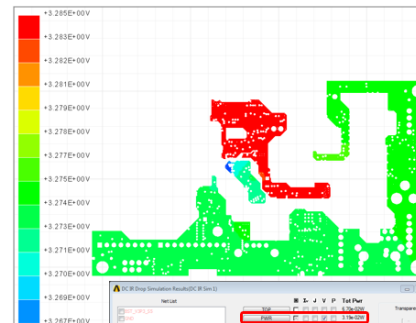
Resonance Analysis



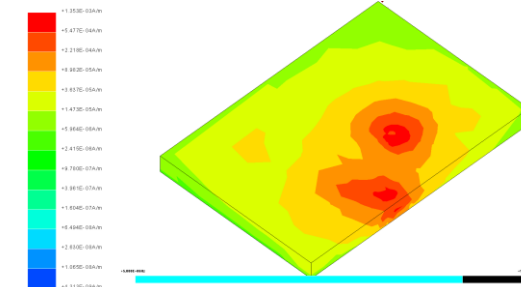
Impedance analysis



DCIR – Drop analysis



Thermal analysis

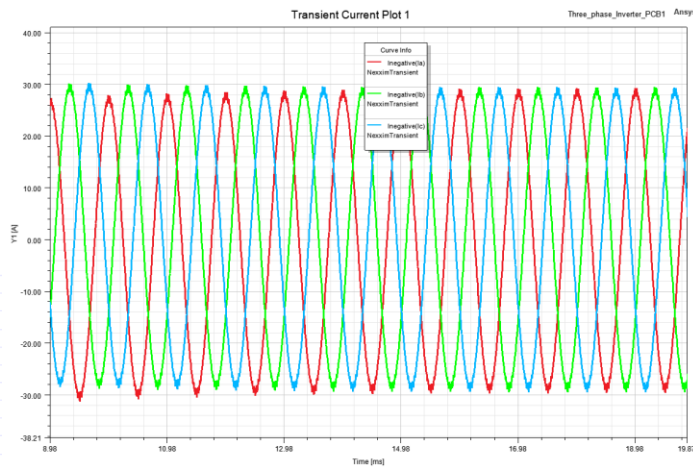
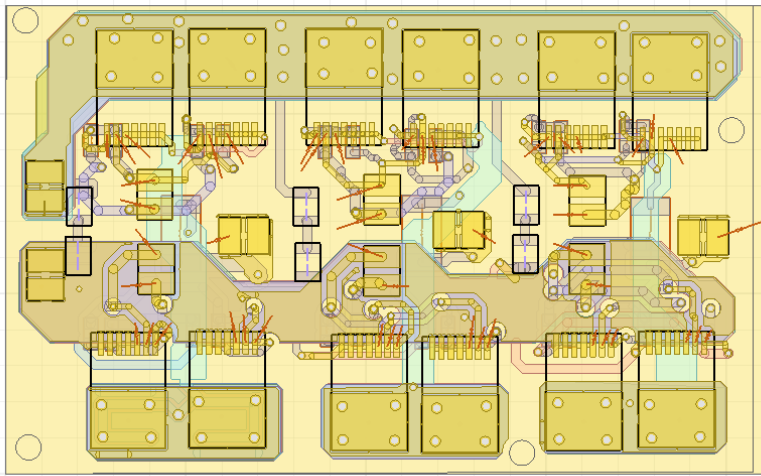


PCB Functional Analysis

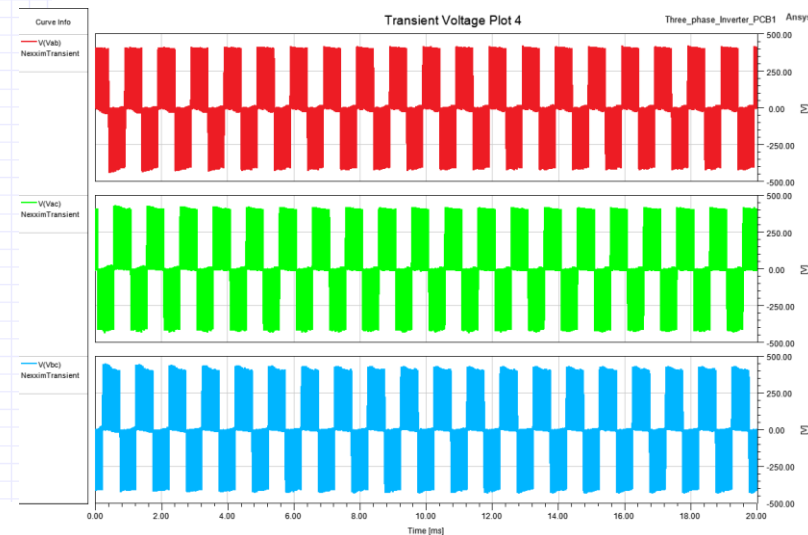
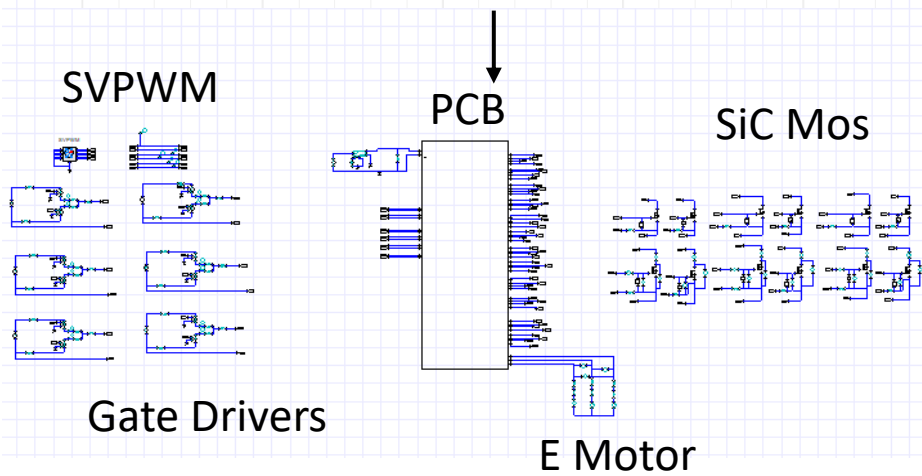
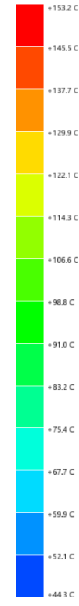
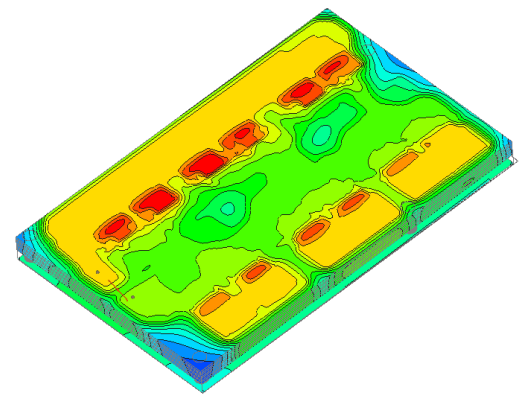
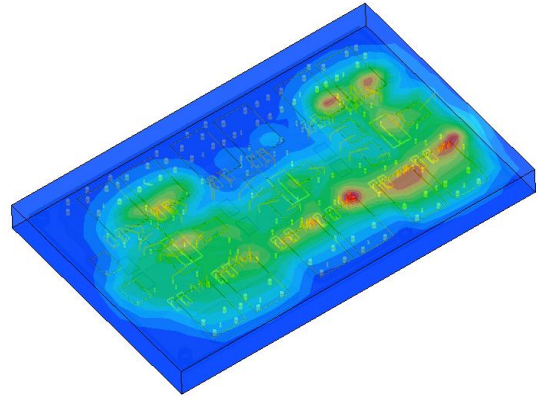
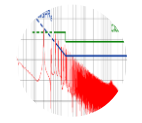
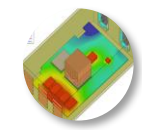
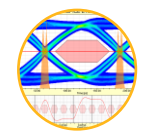
PCBs

Thermal & Mechanical Integrity

EMI/EMC



Current and voltages on the E Motor

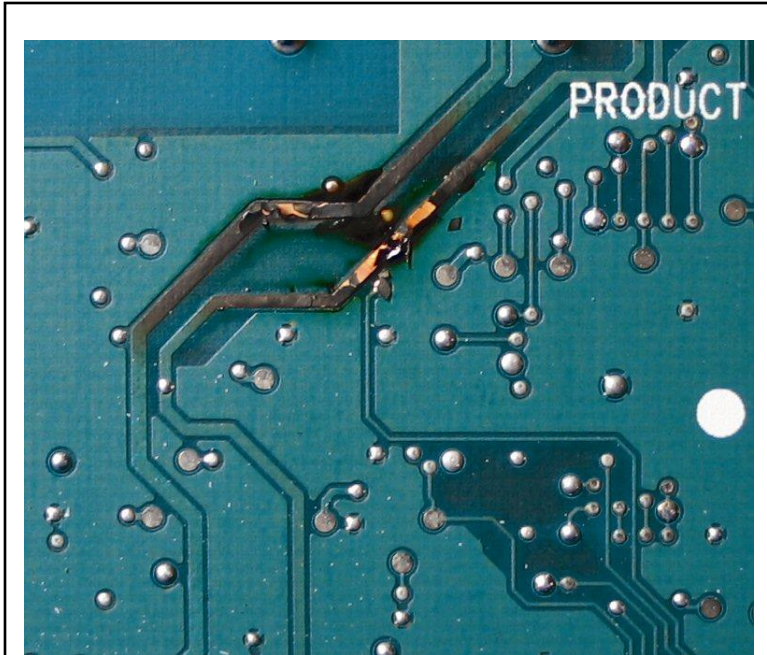




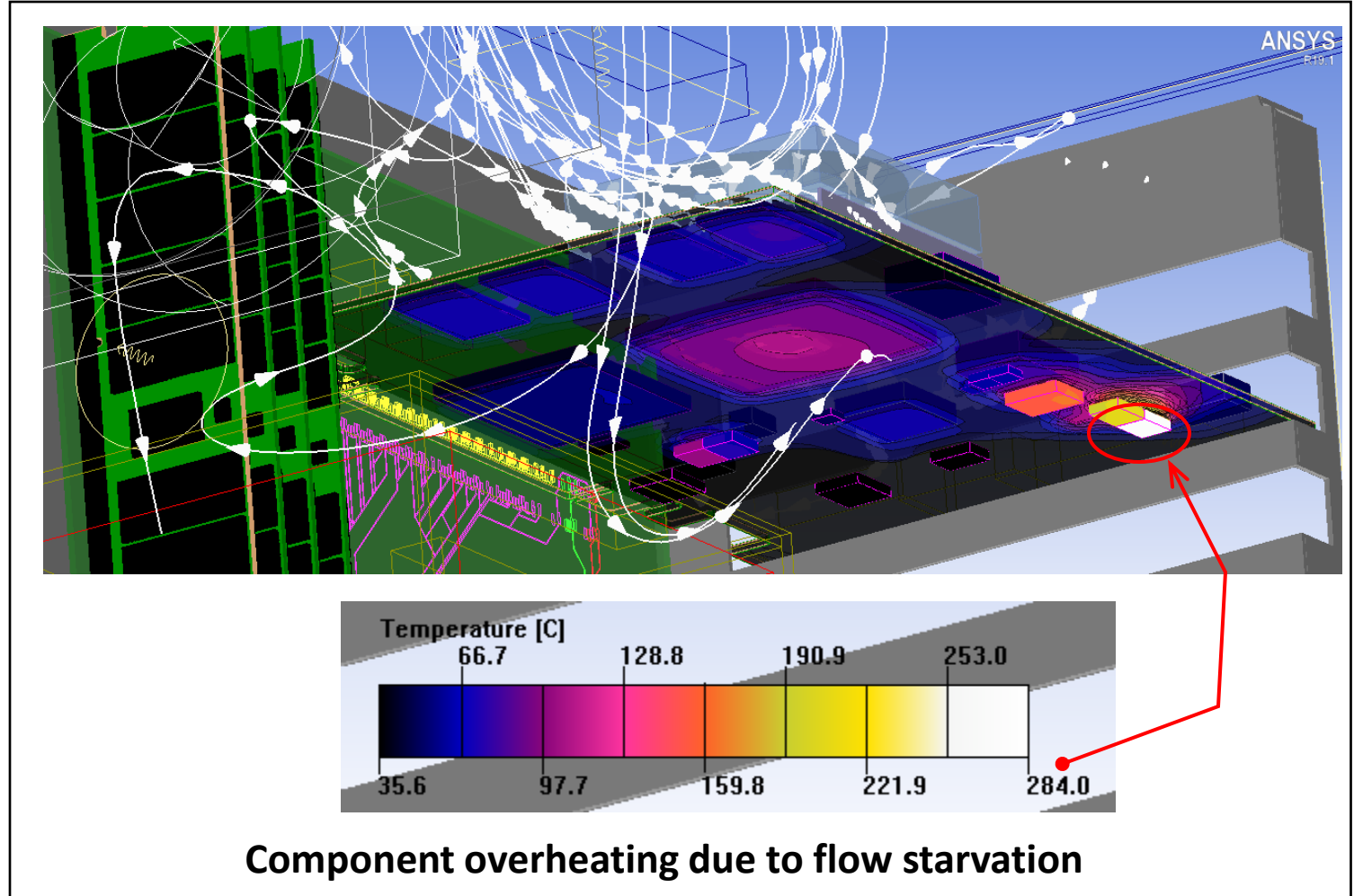
Electro-Thermal Design

Importance of Electronics Thermal Management

- Catastrophic failures:

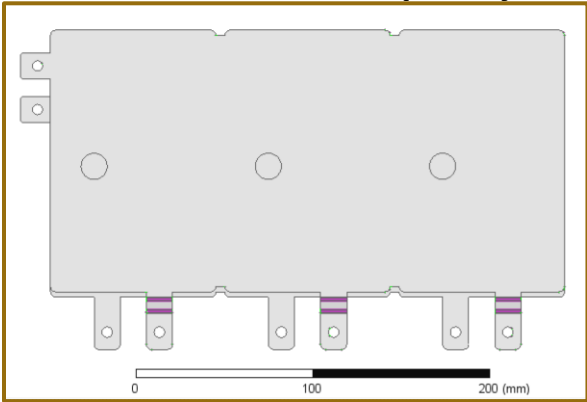


Trace and via burnout from excess current combined with poor cooling

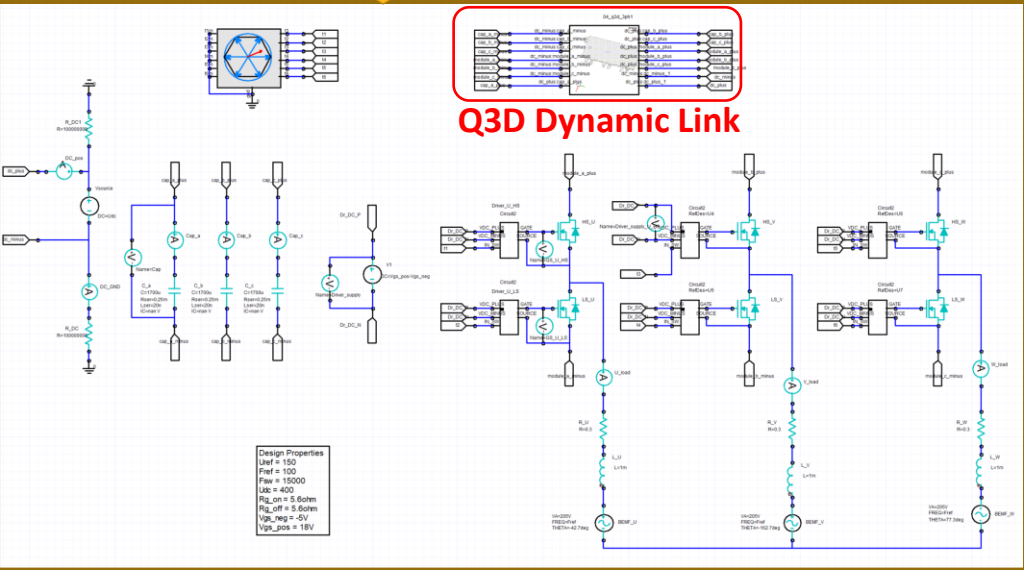


Harmonic Loss Calculation

Solve DC RL + AC RL + Frequency Sweep

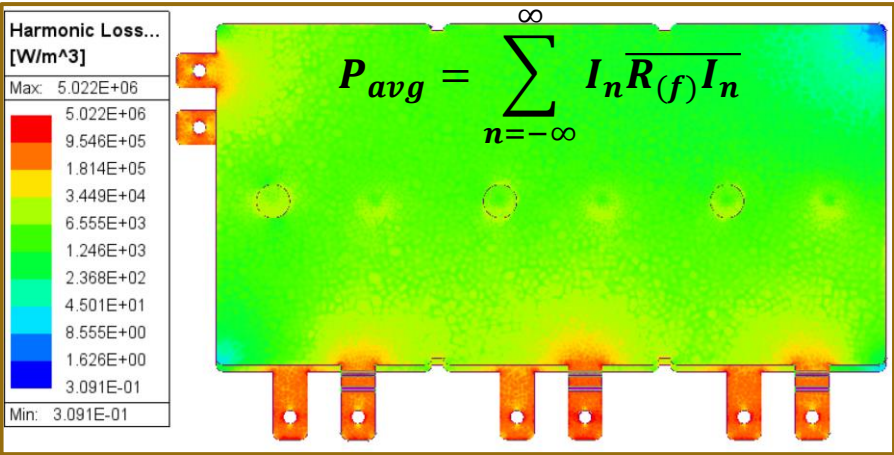


TR Circuit Analysis with
Q3D Dynamic Link



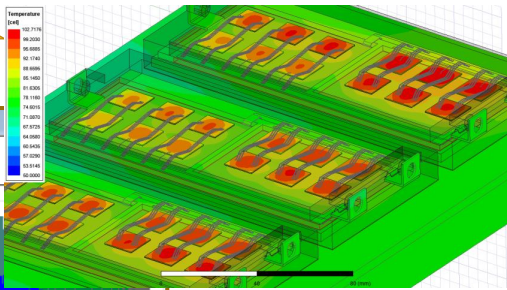
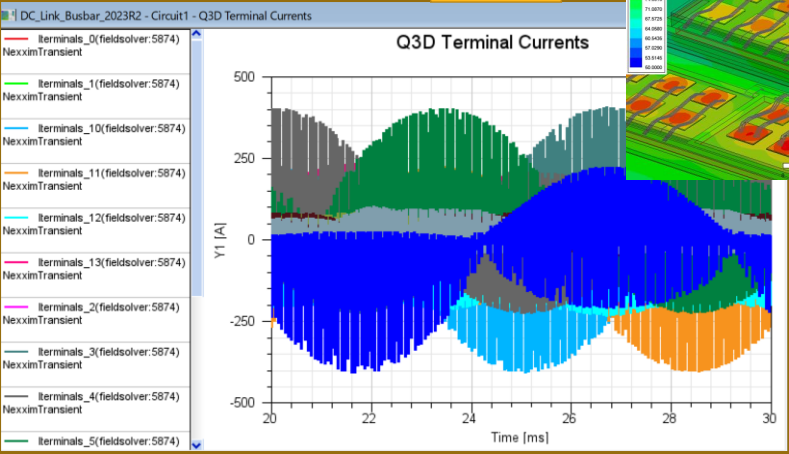
Push Excitations

Input Currents from Circuit dynamic links and DC R solution
scaled with the Re and Im currents at each harmonic



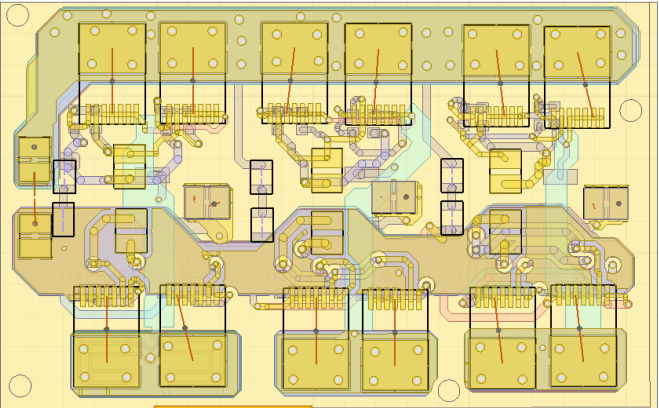
Link to Icepak

FFT



Harmonic Loss Calculation with Slwave

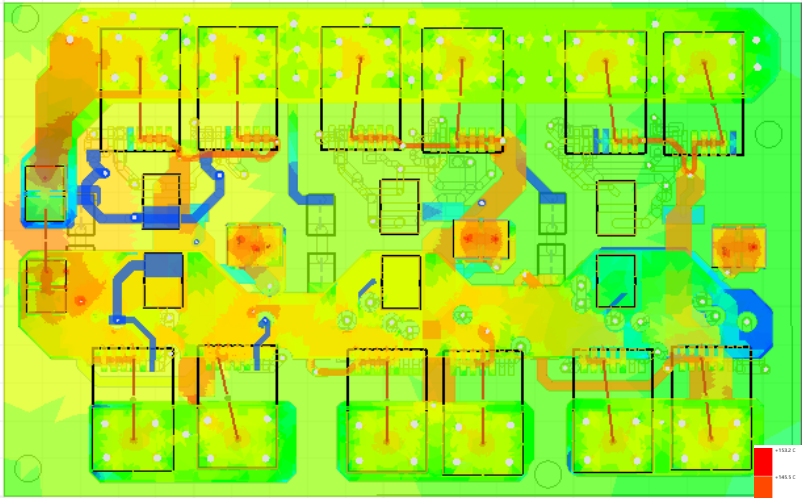
SYZ-Parameters Calculation in Slwave



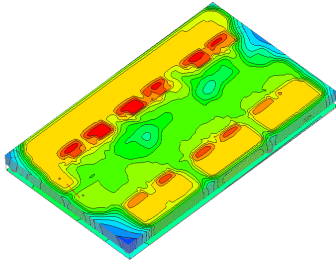
DC IR solution scaled with the Re and Im currents at each harmonic

$$P_{avg} = \sum_{n=-\infty}^{\infty} I_n \overline{R_{DC}} I_n$$

Harmonic Loss Power Density

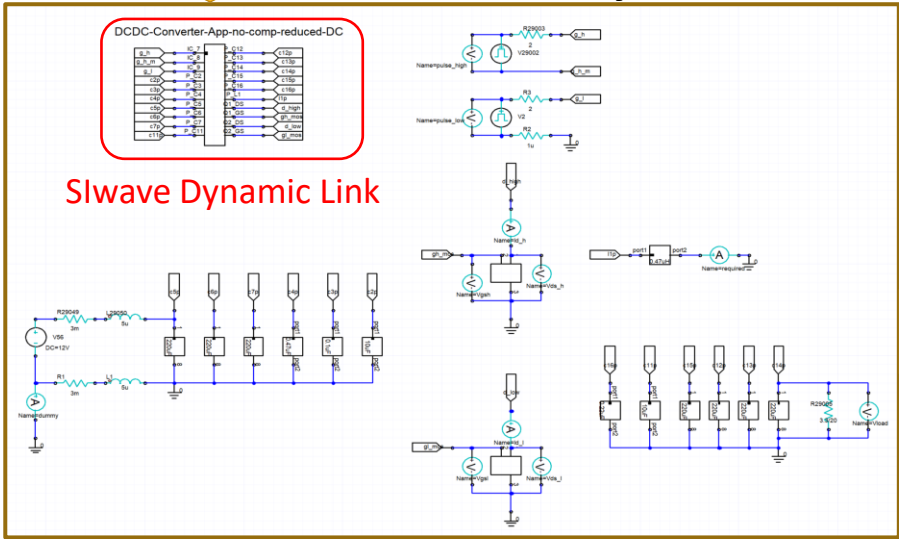


Link to Icepak

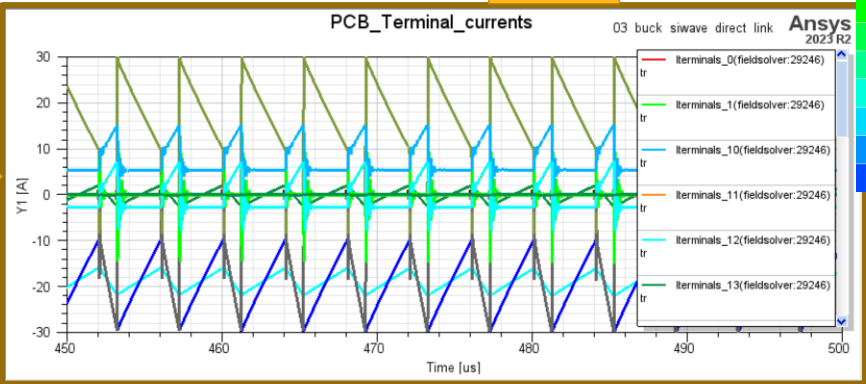


S-Param

TR Circuit Analysis with Slwave Dynamic Link



Push Excitations



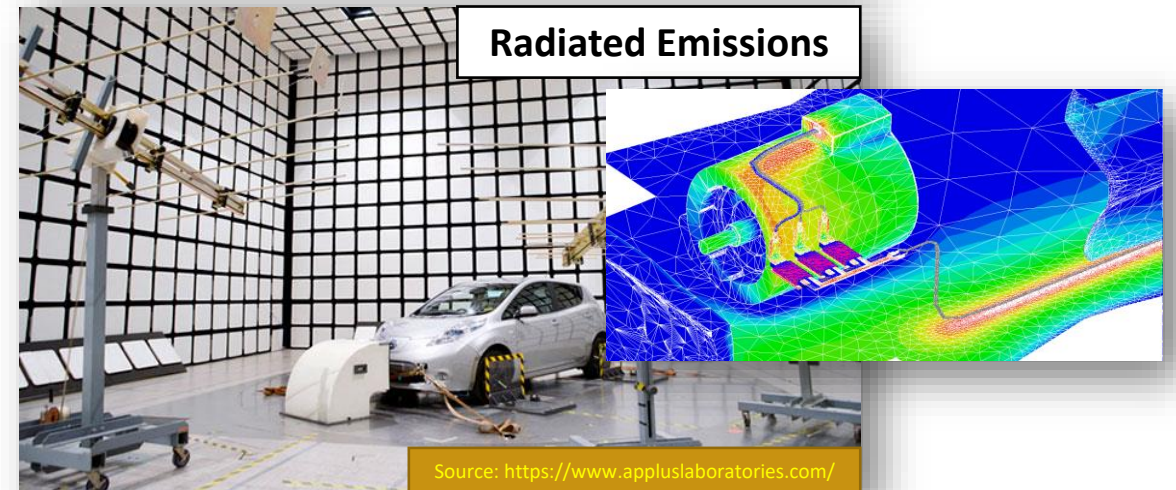
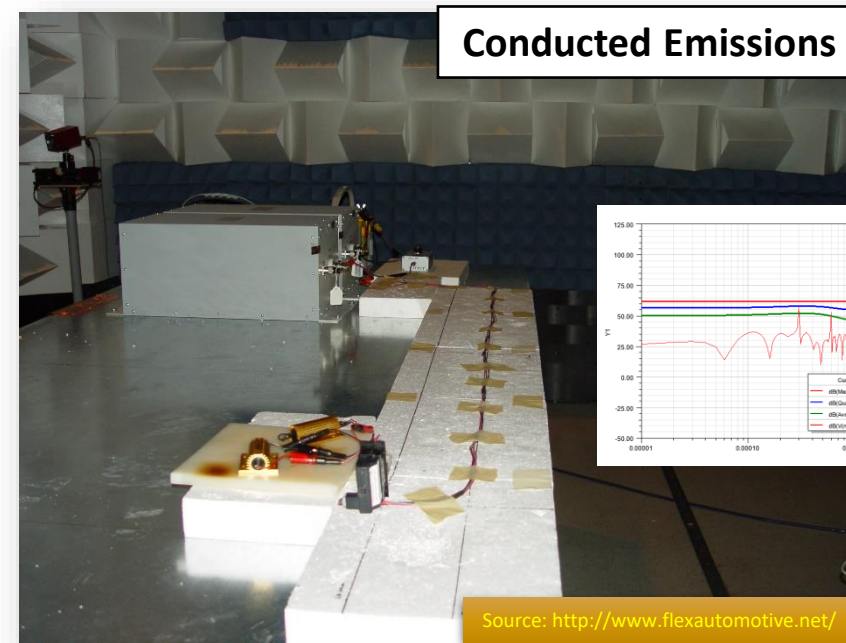
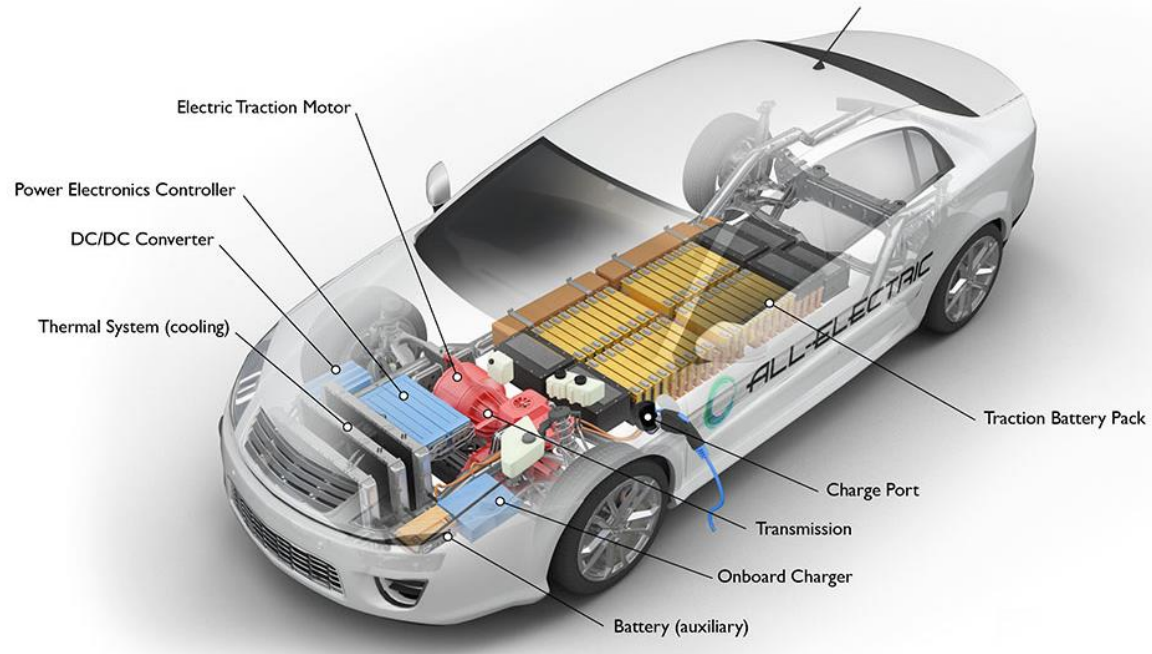
FFT



EMI/EMC

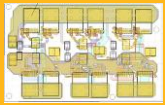
System Level Solutions

EMC of Electrification



E-Powertrain Emissions Workflow

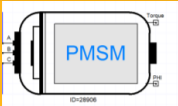
Power Electronics PCBs



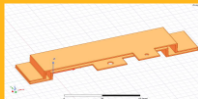
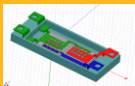
SiC/ GaN IGBT Spice Models



E Motor model



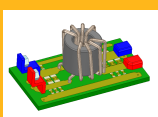
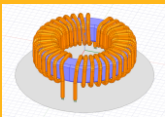
Busbar and Power Modules



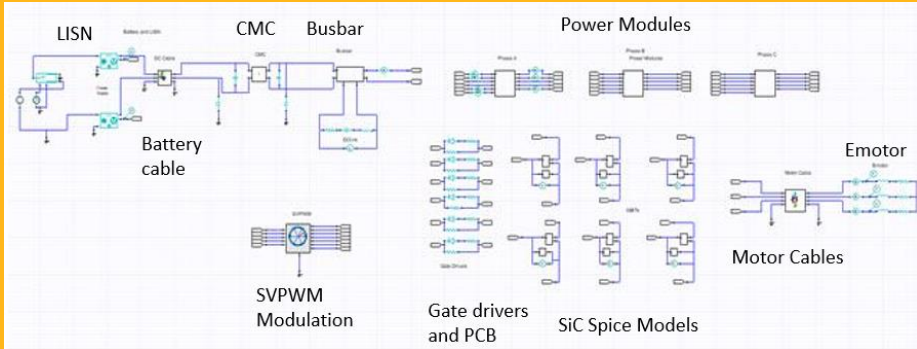
Motor and Battery cables



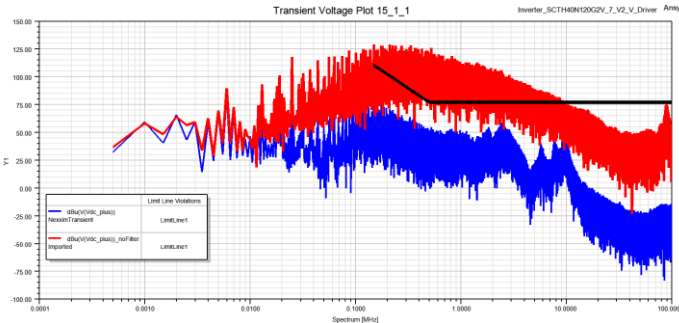
Common Mode Chokes and EMI Filters



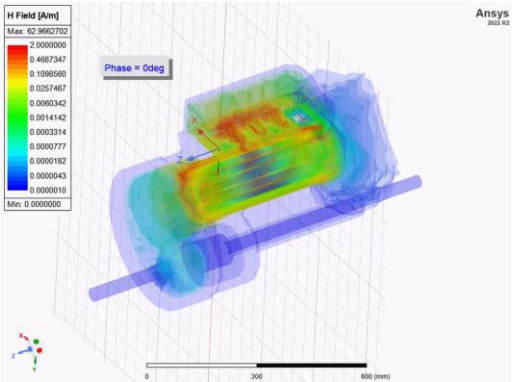
CISPR 25 System Simulation in Ansys Circuit



Conducted Emissions

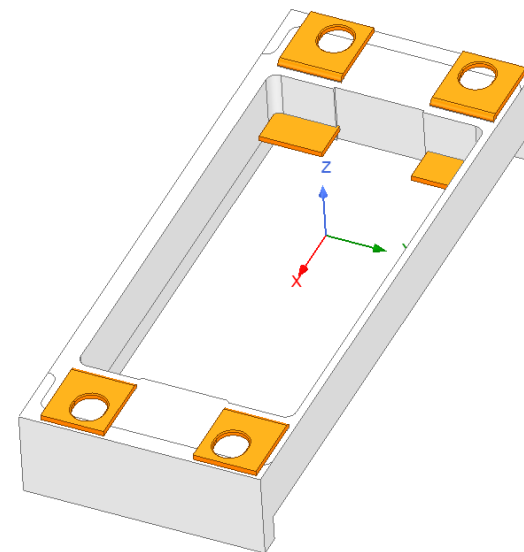
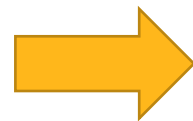
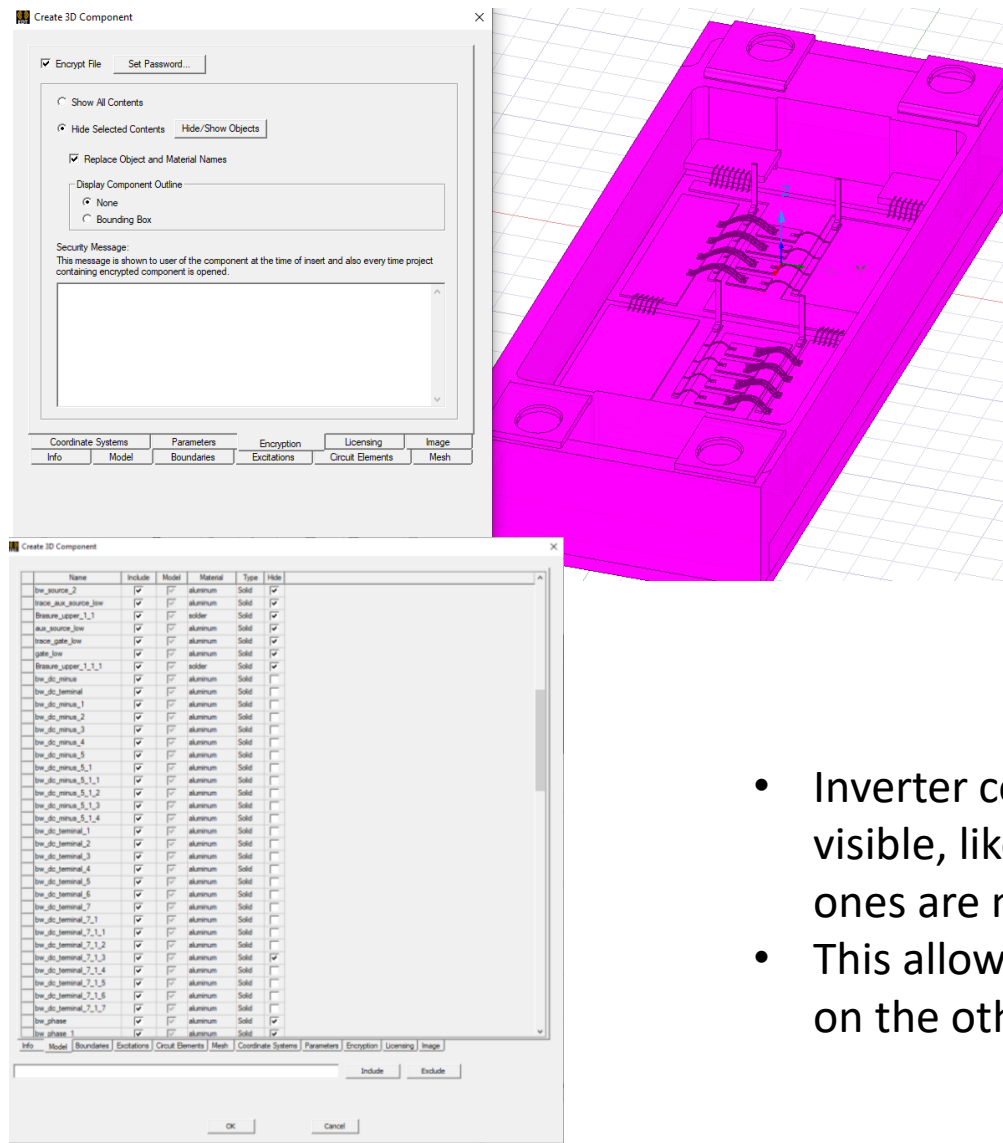


Radiated Emissions



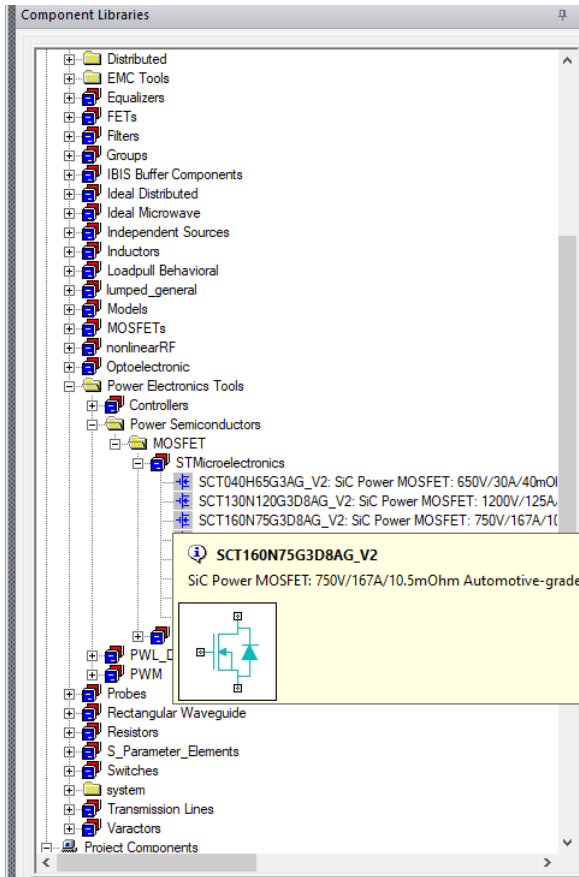
Homologation constraints and higher performances goals need virtual validation

3D Component Encryption for the Ecosystem

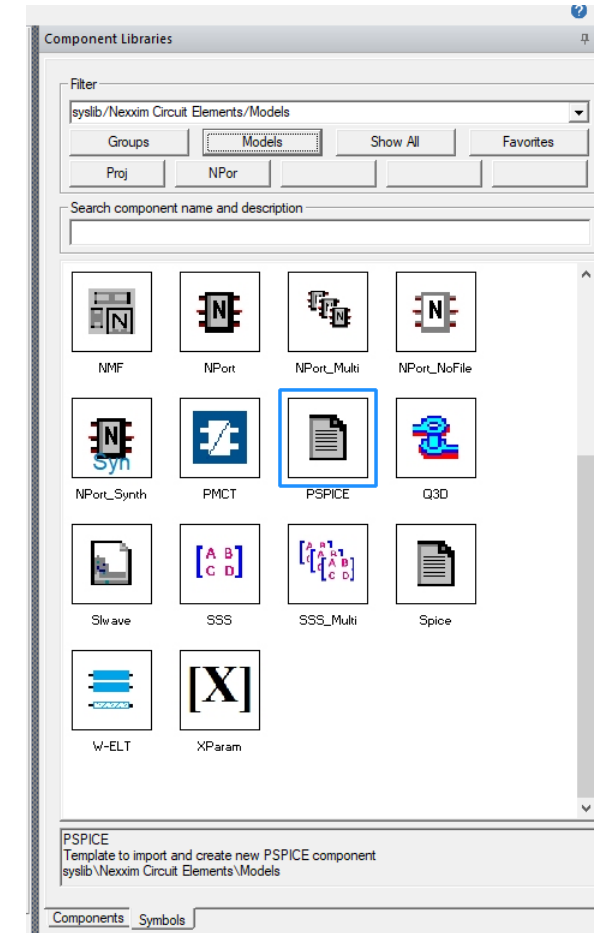


- Inverter components can be encrypted selecting the objects which need to be visible, like busbar connection for connecting pins. All parts including non-visible ones are meshed and solved in 3D including material characteristics.
- This allows final users to have a complete and accurate simulation model, and on the other hand, automotive suppliers to protect their intellectual propriety.

ST Microelectronics SiC models and PSPICE PowerMOS import



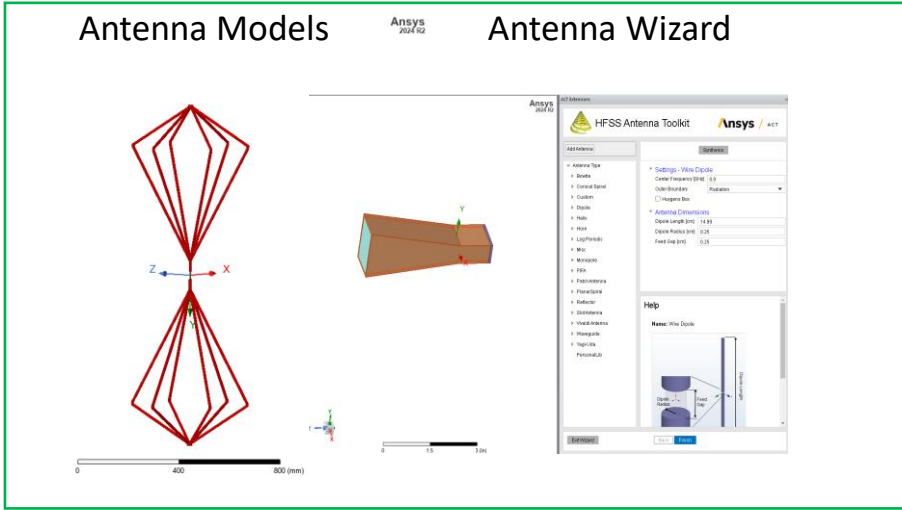
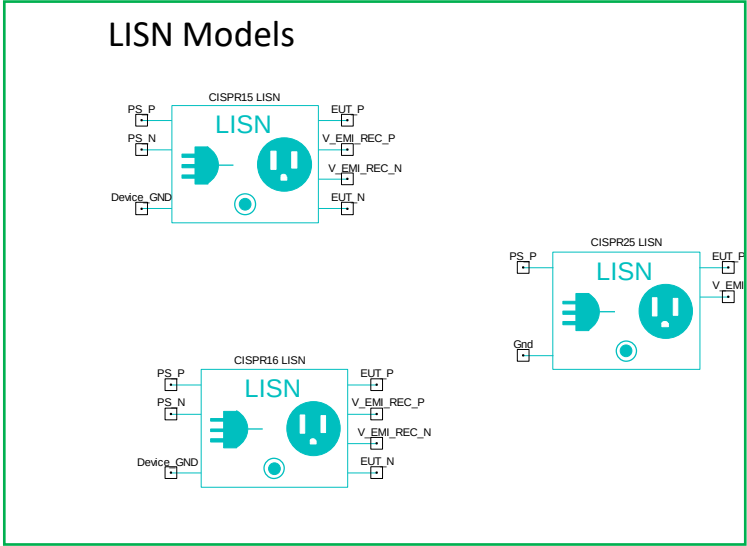
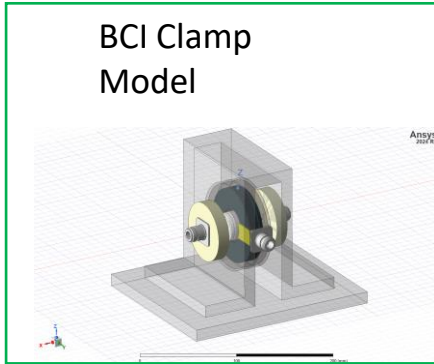
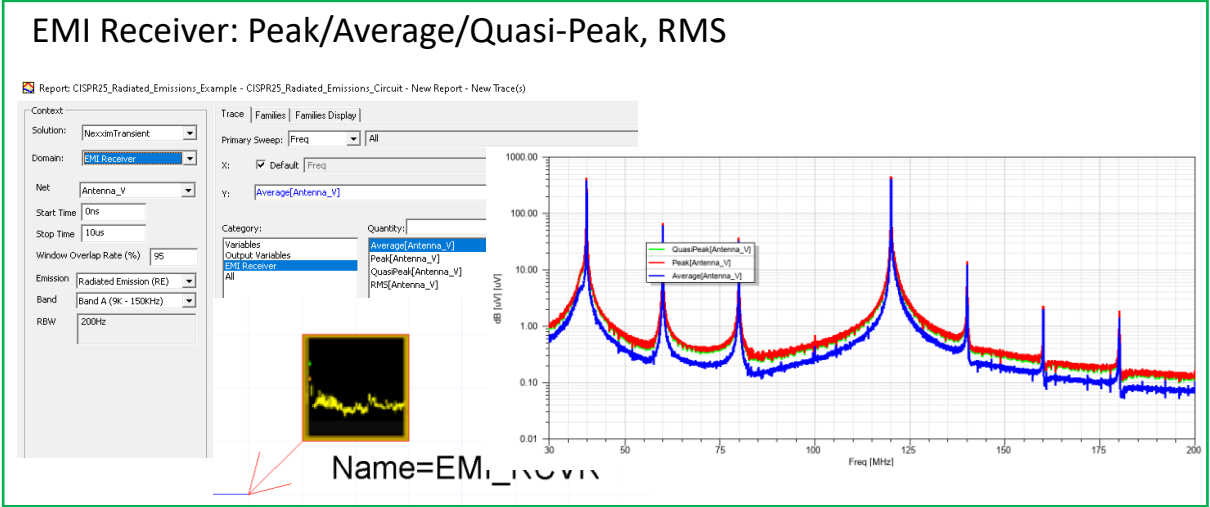
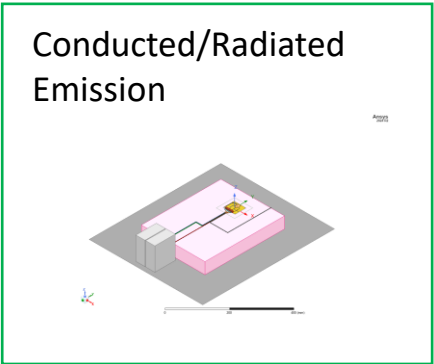
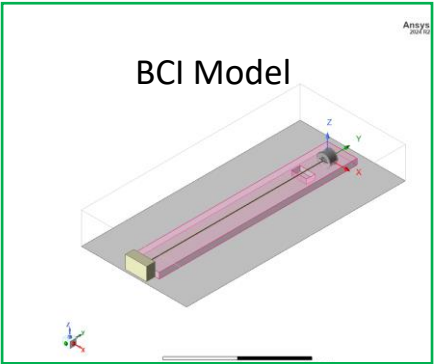
SiC spice models can be drag and drop from ST Microelectronics integrated library or imported from PSPICE .lib external models. Spice models can be encrypted by suppliers in the Ansys format.



<https://www.ansys.com/resource-center/webinar/how-stmicroelectronics-leverages-simulation-to-build-efficient-ev-traction-inverters>

EMI/EMC with Ansys Electronics Desktop

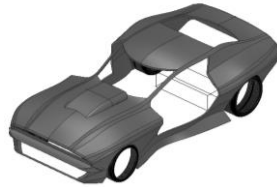
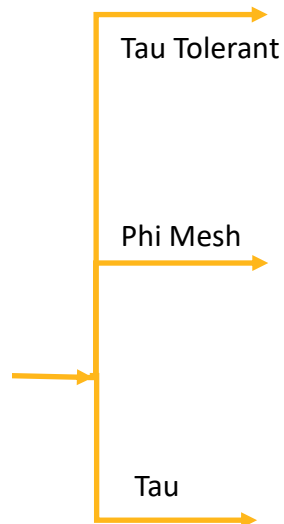
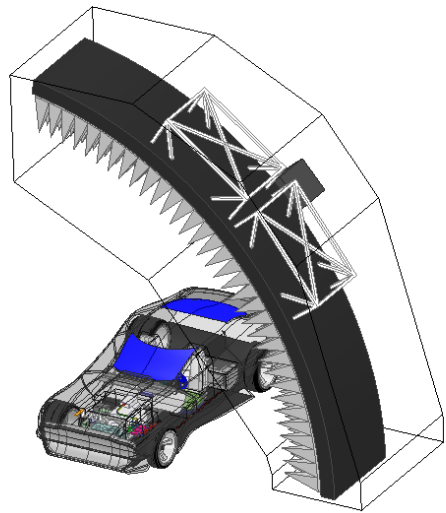
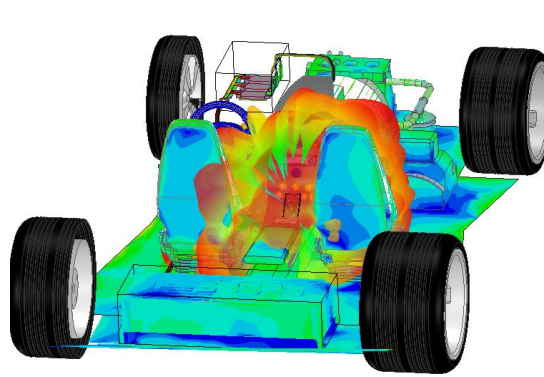
AED including embedded component library allows to conduct EMC Virtual Validation.



EMC & Ansys Mesh Fusion

- Mesh Fusion **Advantages**

- **Robust:** Higher overall Mesh Quality
 - Component level mesh settings
 - Mesh tolerance at scale of component
- **Faster:** Concurrent (i.e. parallel) mesh generation
- **Scalable:** Mesh larger and more complex complete “Electromagnetic Systems”
- **No Limits!**



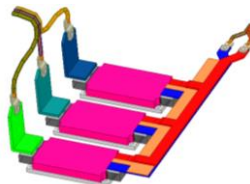
Tau Tolerant

Complex Imported
3D MCAD



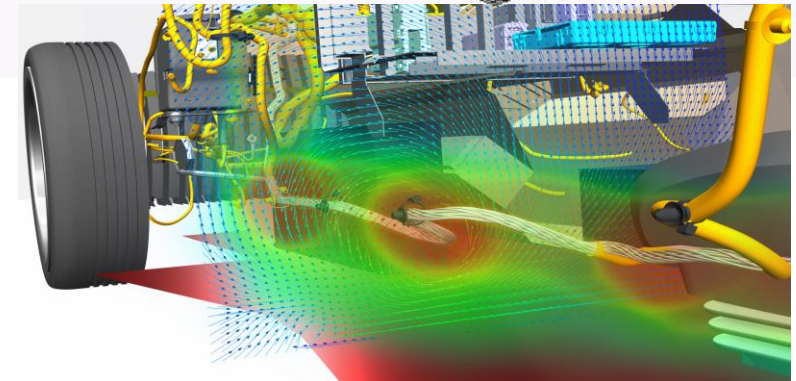
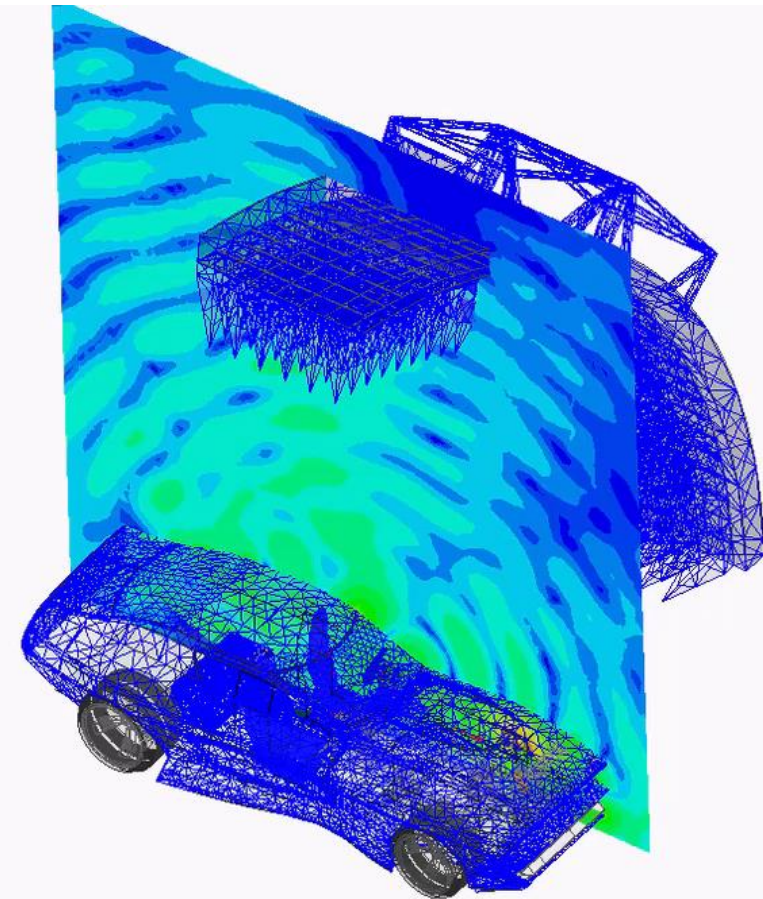
Phi Mesh

Planar objects and
ECAD, PCBs



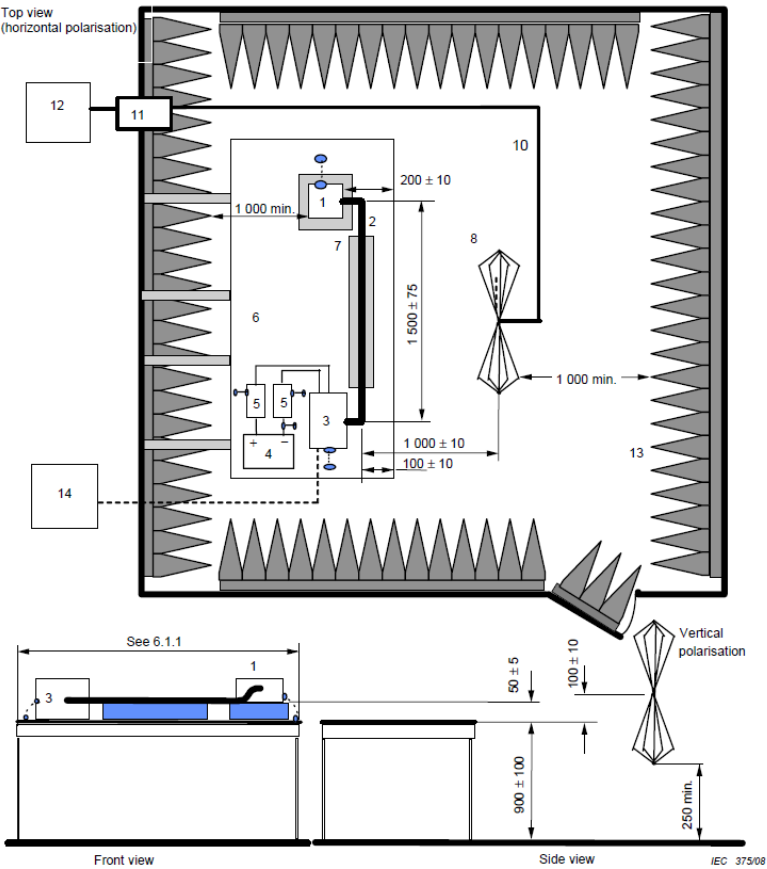
Tau

3D Objects and
imported MCAD

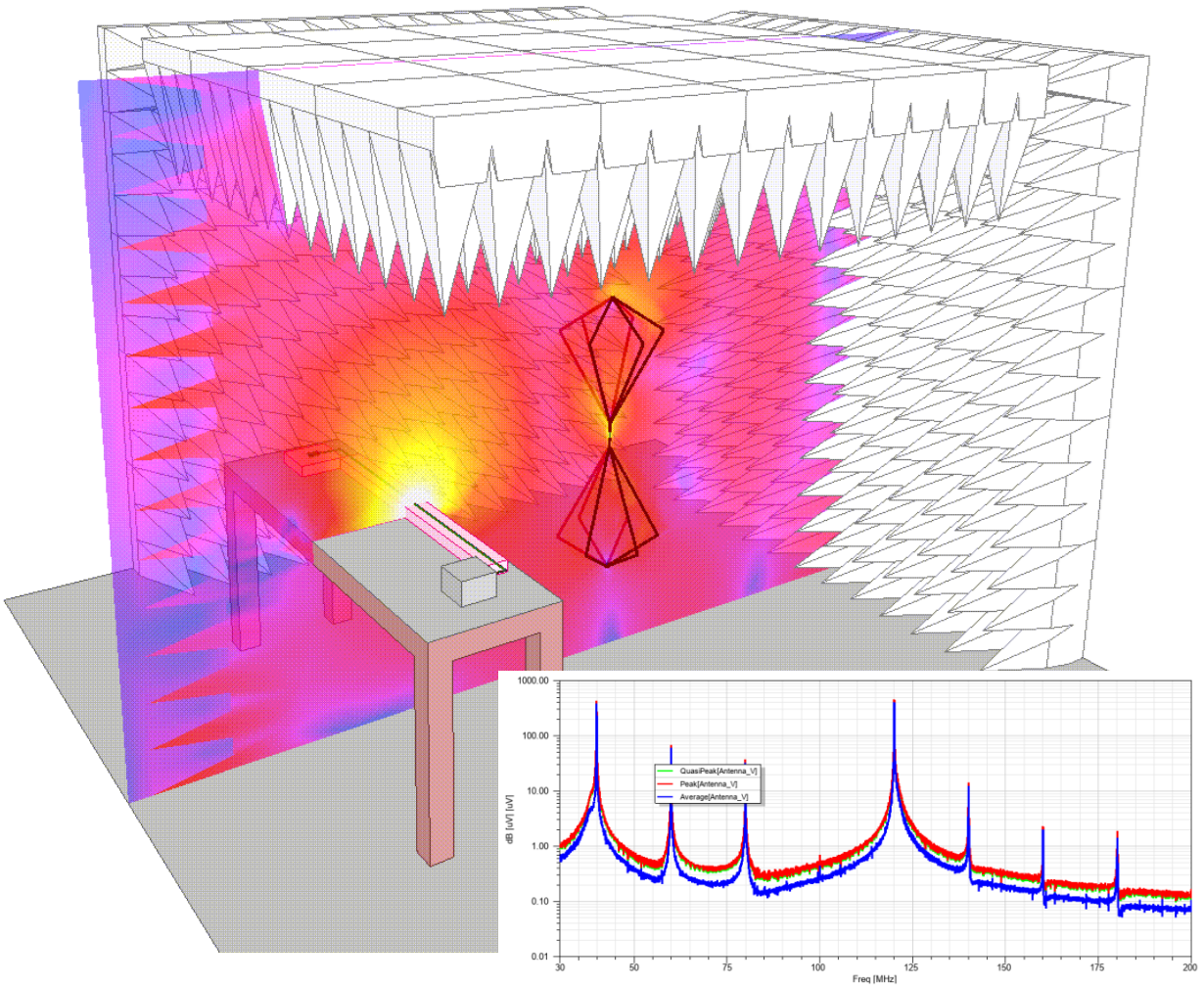


Conducted/Radiated Emissions

CISPR25 Standard



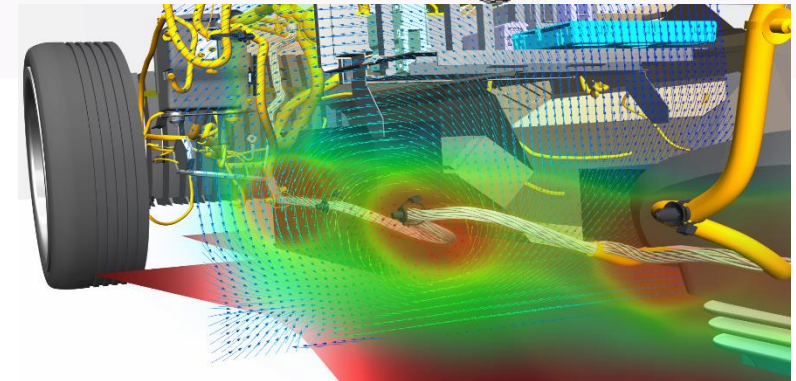
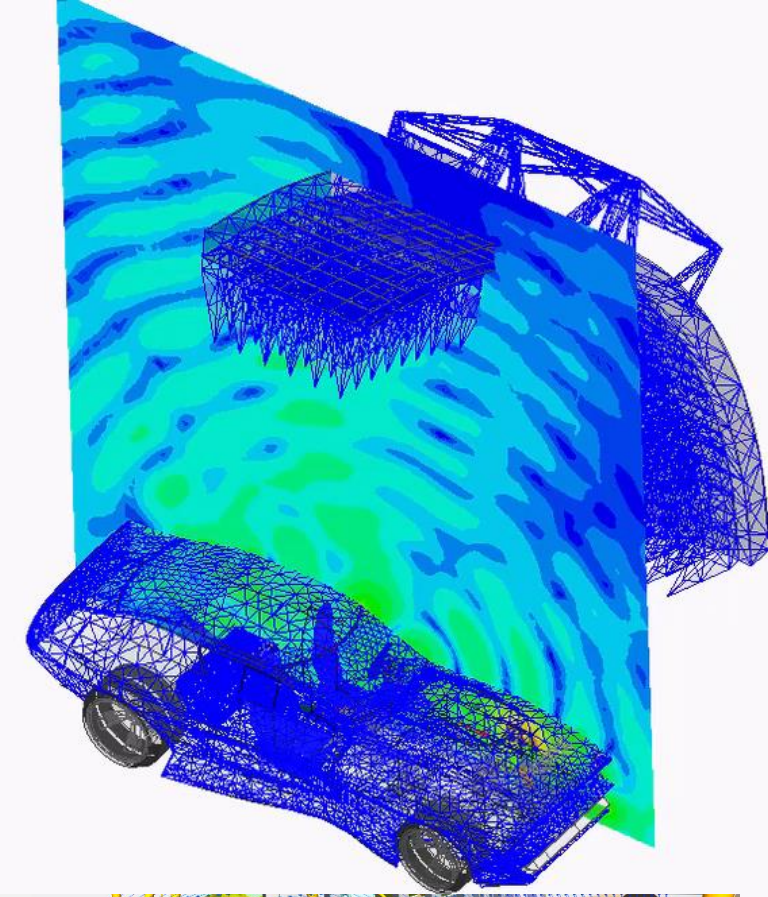
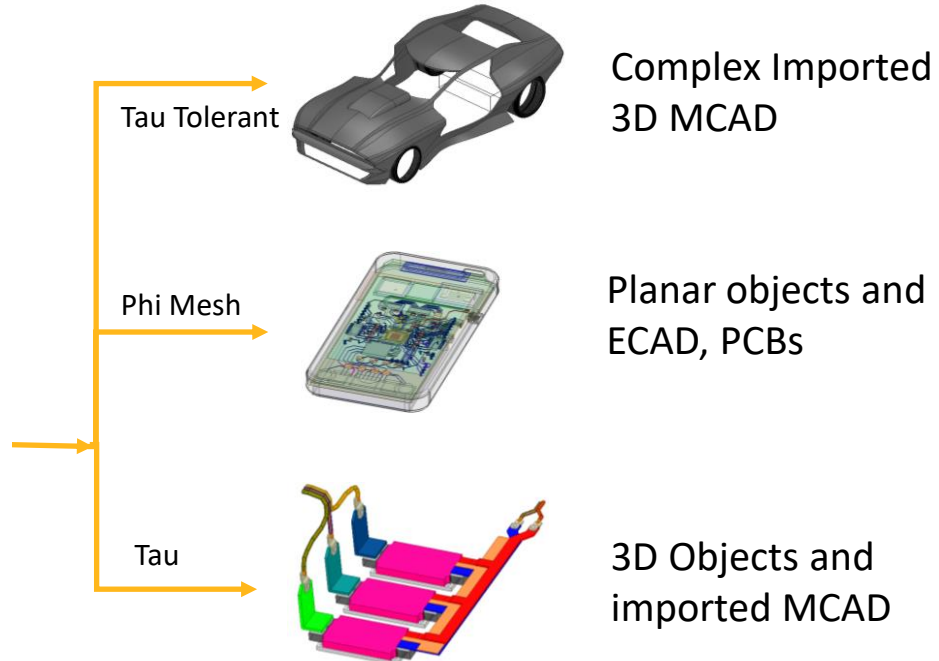
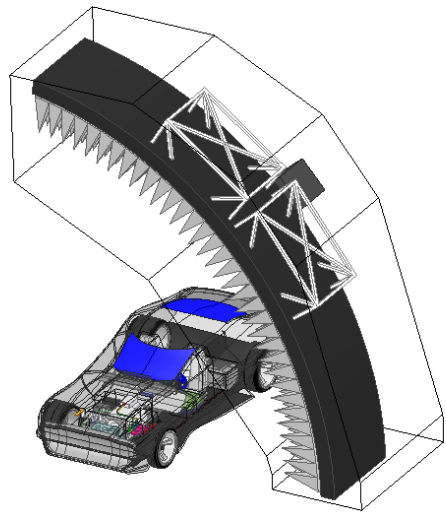
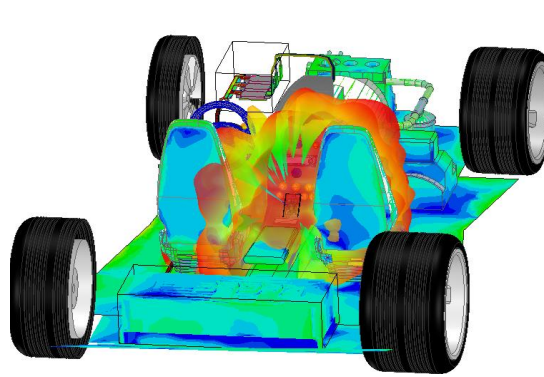
ANSYS Test Bench Model



EMC & Ansys Mesh Fusion

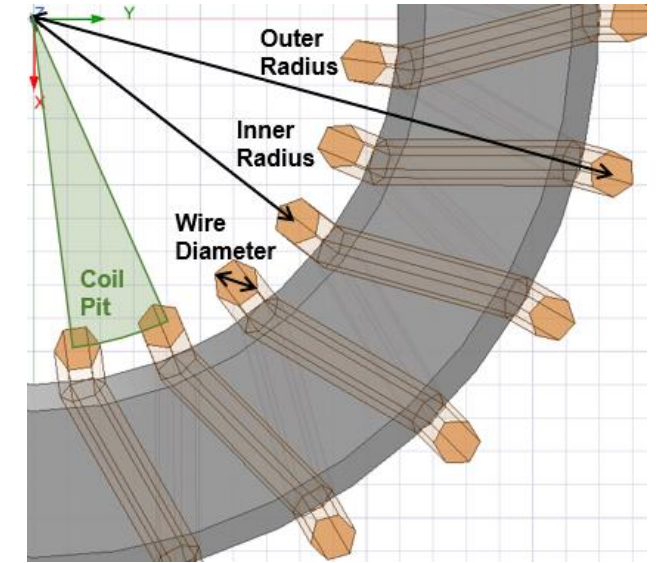
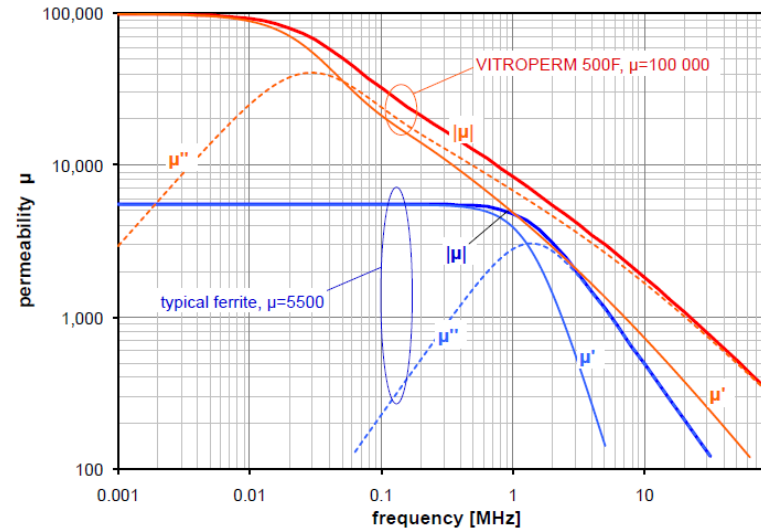
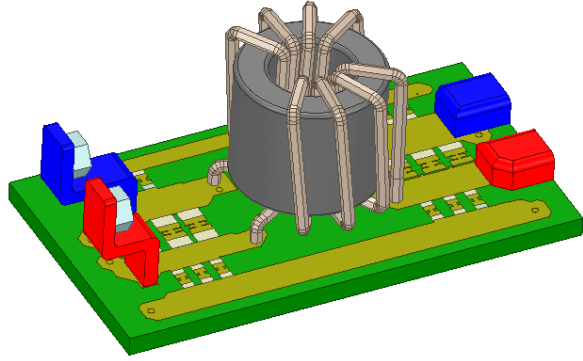
- Mesh Fusion **Advantages**

- **Robust:** Higher overall Mesh Quality
 - Component level mesh settings
 - Mesh tolerance at scale of component
- **Faster:** Concurrent (i.e. parallel) mesh generation
- **Scalable:** Mesh larger and more complex complete “Electromagnetic Systems”
- **No Limits!**

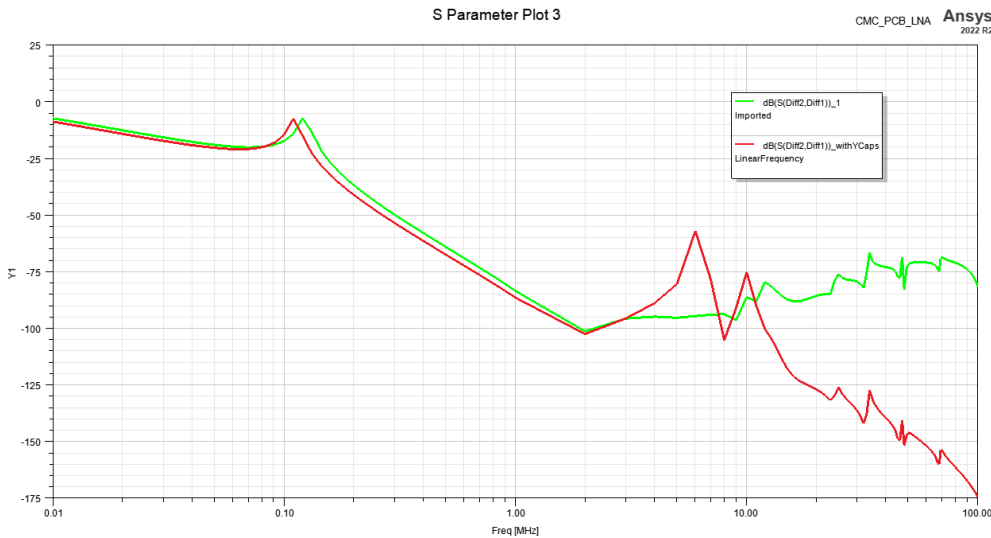


EMI Filter

EMI Filter PCB with Common Mode Choke



Simulated EMI Filter insertion loss with and without Y Caps

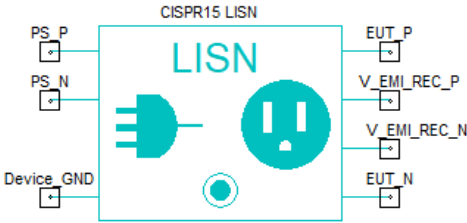
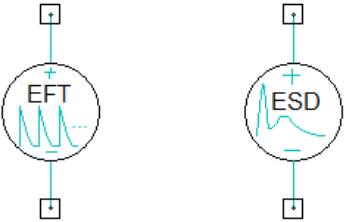


Coil :	
Name	Coil
Inner Radius (mm)	10
Outer Radius (mm)	18
Height (mm)	9
Wire Diameter (mm)	1.4
Coil Turns	21
Coil Pit (deg)	7.499
Occupation(%)	91.6544444444

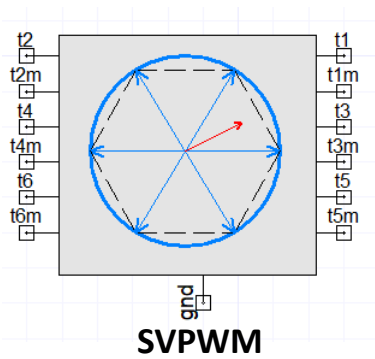
- A dedicated toolkit for CMC in Ansys HFSS helps to load frequency dependent material properties and create the 3D geometry;
- Several configuration of EMI filter can be checked in order to get in advance on virtual prototype the insertion loss in differential and common mode configurations.

System Modelling – Conducted Emissions

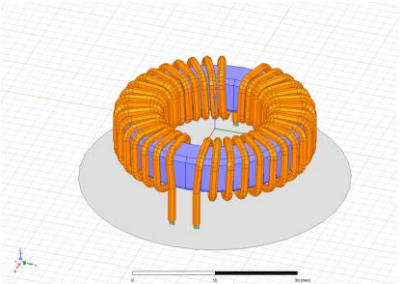
- **Accurate EM Extraction**
 - S-Parameter and Parasitic RLCG models
- **Create and Solve Transient Circuit Models**
 - SPWM, SVPWM, ESD, LISN, and EFT sources
- **IGBT PSpice Models import**



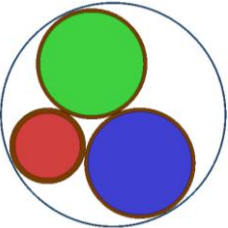
EMI Models



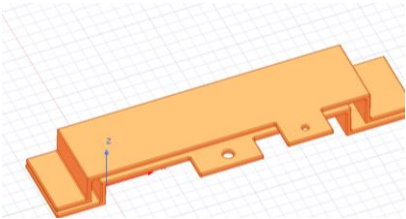
SVPWM



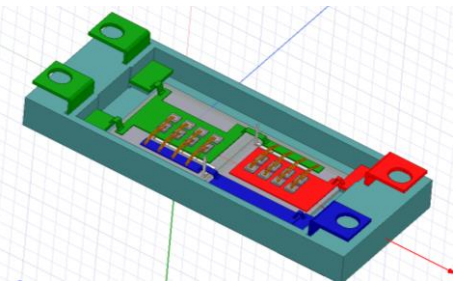
CMC



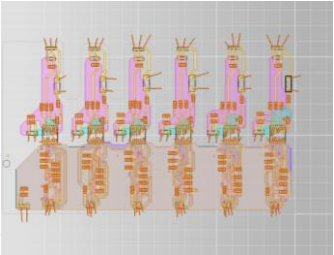
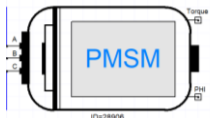
Cable



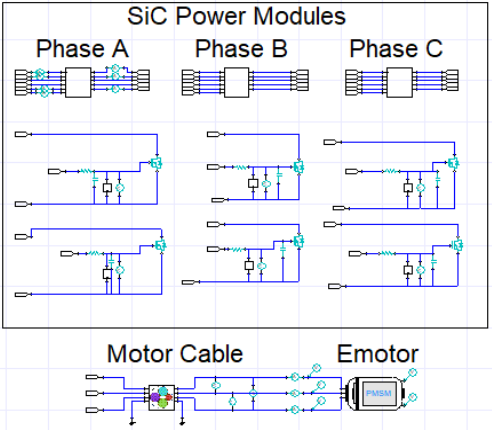
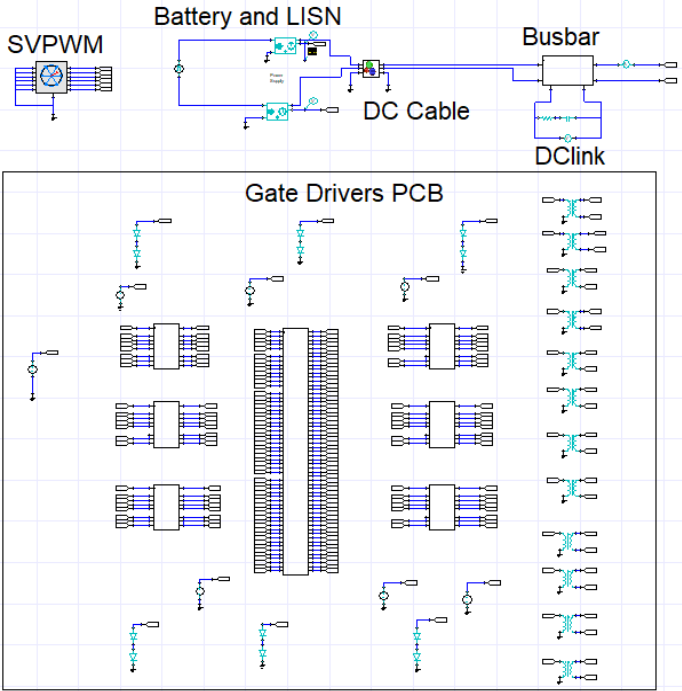
BusBar



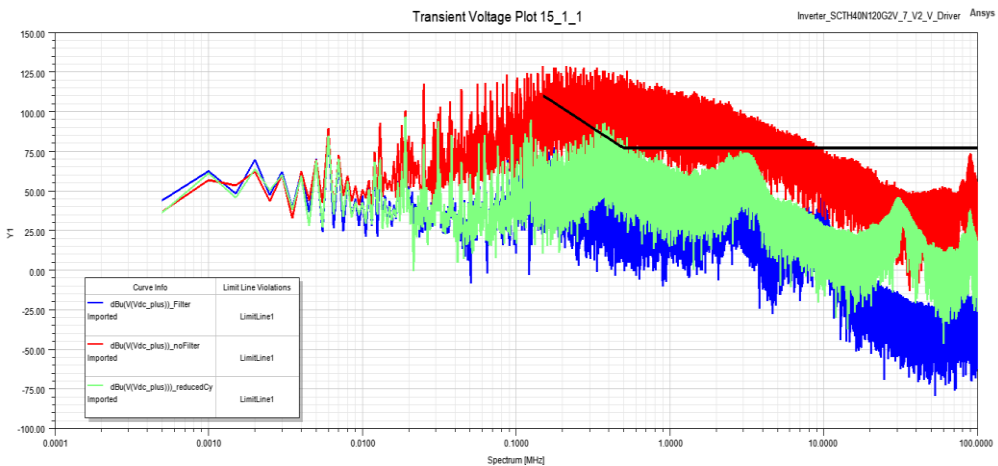
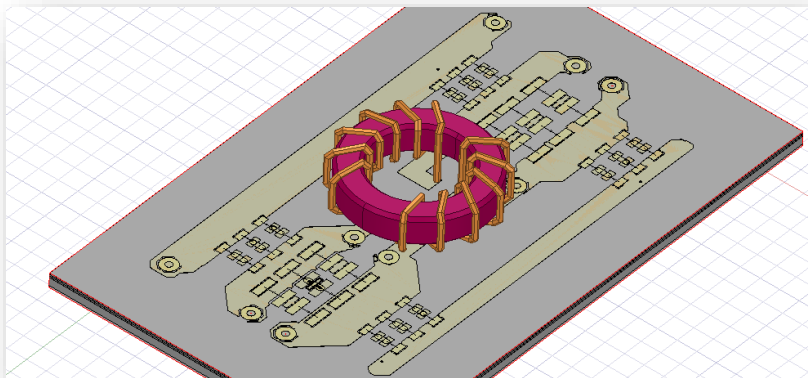
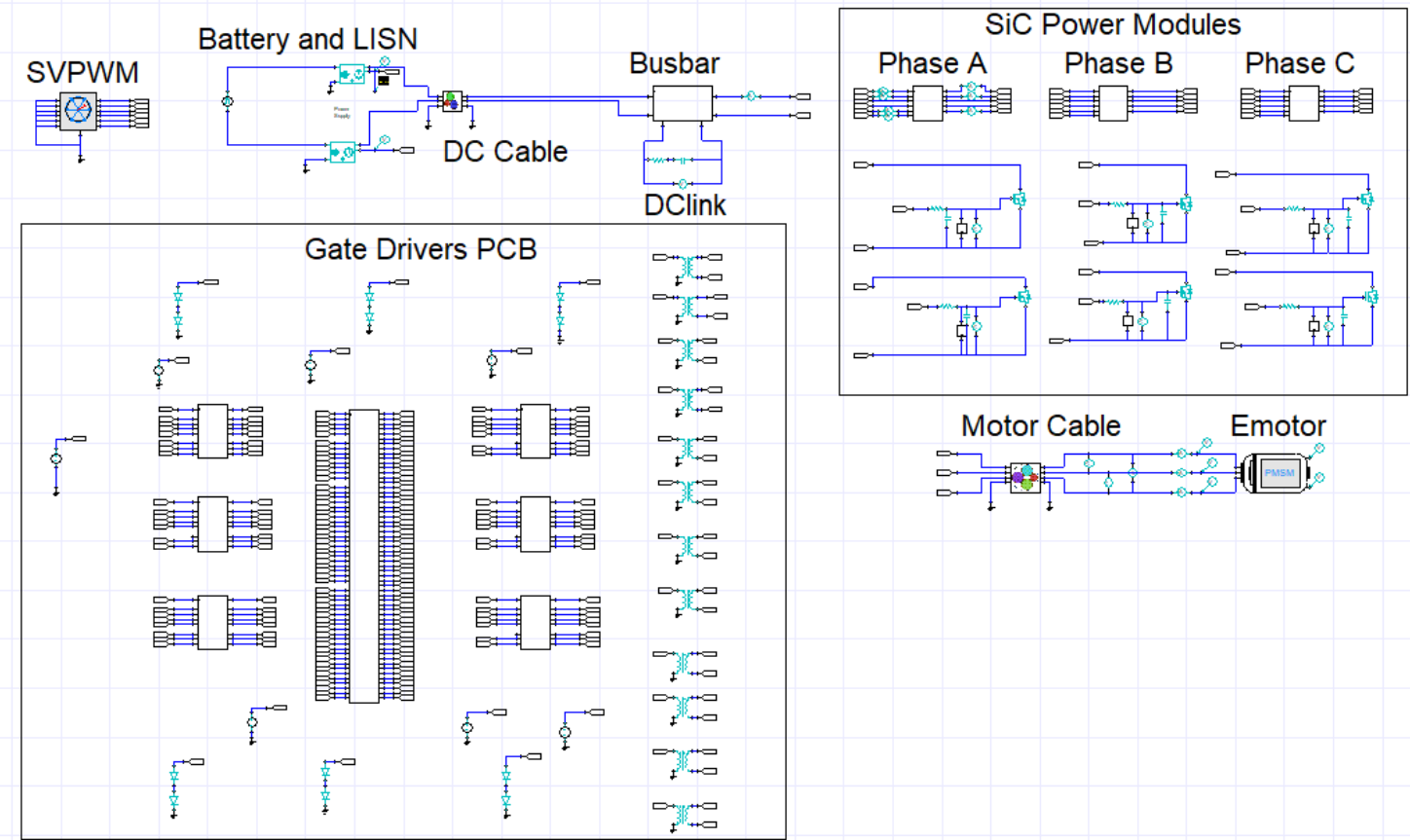
Power Modules



Gate Driver- Control PCB

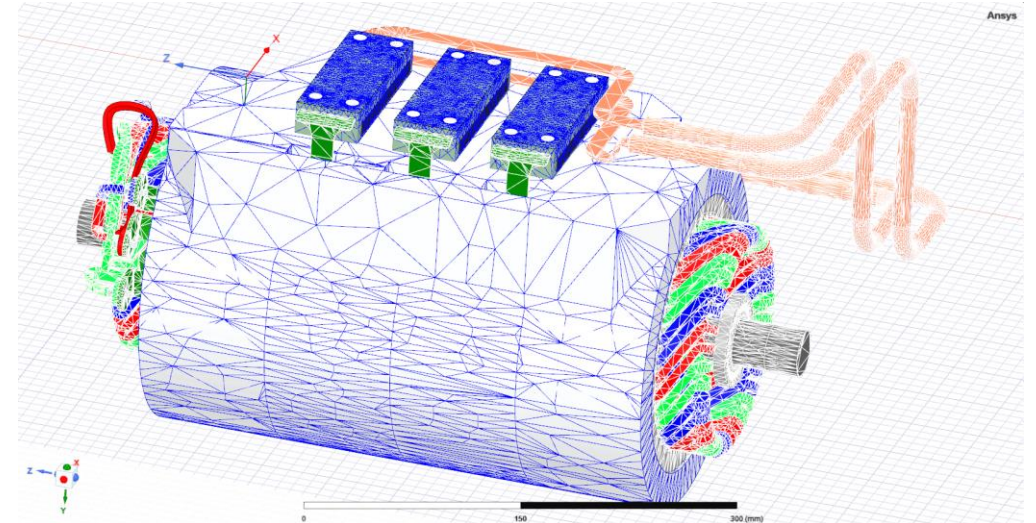
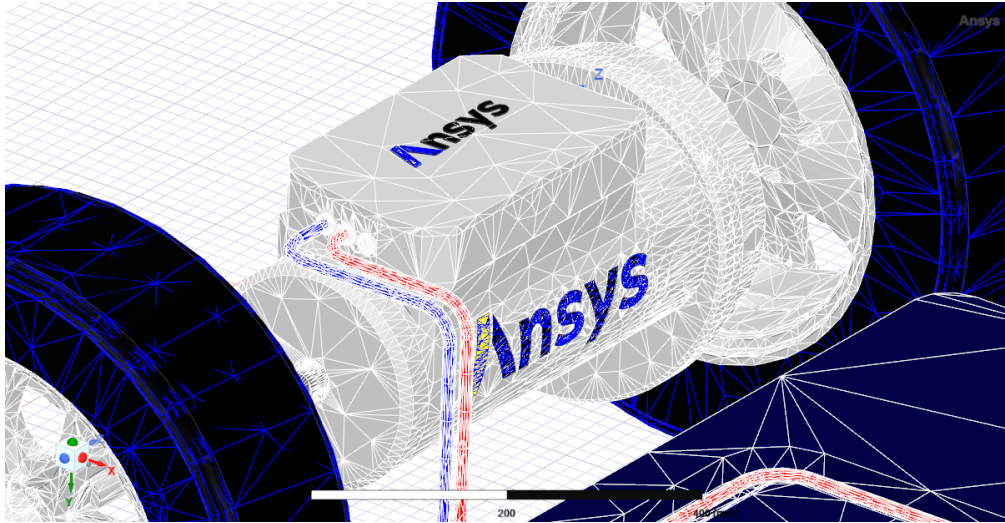
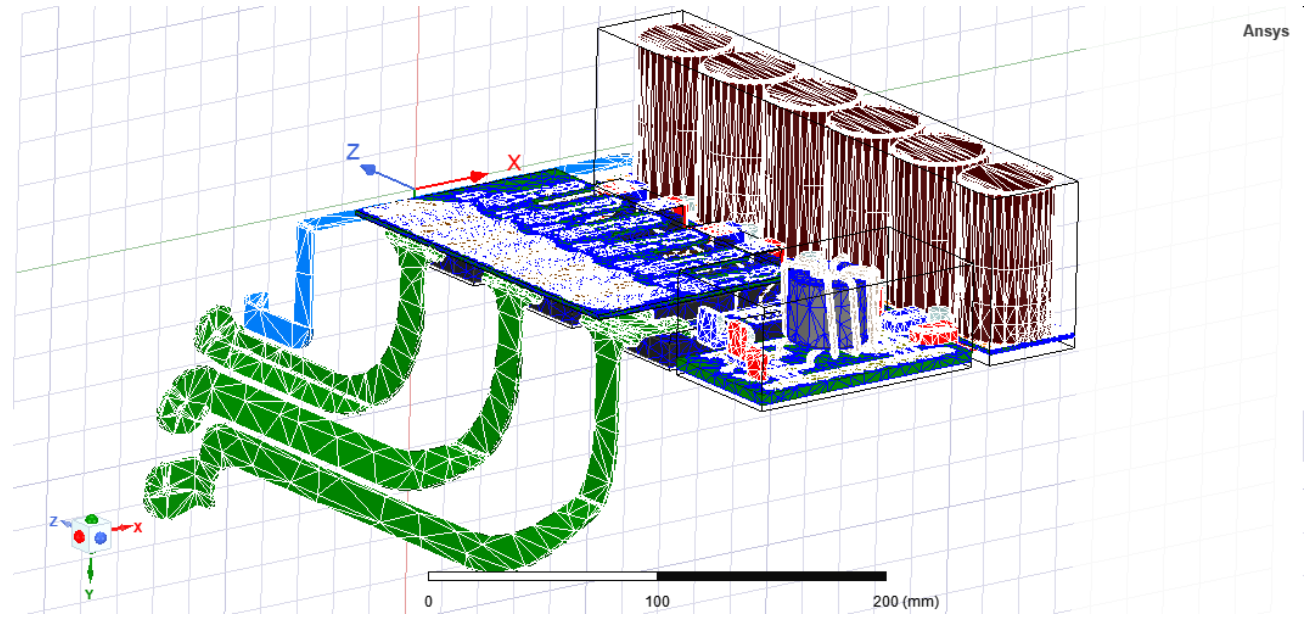
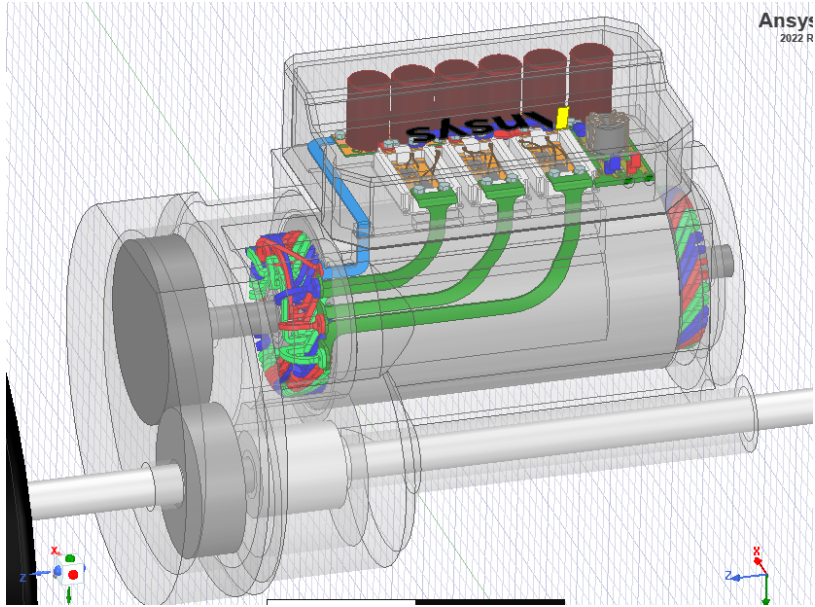


CISPR 25 Conducted/Radiated Emissions

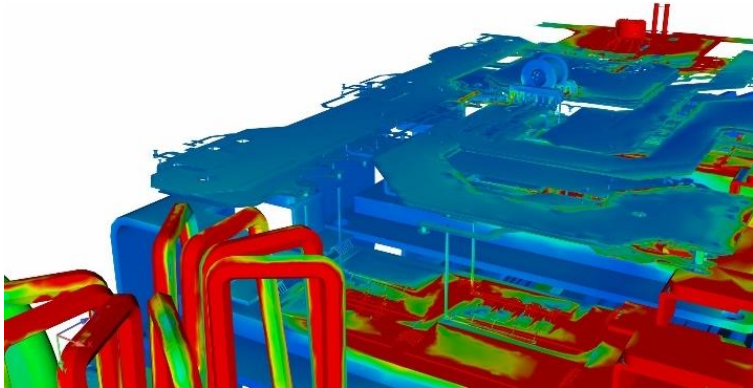


The Result with Filter , reduced Cy and No Filter. The result shows how effectively the Cy impact on the Filtering.

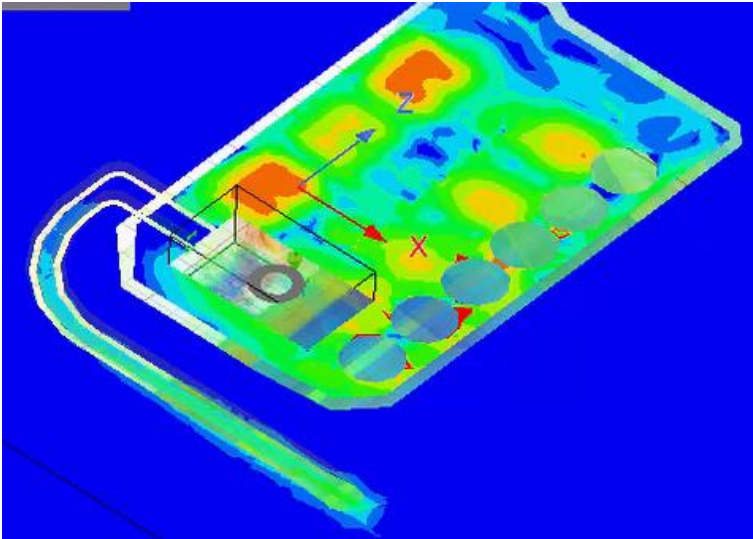
3D E-Powertrain



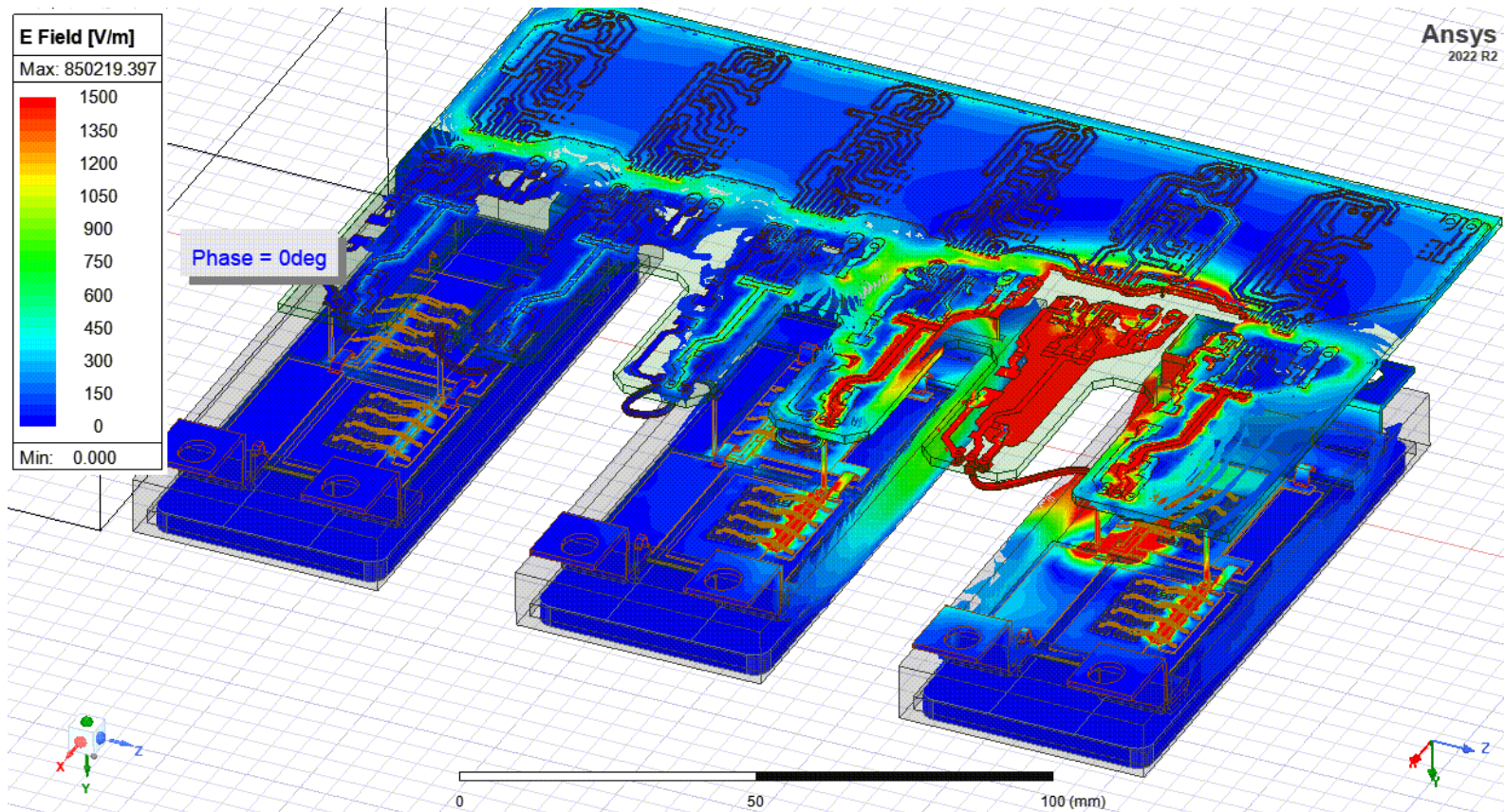
Gate driver PCB and Power Modules E field



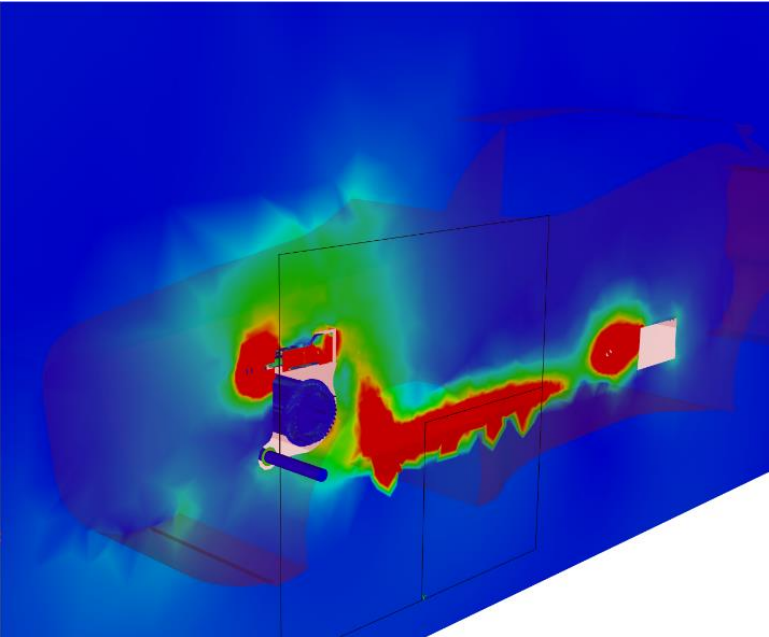
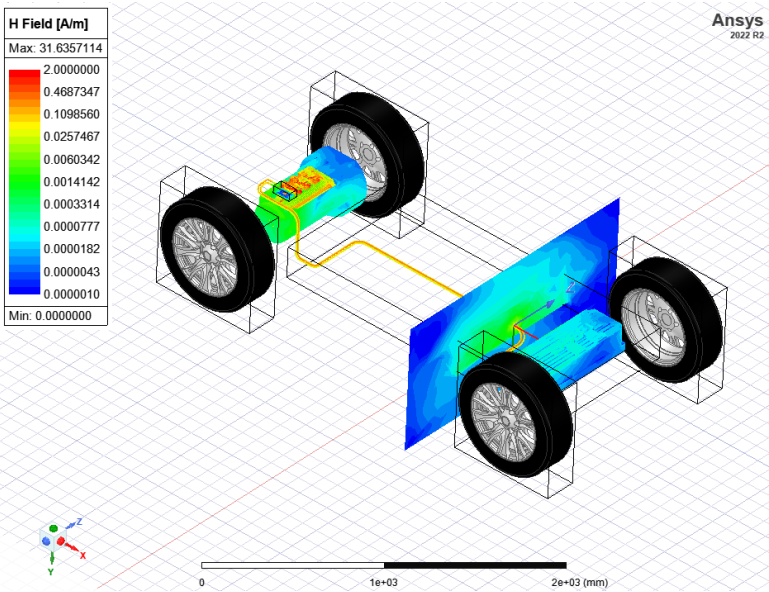
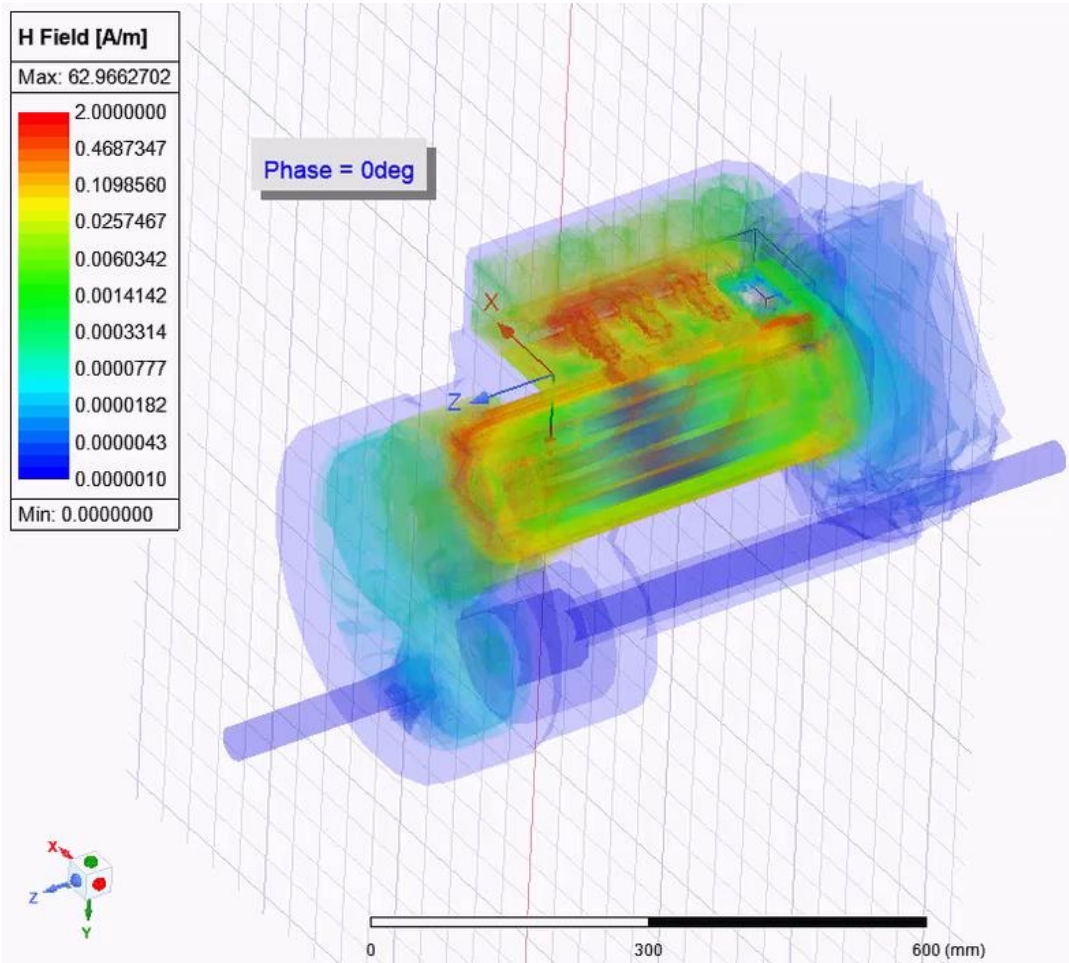
E field on cut plane @5.6MHz



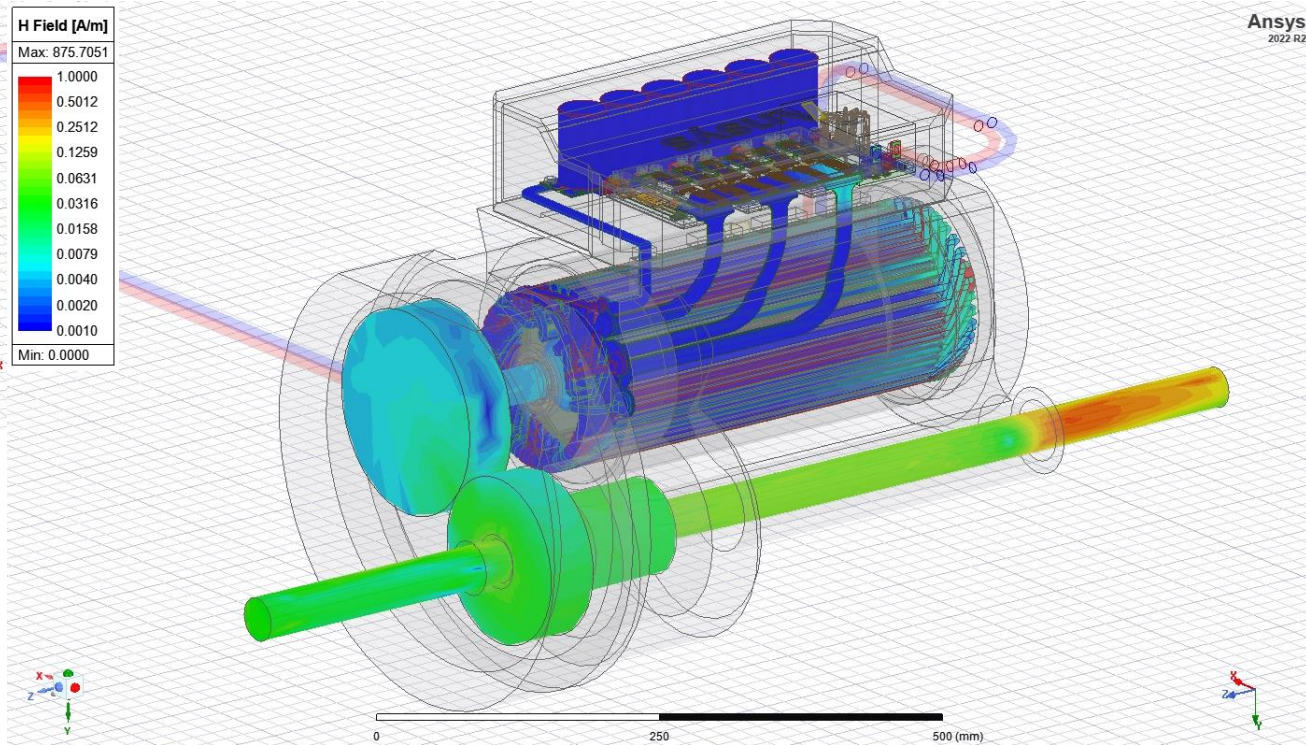
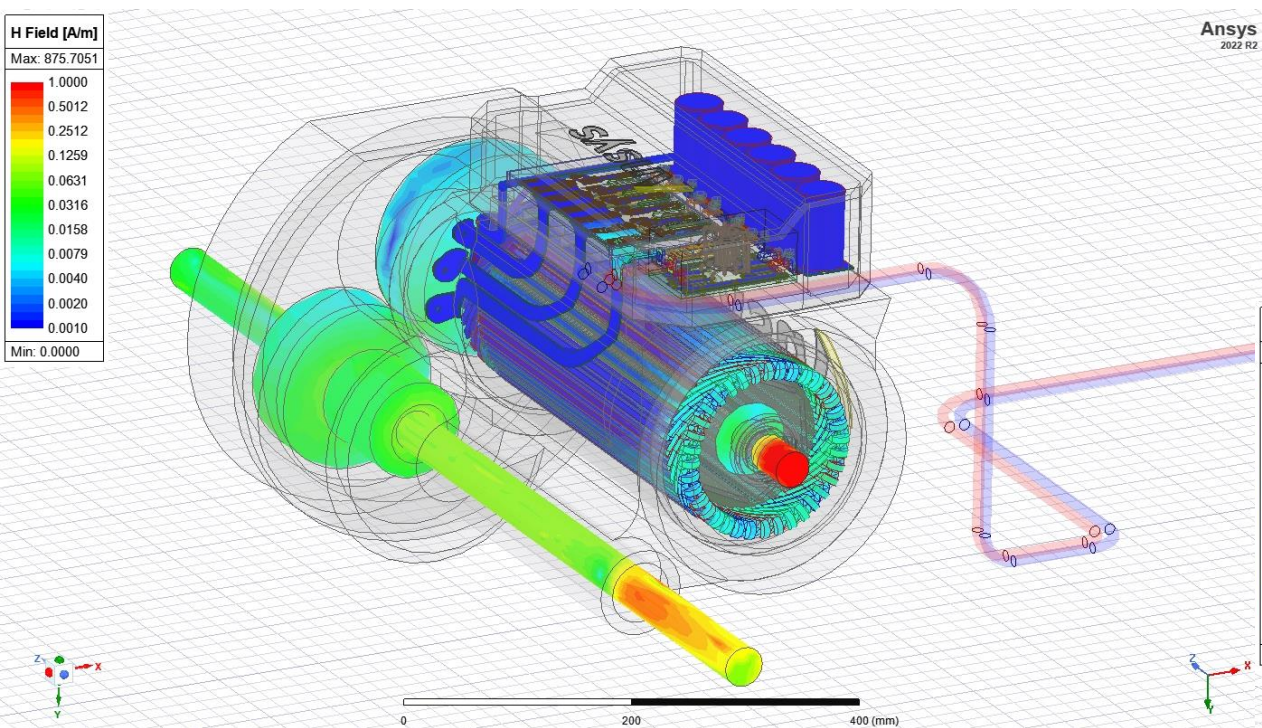
Control Board driving gate signals to Power Modules



Magnetic Field @5.6MHz



Currents induced on Bearing and Gearbox



Current density induced by electronics component on the bearing and gearbox can be plot at all frequencies.



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