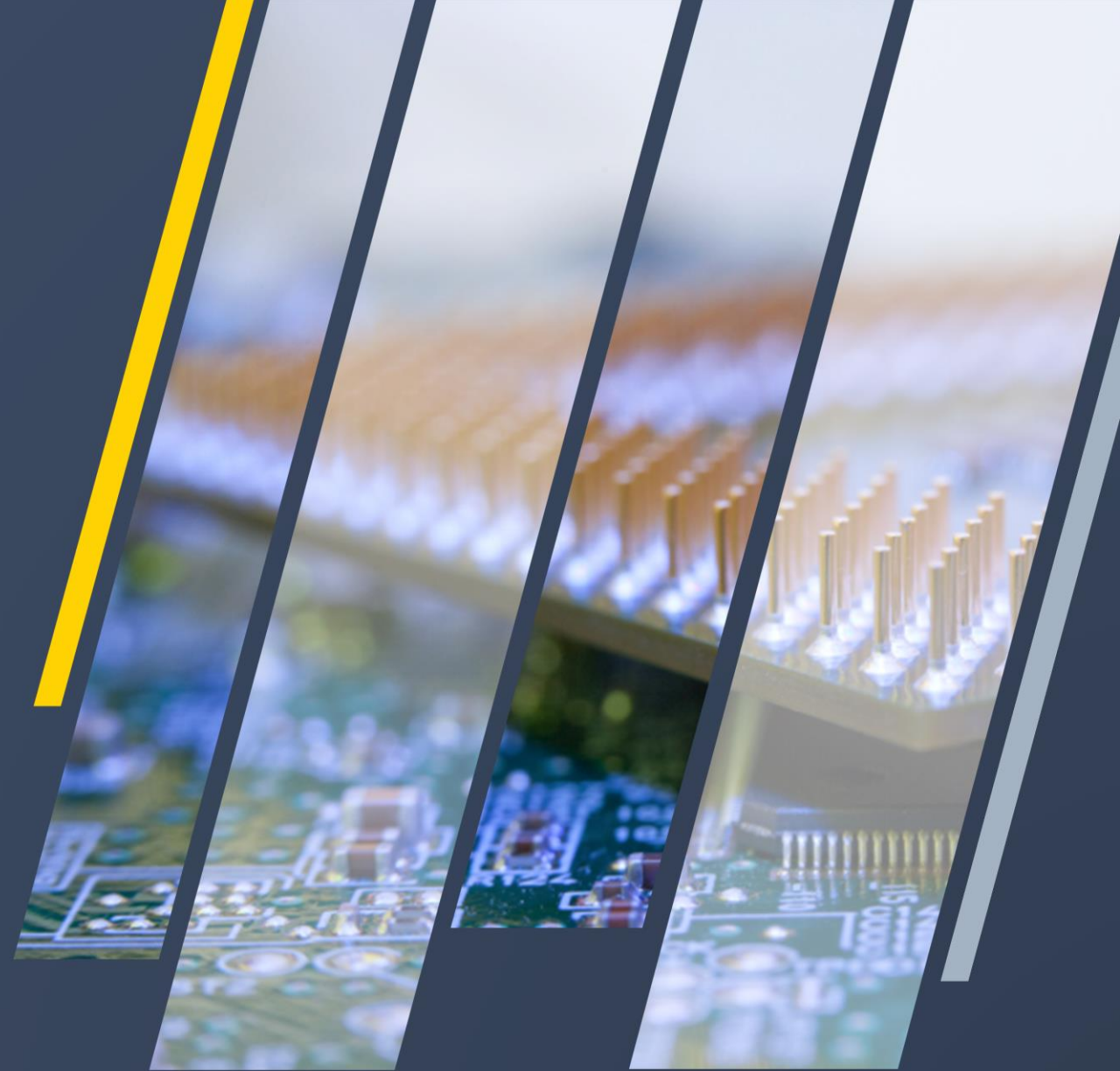




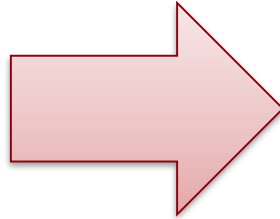
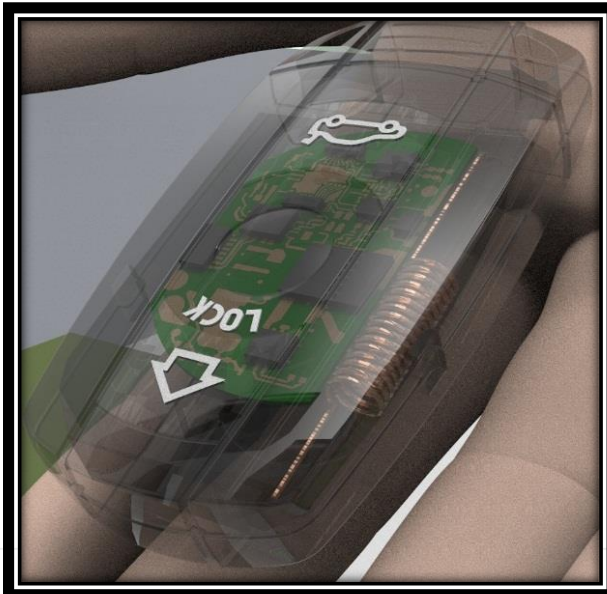
EMI/EMC Applications

EBU Product Management

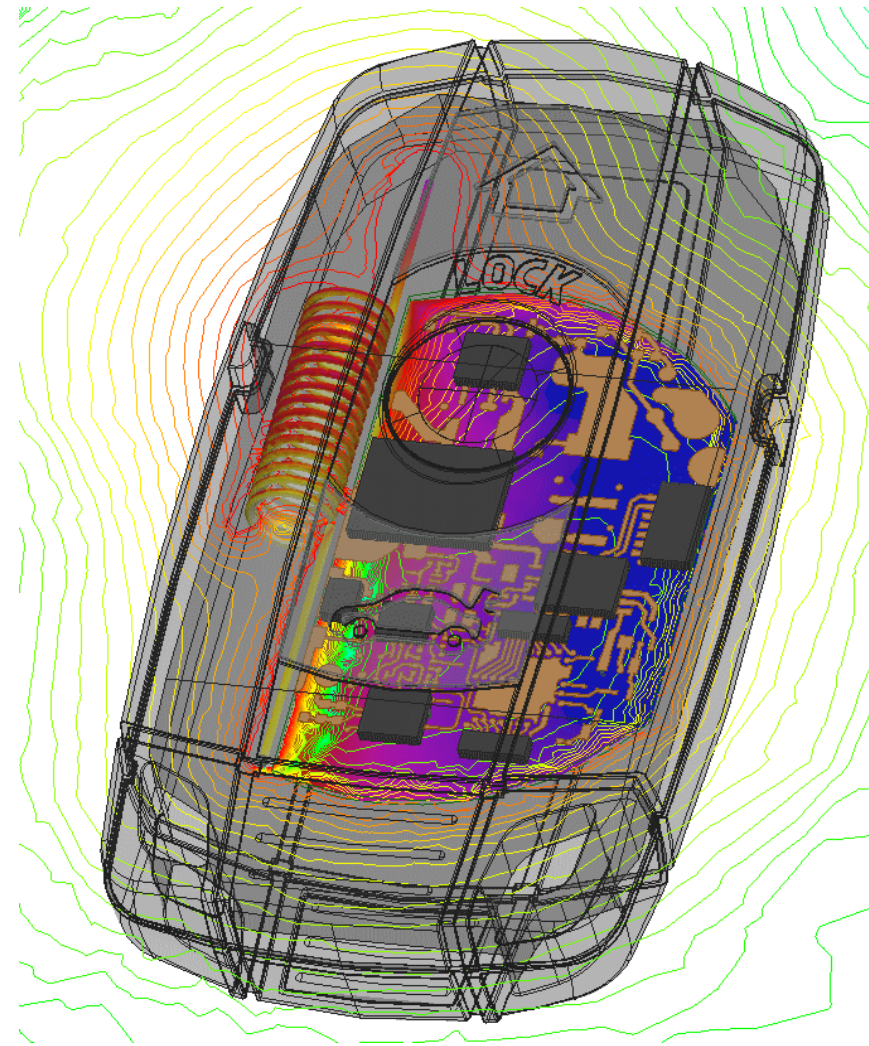


ELECTROMAGNETIC SIMULATION

REAL PRODUCT

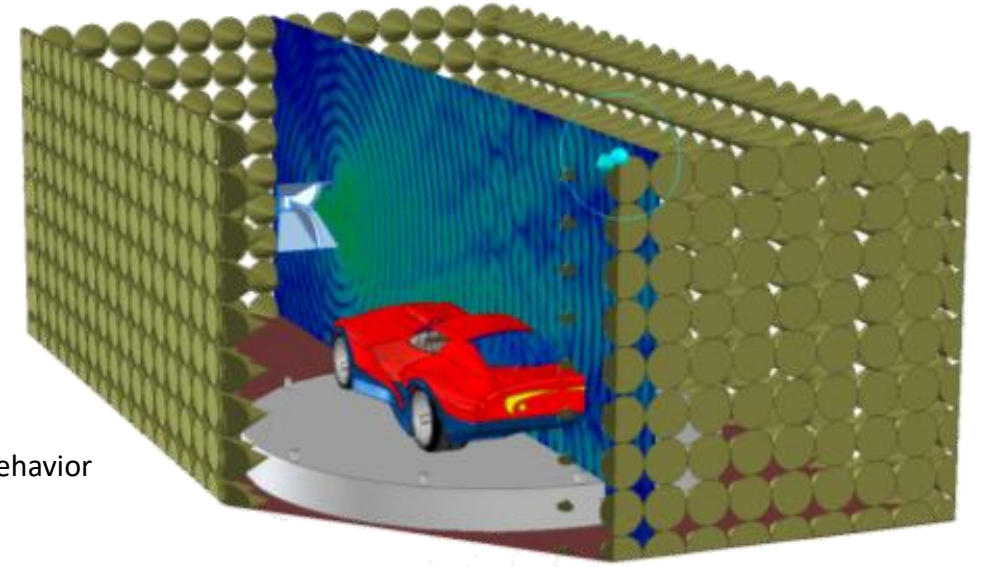


NUMERICAL MODEL – VIRTUAL PROTOTYPE

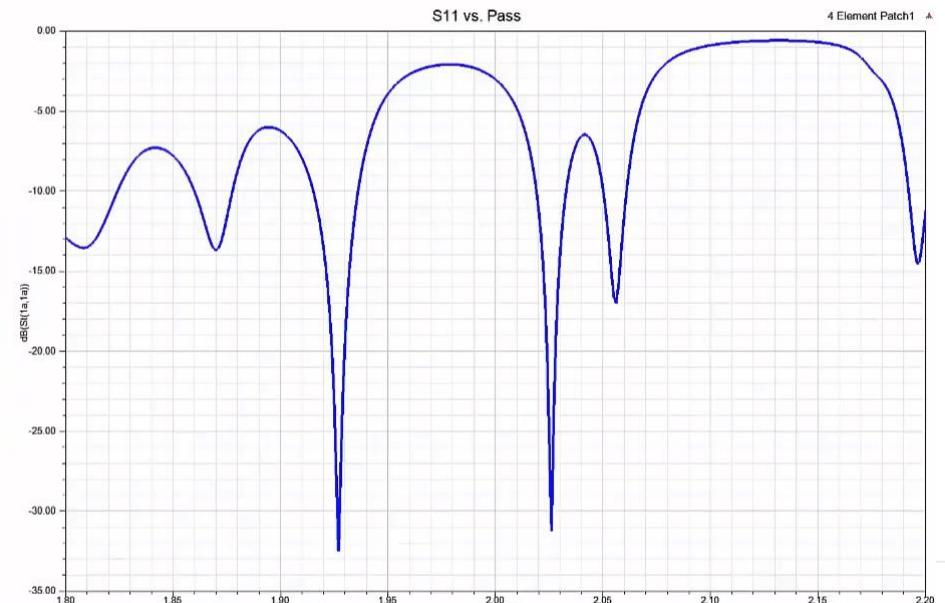
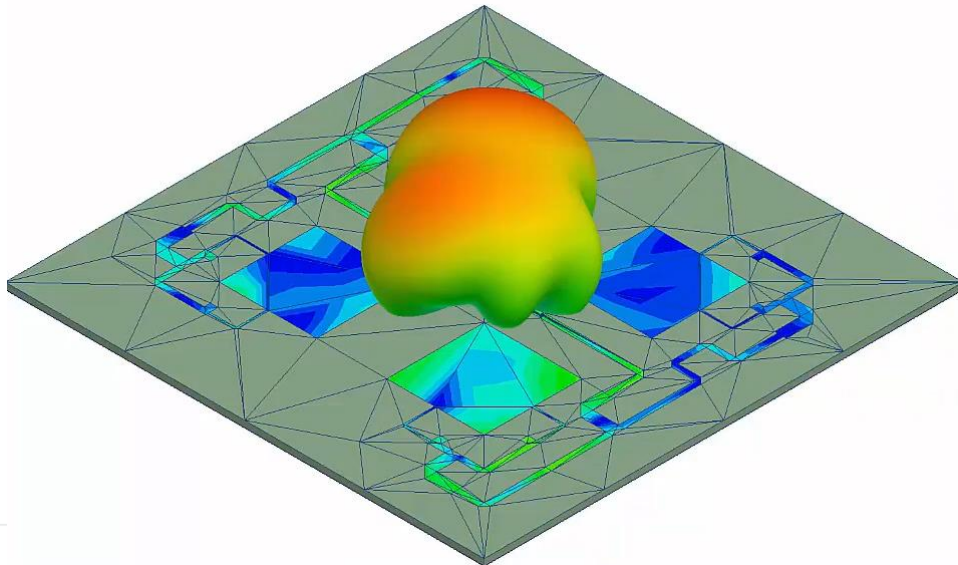


ANSYS HFSS

- Automated Precision
- Automated Mesh
- Automated Accuracy
 - Meshing algorithm adaptively refines mesh throughout geometry
 - Iteratively adds mesh elements in areas where a finer mesh is needed to accurately represent field behavior
 - Resulting in an accurate and efficient mesh



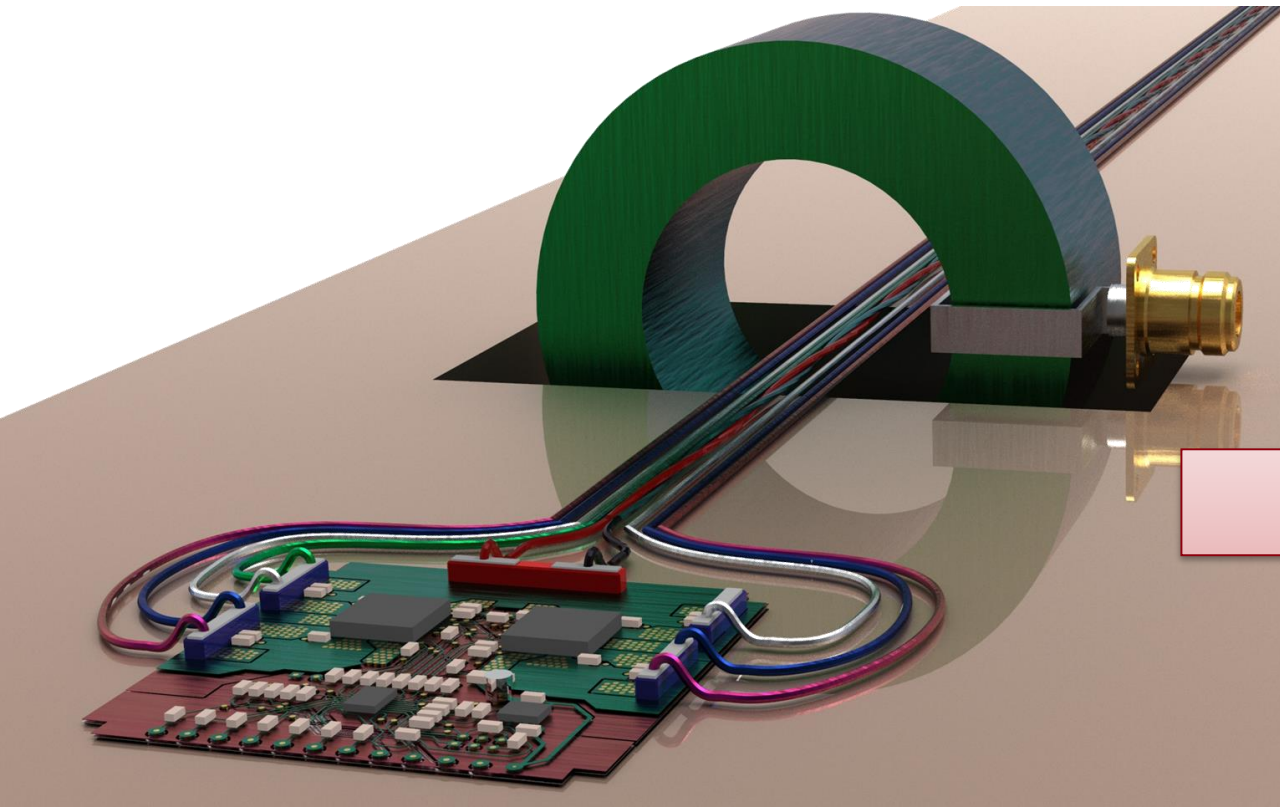
ADAPTIVE MESH REFINEMENT



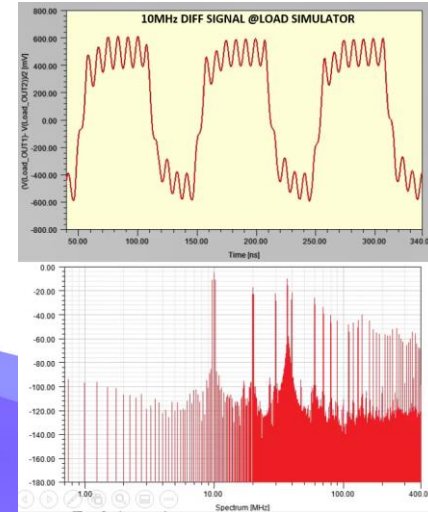
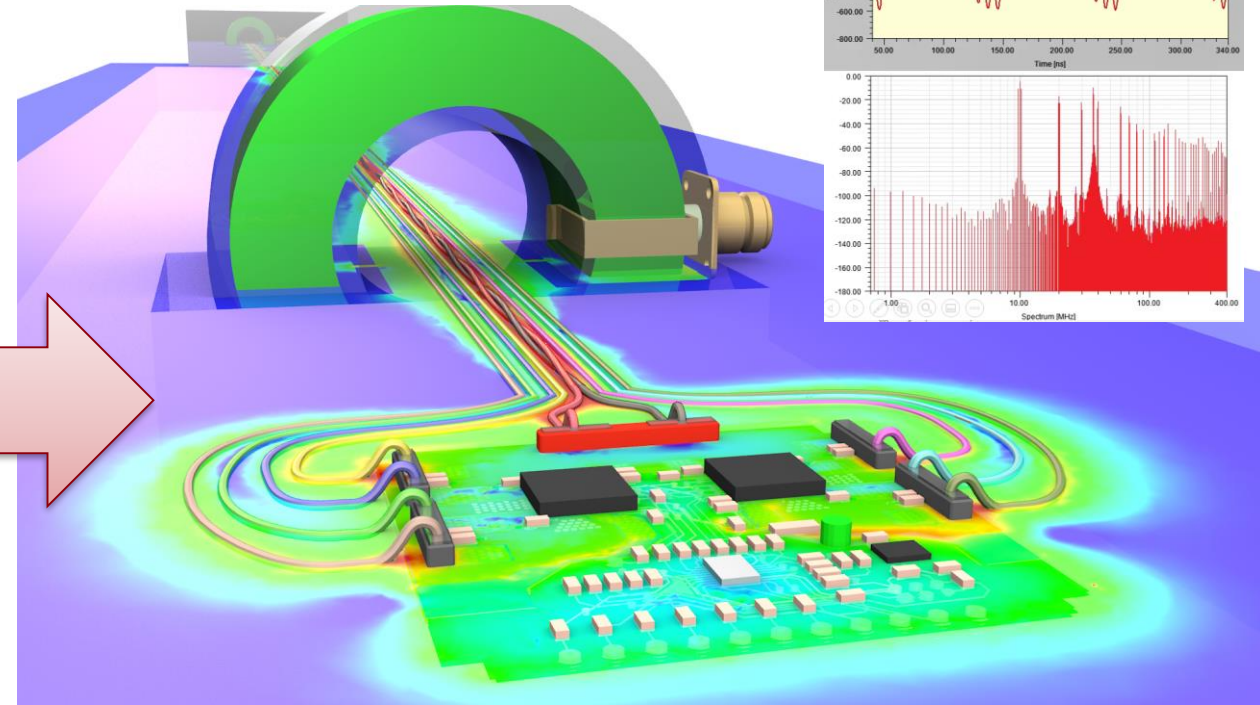
ANSYS SIMULATION TECHNOLOGY

ISO 11452-4 Example - BCI

REAL EMC TEST



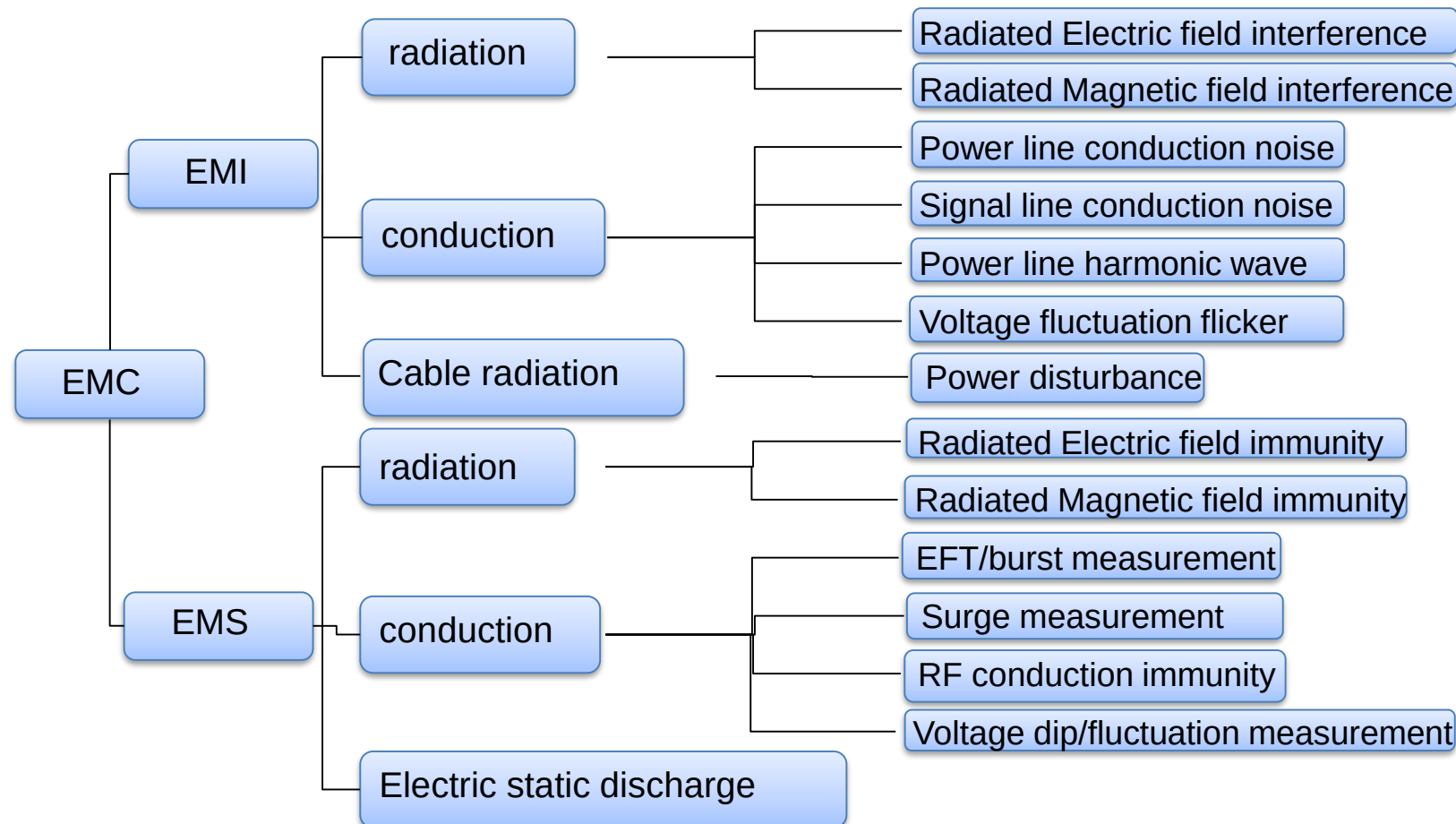
VIRTUAL EMC TEST



$$\text{EMI} = \int (\text{SI, PI, PCB, Antenna, Cables, Connectors, Housing, Environment...})$$

EMI/EMC

Electromagnetic compatibility (EMC) is the branch of electrical engineering concerned with the unintentional generation, propagation and reception of electromagnetic energy which may cause unwanted effects such as electromagnetic interference (EMI) or even physical damage in operational equipment.



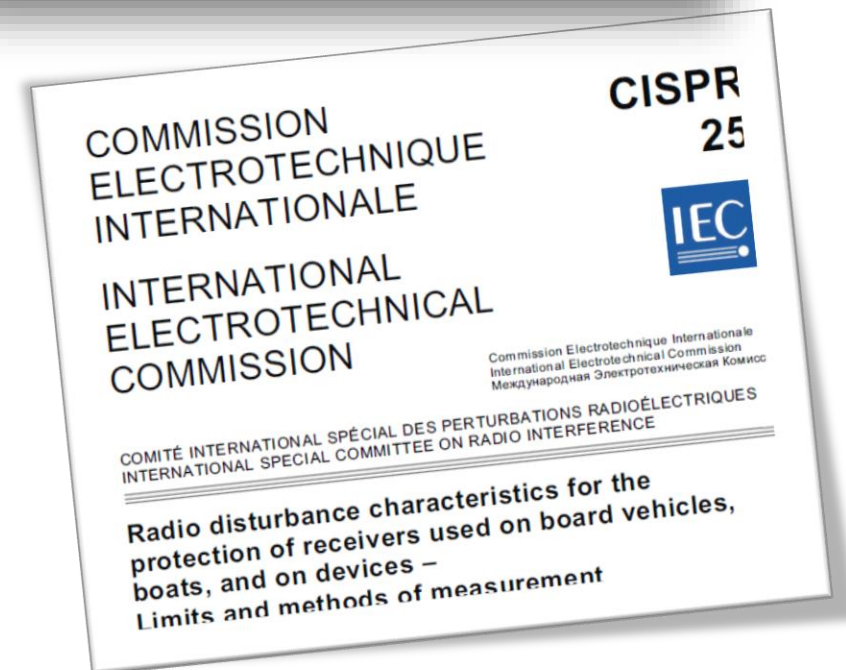
INDUSTRY STANDARDS

– Conducted and Radiated Emissions:

- CISPR 11 – Industrial Scientific and Medical
- CISPR 14 – Appliances
- CISPR 15 – Illumination
- CISPR 22 – Information Technology
- CISPR 25 – Embedded (Automotive)

– Conducted and Radiated Immunity:

- IEC 61000-4-2 – Electrostatic Discharge (ESD)
- IEC 61000-4-3 – RF Electromagnetic Fields
- IEC 61000-4-4 – Electrical Fast Transient (EFT)
- IEC 61000-4-5 – Voltage Transients (transientes)
- IEC 61000-4-6 – Conducted (induced by RF)
- IEC 61000-4-8 – Magnetic Field
- Automotive:
 - CISPR 25
 - ISO 11451
 - ISO 11452
 - ISO 7637



TRADITIONAL WORKFLOW

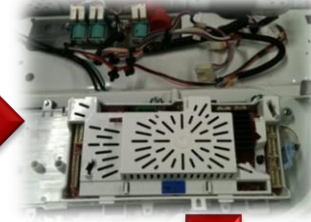
**Do design following
some EMC rules**



**Build prototypes
and do bench tests**



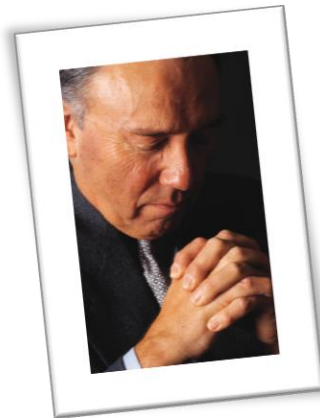
PCB Integration



**Design
Review**



**Perform EMC
Tests**



PRAY

EMC Simulation Effort

Easy simulations with good benefits

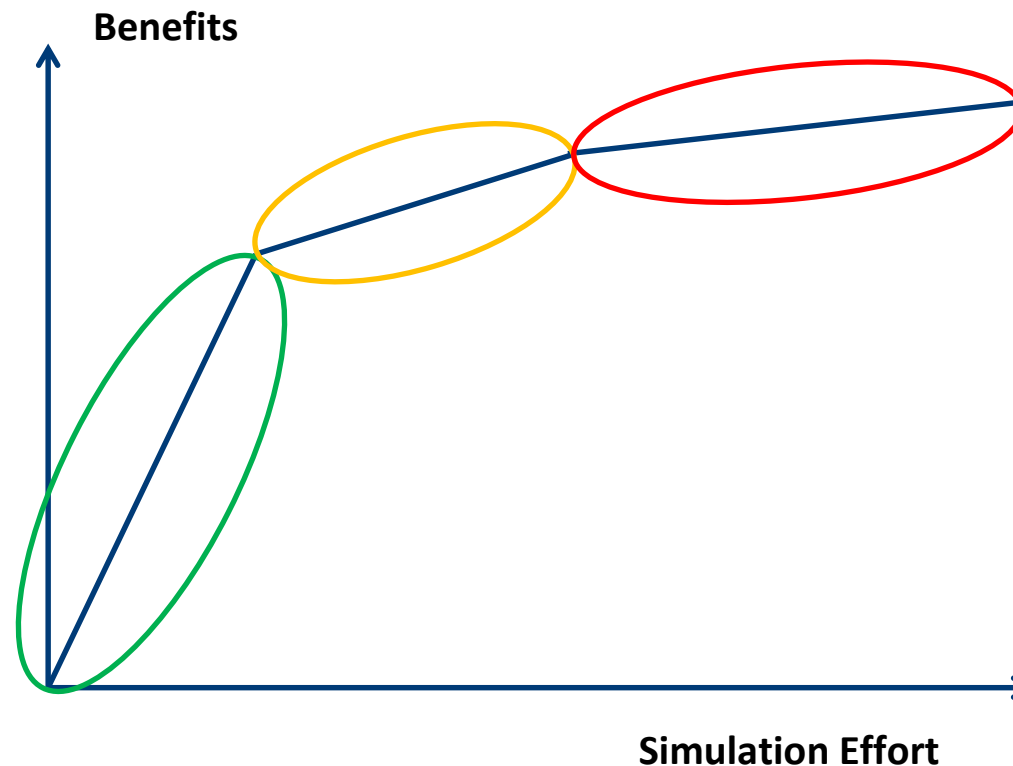
- EMI Scanner
 - Geometry Based EMI Rule Check
- Board level, passive behavior:
 - Trace impedances
 - Plane impedances
 - Resonances
 - Loop inductances
 - Filter Design
 - SYZ parameters
 - RF Cosite

Considerable effort

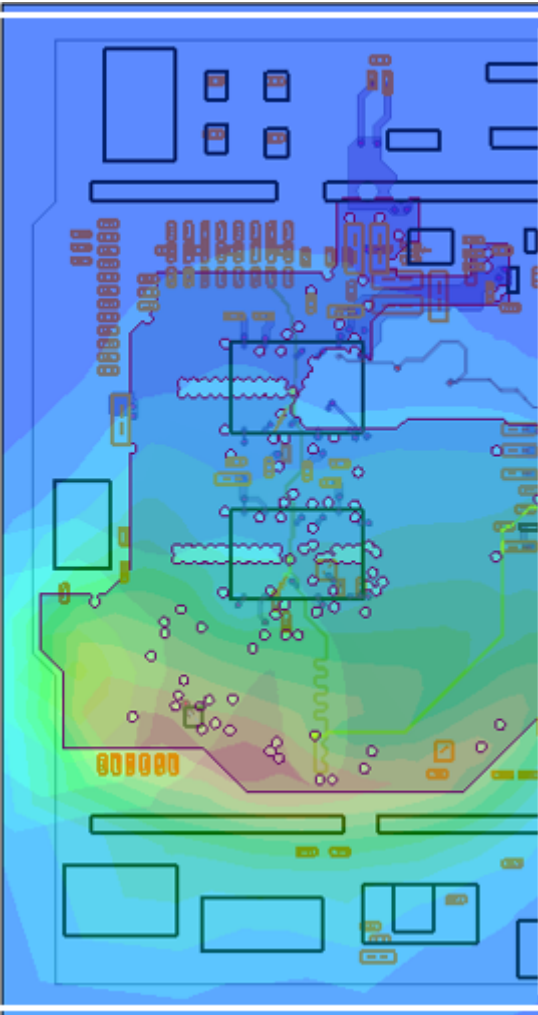
- Transient signals that depend on driver models
 - Switching behavior
 - Real Waveform
 - IBIS, SPICE Models
- Near and Far fields from PCBs

A great deal of effort

- PCB + Cable + Housing
- Full EMC Environment
 - Anechoic Chamber
 - Absorber Elements
 - Antennas
- Too many variables



EMI Scanner

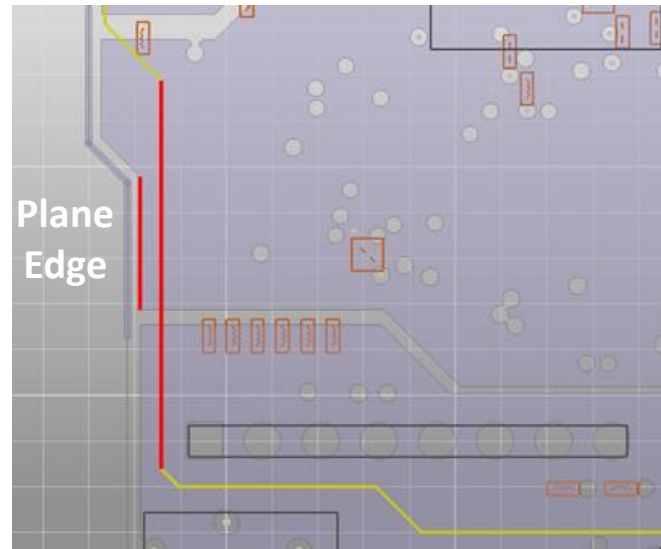


- **ANSYS EMI Scanner**
 - Geometry based EMI, SI, and PI rule checker for Printed Circuit Boards (PCBs)
 - Provides insight into common board-level EMI violations and best-practices
- **What does it do?**
 - Checks design for violations of important EMI rules
 - Contains rules for the following elements:
 - Signal nets (including differential pairs)
 - Power/Ground planes
 - Vias
 - Decoupling Capacitors
 - Decreases time spent manually reviewing PCBs for EMI compliance and ensures basic EMC design consistency across products

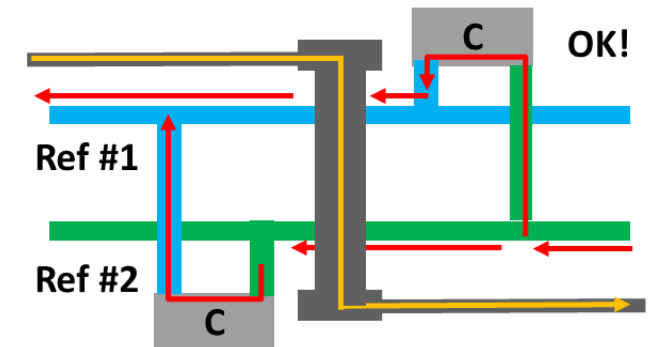
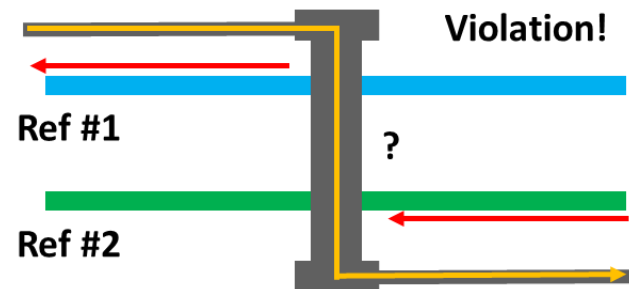
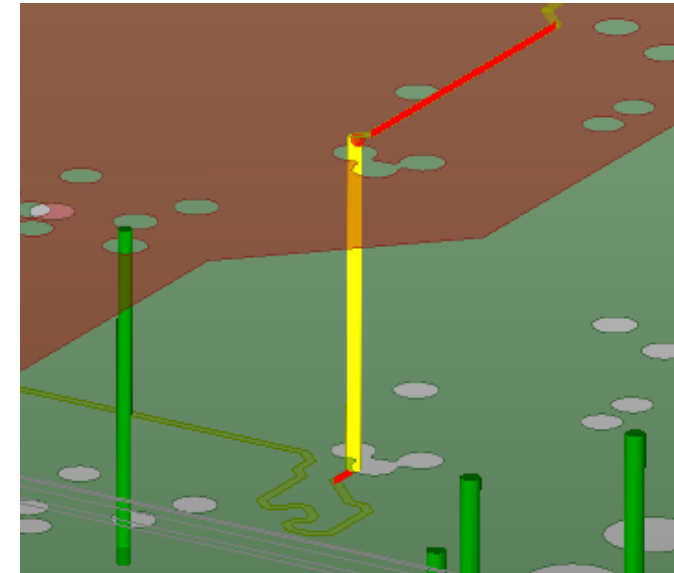
Electromagnetic Interference Rules

- **Signal Reference**
 - Net Crossing Split
 - Net Changing Reference
 - Net Near Edge of Reference
- **Wiring/ Crosstalk**
 - Critical Net Near I/O Net
 - Exposed Critical Trace Length
 - Critical Net Isolation
 - Critical Differential Net Matching
- **Placement**
 - I/O Filter Distance
 - Distance from Oscillator to Clock Driver

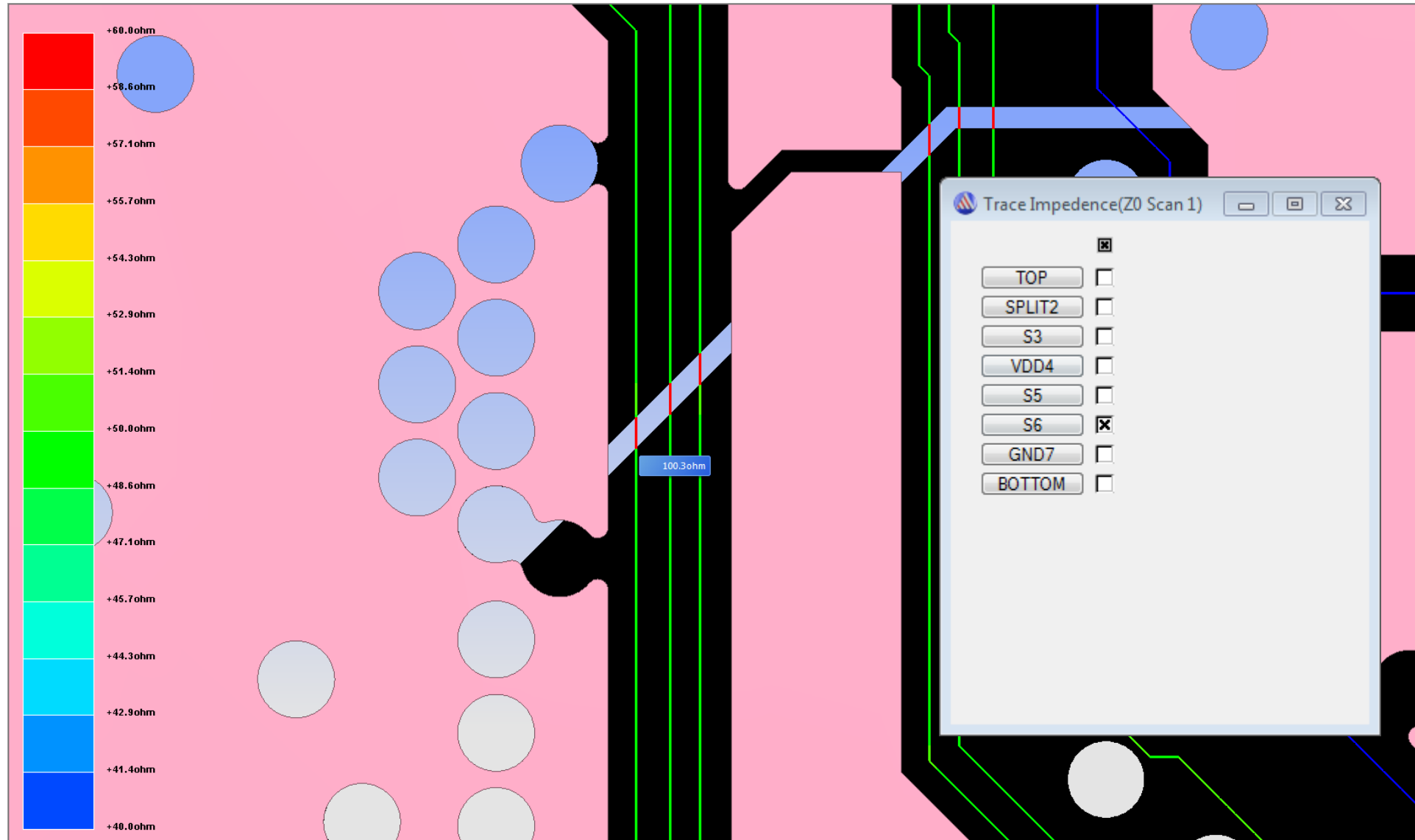
Net Near Edge of Reference



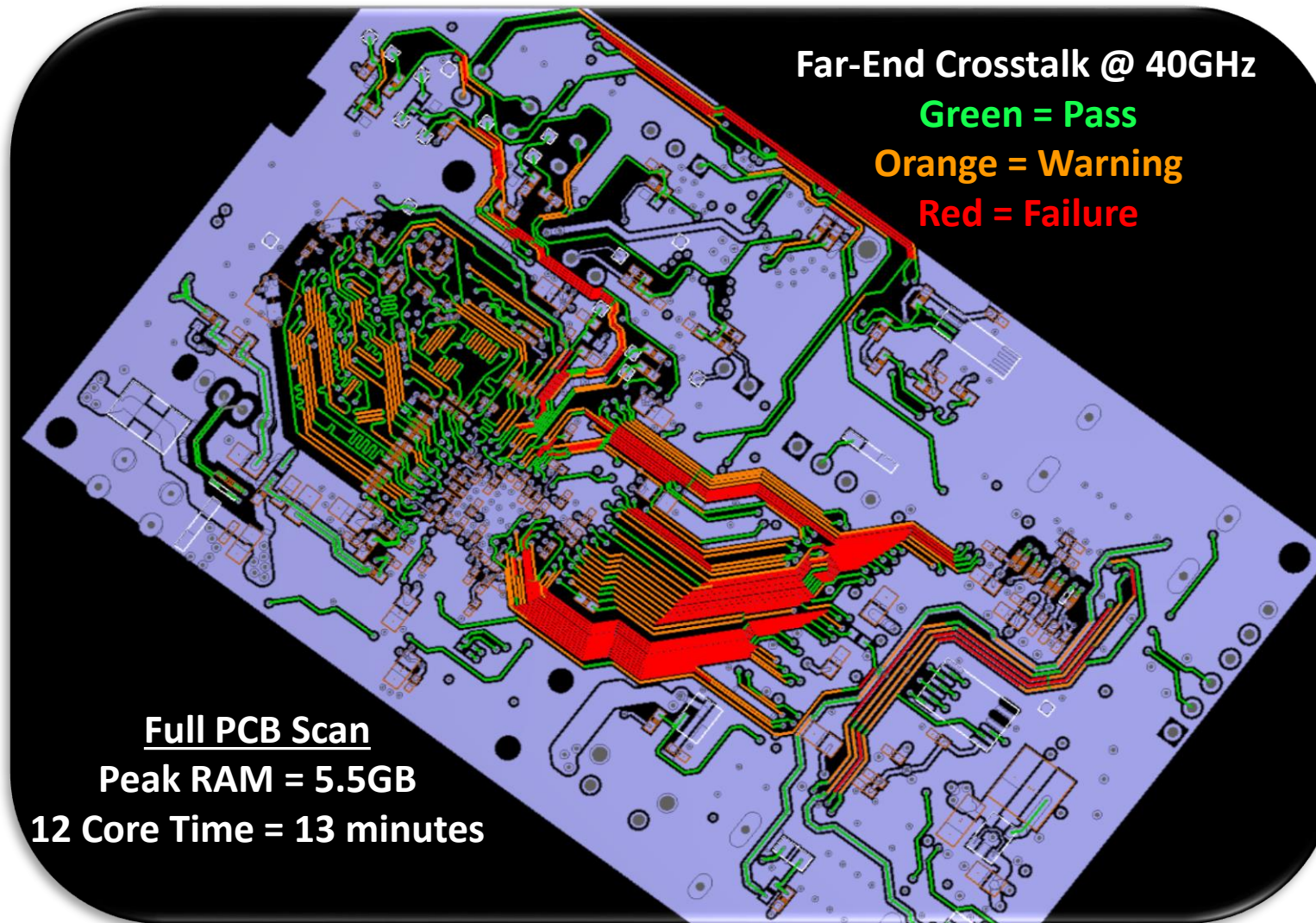
Net Changing Reference



SIwave Z0 Scan

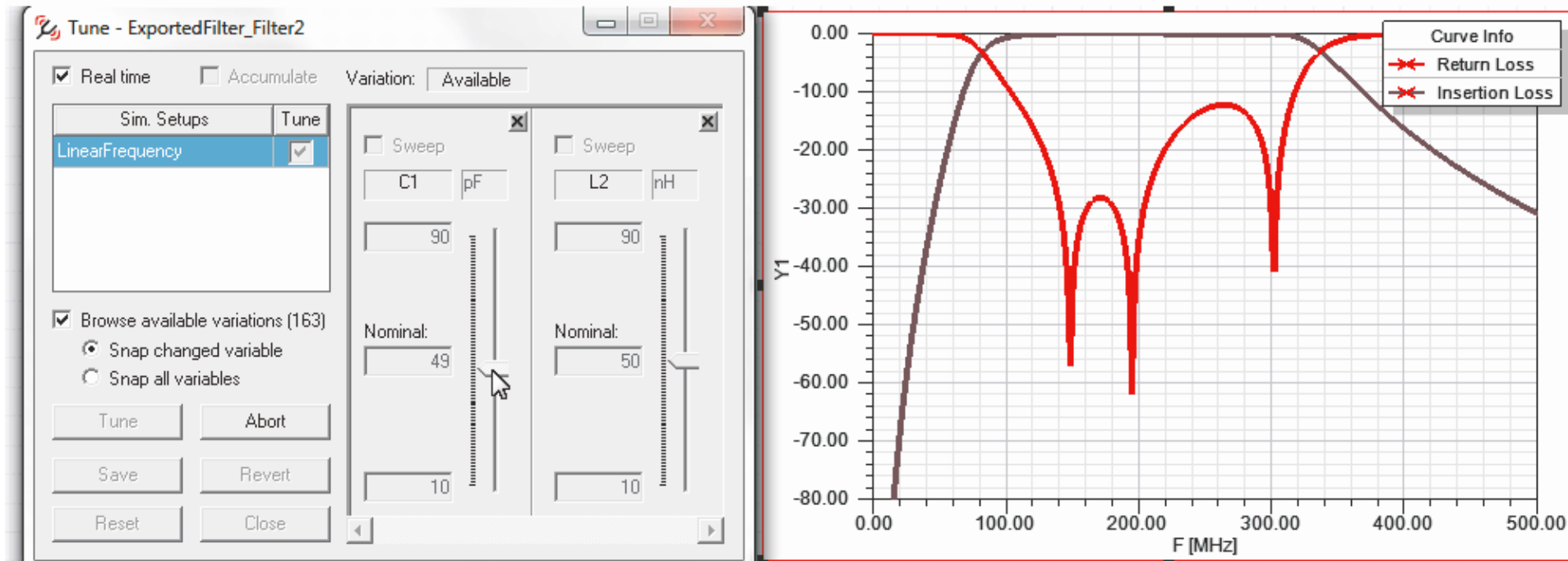
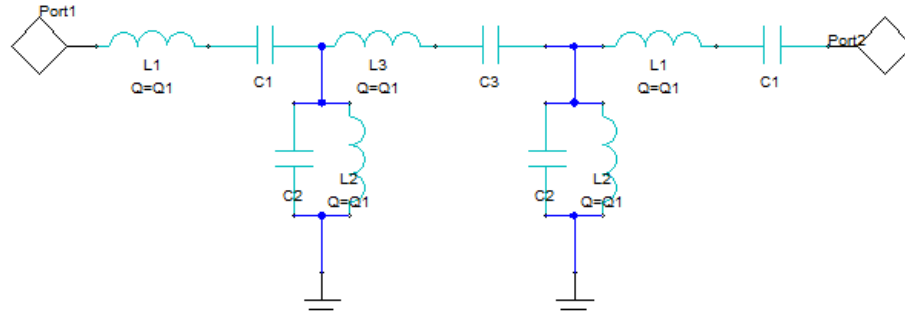


SIwave – XTALK Frequency Domain



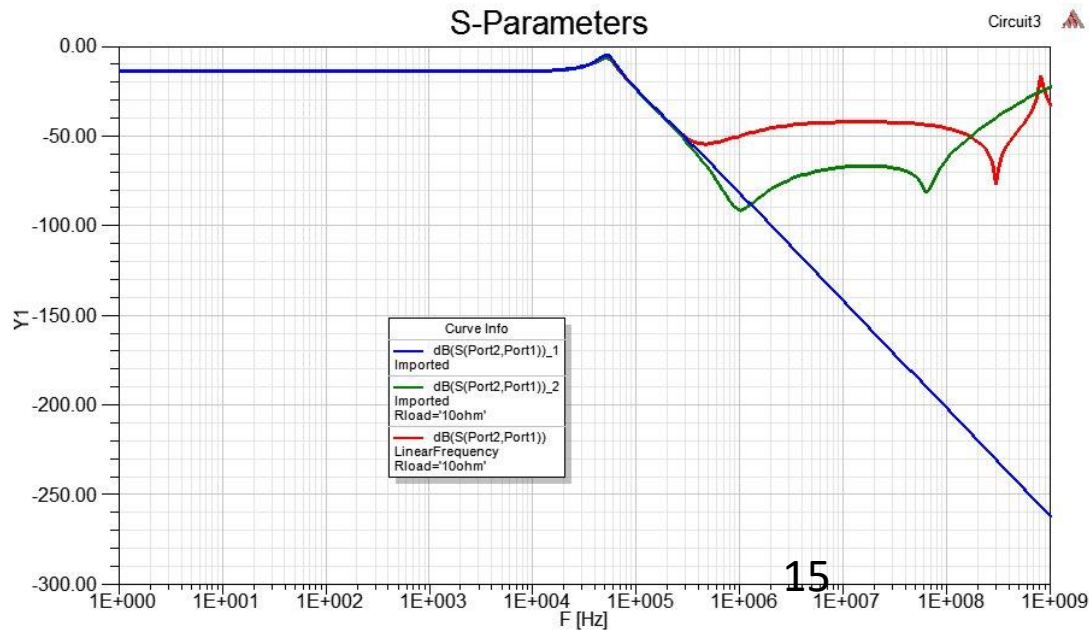
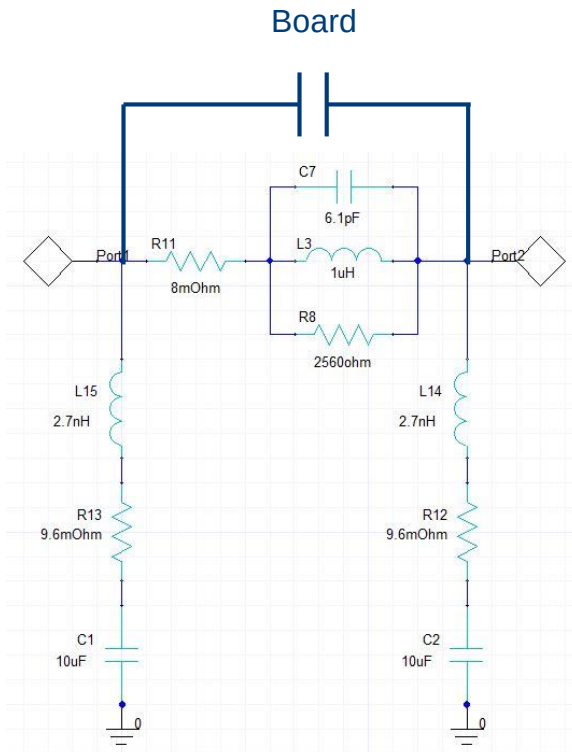
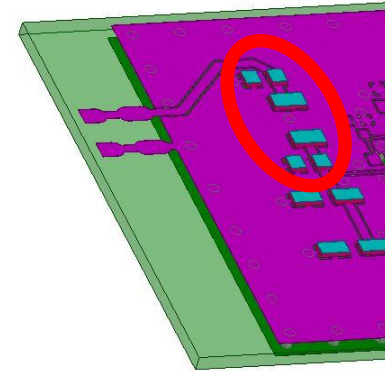
FILTER DESIGN

A filter is usually designed at the entrance of the system to suppress noise. ANSYS helps design Filters including the real component behavior.



FILTER DESIGN

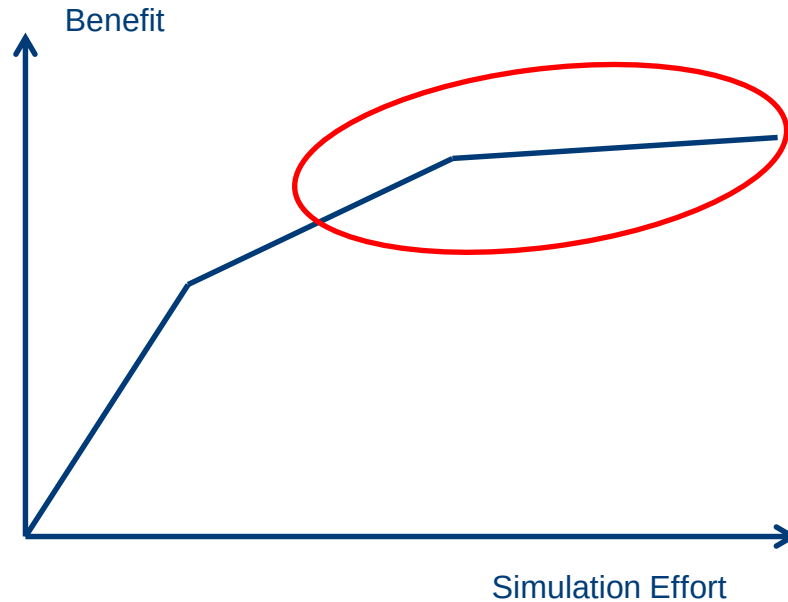
Parasitic Effects reduce the performance of a filter



EMC Simulation Effort

Easy

- EMI Scanner
 - Geometry Based EMI Rule Check
- Board level, passive behavior:
 - Trace impedances
 - Plane impedances
 - Resonances
 - Loop inductances
 - Filter Design
 - S-parameters

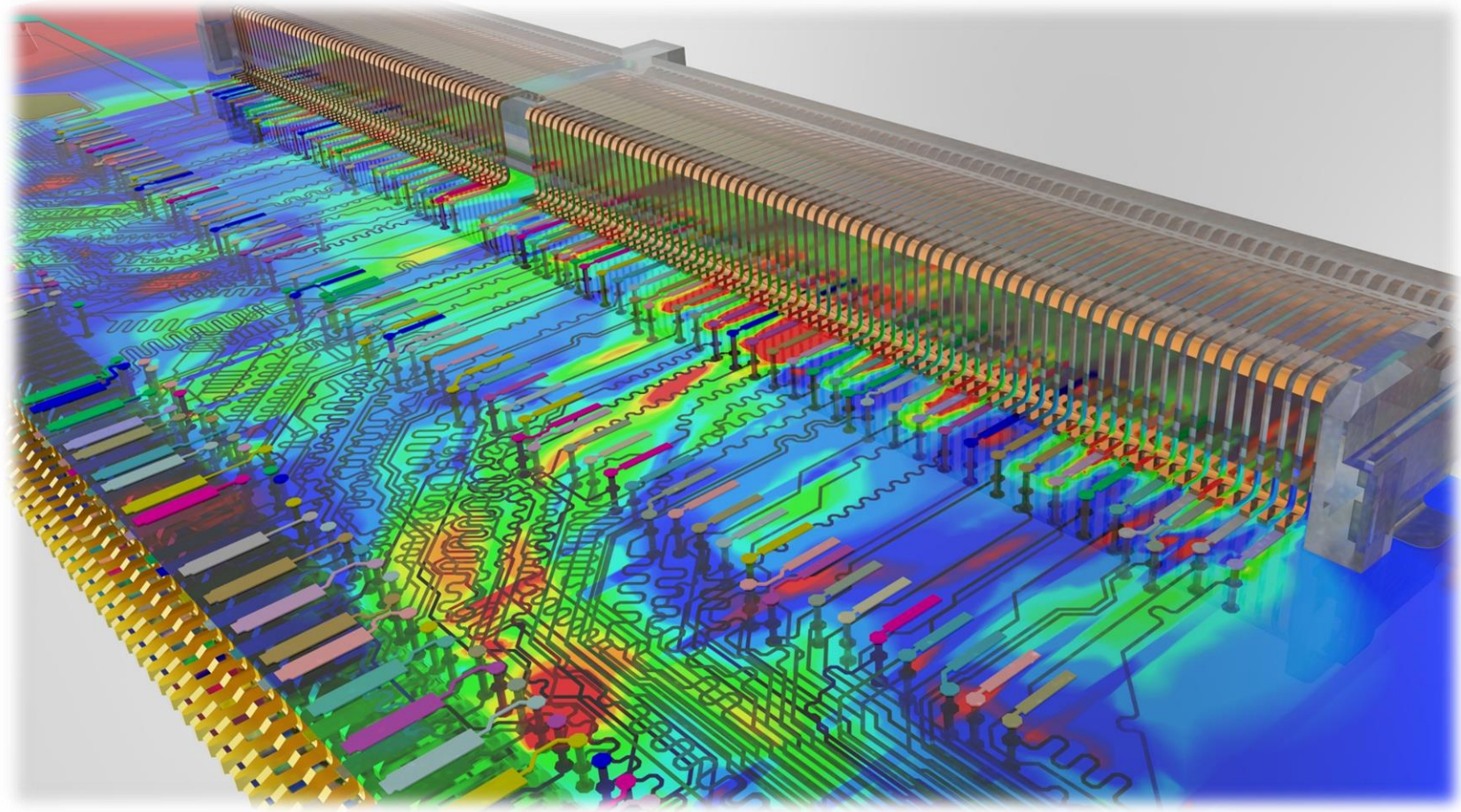


More Effort

- Transient signals that depend on driver models
 - Switching behavior
 - Real Waveform
 - IBIS, SPICE Models
- Board + cable + housing
 - EMI
- Full EMC Environment
 - Anechoic Chamber
 - Absorber Elements
 - Antennas

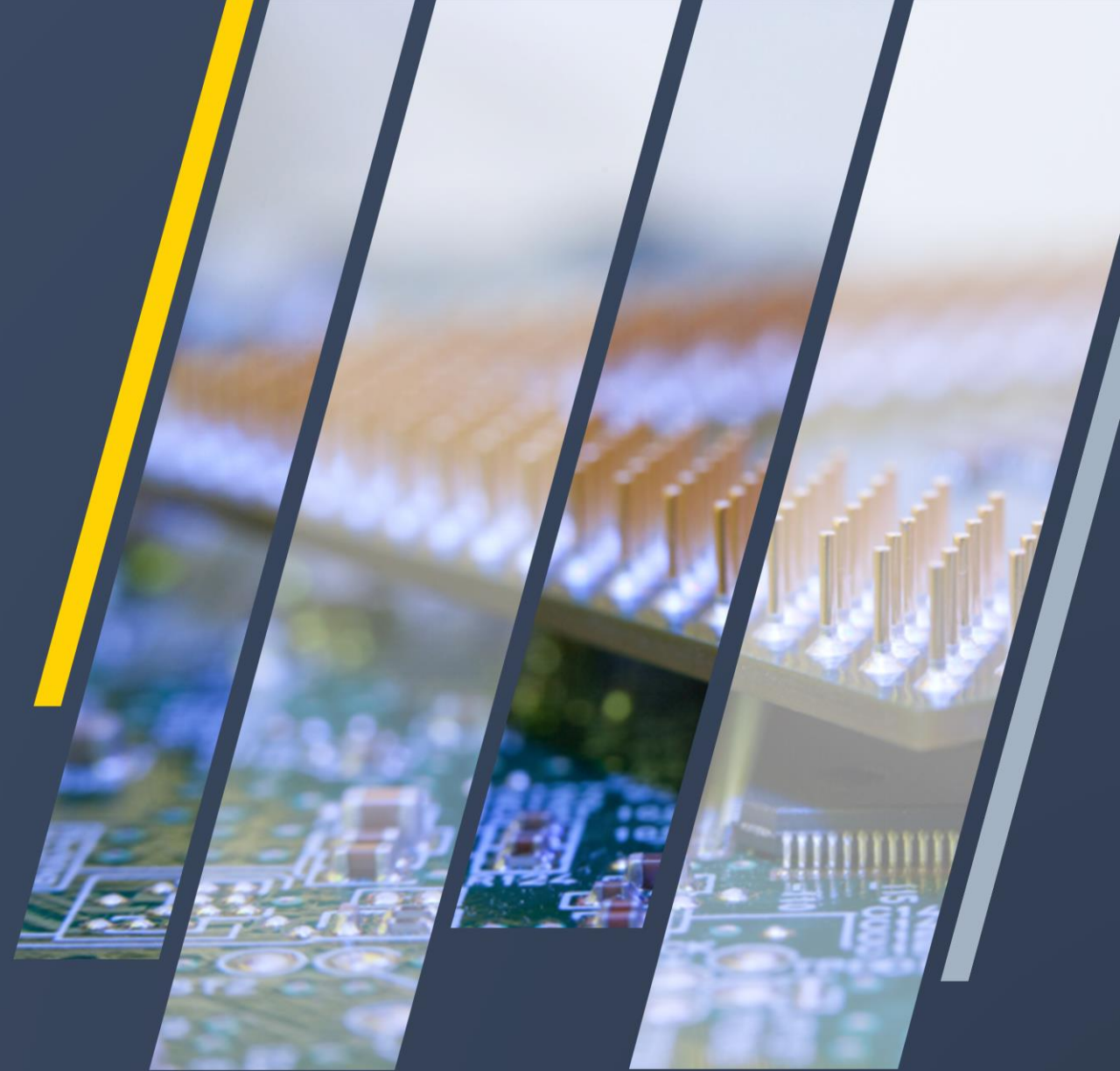
EMI/EMC Applications

1. Conducted Emissions
2. Radiated Emissions
3. Radiated Immunity
4. Crosstalk and General EMI
5. Lightning and ESD
6. RF Immunity
7. Summary



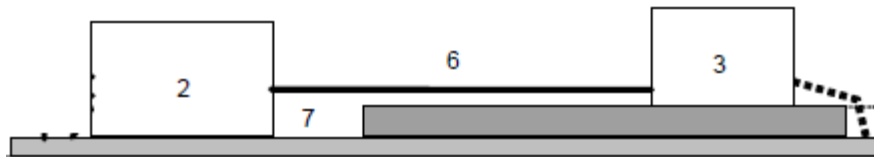
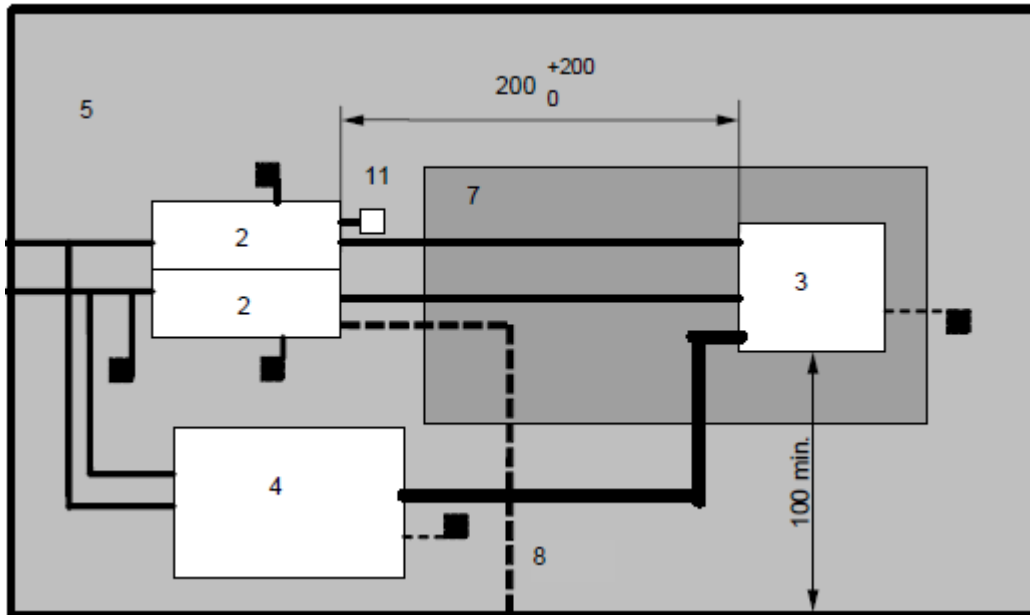


Conducted Emissions

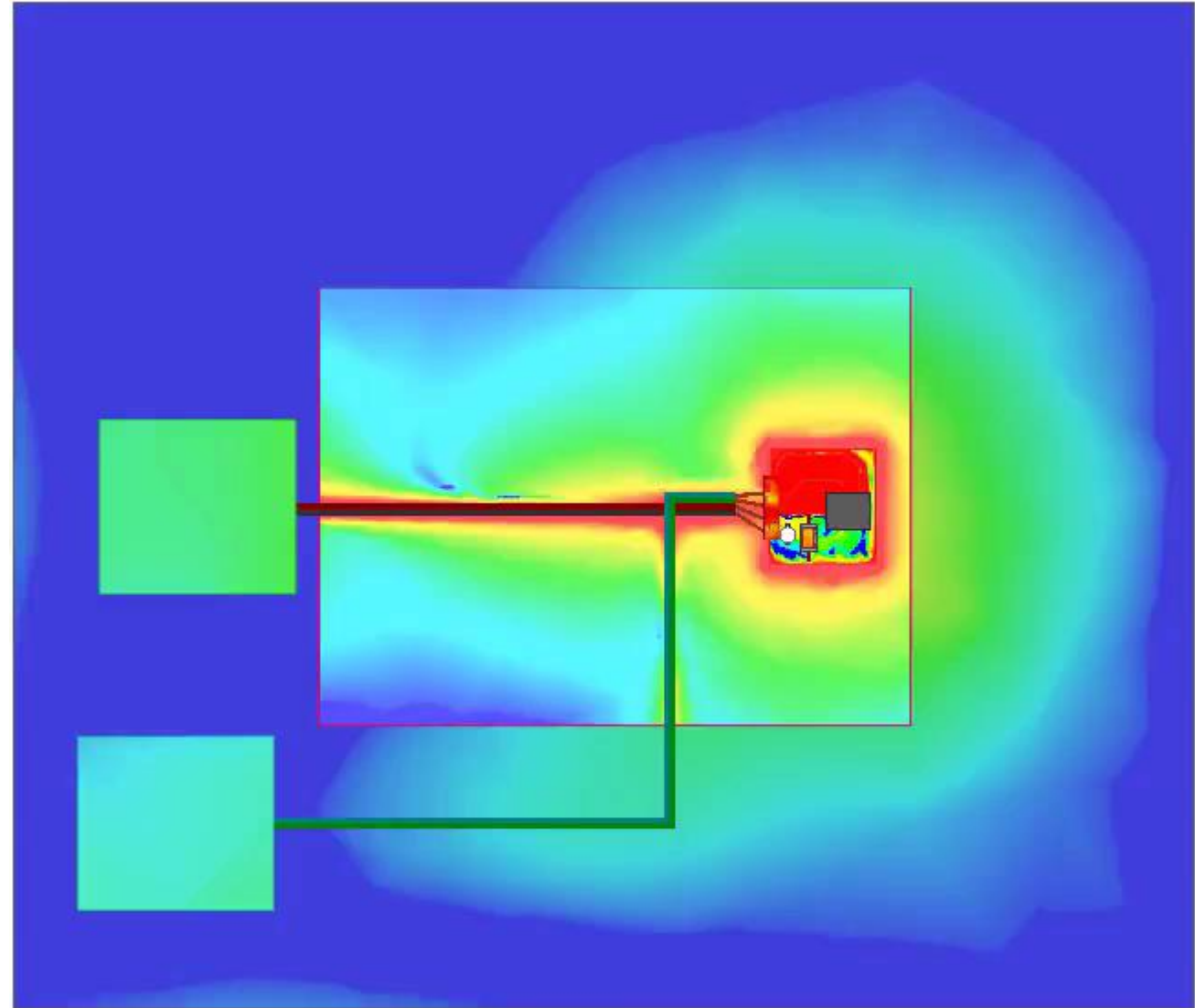


CONDUCTED EMISSIONS

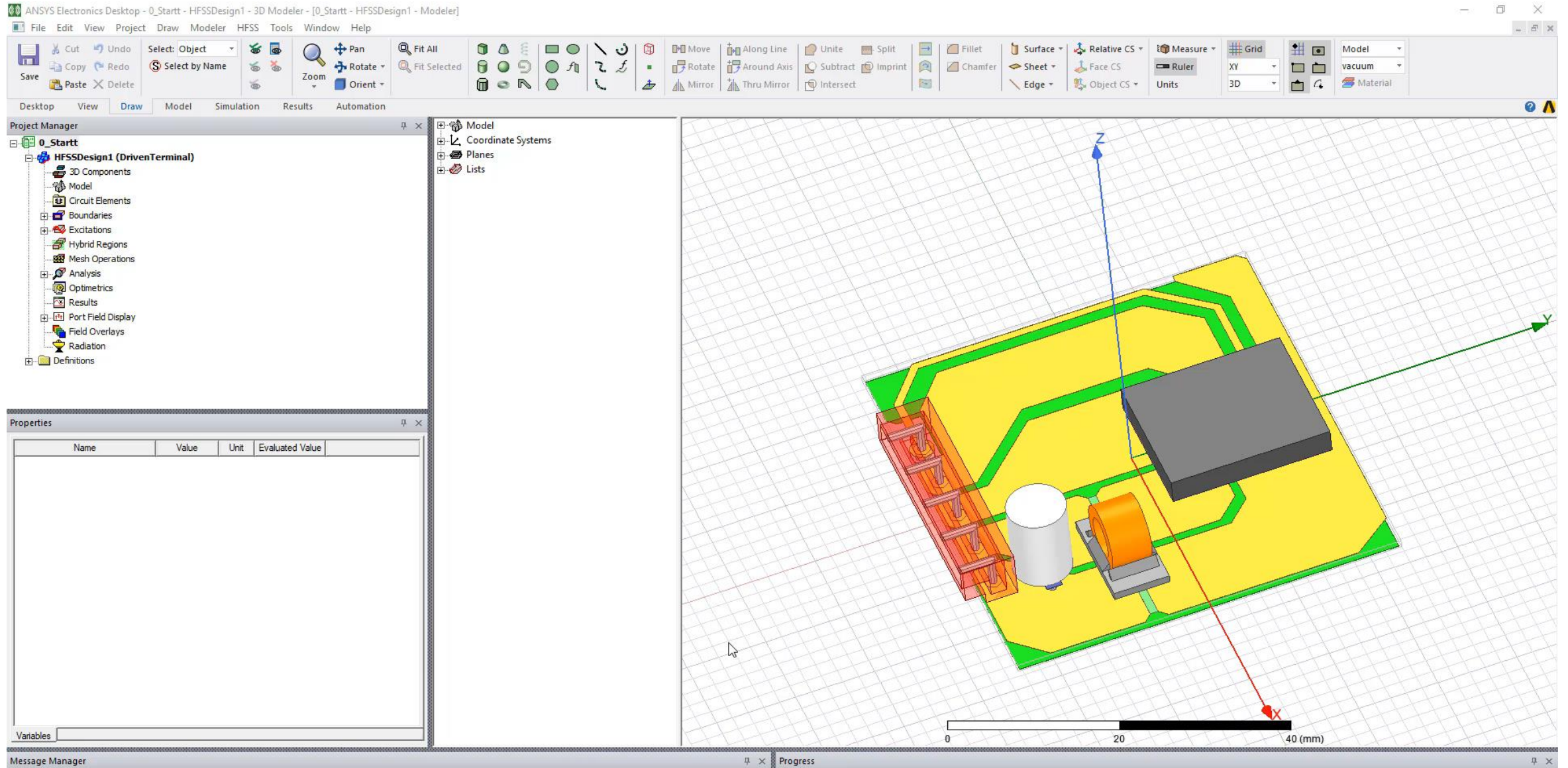
CISPR25 Standard



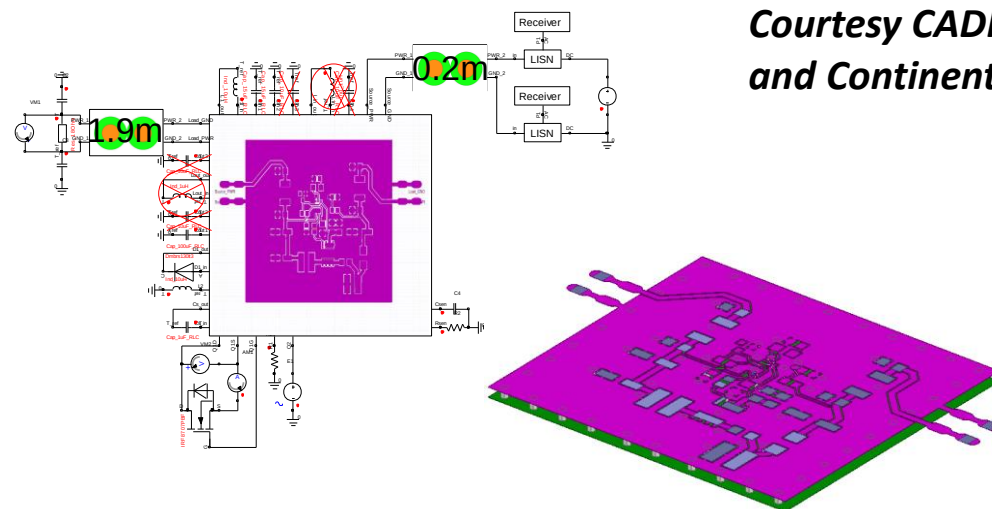
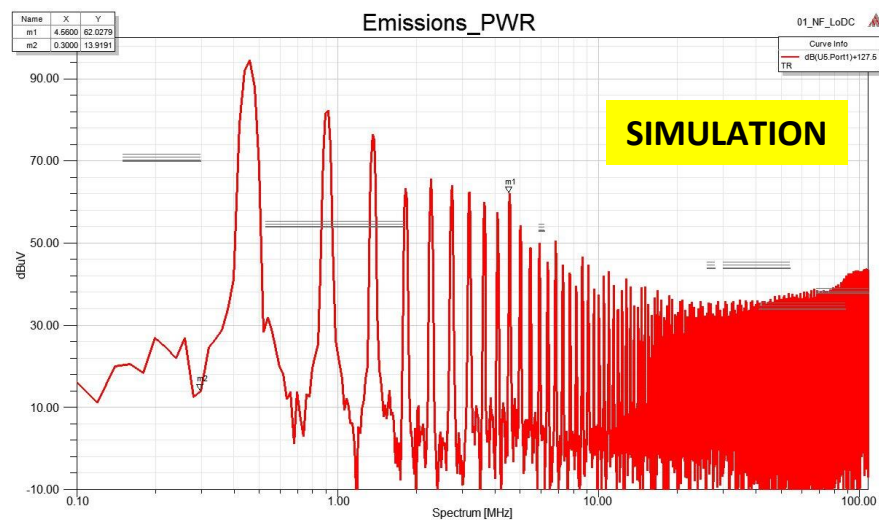
ANSYS Test Bench Model



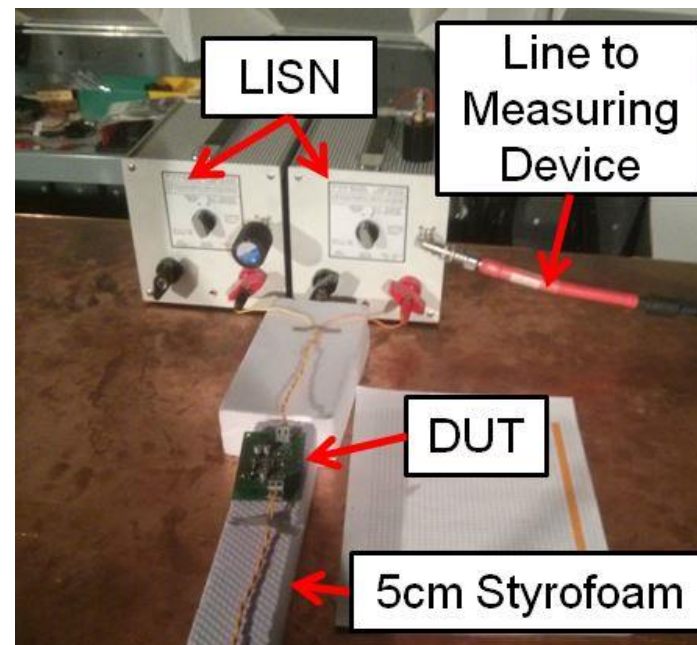
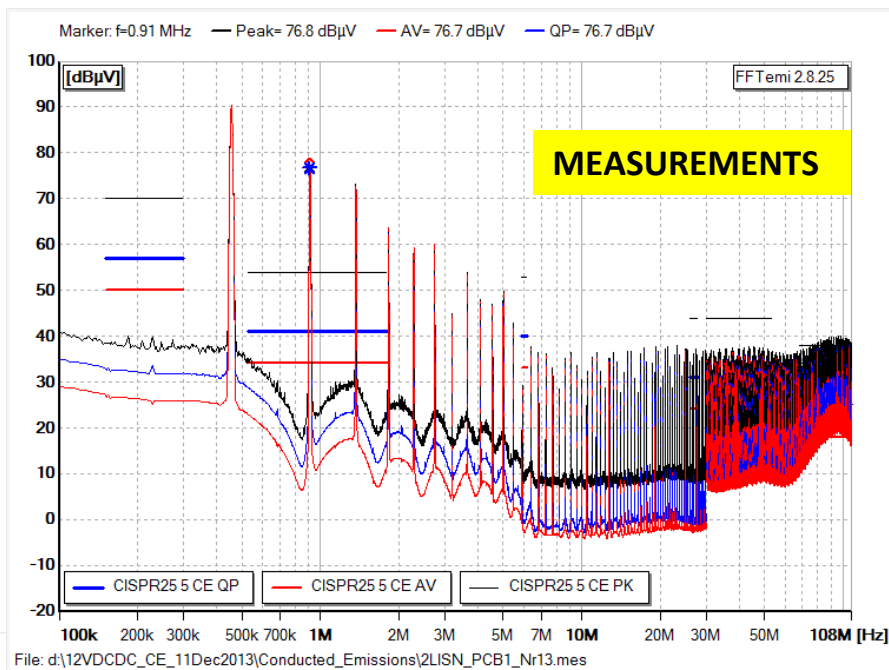
Workflow POC – CISPR25 CE



CONDUCTED EMISSIONS



*Courtesy CADFEM Germany
and Continental*

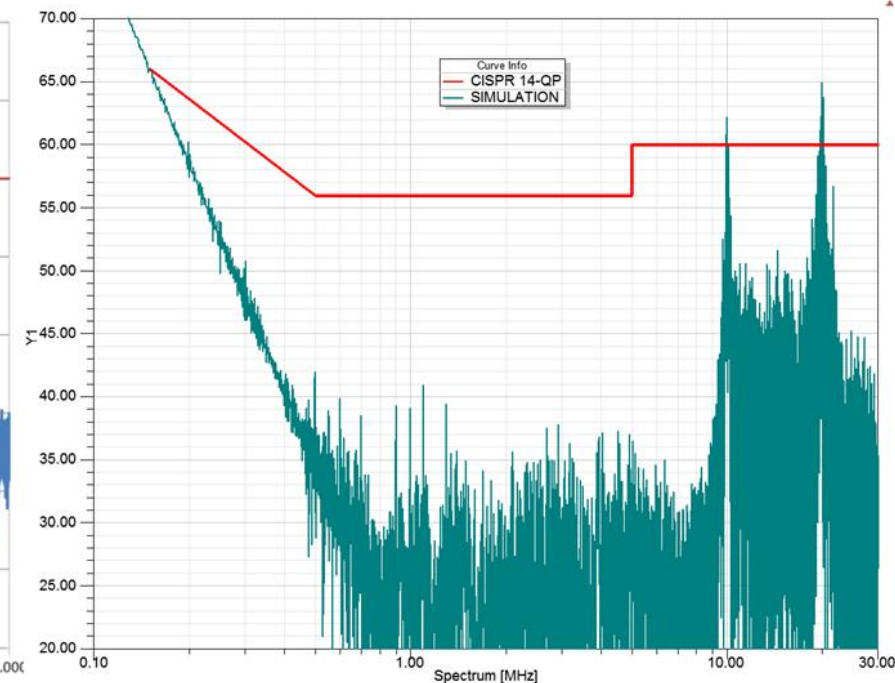
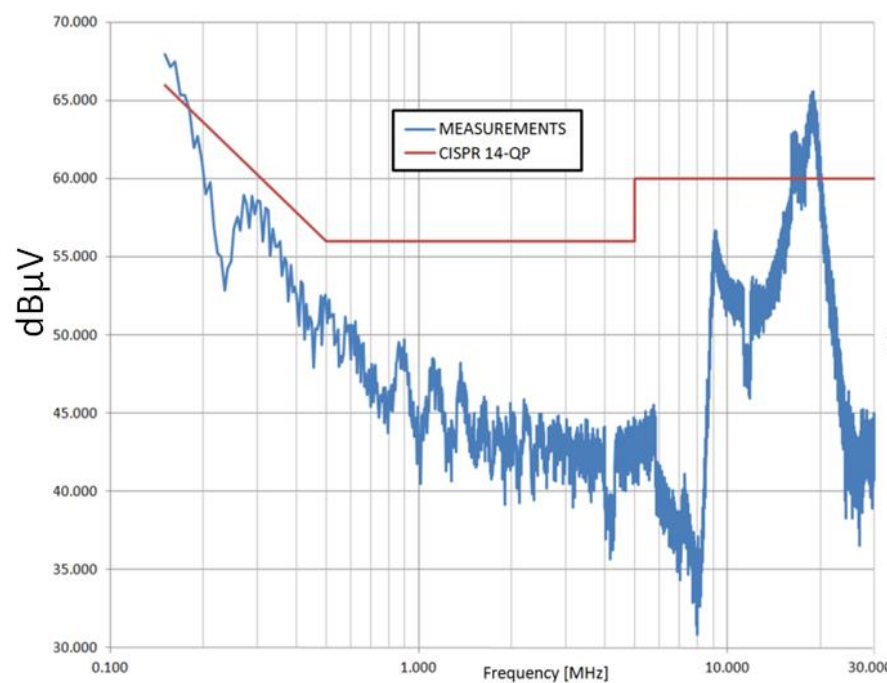
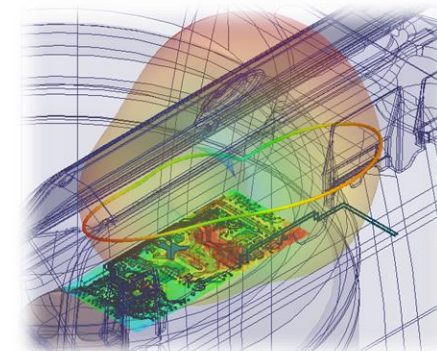
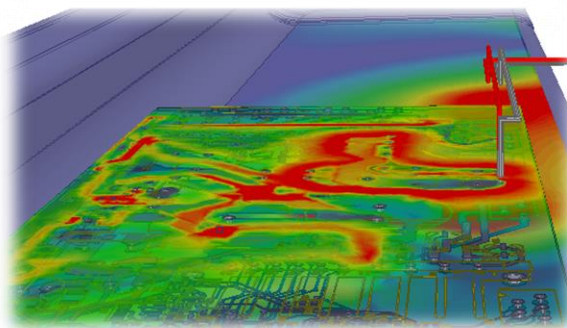
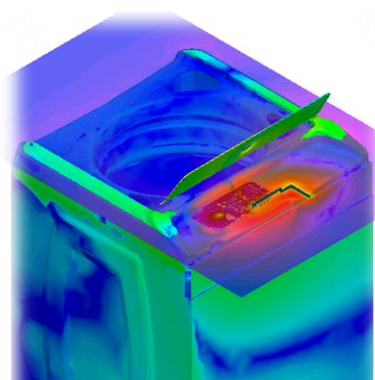


CONDUCTED EMISSIONS

Presented at:



Courtesy
Whirlpool



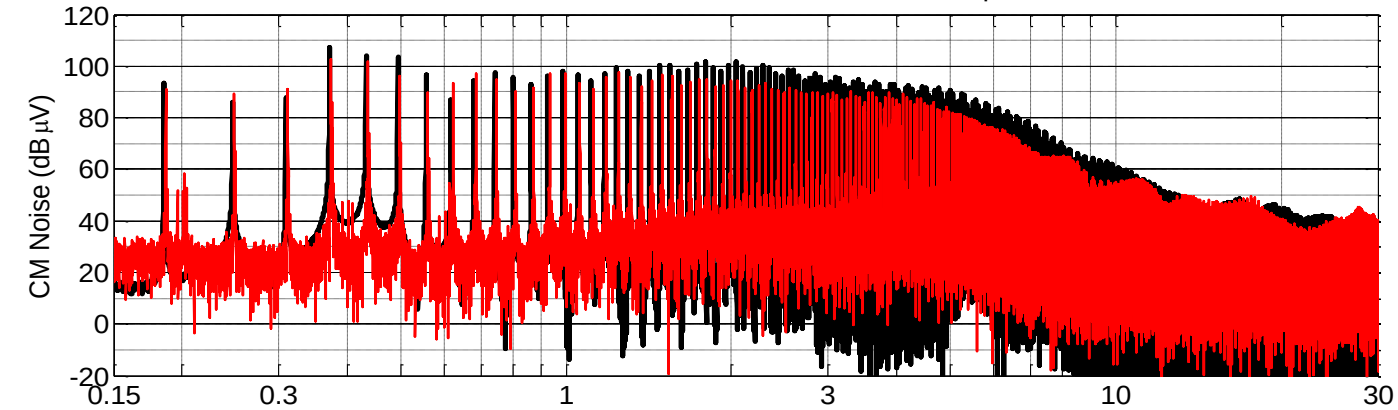
J. F. Mologni, G. Eguni, C. L. R. Siqueira, M. Kopp and M. A. R. Alves, "A hybrid method combining static and full wave techniques to solve conducted emissions problems," 2013 IEEE International Symposium on Electromagnetic Compatibility, Denver, CO, 2013, pp. 277-281. doi: 10.1109/ISEMC.2013.6670423

CONDUCTED EMISSIONS

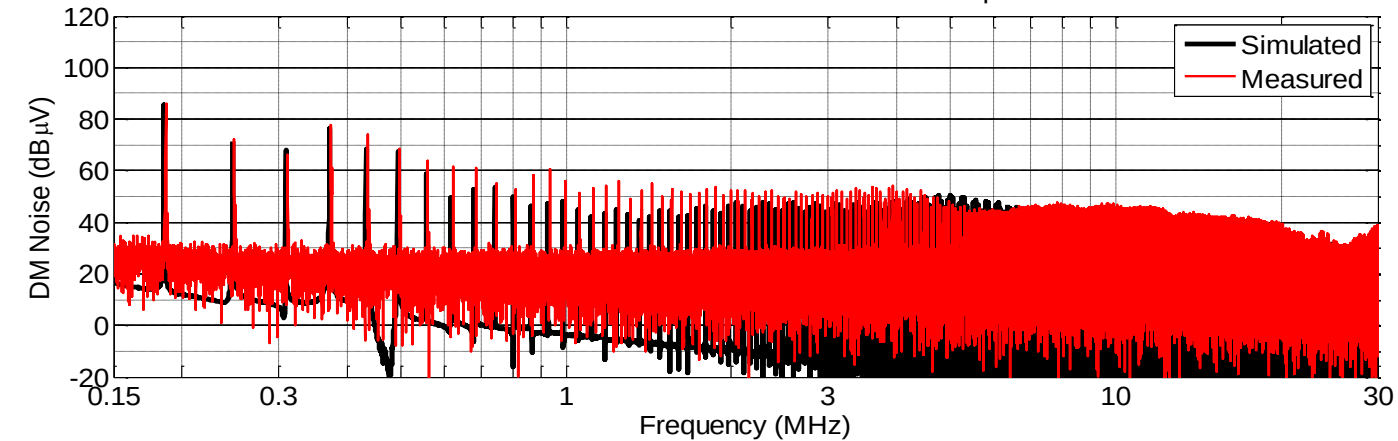
Conducted emissions of a SMPS.

*Courtesy
Rockwell Automation*

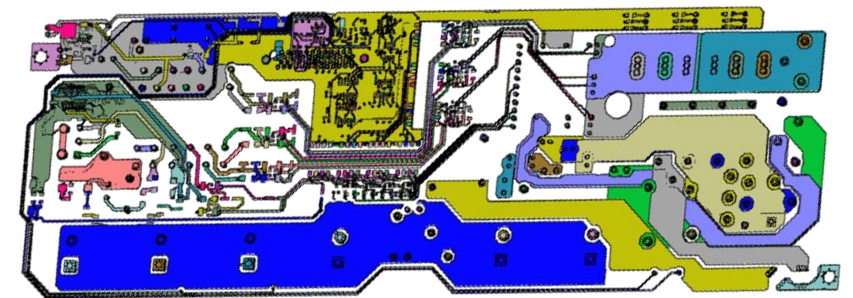
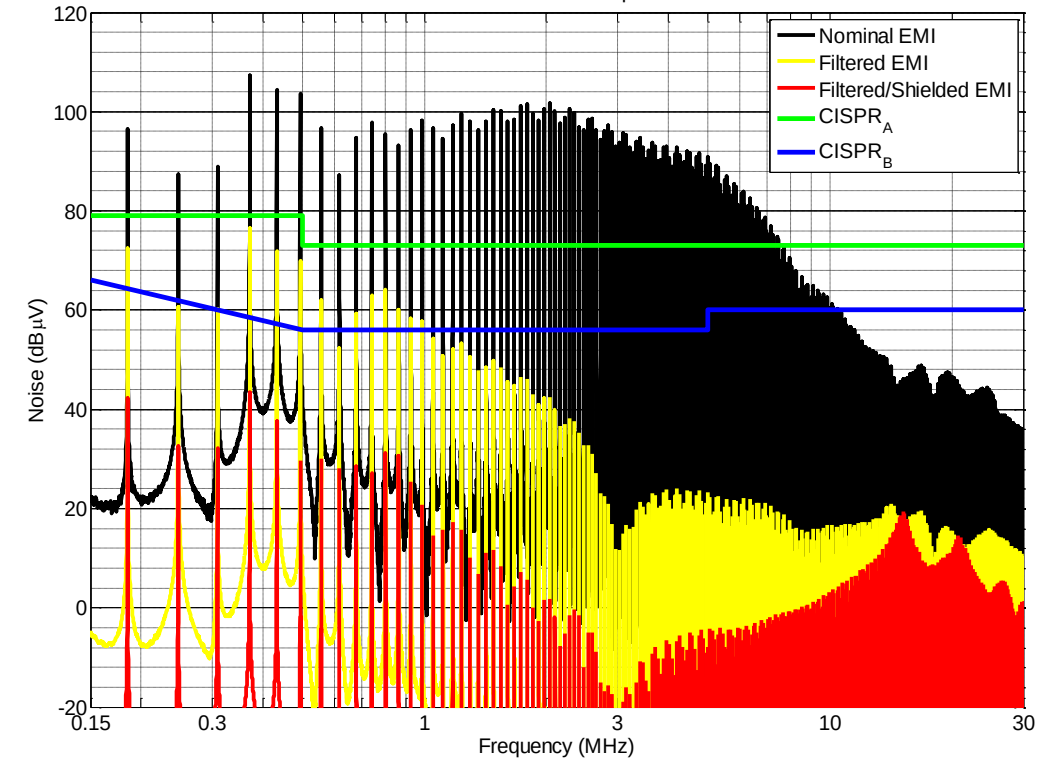
Simulated -Black vs Measured -Red CM EMI Spectrum



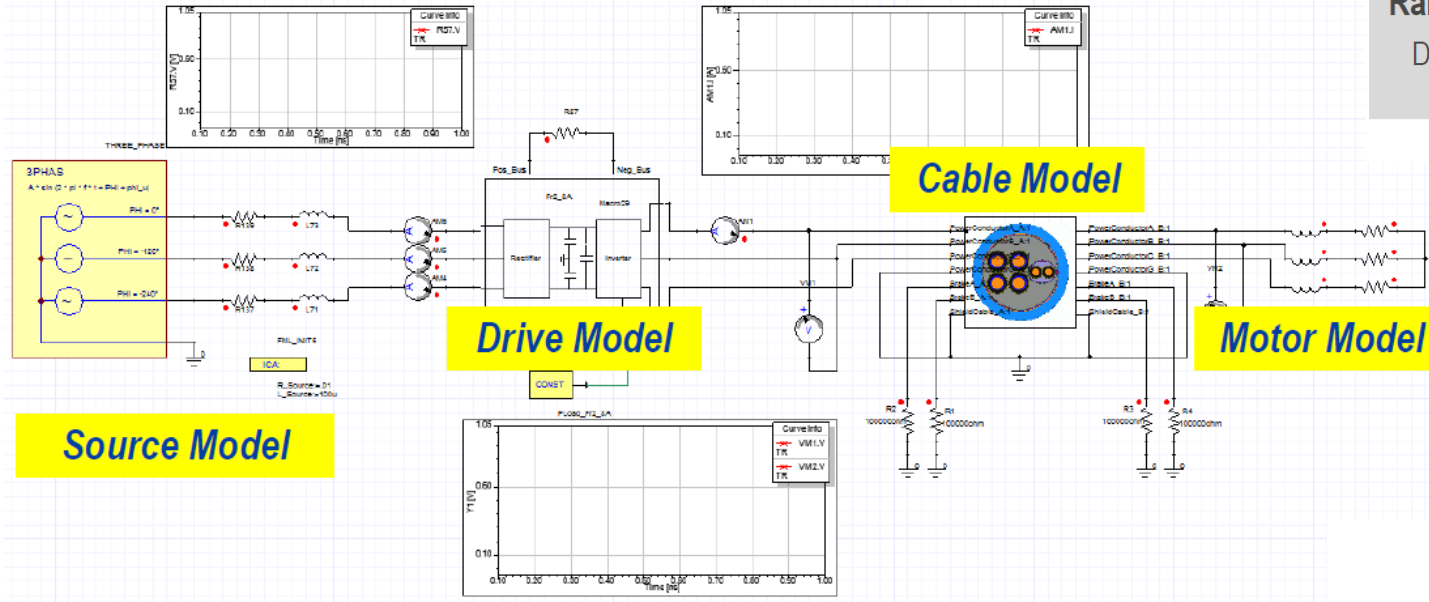
Simulated -Black vs Measured -Red DM EMI Spectrum



Simulated Total EMI Spectrum



Drivetrain Simulation



Frequency-Dependent Multi-Conductor Cable Modeling and Simulation for AC Drive System Applications

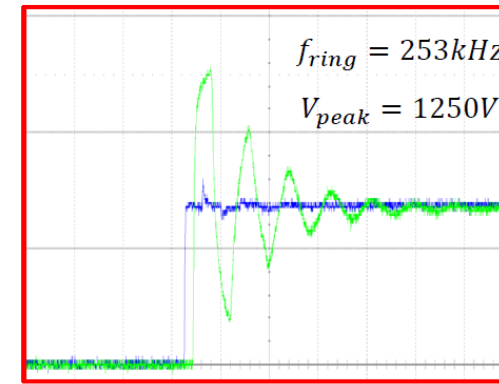
Ranga Tallam, Richard Lukaszewski
Drives Business, Rockwell Automation
Mequon WI

Mark Solveson
ANSYS
Brookfield WI

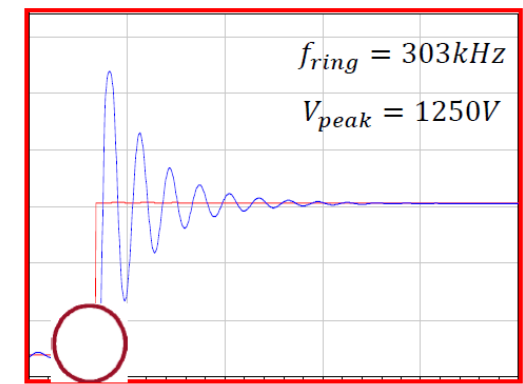
Presented at the 2014 ANSYS Regional Conference Chicago May 23, 2014

Motor Over-voltage

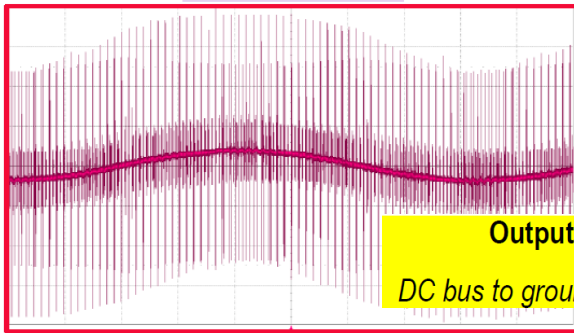
Experiment



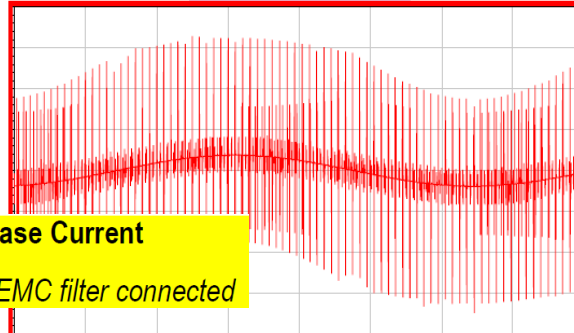
Simulation



Experiment



Simulation

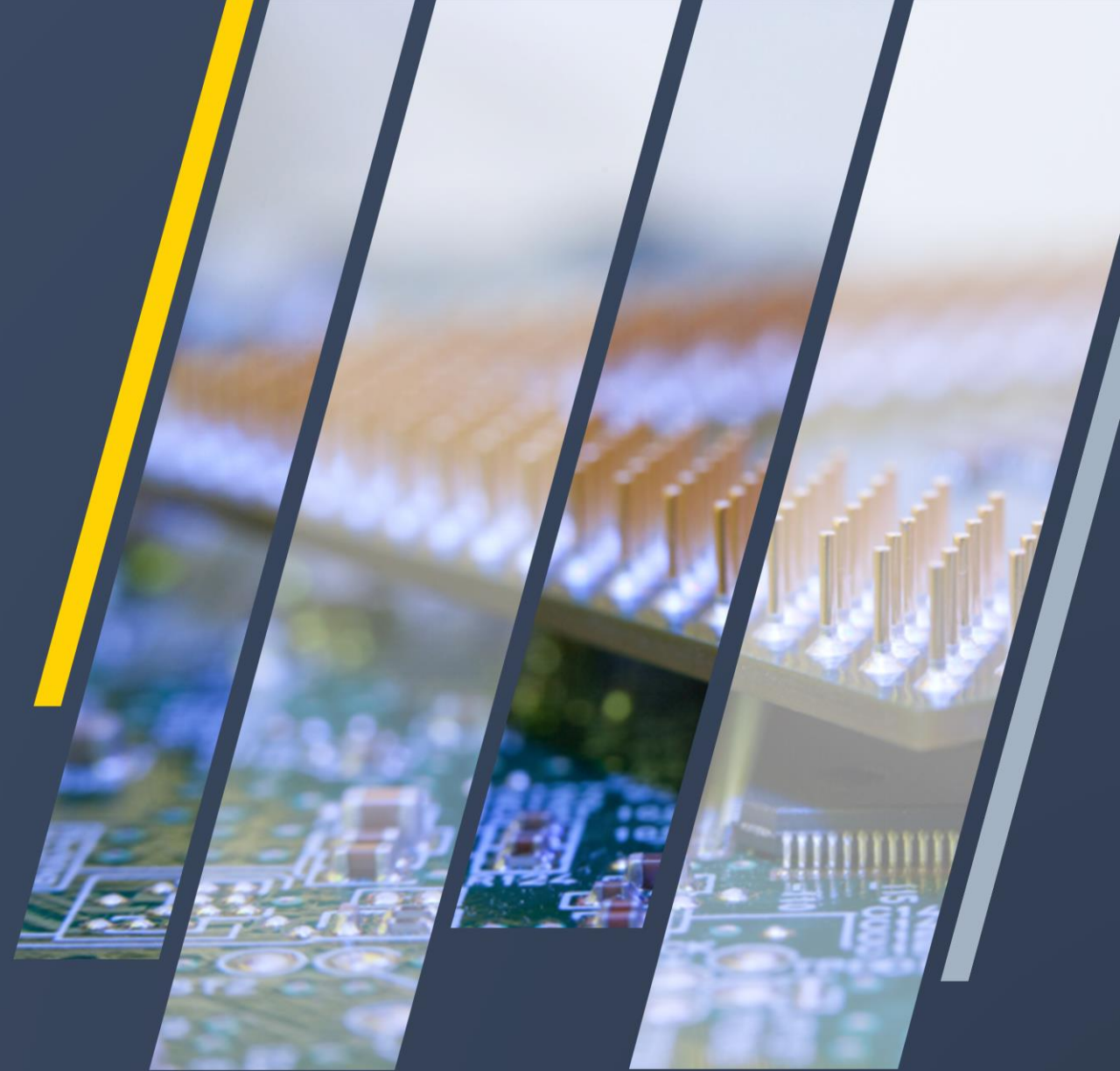


Output Phase Current

DC bus to ground EMC filter connected

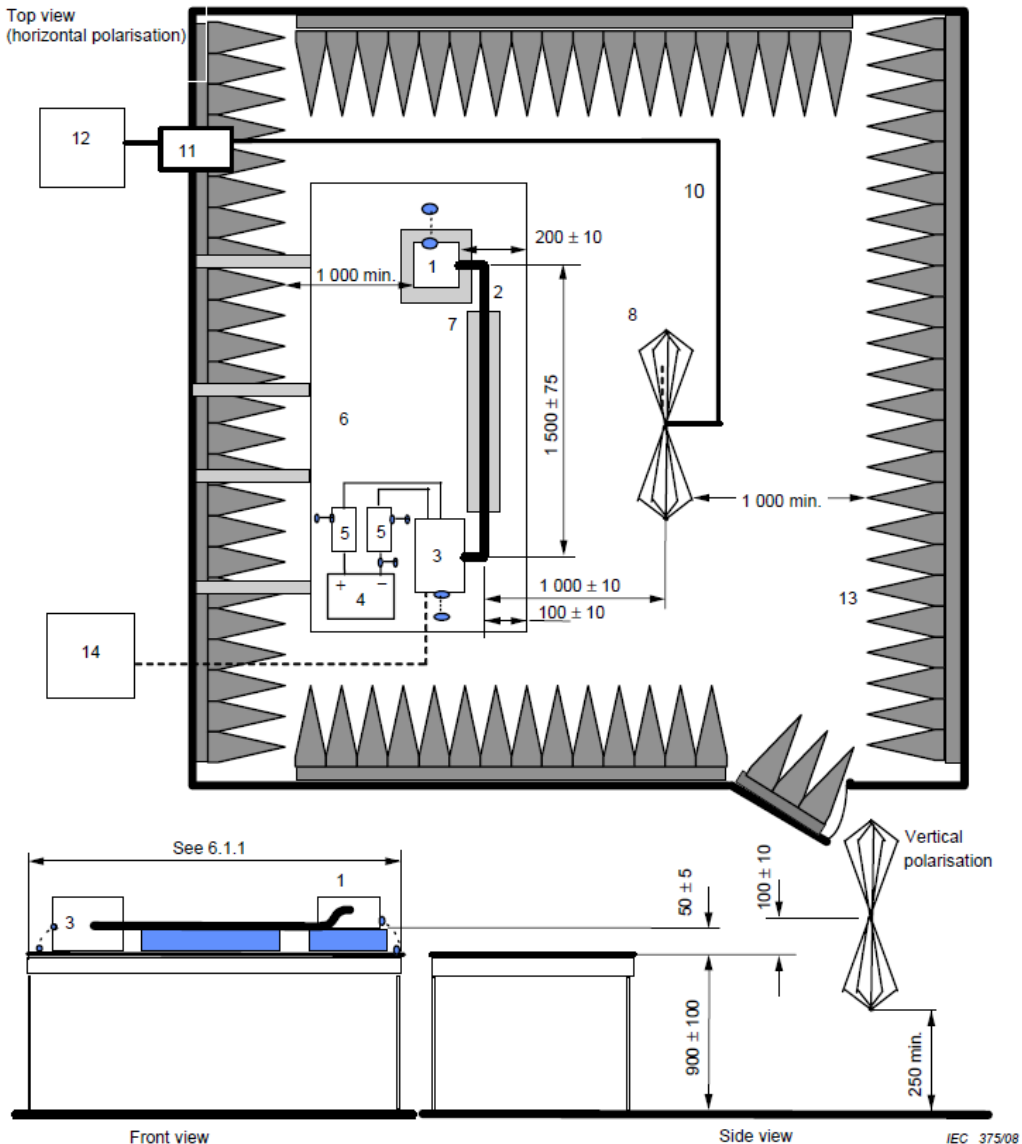


Radiated Emissions

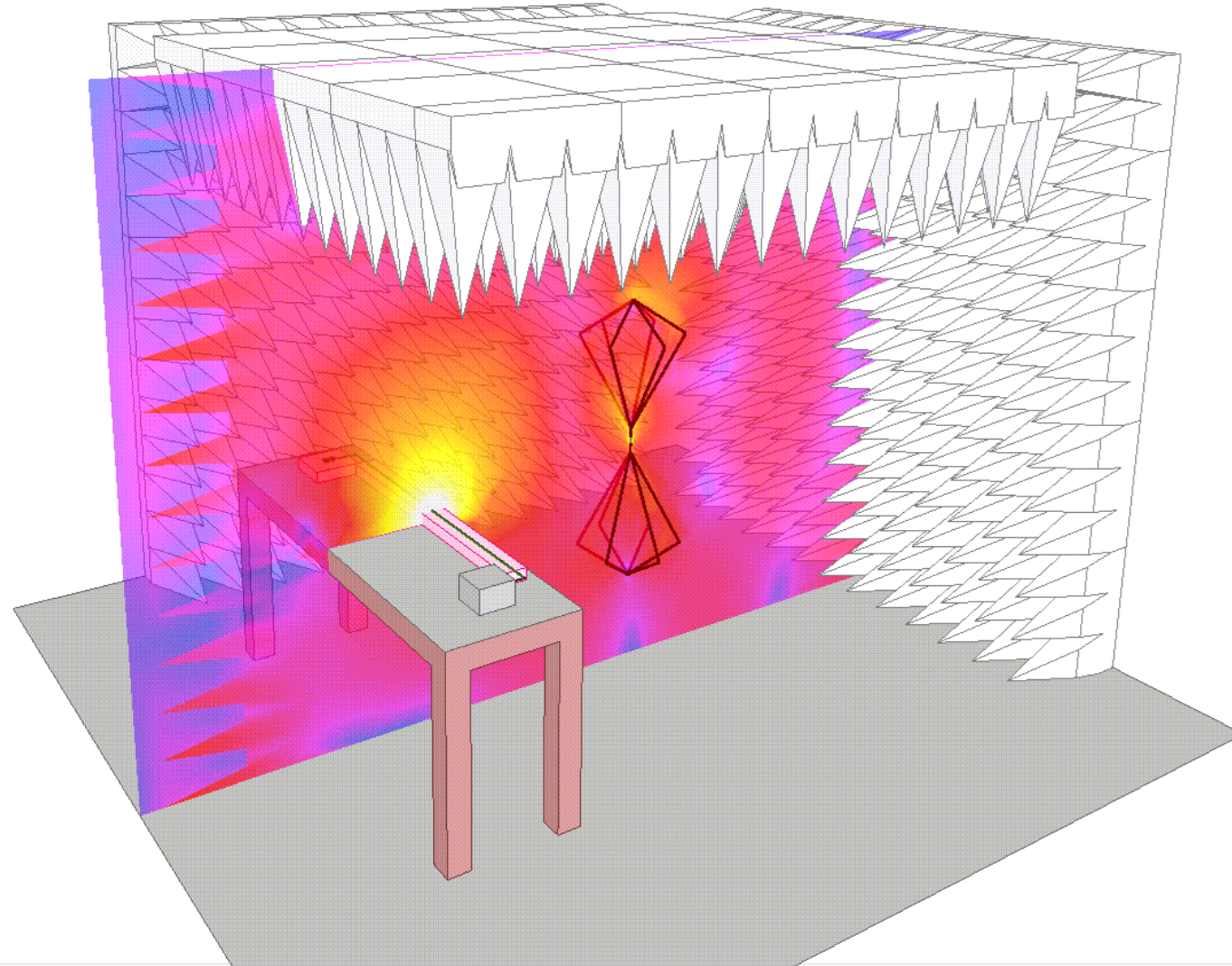


RADIATED EMISSIONS

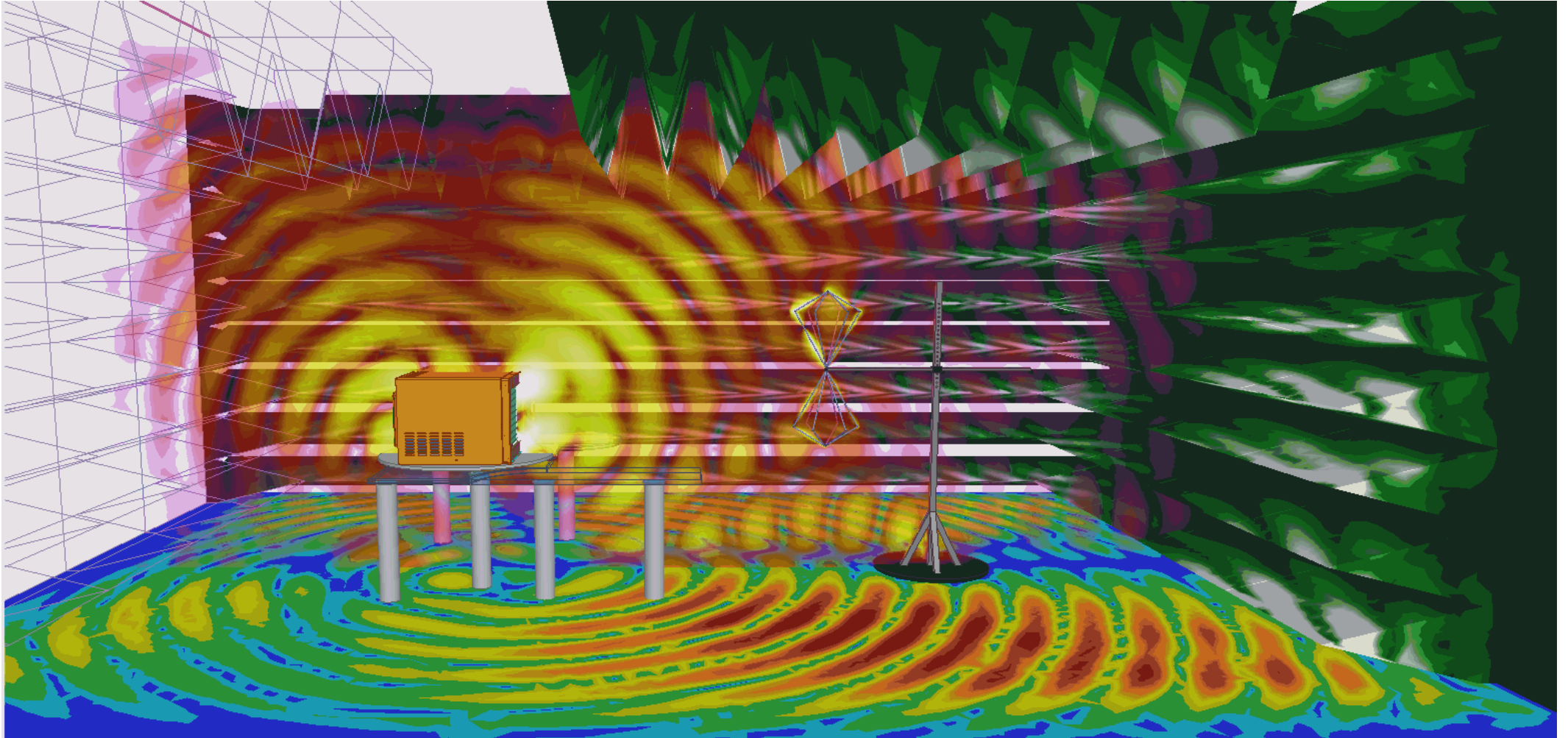
CISPR25 Standard



ANSYS Test Bench Model

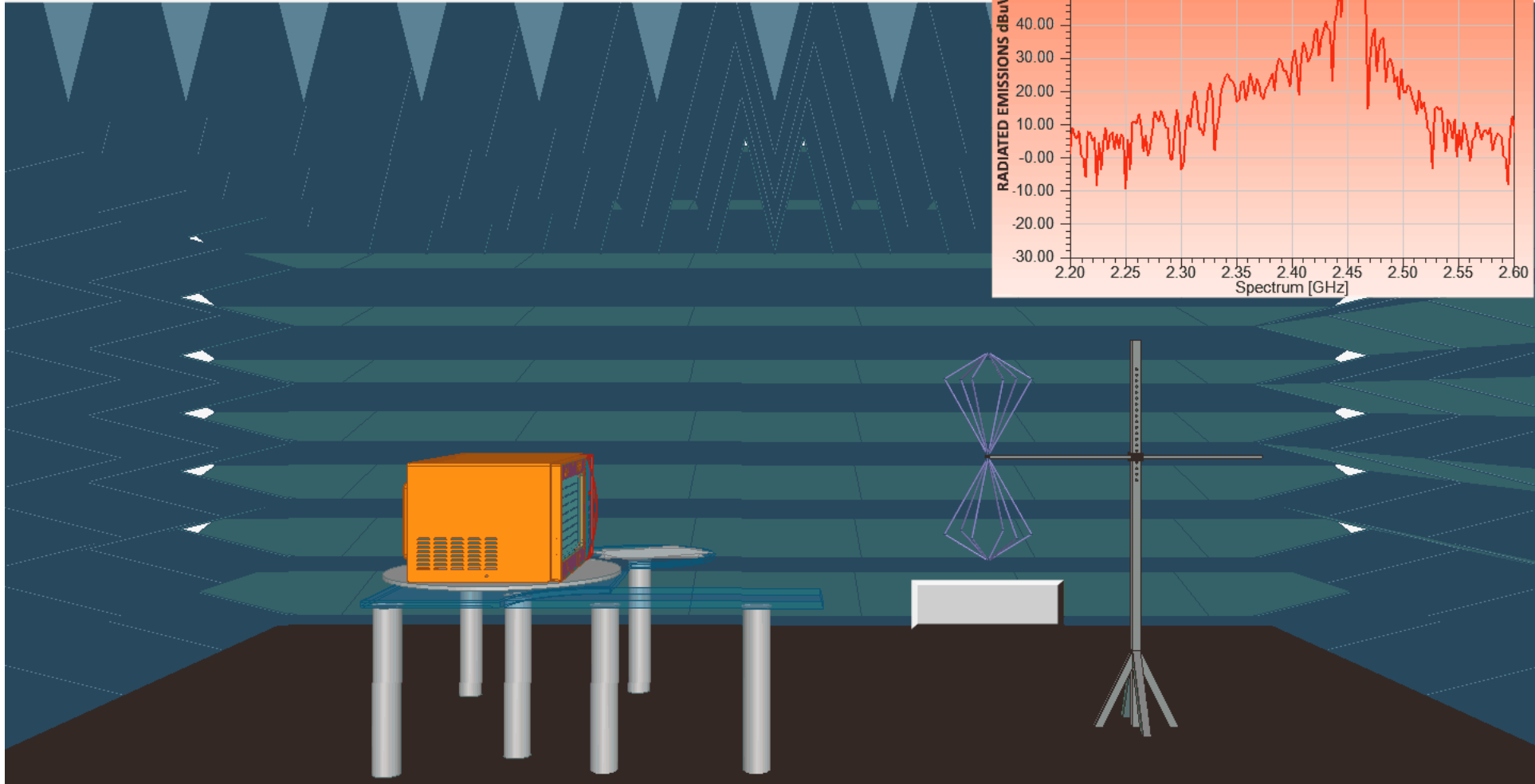


RADIATED EMISSIONS



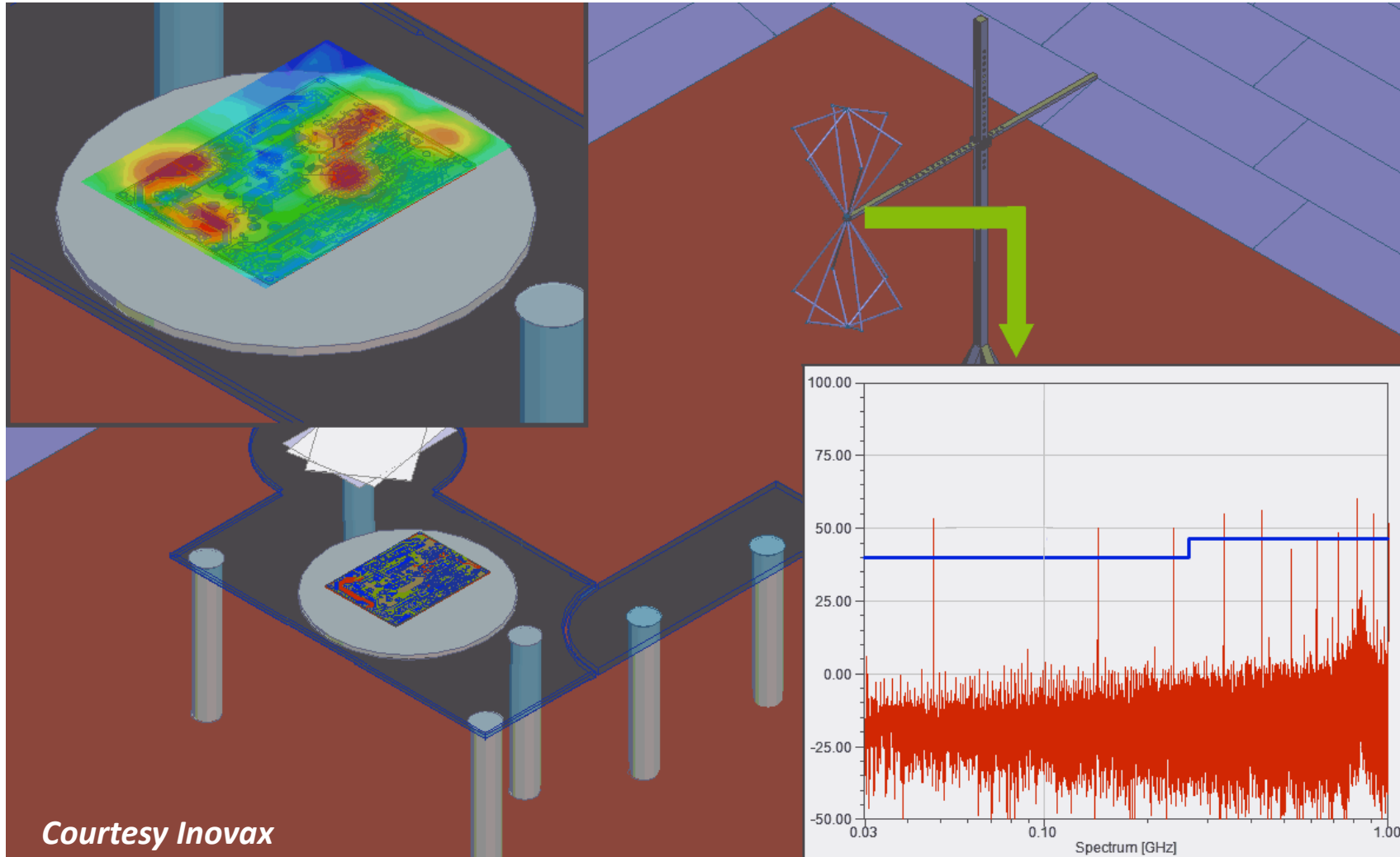
RADIATED EMISSIONS

Radiated emissions is shown [dB μ V/m at antenna placed 1 meter from the oven] as the microwave oven rotates on the turntable. Note the higher values of the spectrum when the microwave oven is facing the antenna.



RADIATED EMISSIONS

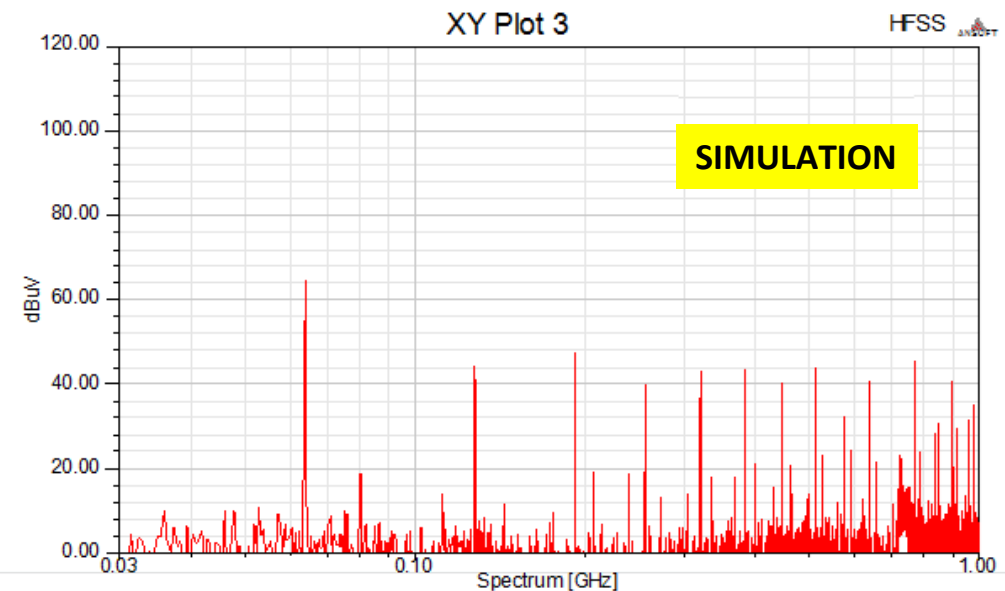
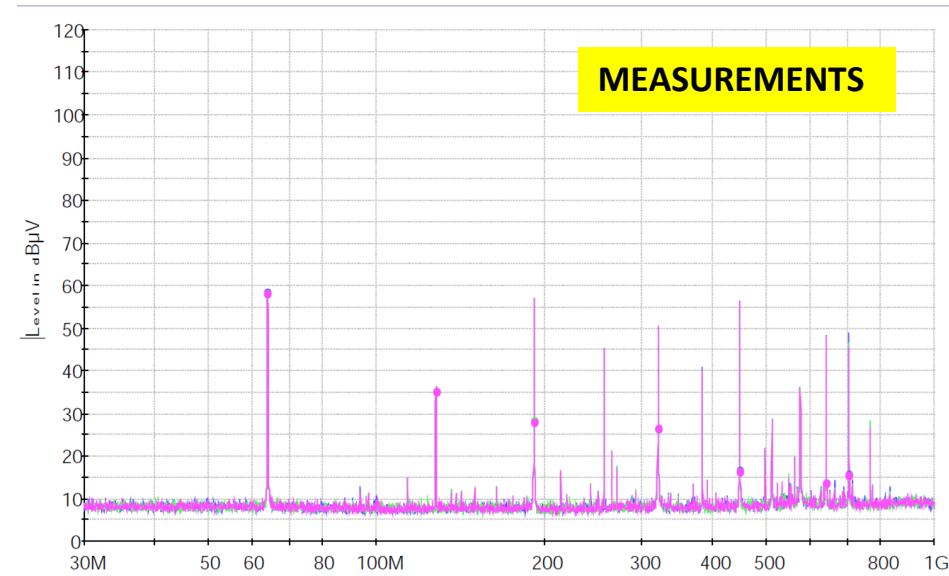
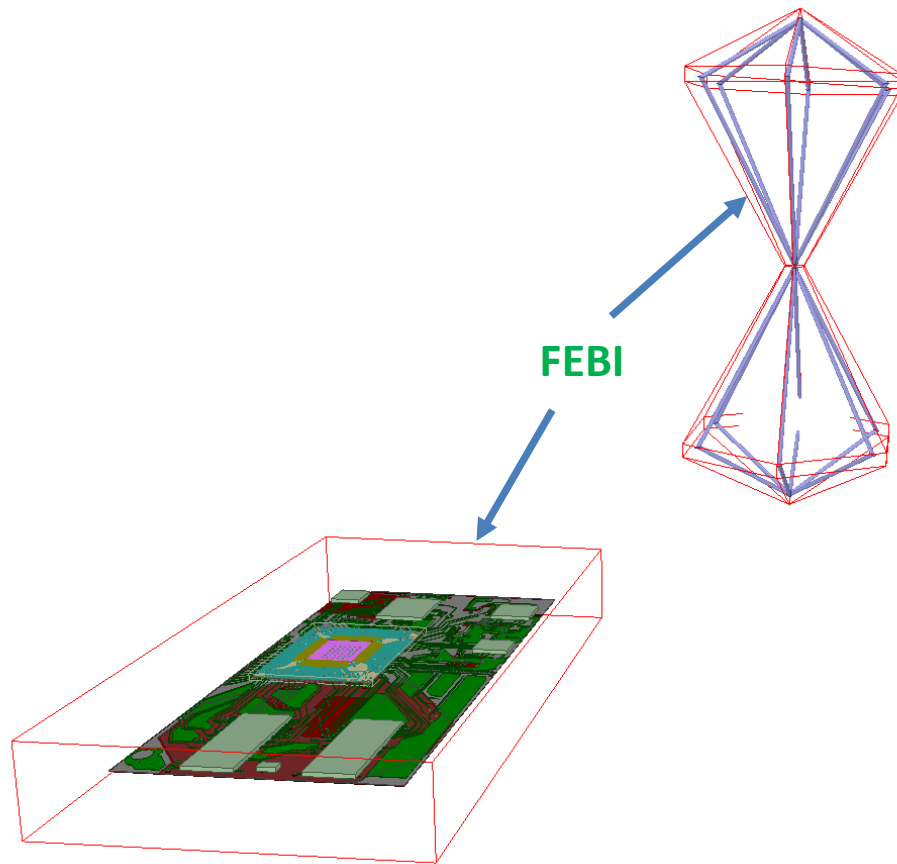
*Courtesy
Inovax*



RADIATED EMISSIONS

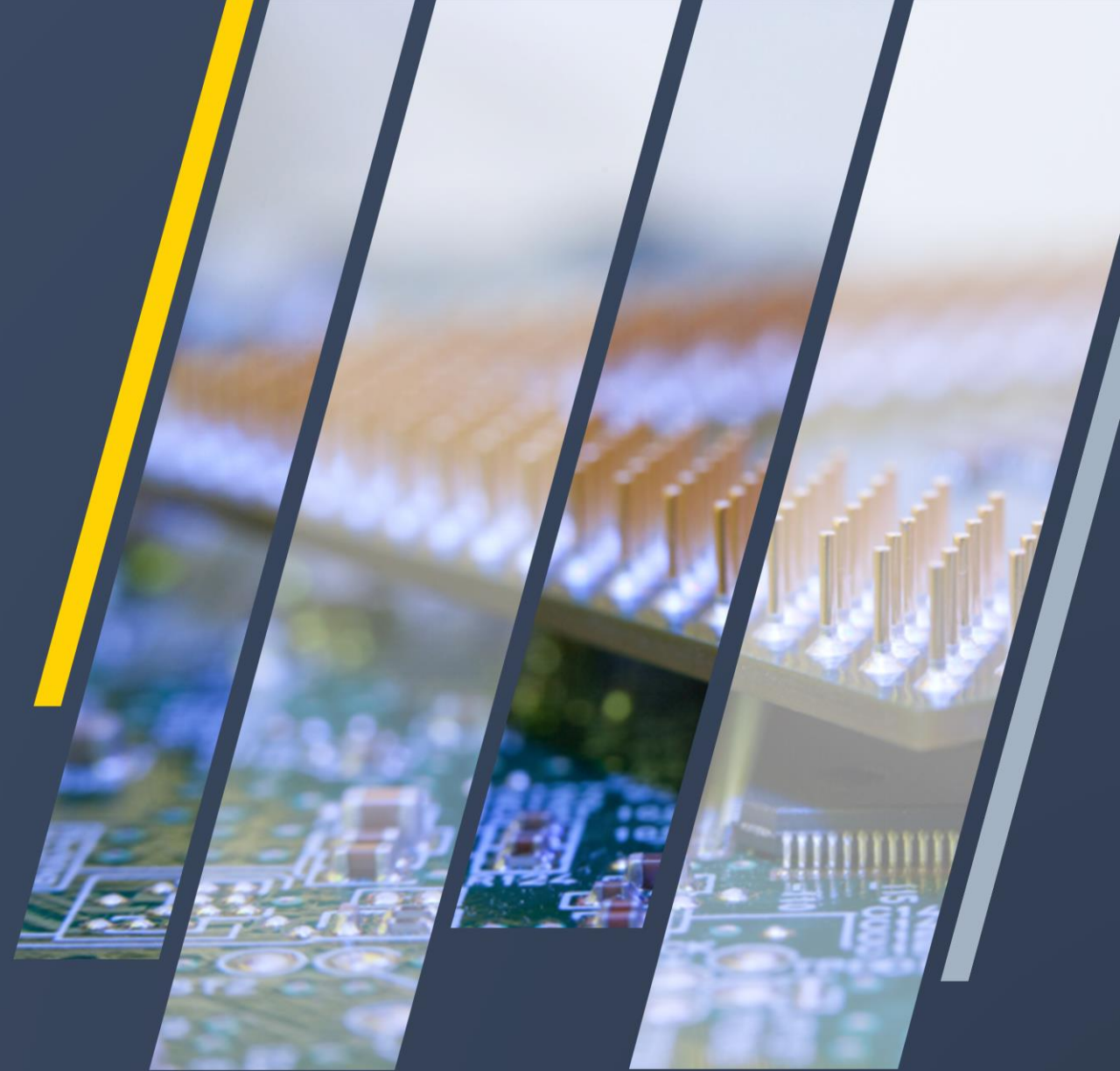
Courtesy
GEMCO/UFSC

Radiated emissions at a 3 meter distance. Comparison between measurements and simulations shows a very good agreement both in magnitude and frequency. Only the antenna and the DUT was considered.





Radiated Immunity





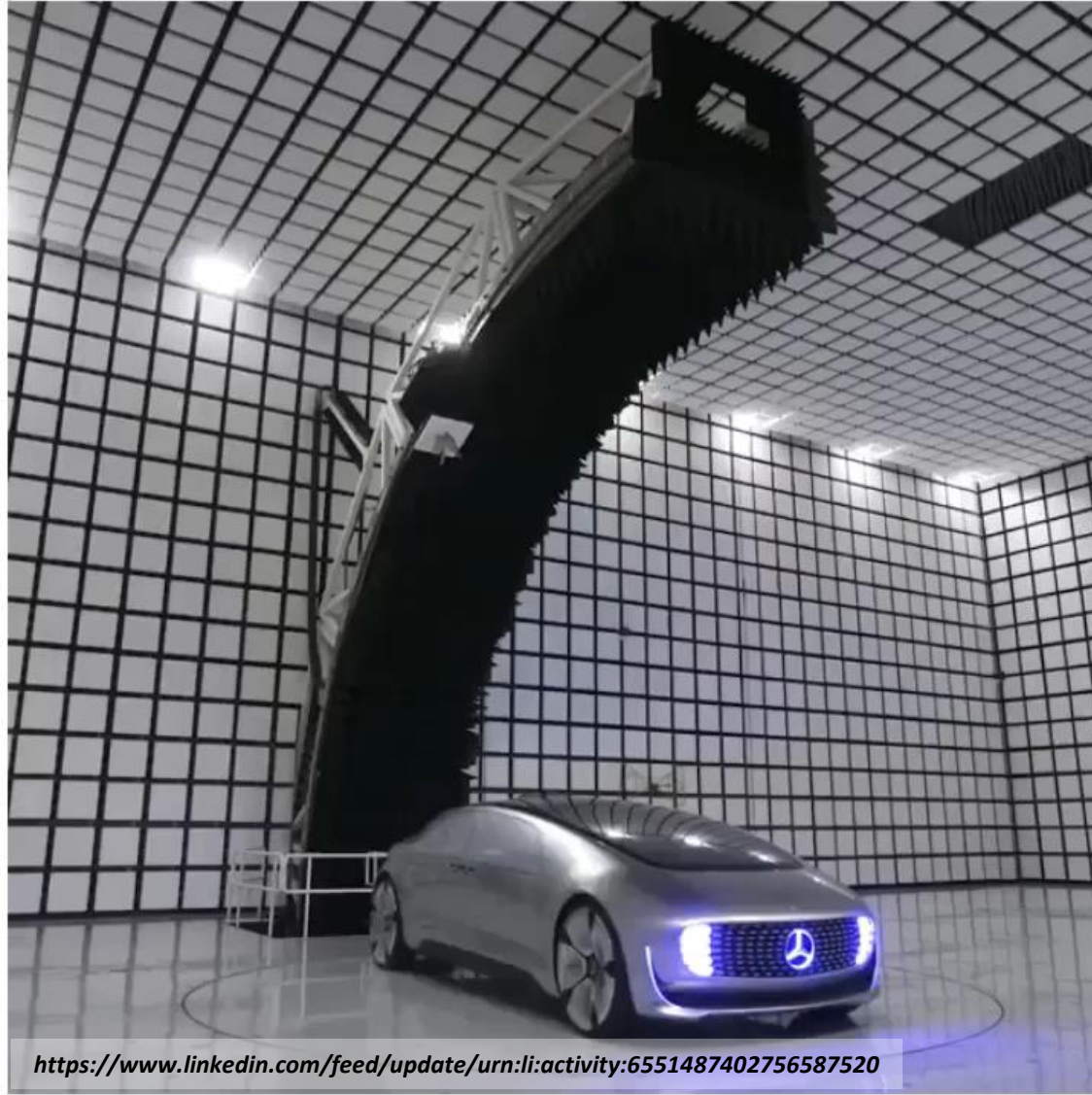
Mercedes-Benz
87,234 followers
1w

+ Follow



Electromagnetic compatibility (EMC) is a key prerequisite for the future topics of connectivity, autonomous driving, shared, and electric drivetrain. With the new test facility, Mercedes-Benz takes an important step as a pioneer in the digitisation of the automotive industry! [#EMC](#) [#MercedesBenz](#) [#autonomousdriving](#)

Read more: <http://mb4.me/EMC>



<https://www.linkedin.com/feed/update/urn:li:activity:6551487402756587520>

DAIMLER



INNOVATION

CASE / VENTURE / DIESEL / EFFICIENCY / DESIGN

Connectivity

Autonomous

Shared & Services

Electric



New testing facility for EMC and antenna systems inaugurated

July 01, 2019

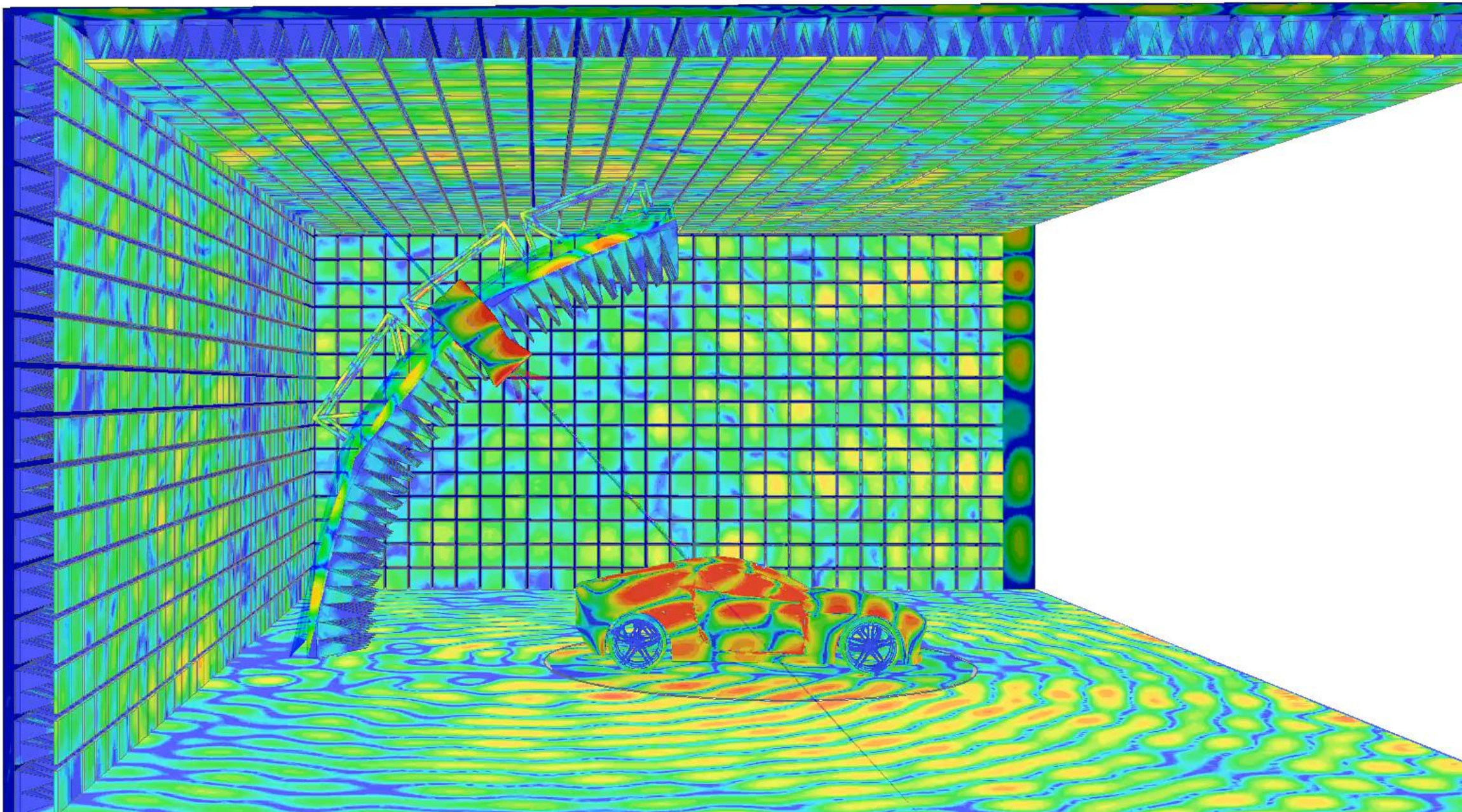
A Mercedes-Benz passenger car can have more than 200 control units; an S-Class vehicle has over five kilometres of wires. **CABLES and ELECTRIFICATION**

Modern vehicles have more than just the classic radio antenna: They are equipped with antennas for radio broadcasts, mobile **DESENSE AND ANTENNA PLACEMENT** central locking system. They all need to be developed to achieve an optimal reception quality. Furthermore, the antennas may not interfere with each other.

RF CO-SITE

The new **5G mobile communications** standard creates additional requirements. One antenna is no longer enough to physically achieve the future data rates.

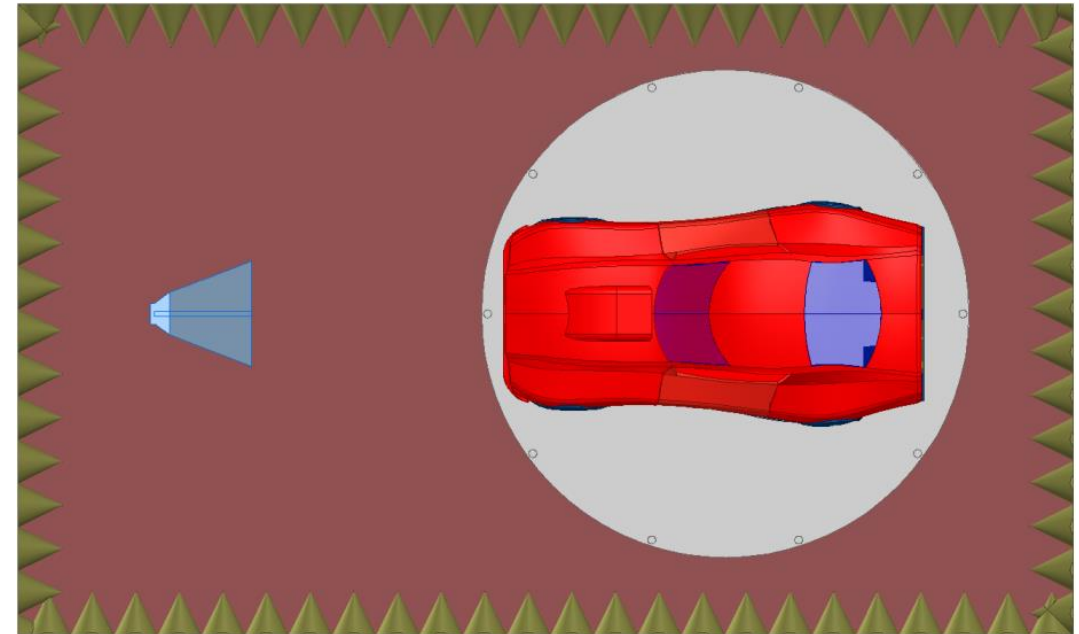
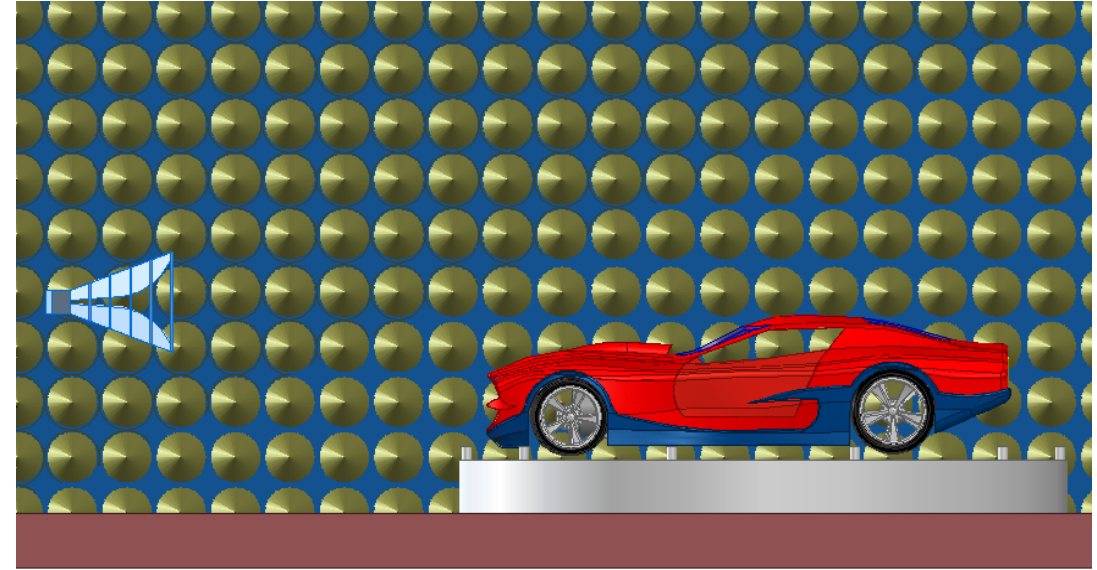
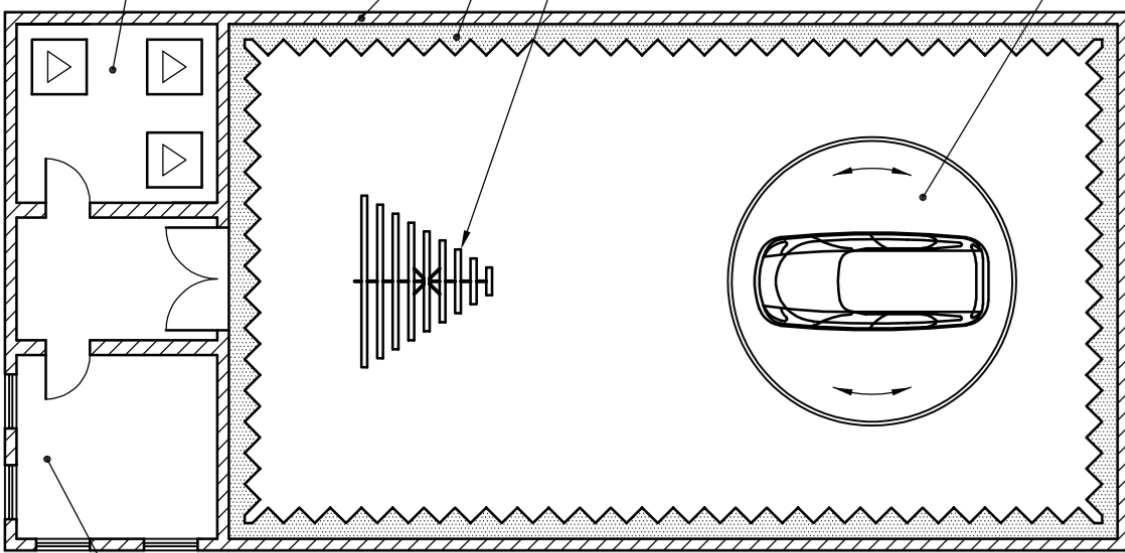
<https://www.daimler.com/innovation/case/connectivity/opening-testing-facility-for-emc.html>

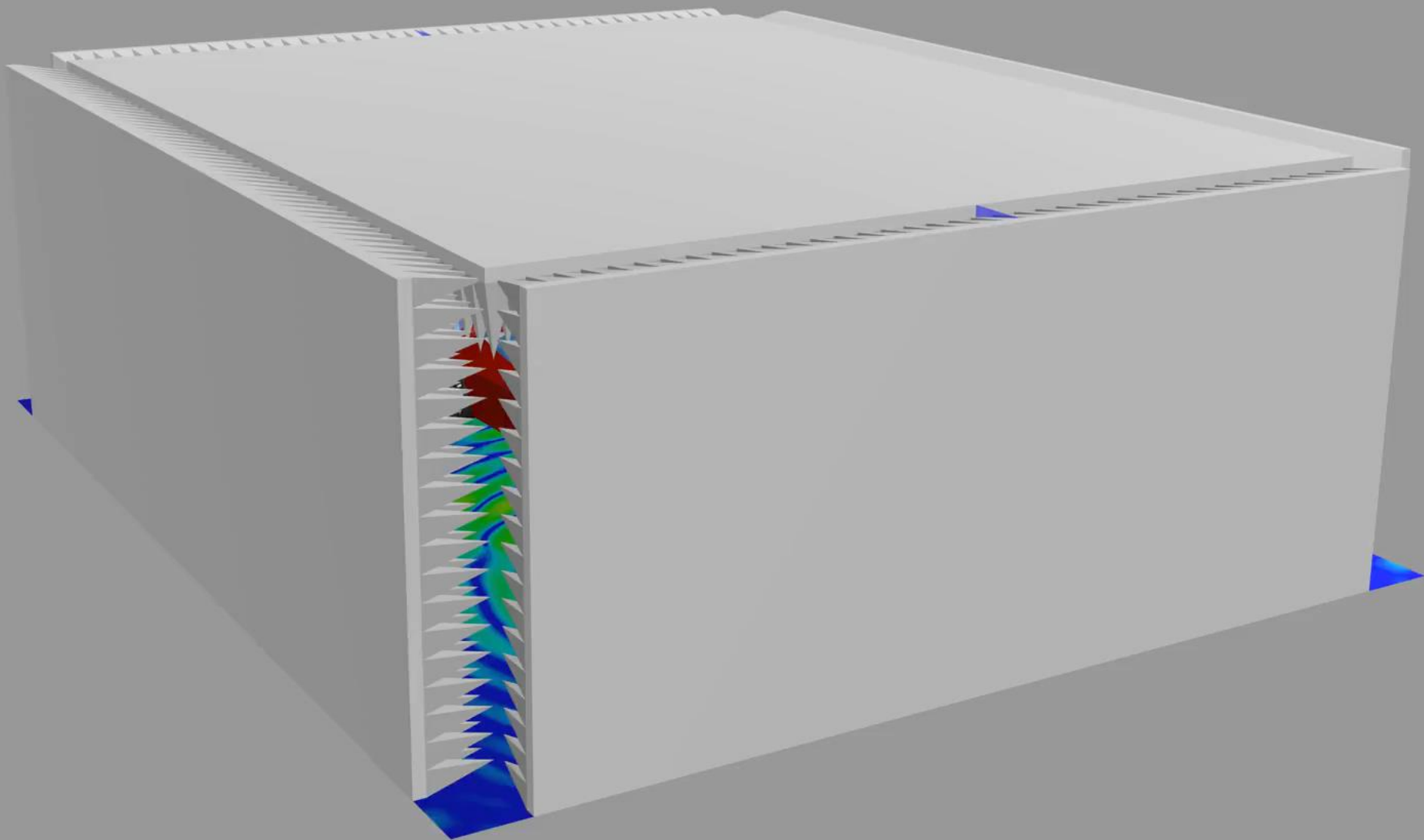


RADIATED IMMUNITY

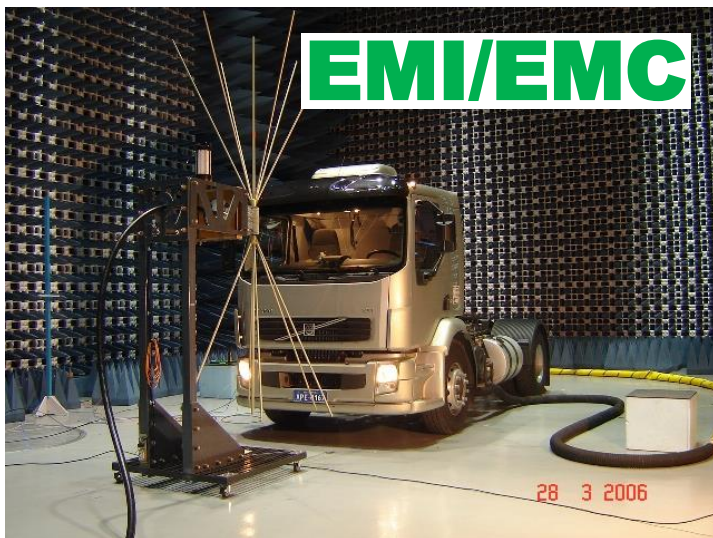
ISO 11451-2

The international standard ISO 11451-2 is applied to road vehicles and describes a vehicle test method for electrical disturbances from narrowband radiated electromagnetic energy. It determines the immunity of passenger cars and commercial vehicles to electrical disturbances from off-vehicle radiation sources, regardless of the vehicle propulsion system. It can also be readily applied to other types of vehicles including hybrid electric vehicles (HEV). The test should be performed in an absorber-lined shielded enclosure, trying to create an indoor electromagnetic compatibility testing facility that simulates open field testing.

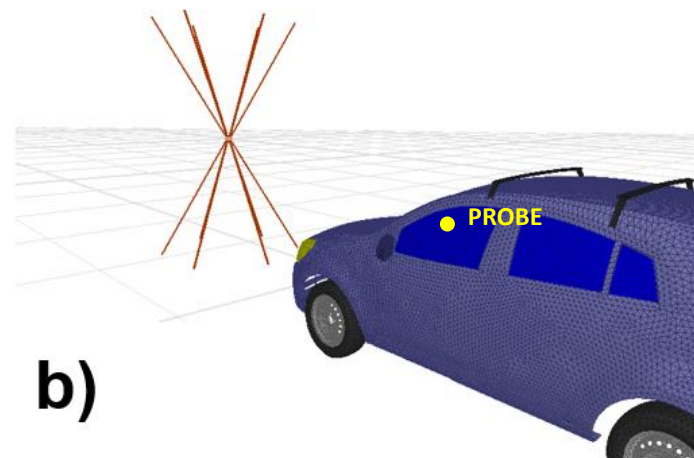
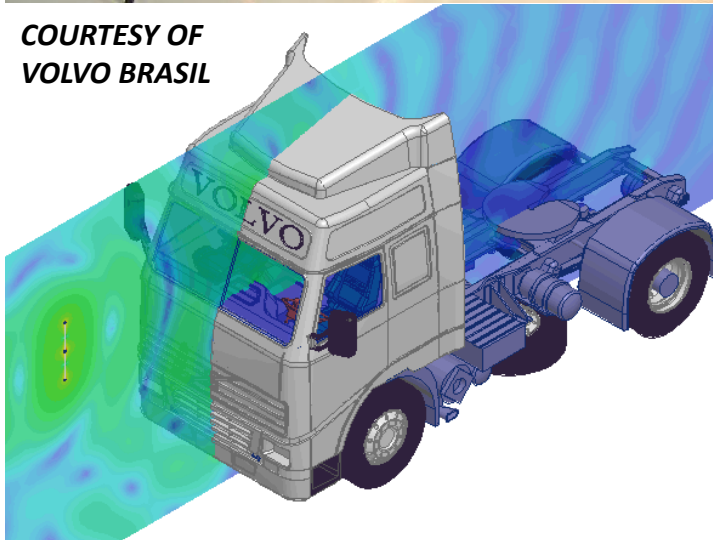




RADIATED IMMUNITY

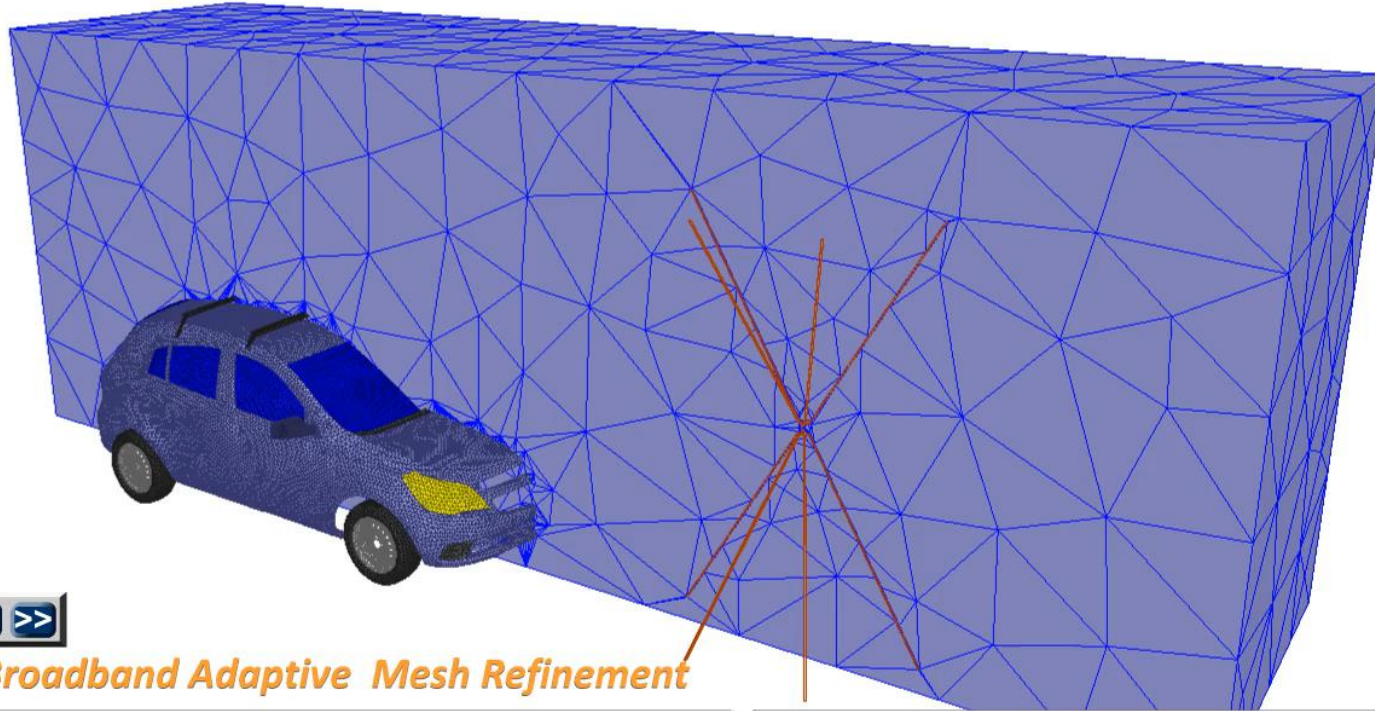


COURTESY OF
VOLVO BRASIL



General Motors do Brasil

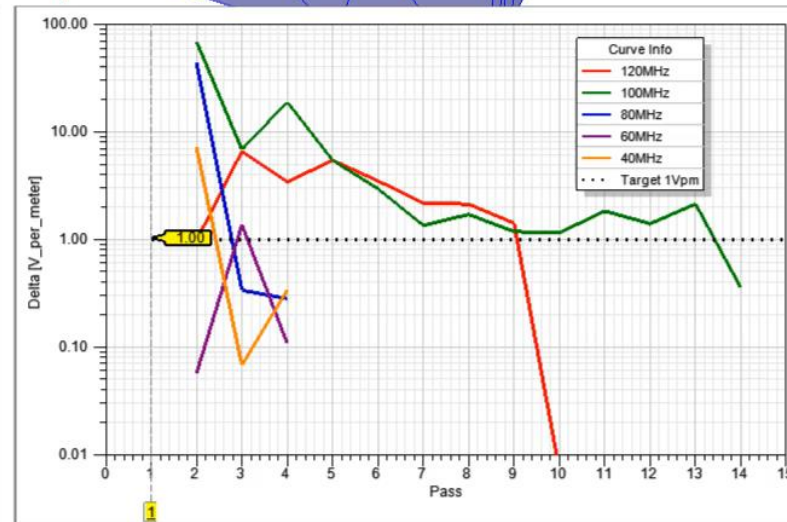
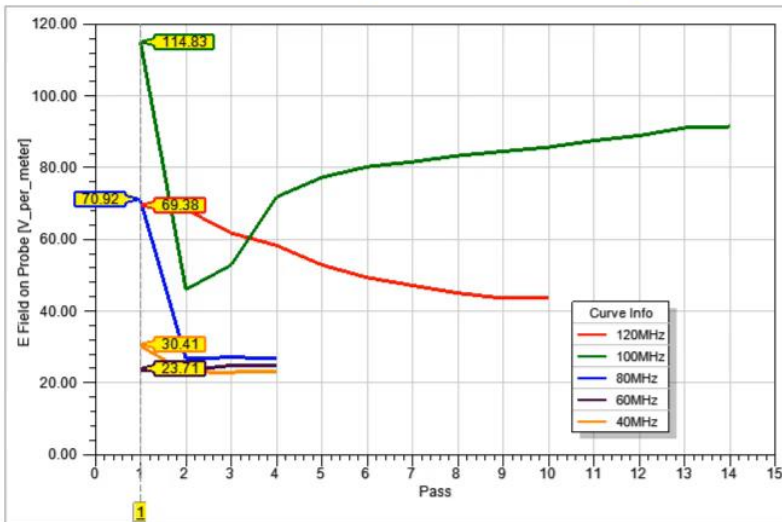
RADIATED IMMUNITY



Smallest Element Size is $\lambda/300$ @100MHz

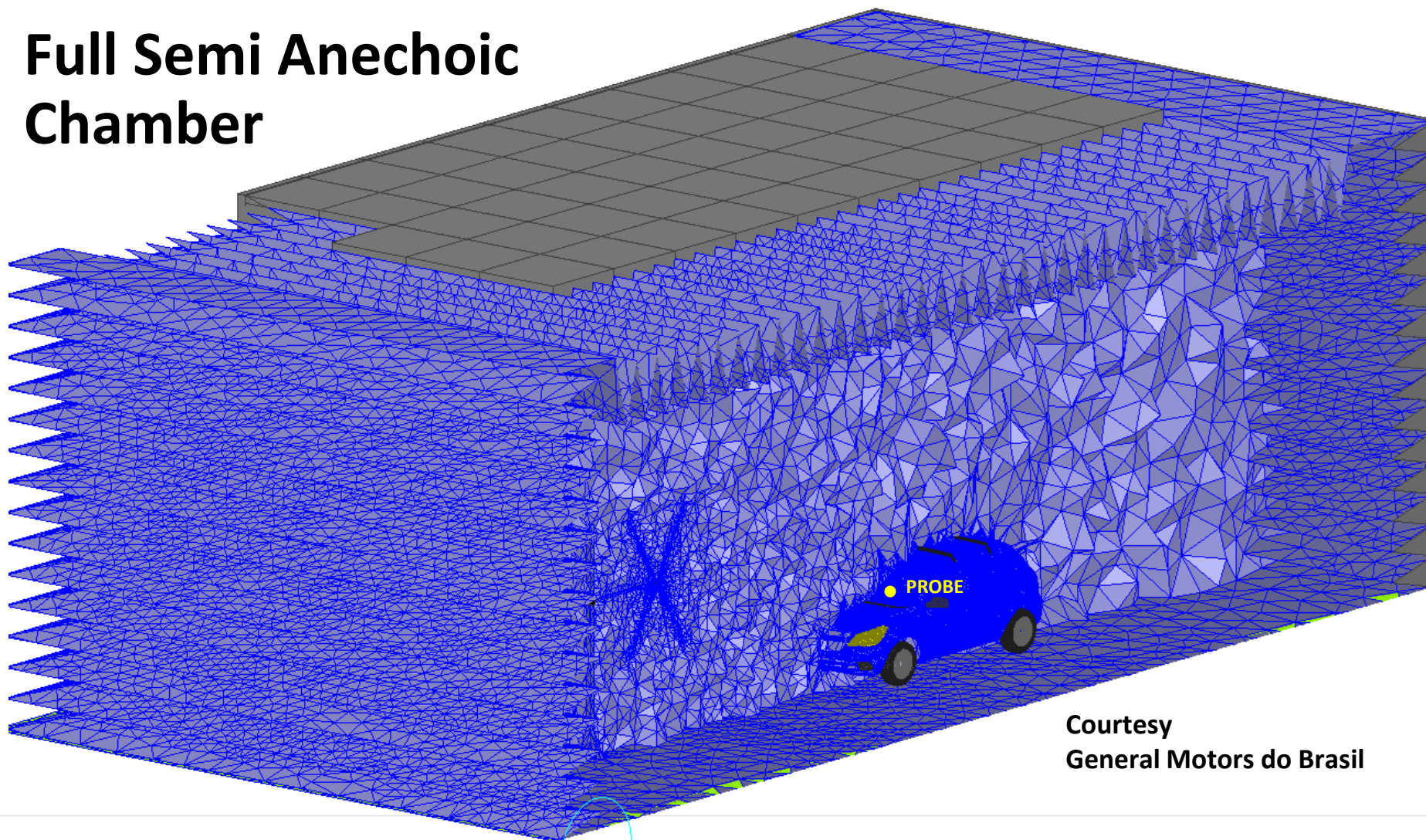


HFSS Broadband Adaptive Mesh Refinement



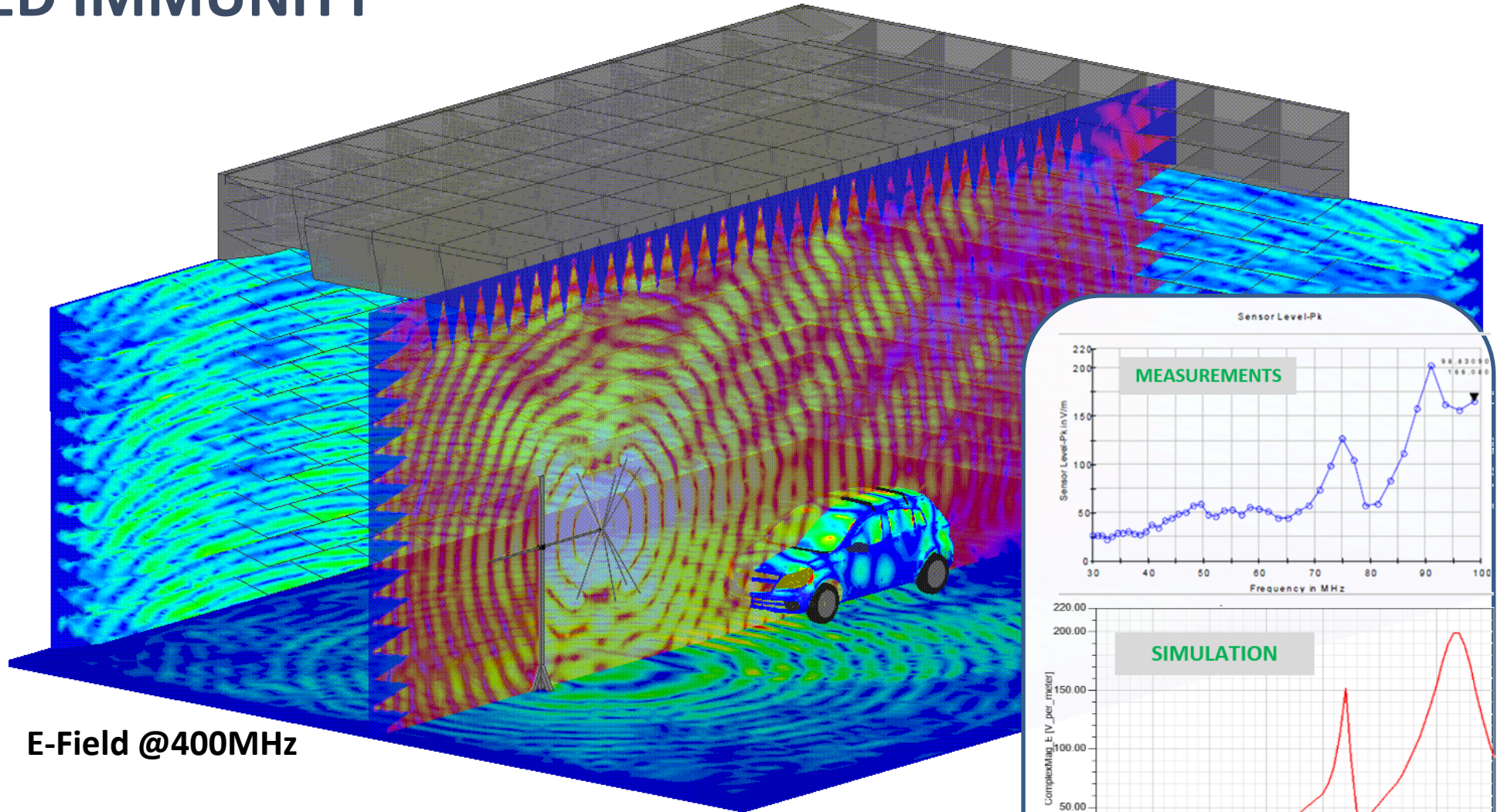
RADIATED IMMUNITY

Full Semi Anechoic Chamber



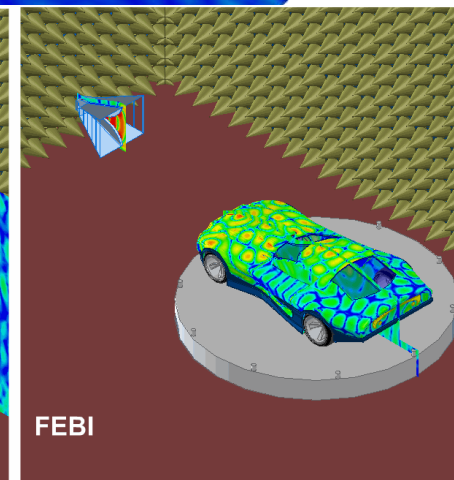
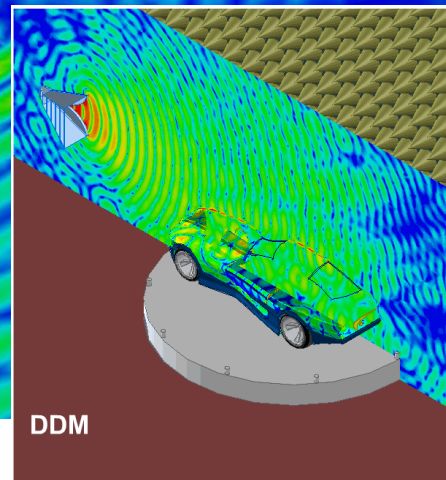
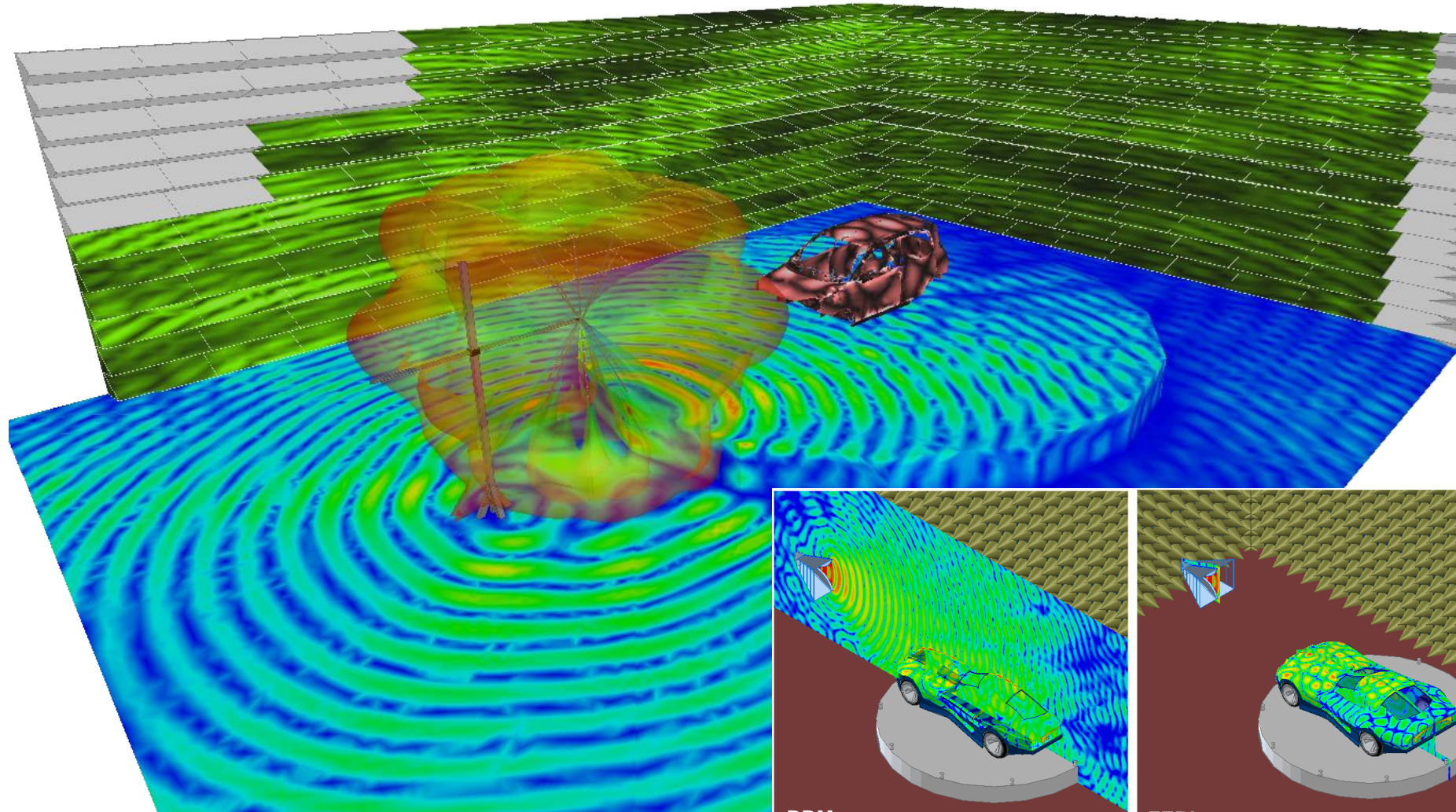
Courtesy
General Motors do Brasil

RADIATED IMMUNITY



J. Mologni, J. Ribas, L. Amaral, J. P. Filho and G. Caixeta, "The significance of specific vehicle parts on automotive radiated immunity numerical simulations," 2015 SBMO/IEEE doi: 10.1109/IMOC.2015.7369065

RADIATED IMMUNITY

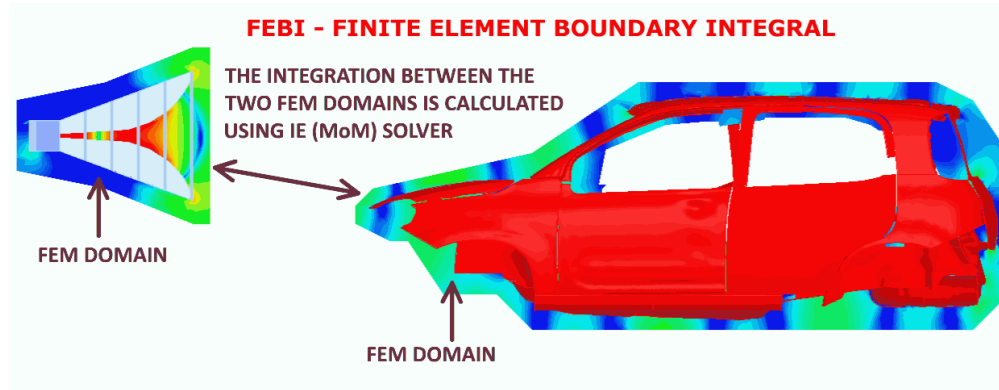


ANSYS Advantage: Test Drive for EMI (FCA BRASIL / ESSS)

A. Collin (FCA), A. Nogueira (FCA), A. Veloso (FCA), J. Mologni (ESSS), M. Kopp (ANSYS)

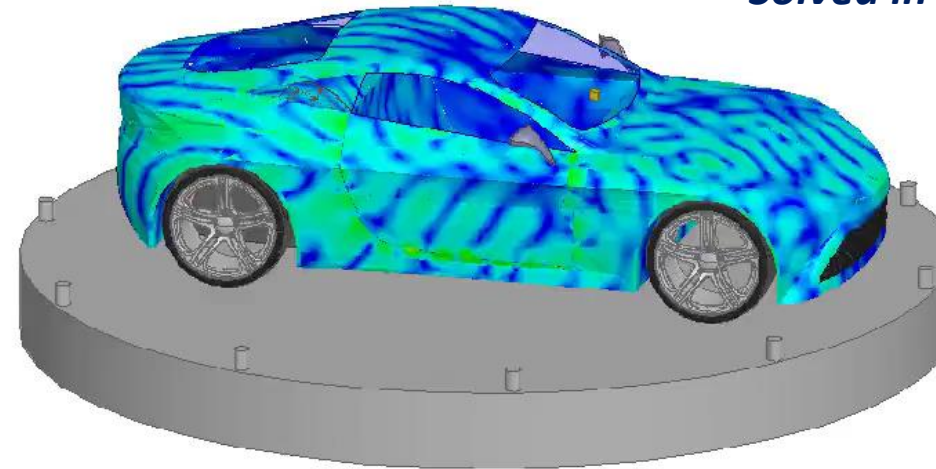
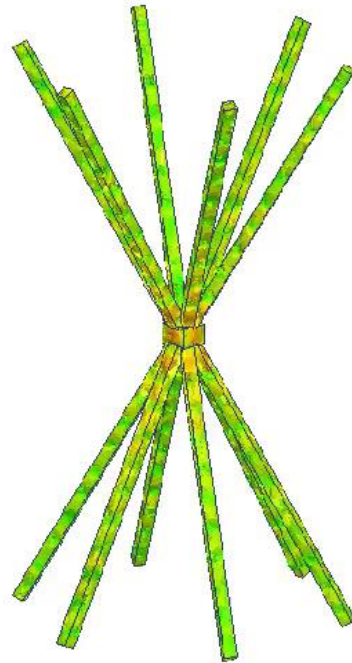
RADIATED IMMUNITY

J. F. Mologni, M. Kopp, C. L. R. Siqueira, A. Colin, A. Nogueira and M. A. R. Alves,
"Automotive EMC analysis using the hybrid finite element boundary integral
approach," *2013 IEEE International Symposium on Electromagnetic Compatibility*, Denver,
CO, 2013, pp. 688–693.doi: 10.1109/ISEMC.2013.6670499



Courtesy
FCA

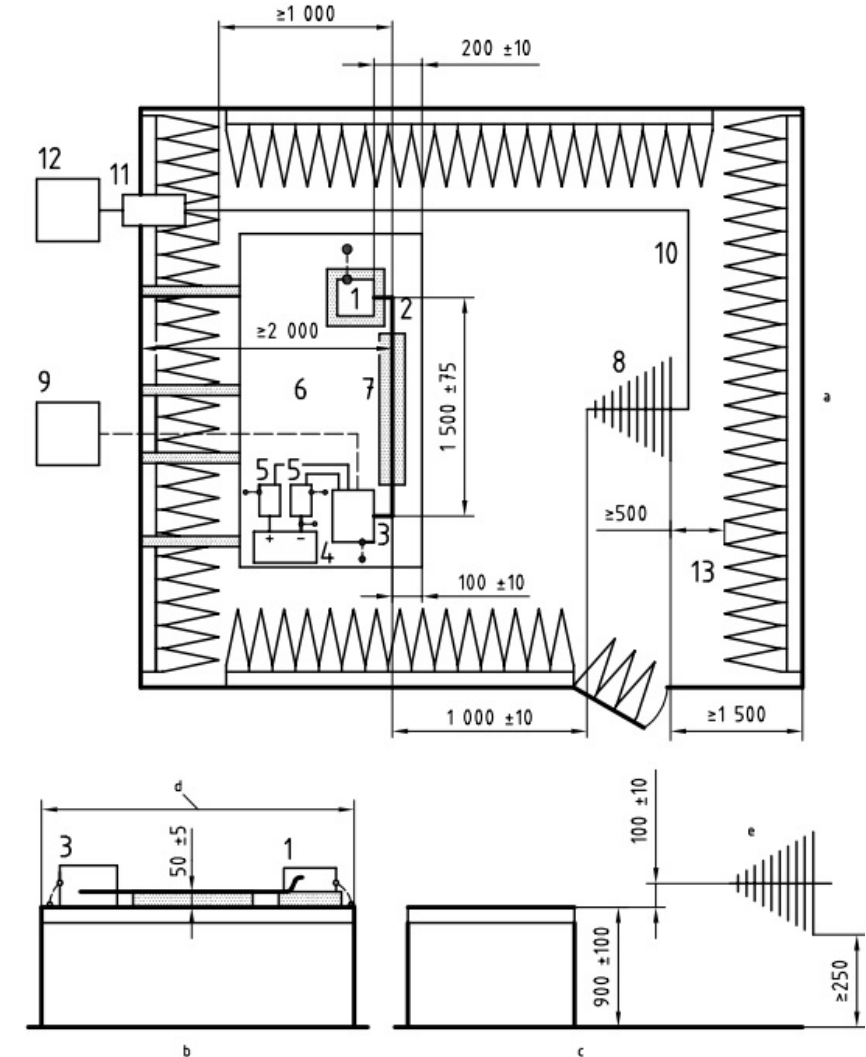
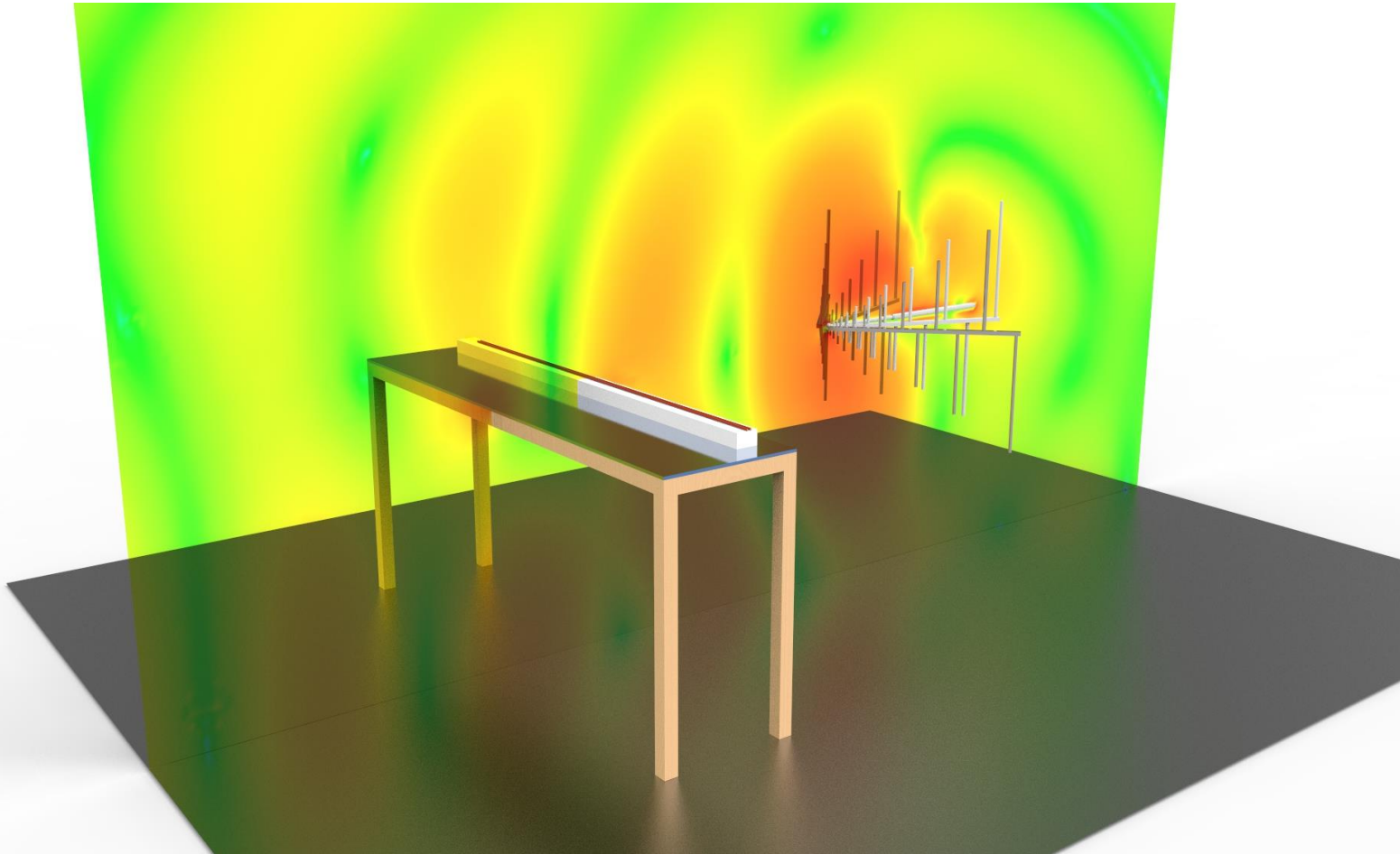
*Electric field @1GHz
Solved in 58 minutes using DSO*



Chassis and Glasses are IE Regions
(no air volume is required around them)

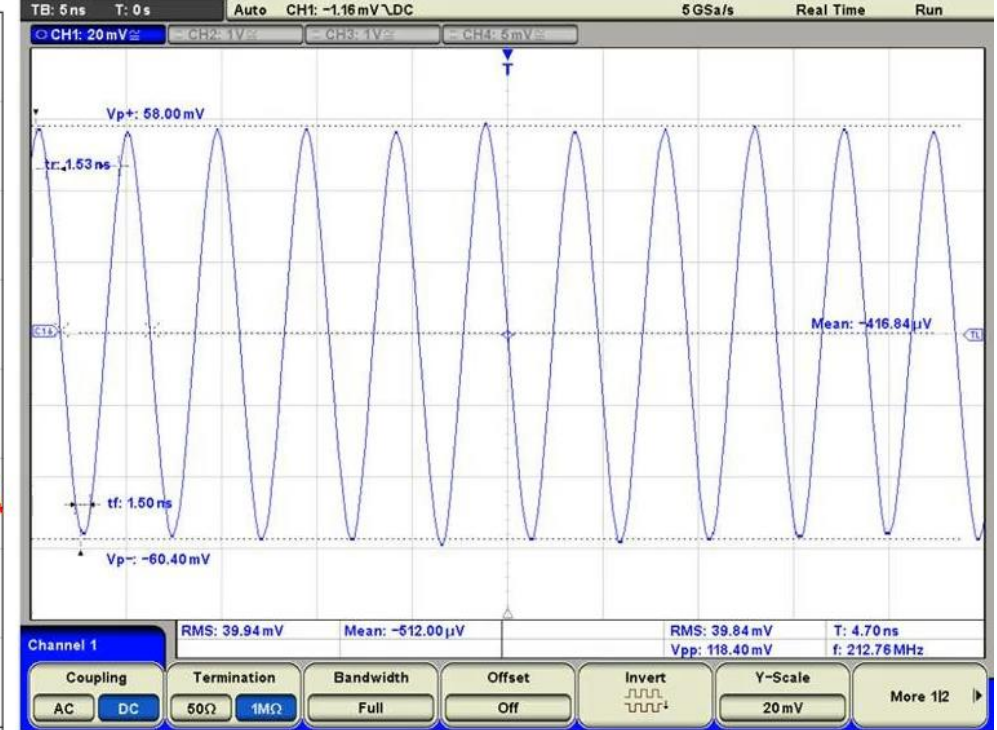
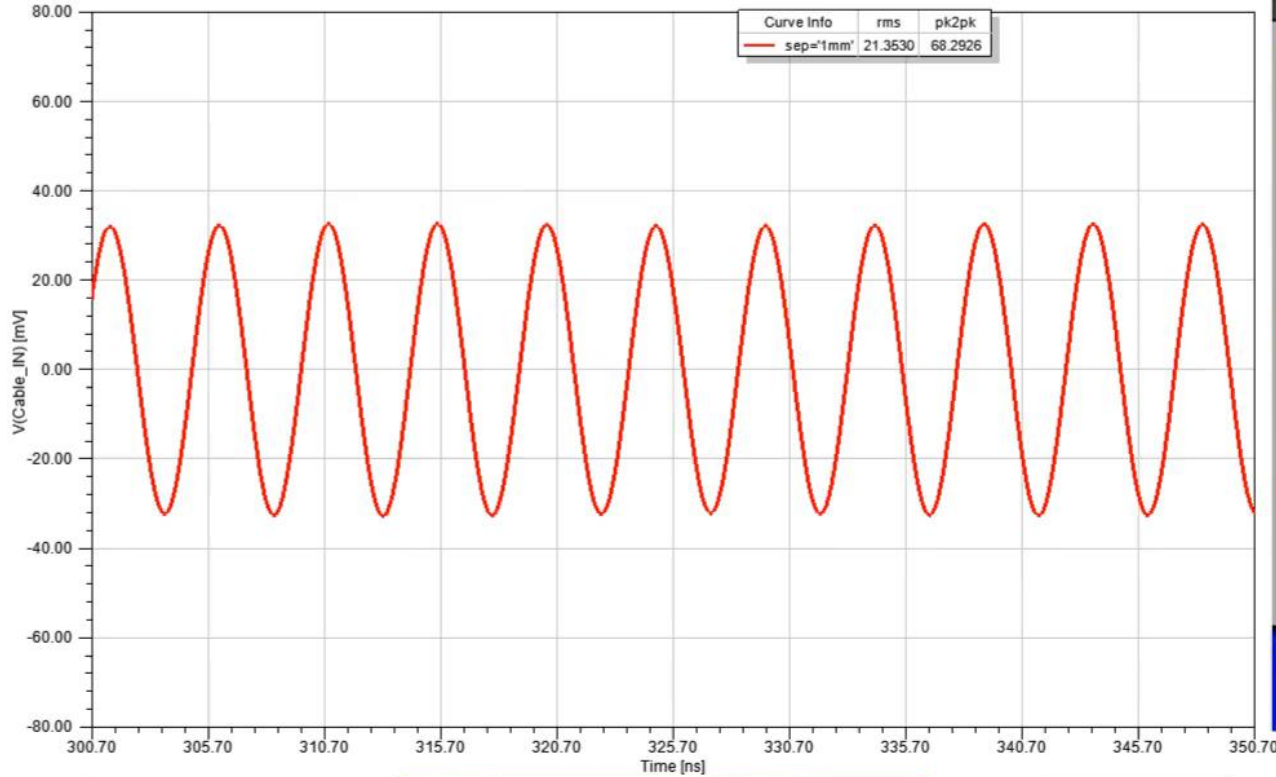
RADIATED IMMUNITY

ISO 11451-2

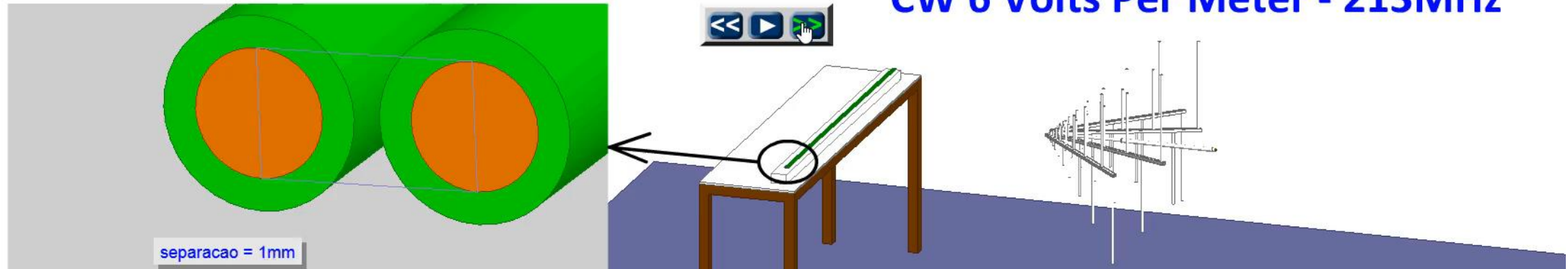


A. José , R. Adriano, U. Resende, M. Menezes, R. Batalha, J. Mologni, " Evaluation of Radiated Immunity Tests Using Adjusted Pulse Modulated Signals", IET Science, Measurement & Technology, 9pp, 2019. DOI: 10.1049/iet-smt.2018.5199

RADIATED IMMUNITY



CW 6 Volts Per Meter - 213MHz



RADIATED IMMUNITY

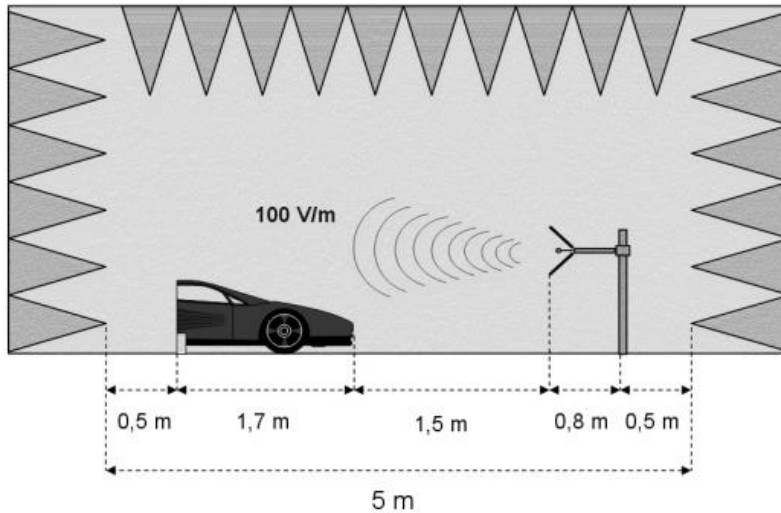
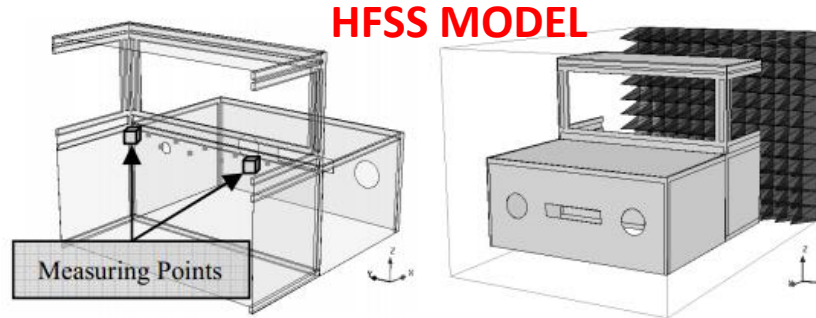
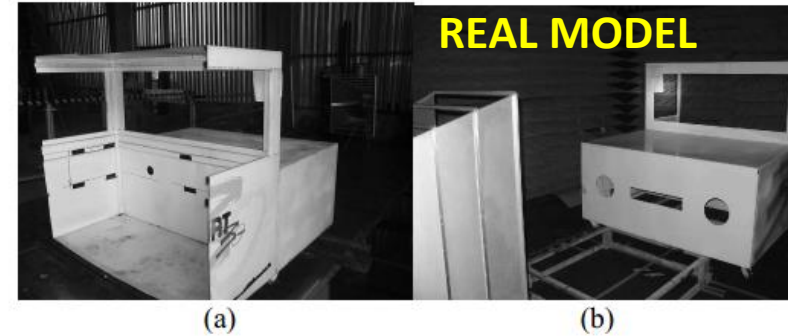
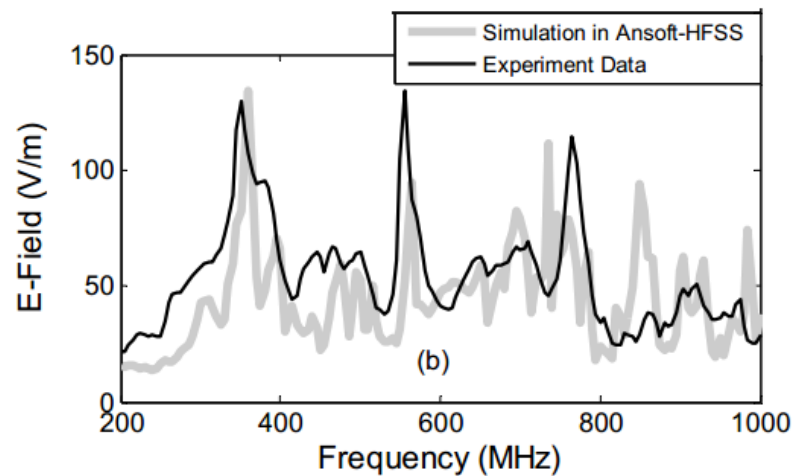


Fig. 1. Schematic experiment illustration of a vehicle inside a half-anechoic chamber with reduced dimensions.



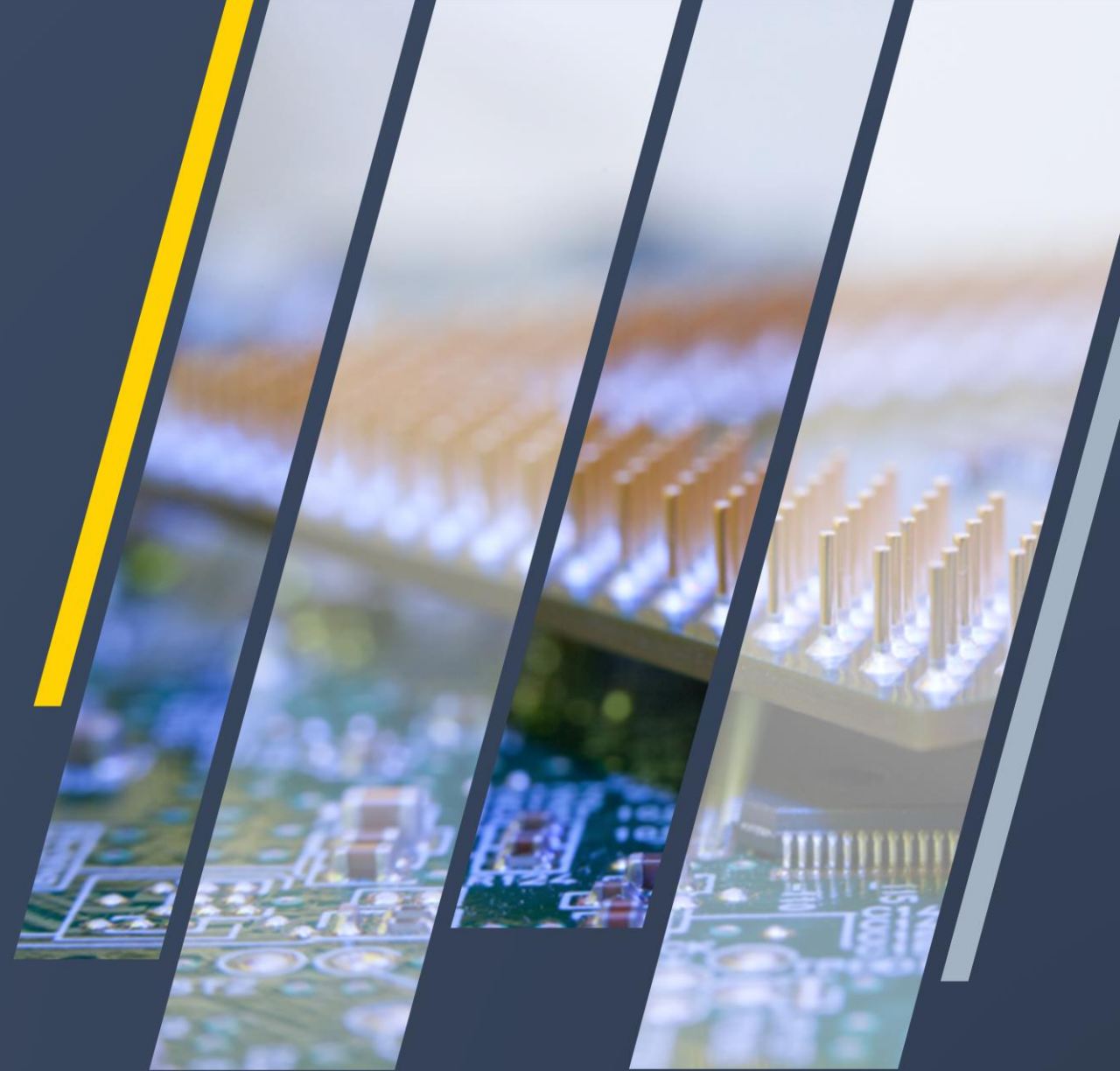
Note that the FEM (Finite Elements Method) tool of HFSS obtained better results than FDTD (Finite Difference Time Domain)

IEEE: Simulation of Automotive Vehicle EMC Experiment Considering Nearness to an Anechoic Wall (CEFET-MG)

Cláudio H. G. Santos, Márcio M. Afonso, Úrsula C. Resende

ANSYS®

HIRF

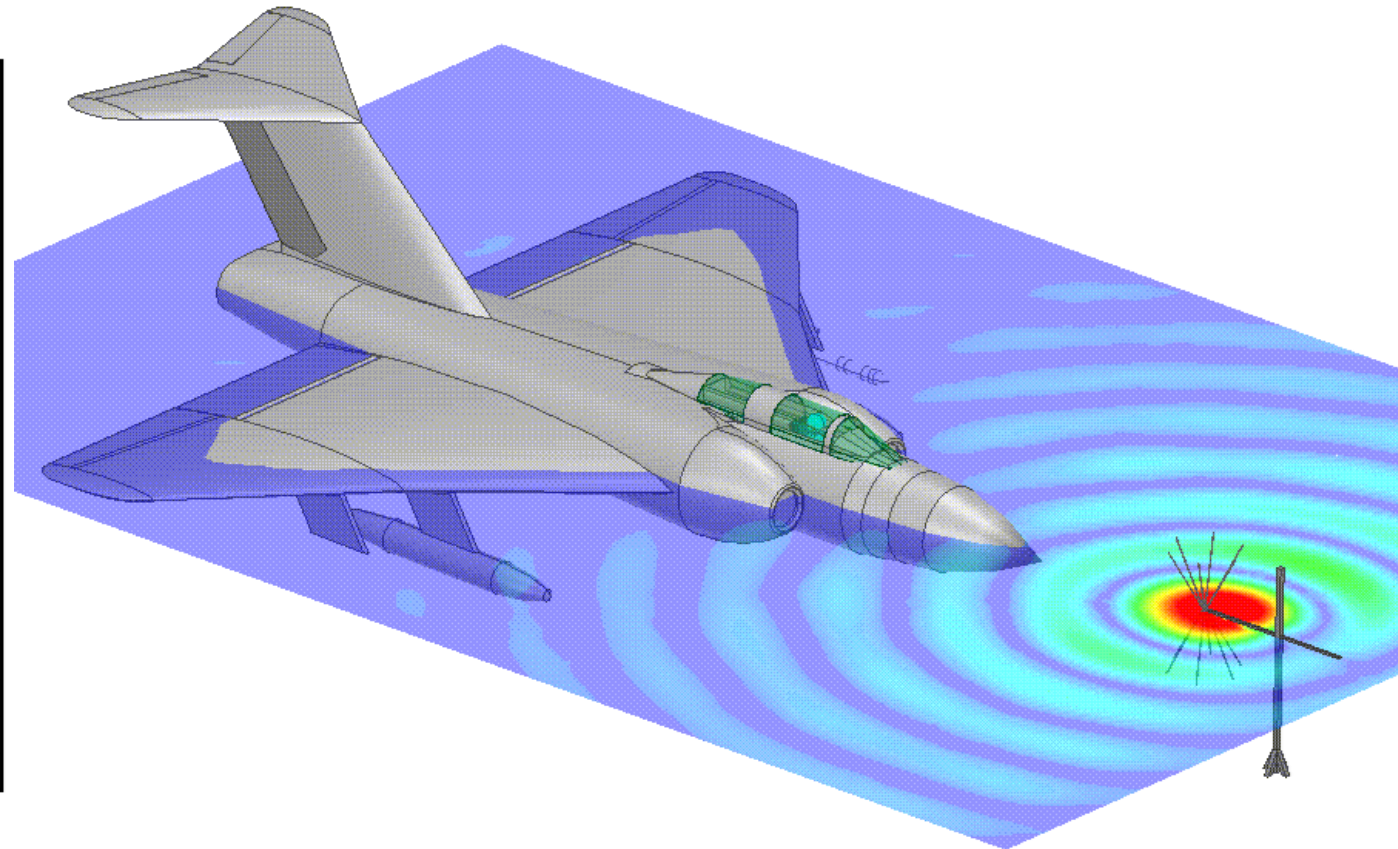


HIRF

HIRF is a radiated immunity test where the performance of a DUT is evaluated under a given radiated field.

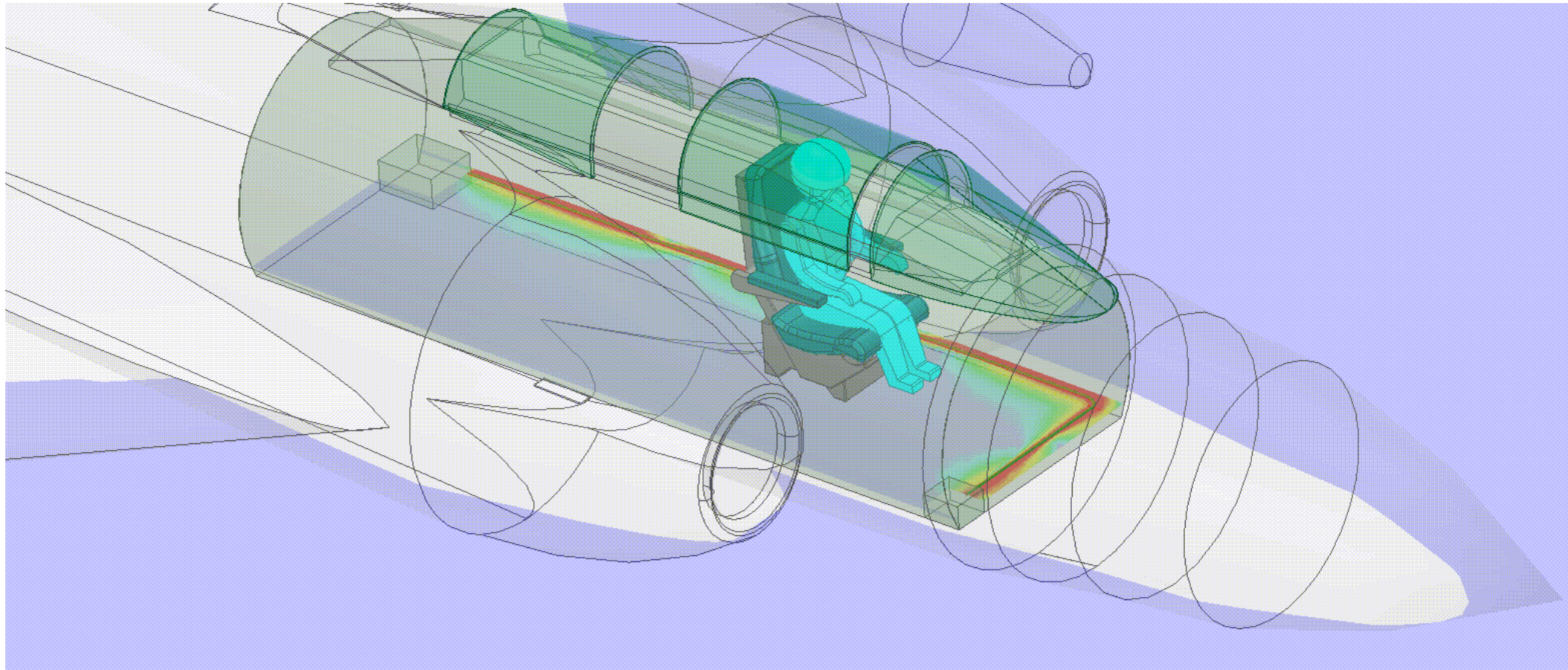
TABLE 2. FIELD STRENGTHS USED FOR COMPARISONS WITH LEVELS
CALCULATED AT AIRCRAFT POSITIONS

Frequency	NPRM Certification Field Strength [V/m]		DO-160B-Derived Field Strength [V/m]		DO-160C-Derived Field Strength [V/m]	
	Average	Peak	Average	Peak	Average	Peak
10 - 100 kHz	50	50	3	3	300	300
100 - 500 kHz	50	50	3	3	300	300
500 kHz - 2 MHz	50	50	3	3	300	300
2 - 30 MHz	100	100	3	3	300	300
30 - 70 MHz	50	50	3	3	300	300
70 - 100 MHz	50	50	3	3	300	300
100 - 200 MHz	100	100	3	3	300	300
200 - 400 MHz	100	100	3	3	300	300
400 - 700 MHz	50	700	3	3	300	300
700 MHz - 1 GHz	100	700	3	3	300	300
1 - 2 GHz	200	2000	3	3	300	300
2 - 4 GHz	200	3000	3	3	300	300
4 - 6 GHz	200	3000	3	3	300	300
6 - 8 GHz	200	1000	3	3	300	300
8 - 12 GHz	300	3000	3	3	300	300
12 - 18 GHz	200	2000	3	3	300	300
18 - 40 GHz	200	600	3	3	300	300



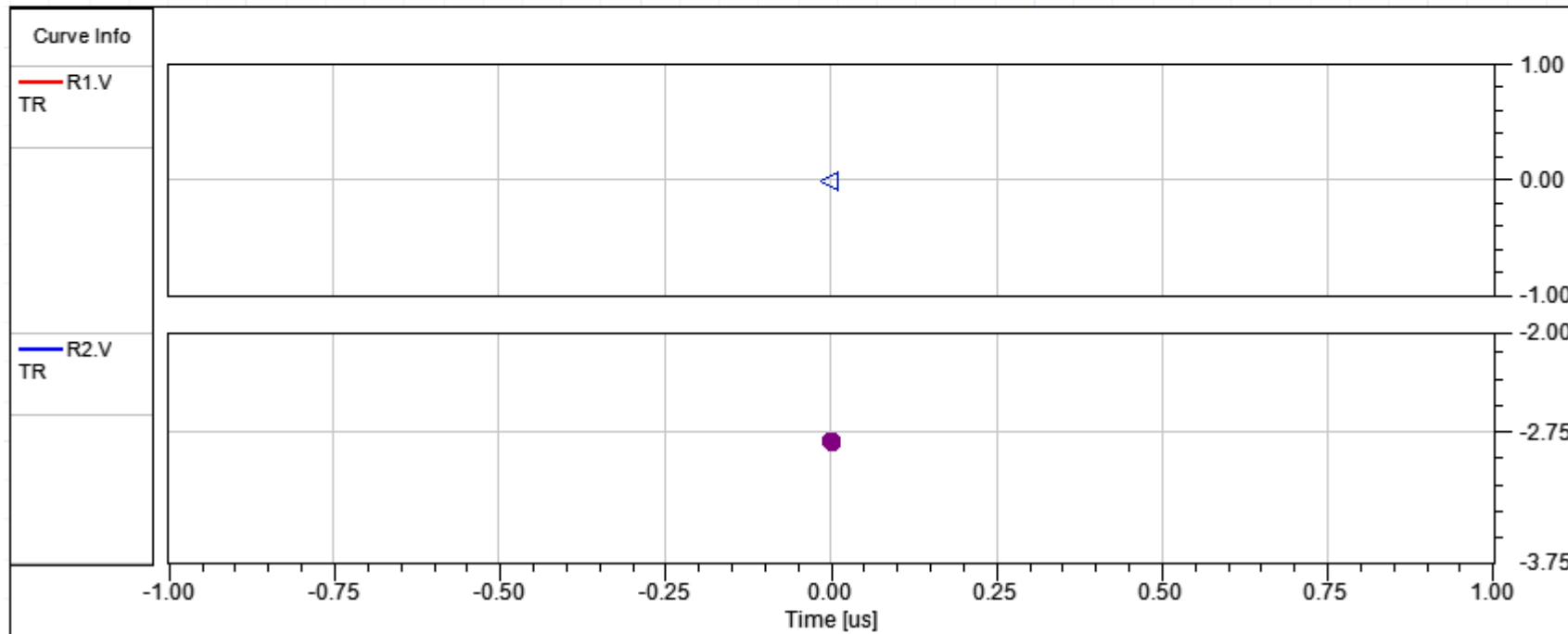
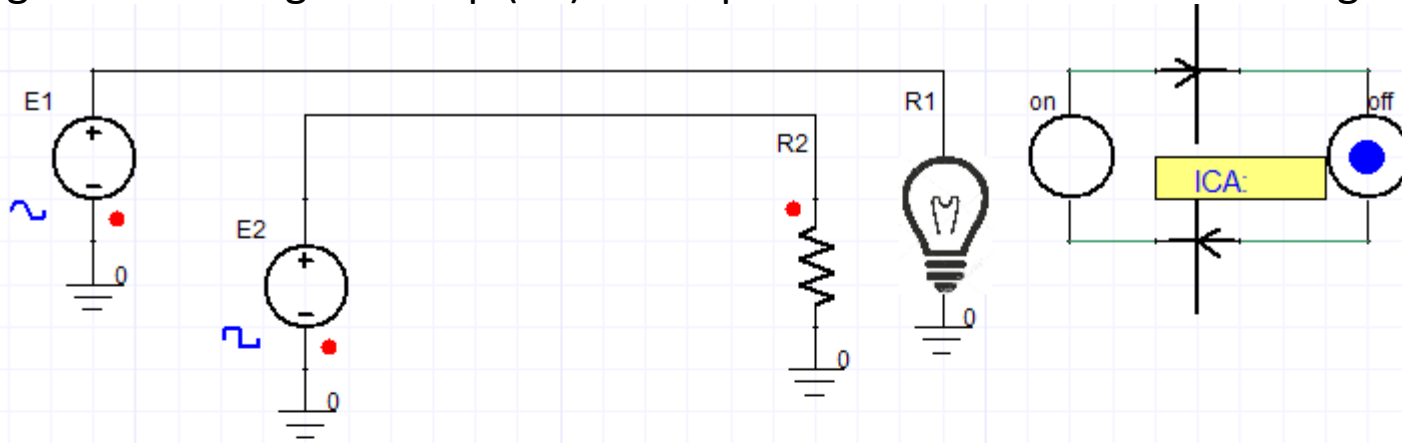
HIRF and Wiring Harness

Wiring Harness design (shielded cable, twisted pair, routing, splices) is one of the most critical components when it comes to HIRF/Susceptibility tests and is usually developed by the aircraft manufacturer.



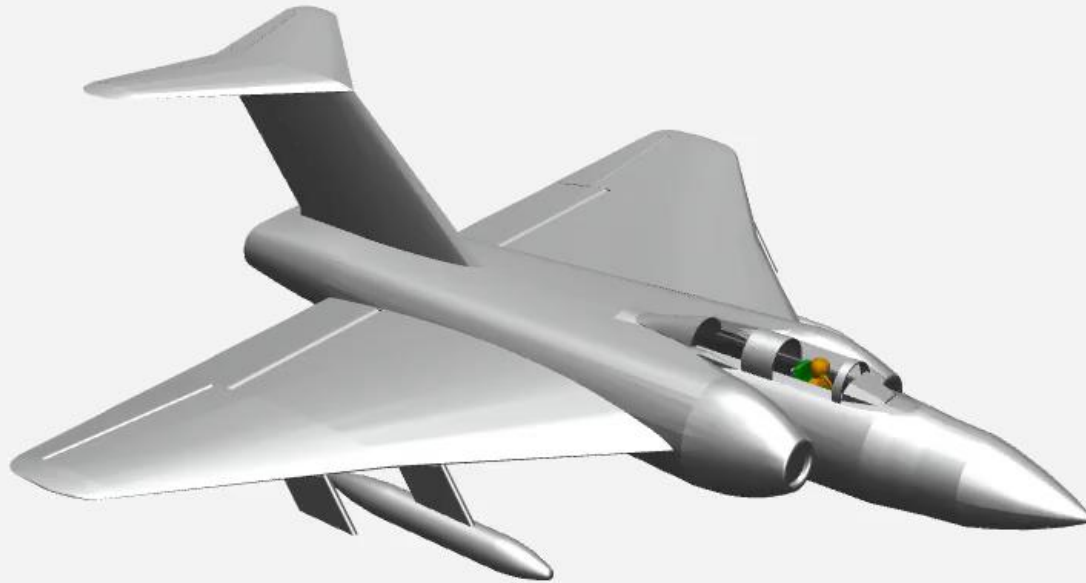
1 – Ideal System

The signal controlling the lamp (R1) is independent of the 100MHz clock signal (R2)



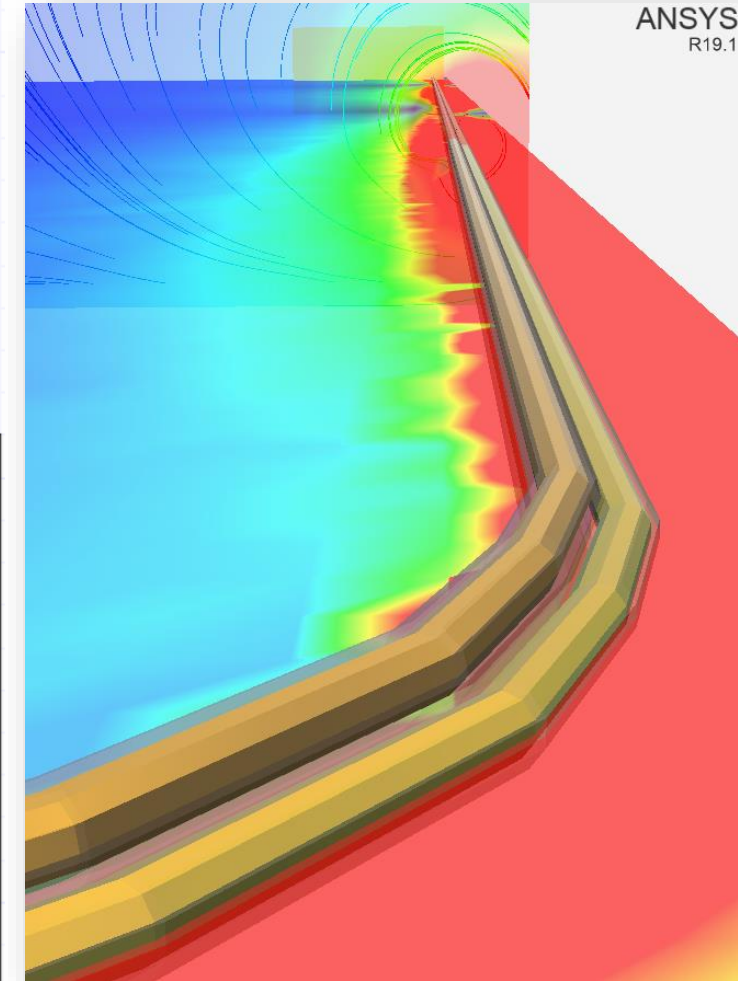
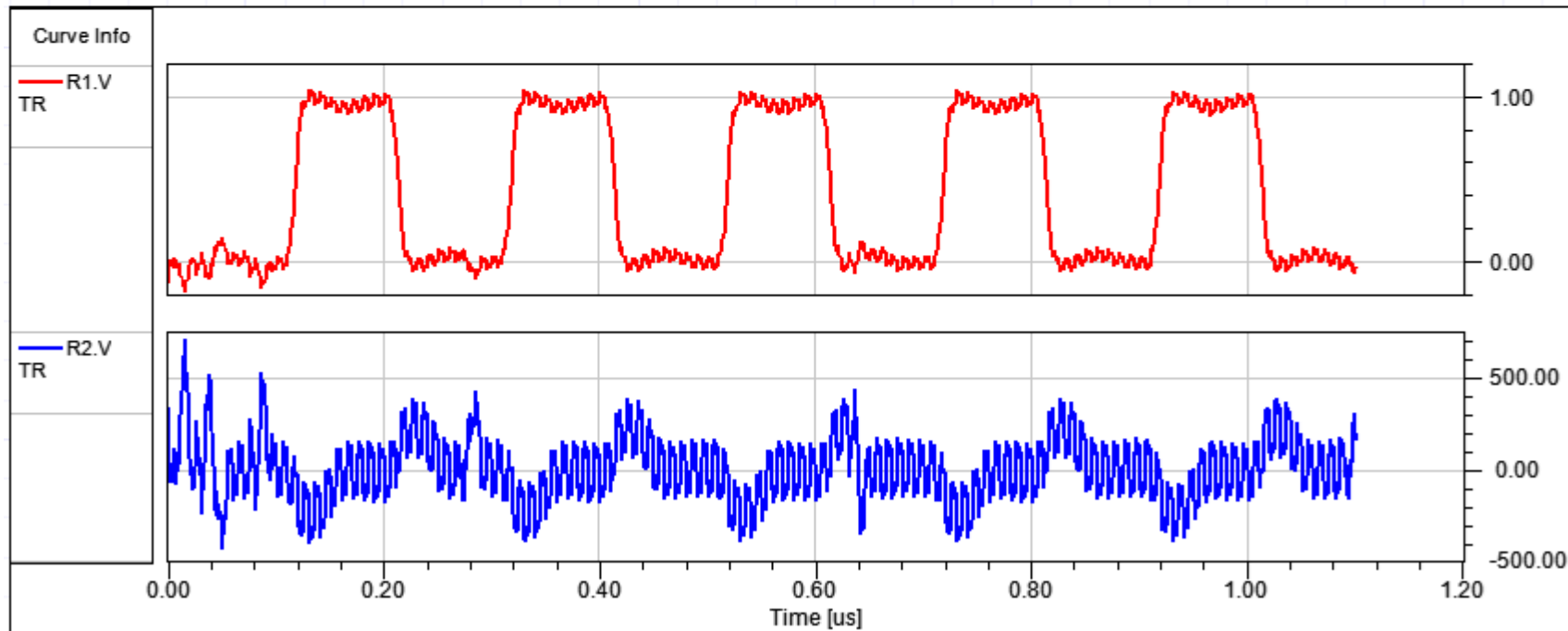
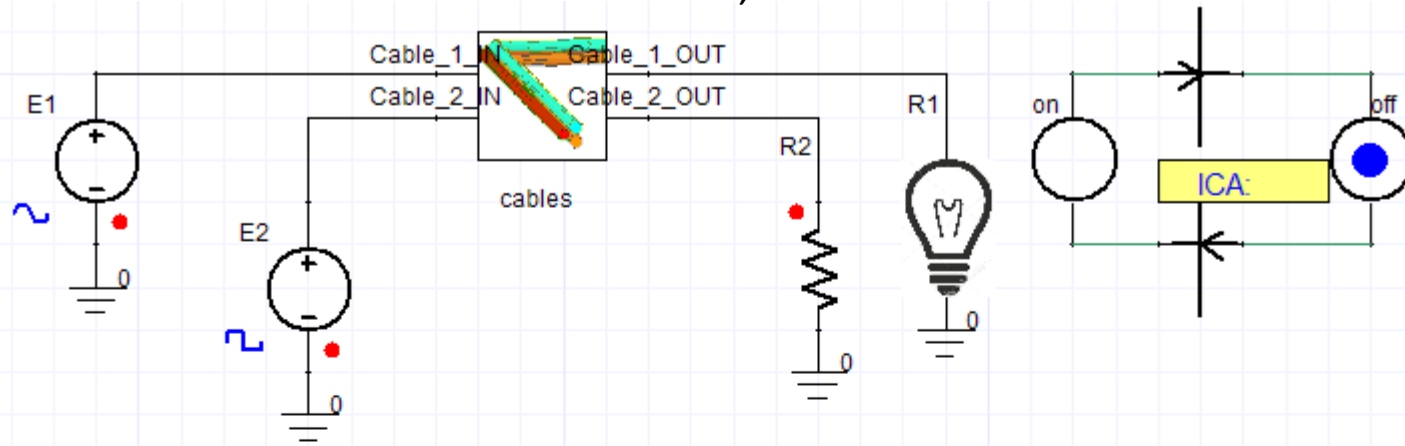
2 – Including the Cable Model

The signals are now transmitted through cables inside the aircraft. This entire 3D model will be included in the simulation



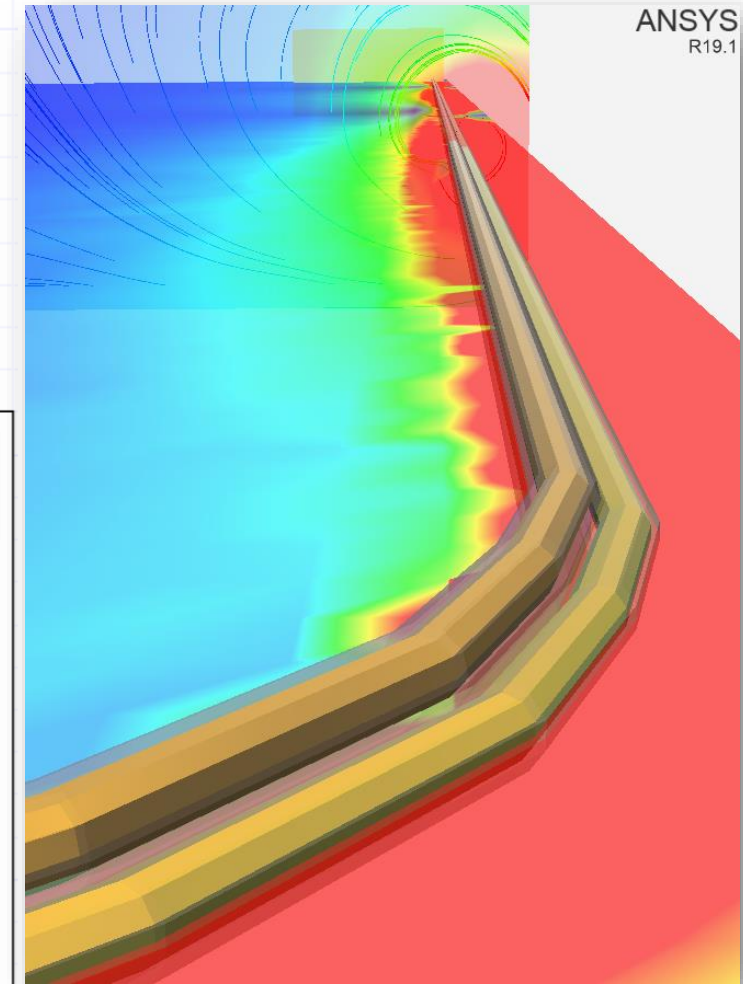
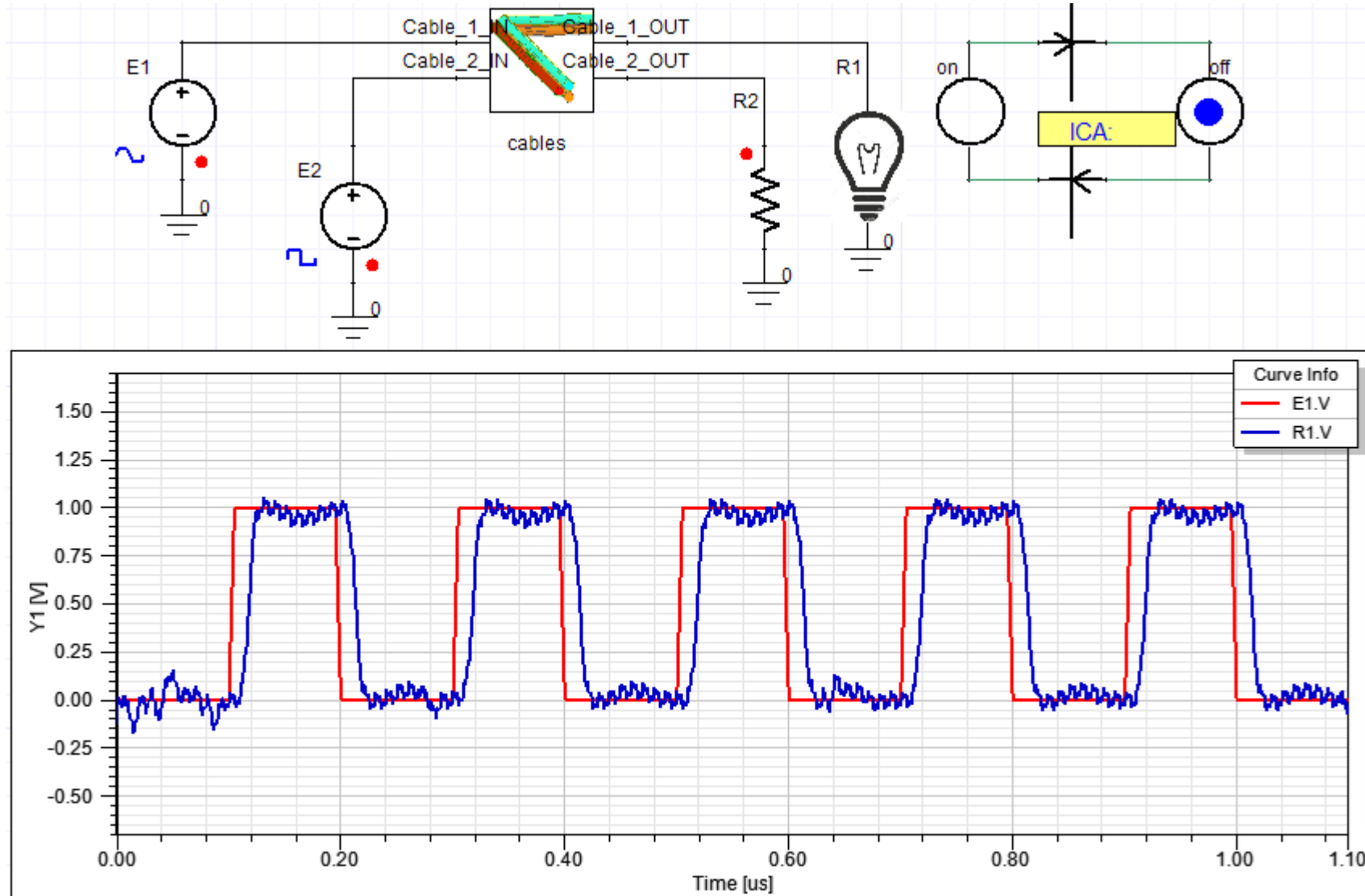
2 – Including the Cable Model

When the 3D FEM cable models is included, Crosstalk is observed



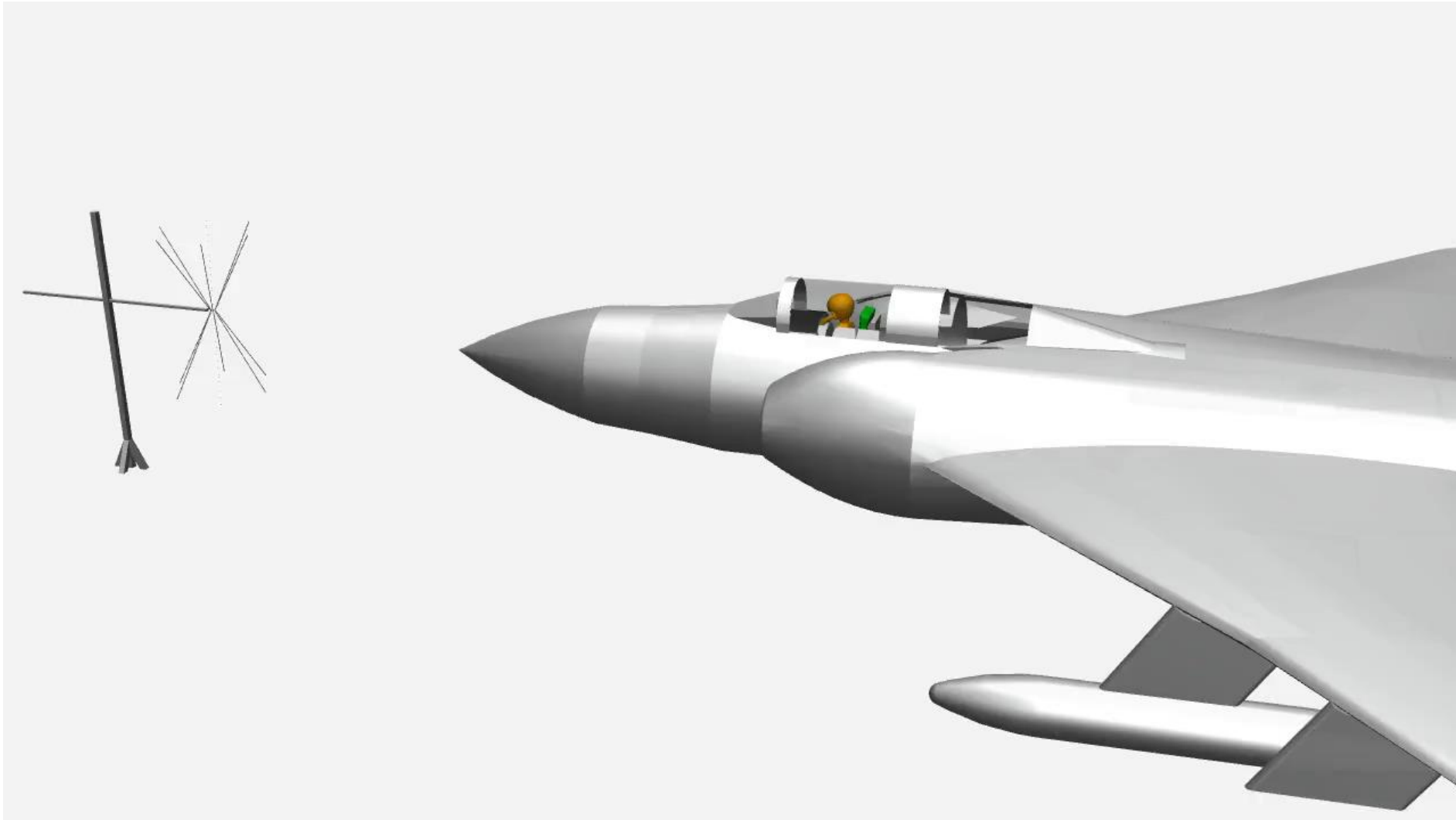
2 – Including the Cable Model

Also the delay, attenuation, distortion and all 3D electromagnetic effects can be observed from the source to the load.



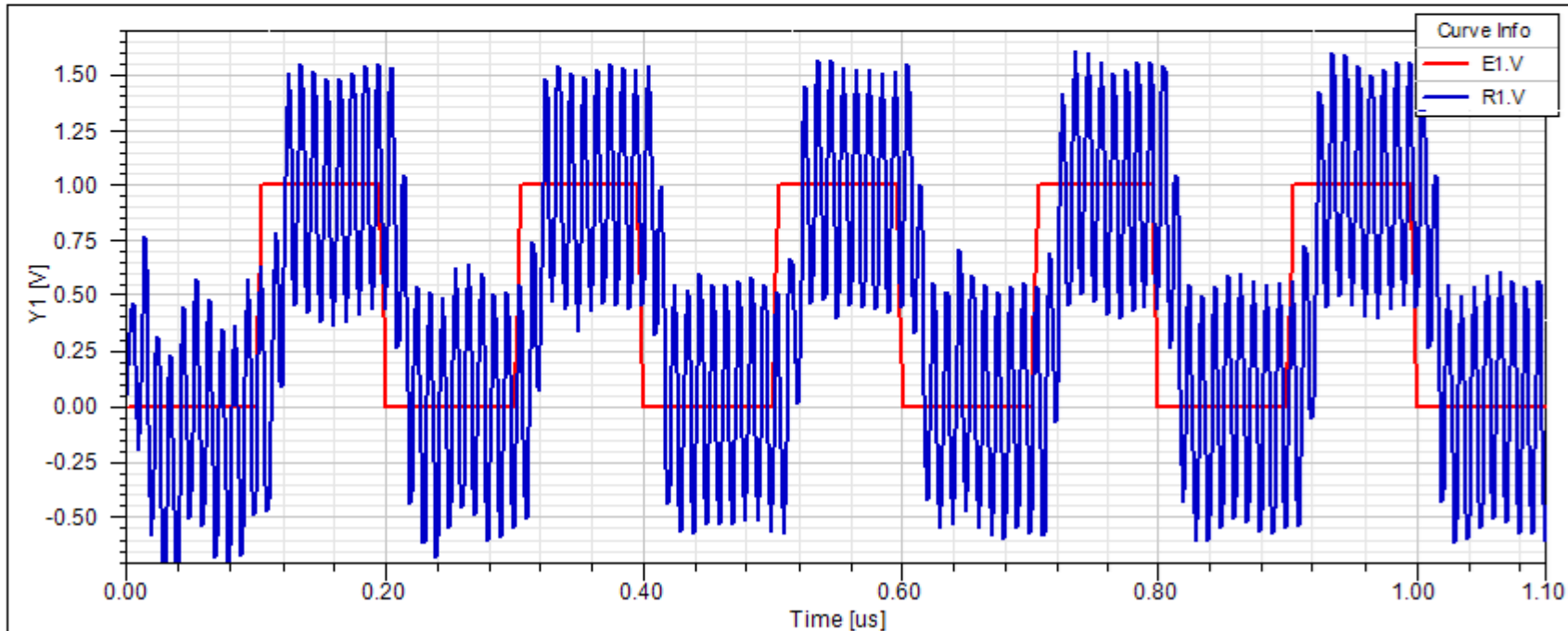
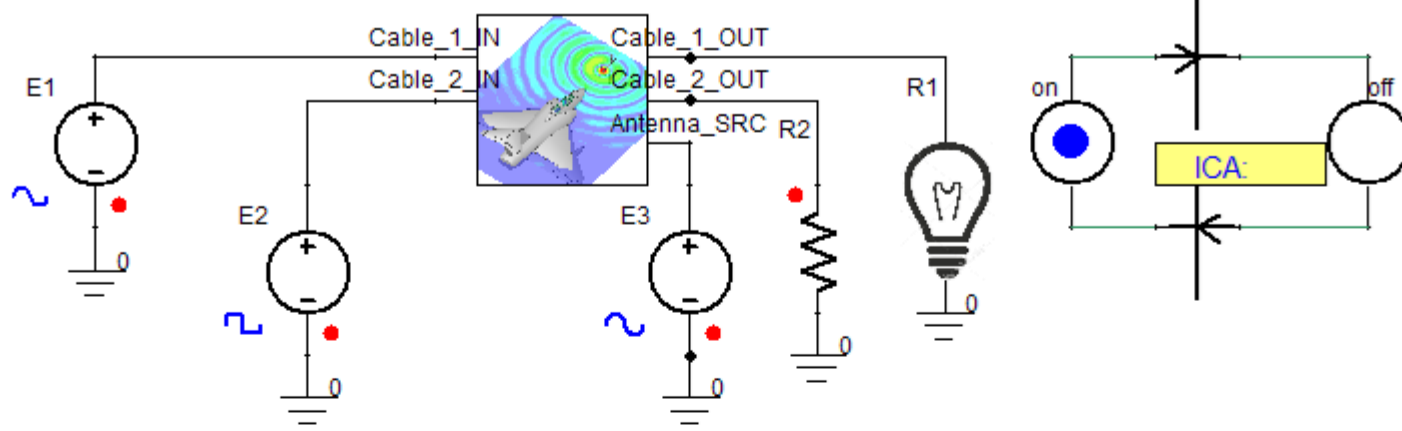
3 – HIRF

An antenna now is added to the model to generate noise



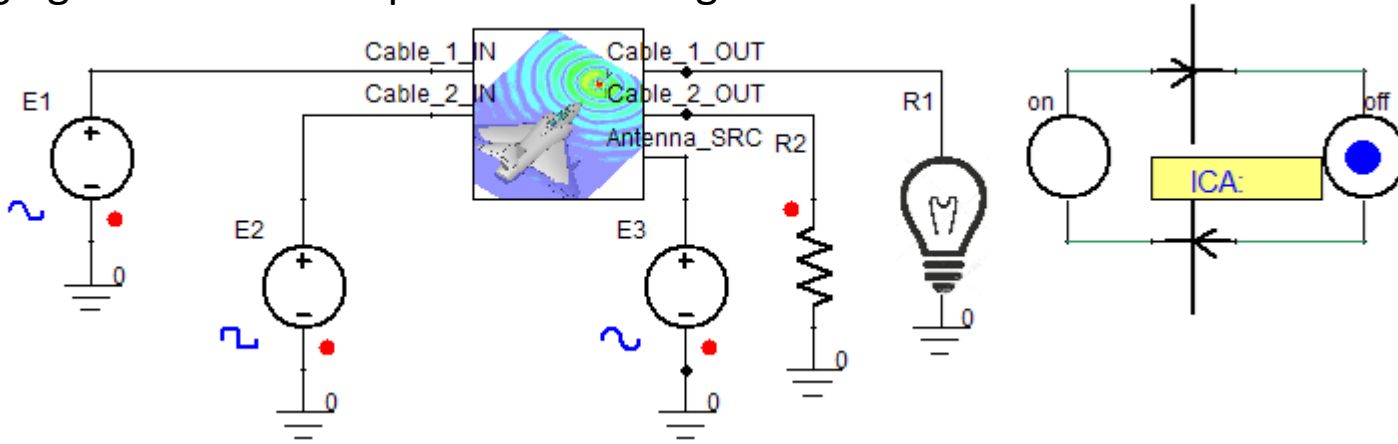
3 – HIRF

The noise generated by the antenna is now coupled to the cables, generating false “ON/OFF” states

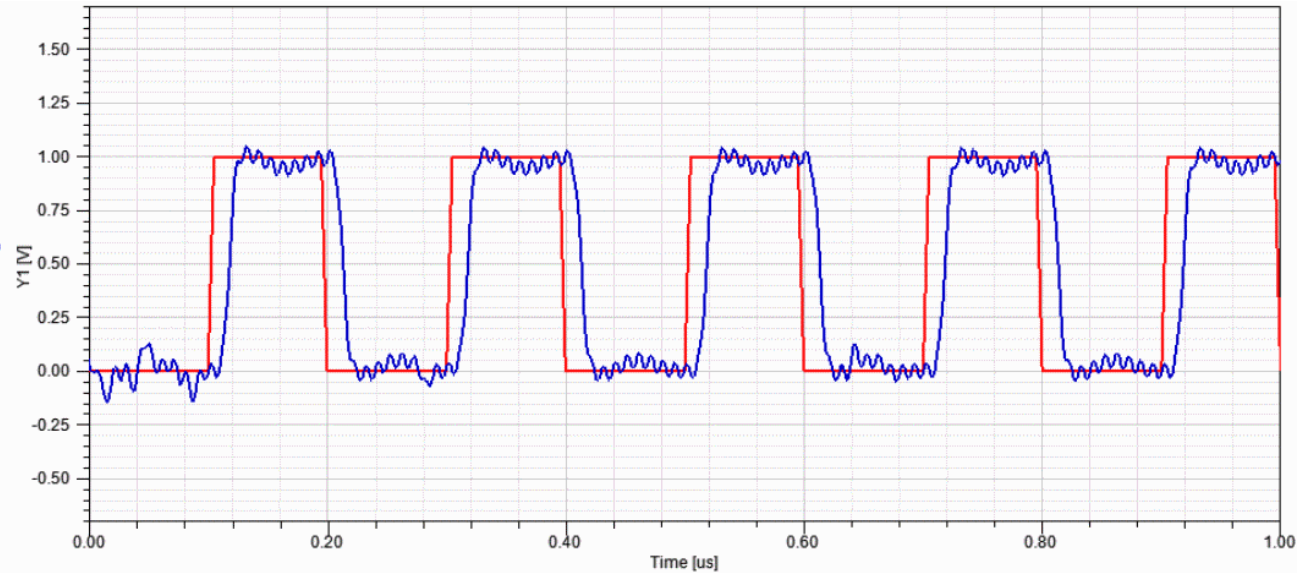
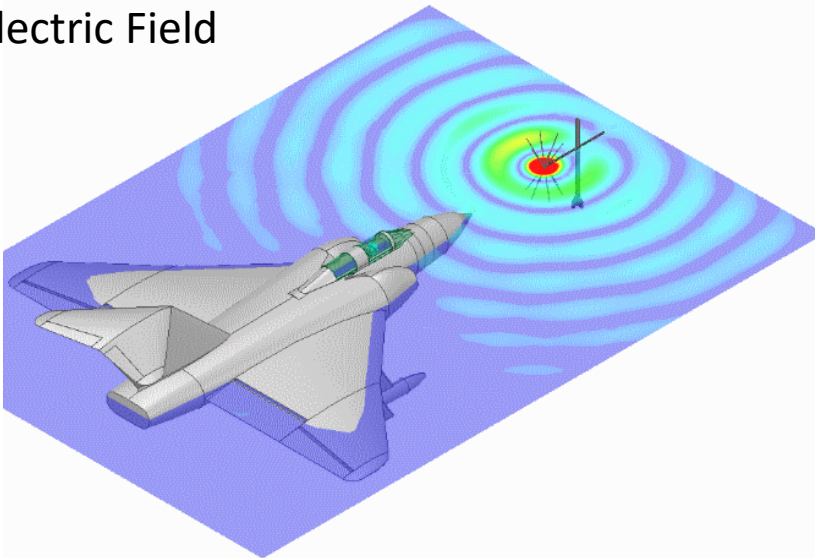


3 – HIRF

Changing the Antenna Tx power will change the electric field and the noise on the signals transmitted on the cables

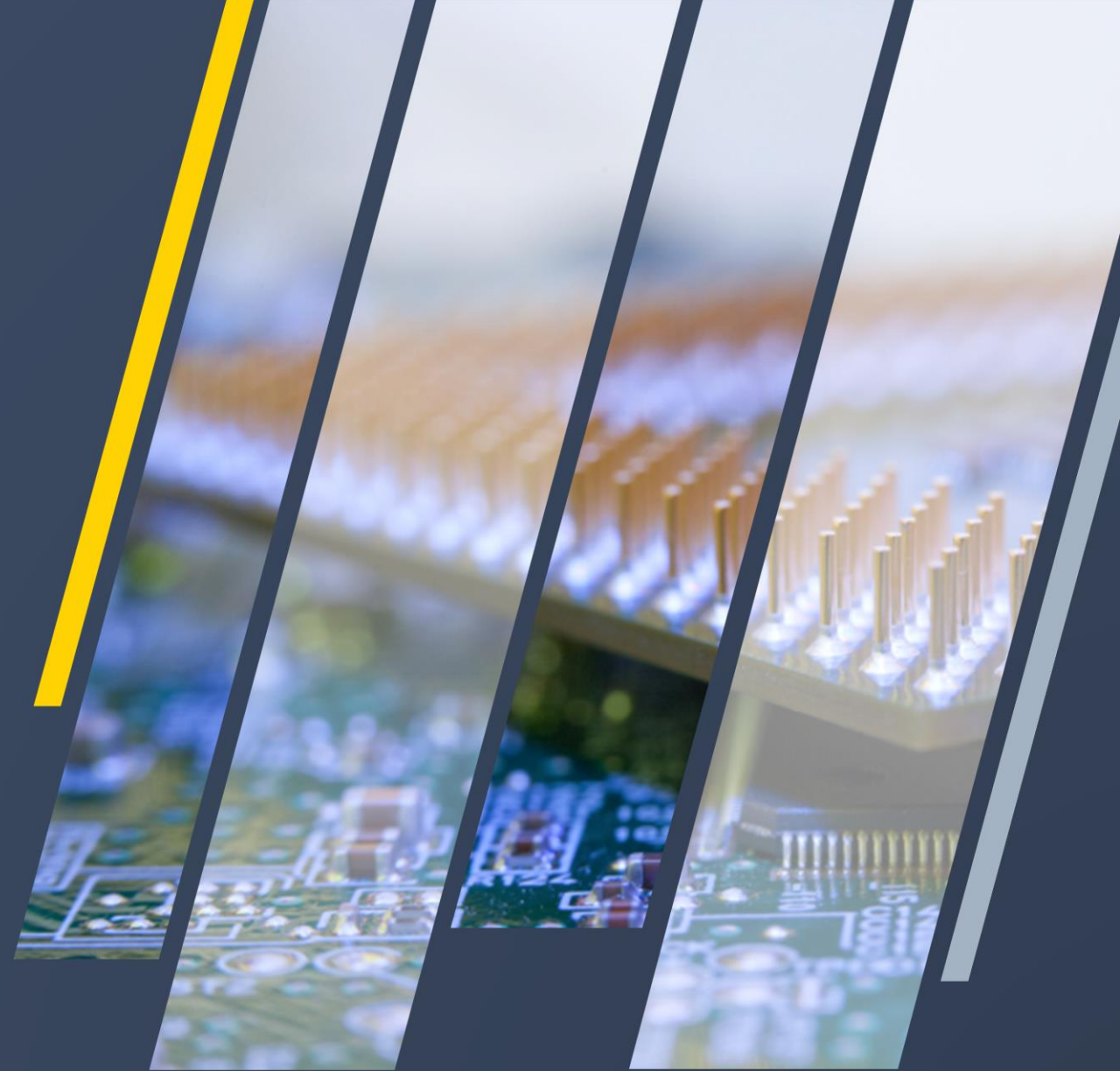


Electric Field





Crosstalk and General EMI

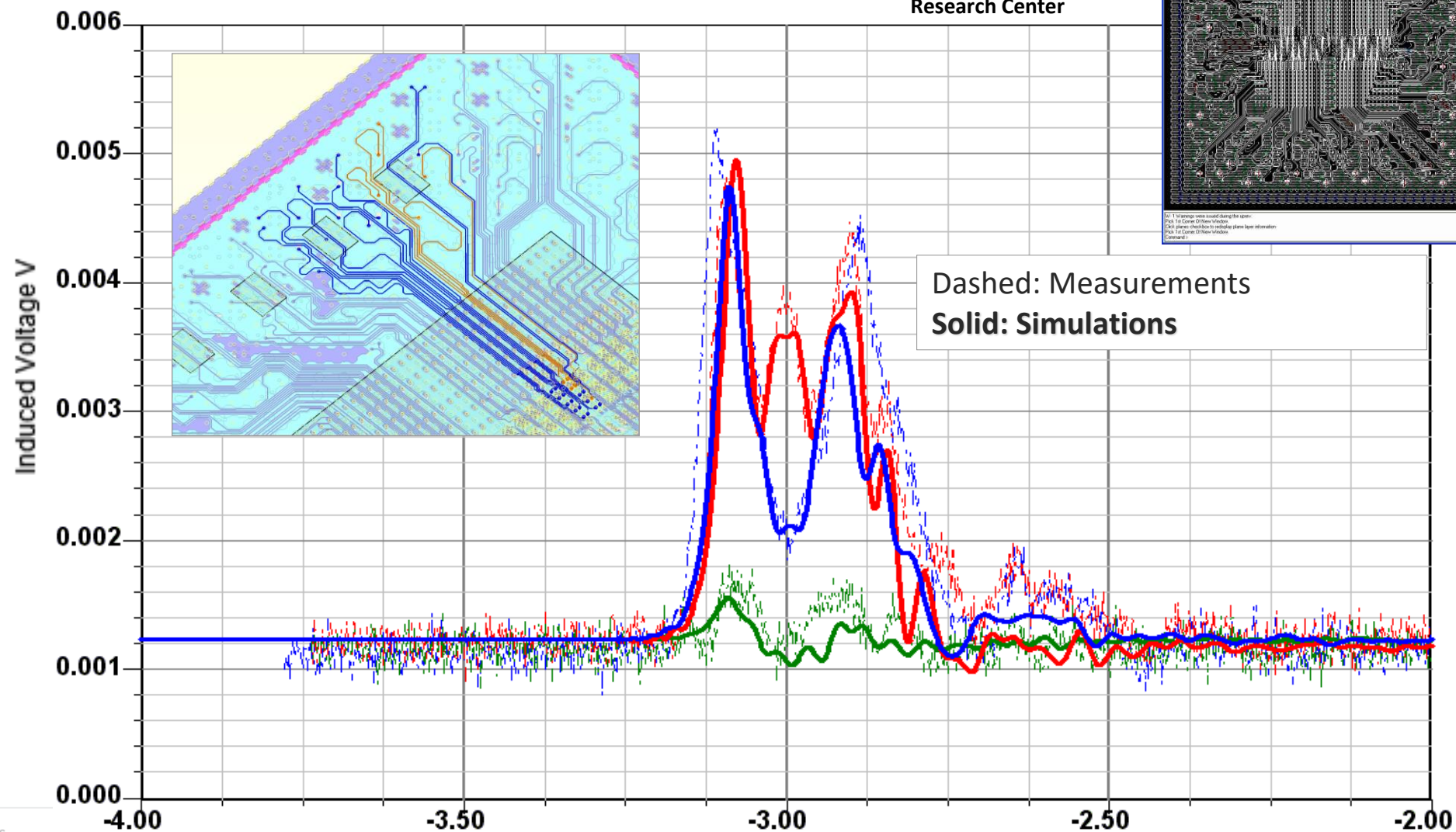
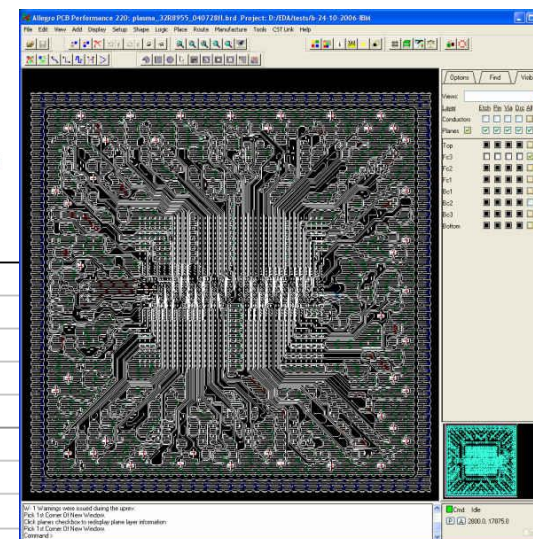


CROSSTALK

- Crosstalk in package



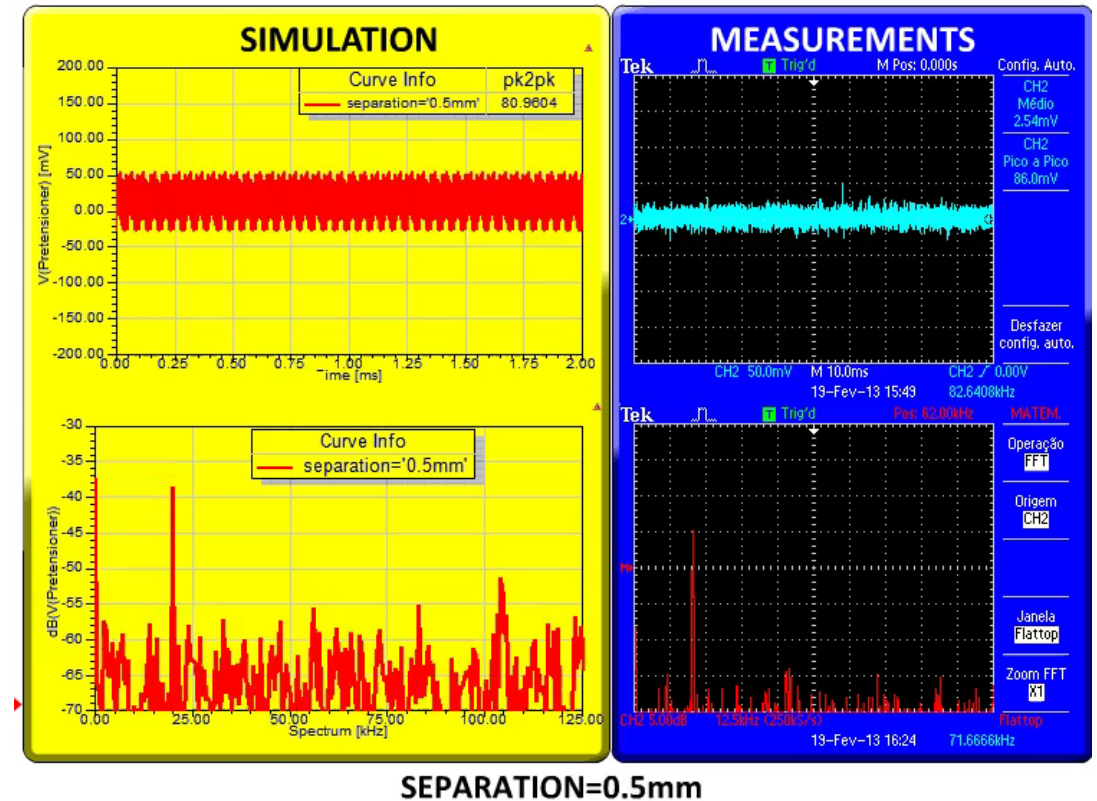
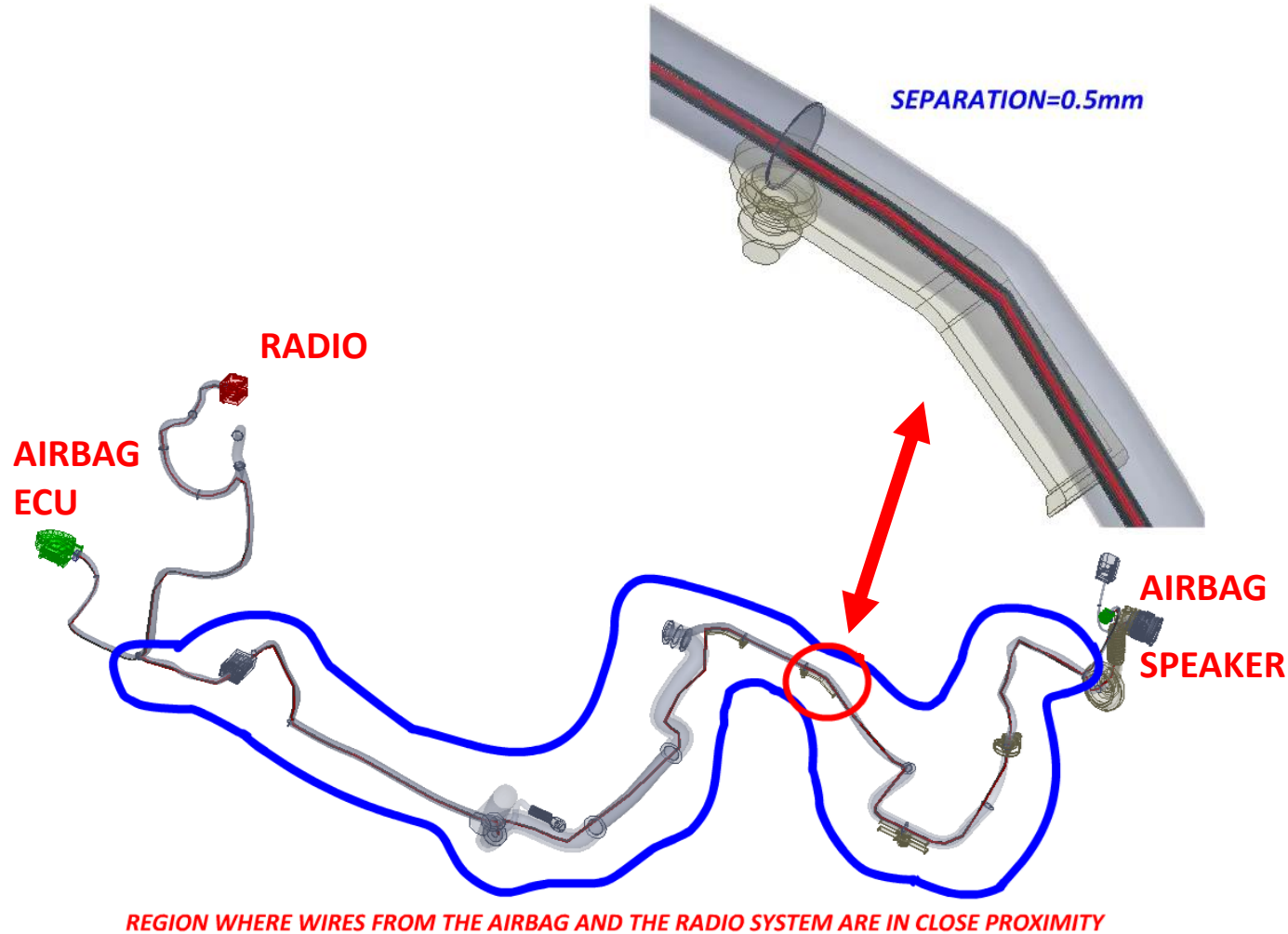
Courtesy of IBM Watson
Research Center



CROSSTALK

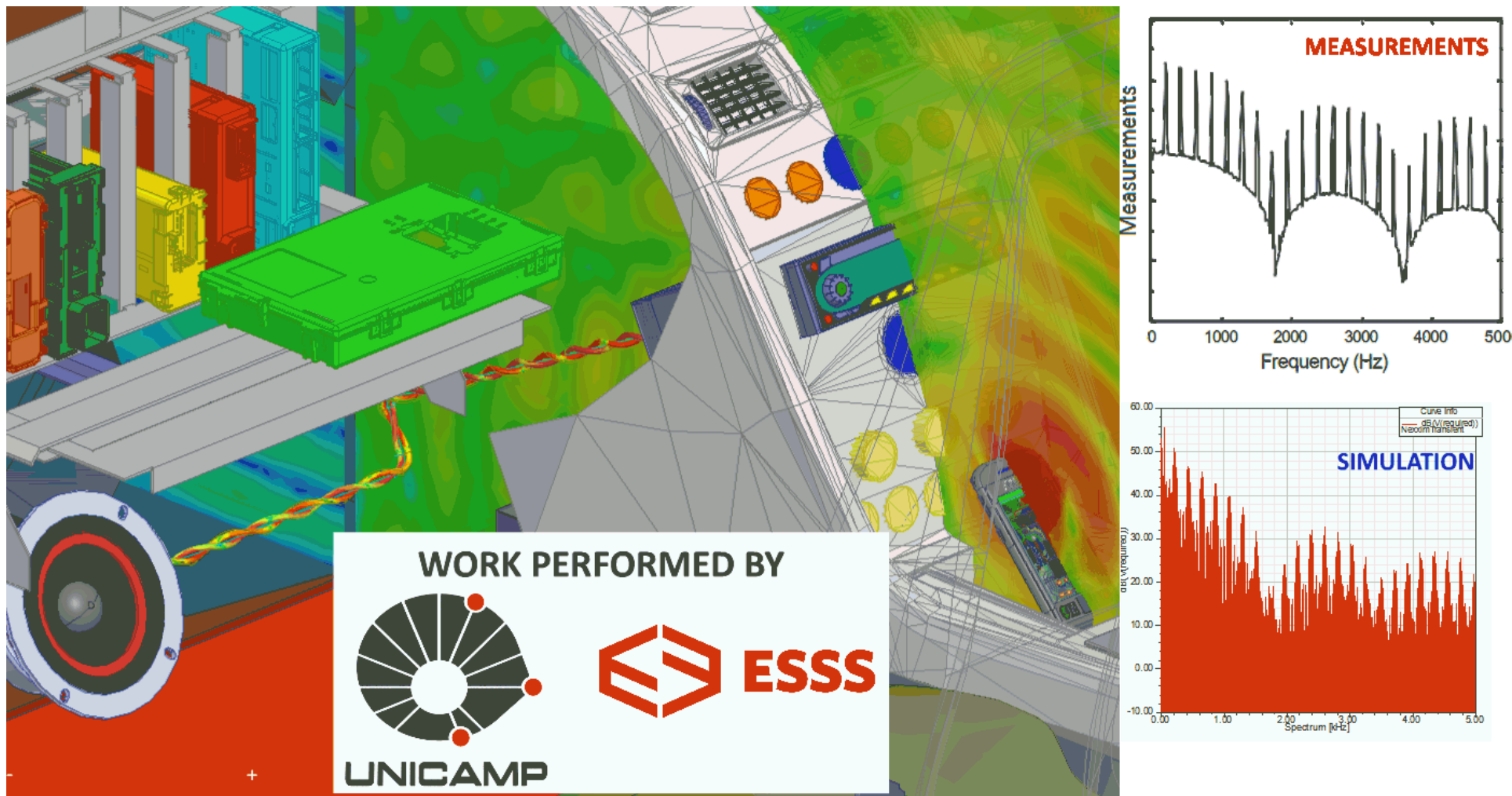
- Interference from automotive radio into airbag system

Courtesy
FCA



CROSSTALK

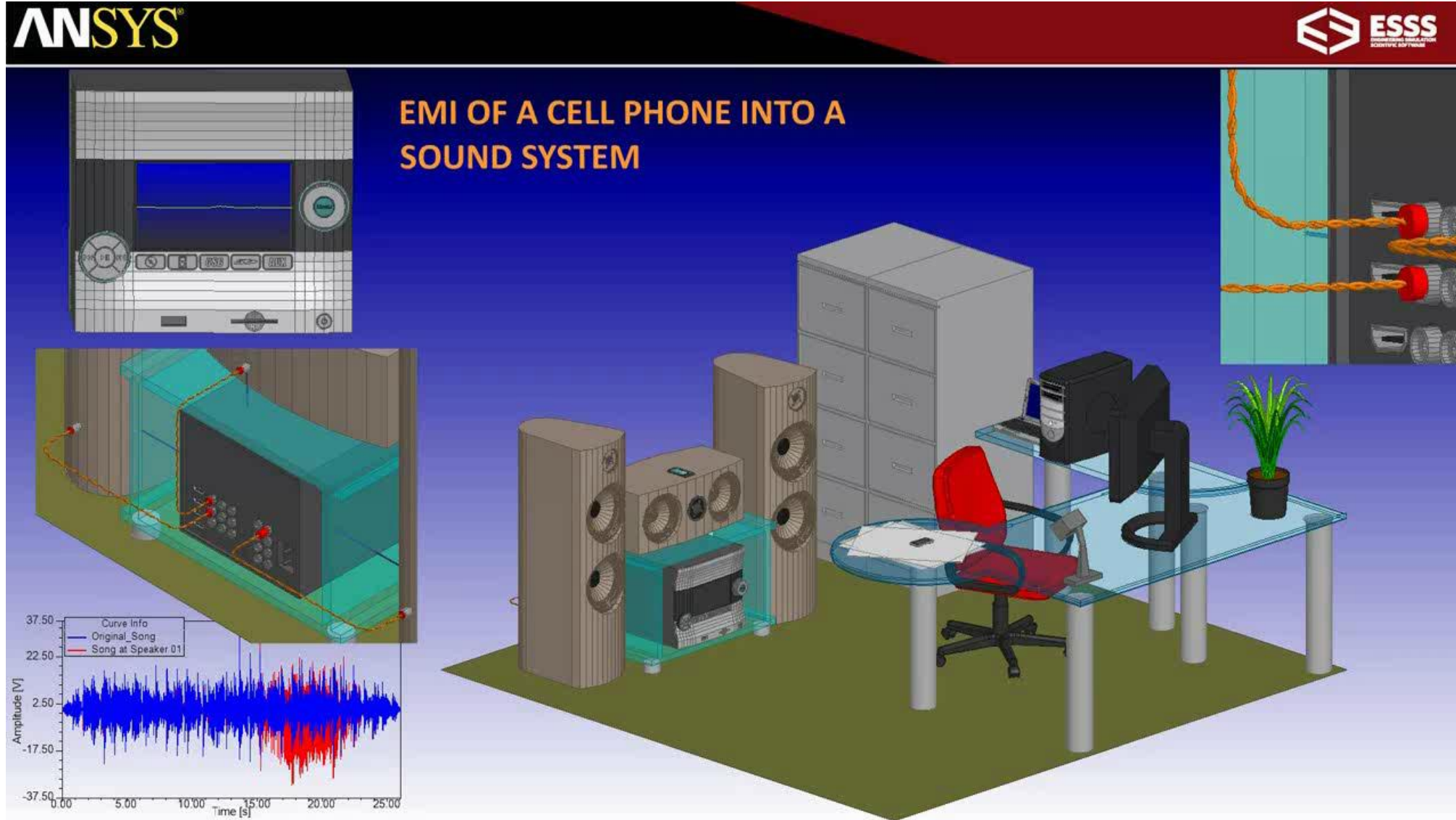
- GSM Noise



SAE: Mologni, J., et al., "Investigating GSM Interference in Automotive Sound Systems Using State of the Art Electromagnetic Simulation," *SAE Technical Paper Series*, 2013-36-0198, 2013. doi: 10.4271/2013-36-0198

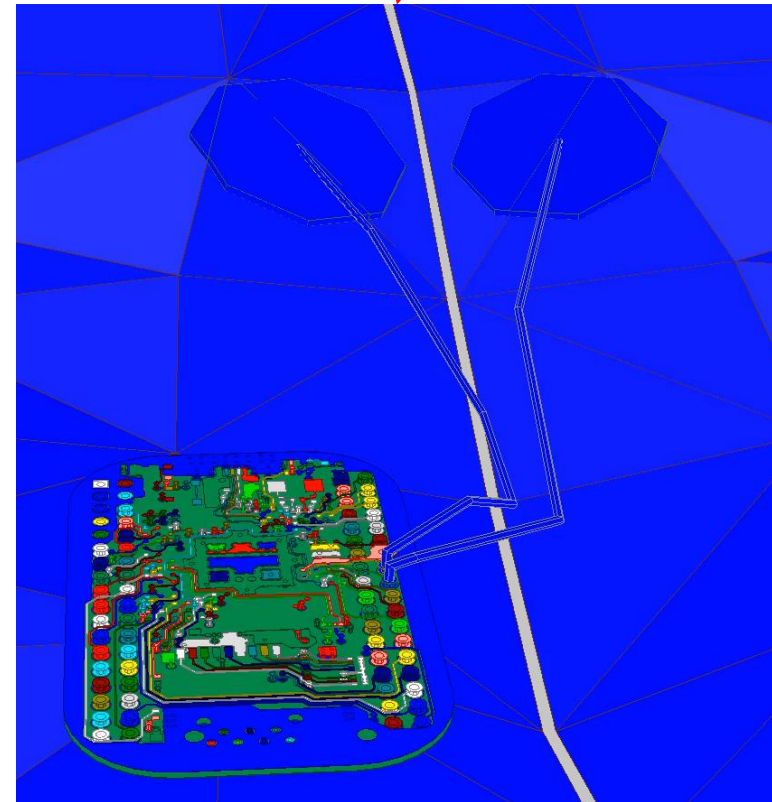
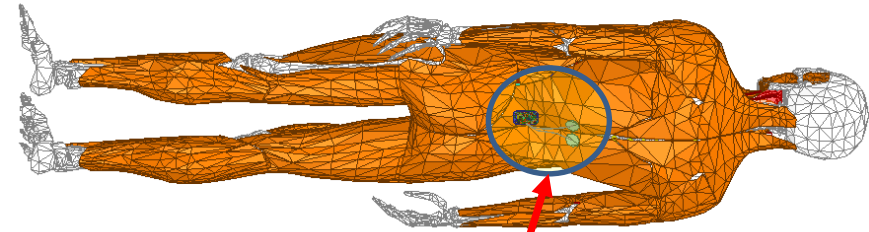
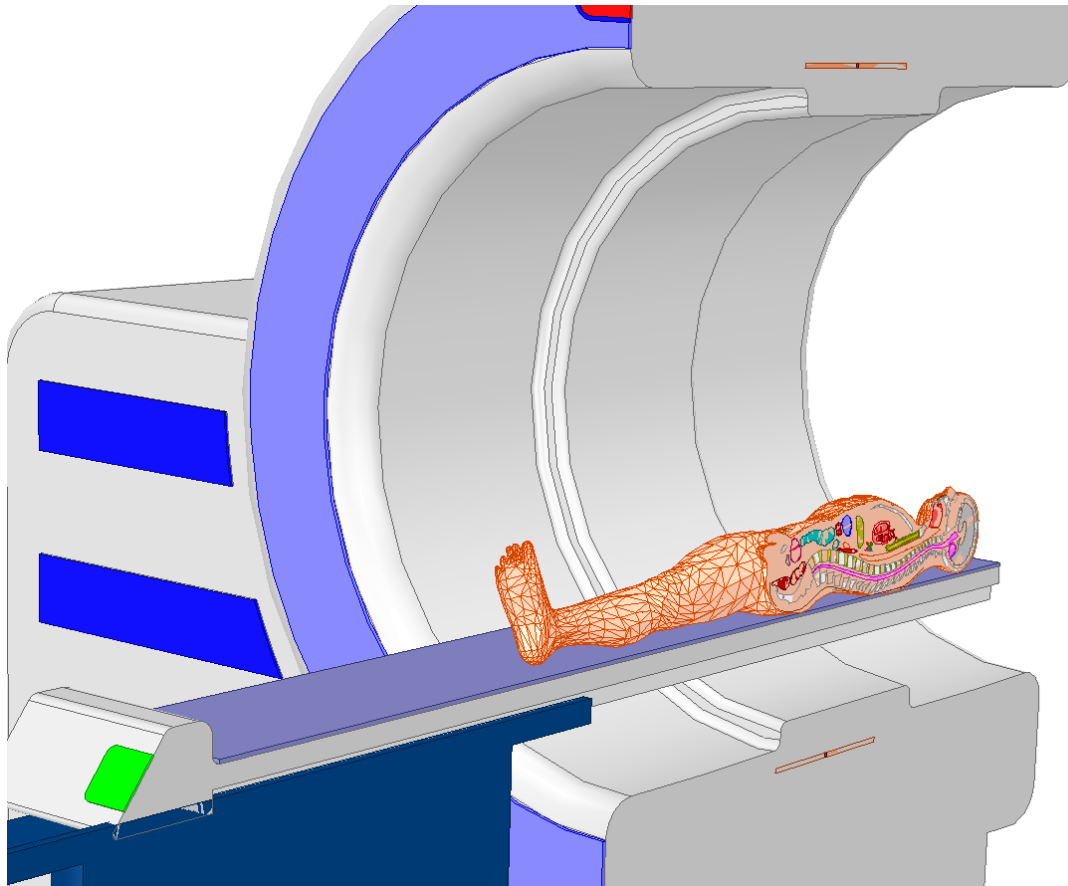
CROSSTALK

- GSM Noise



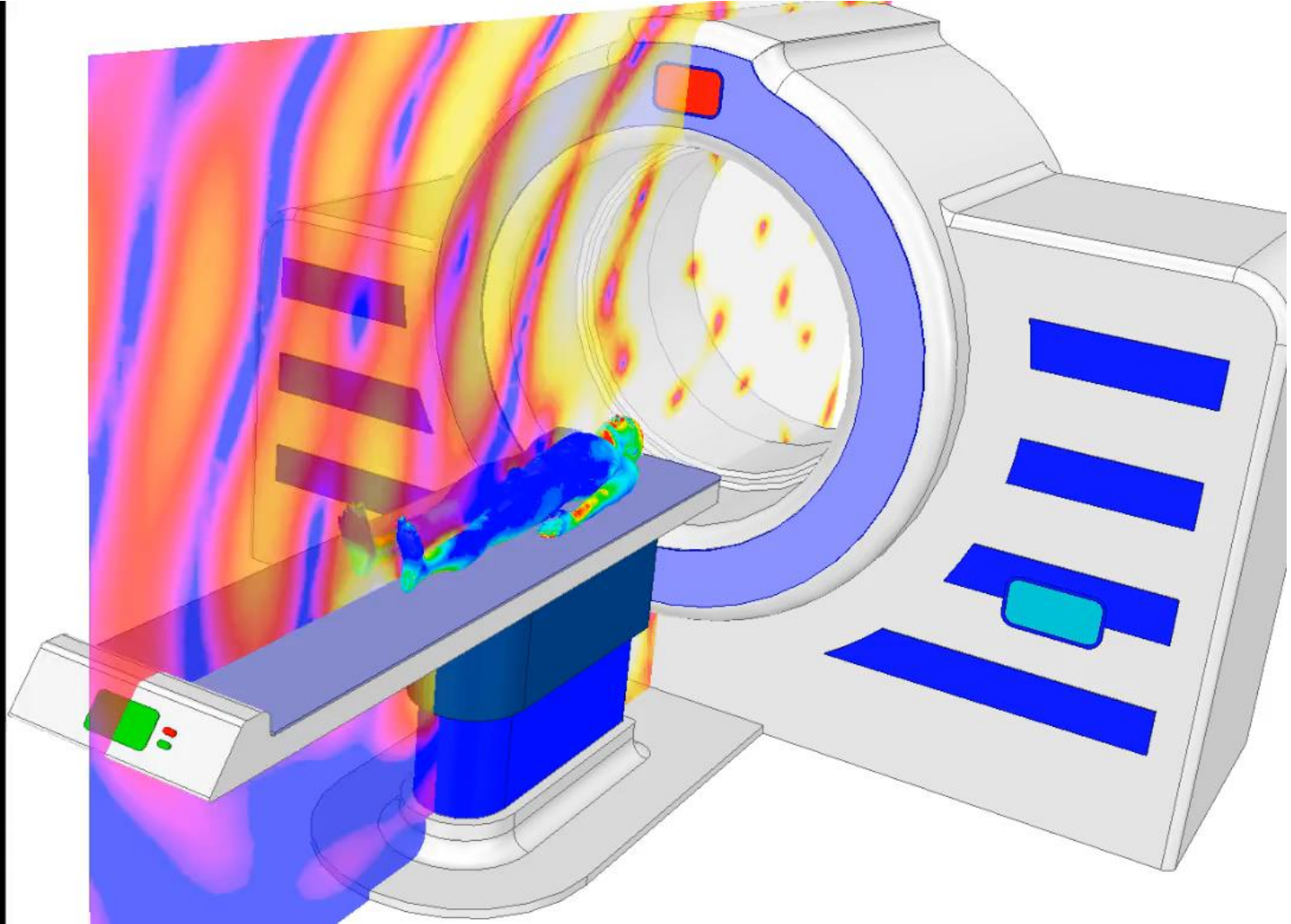
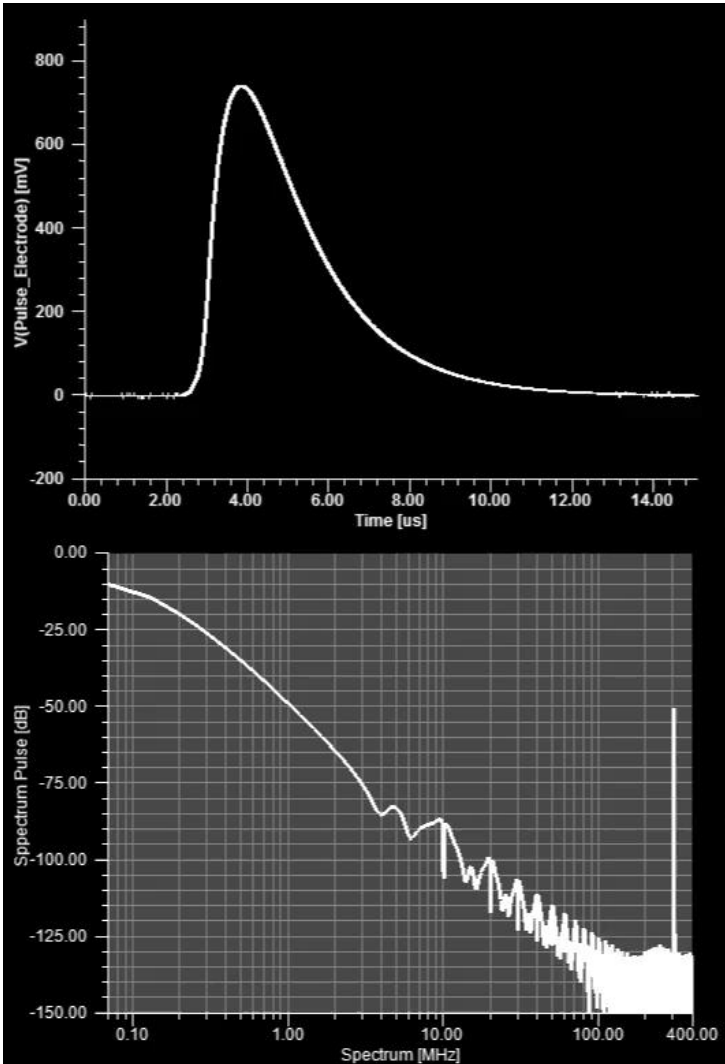
EMI on Pulse Generator

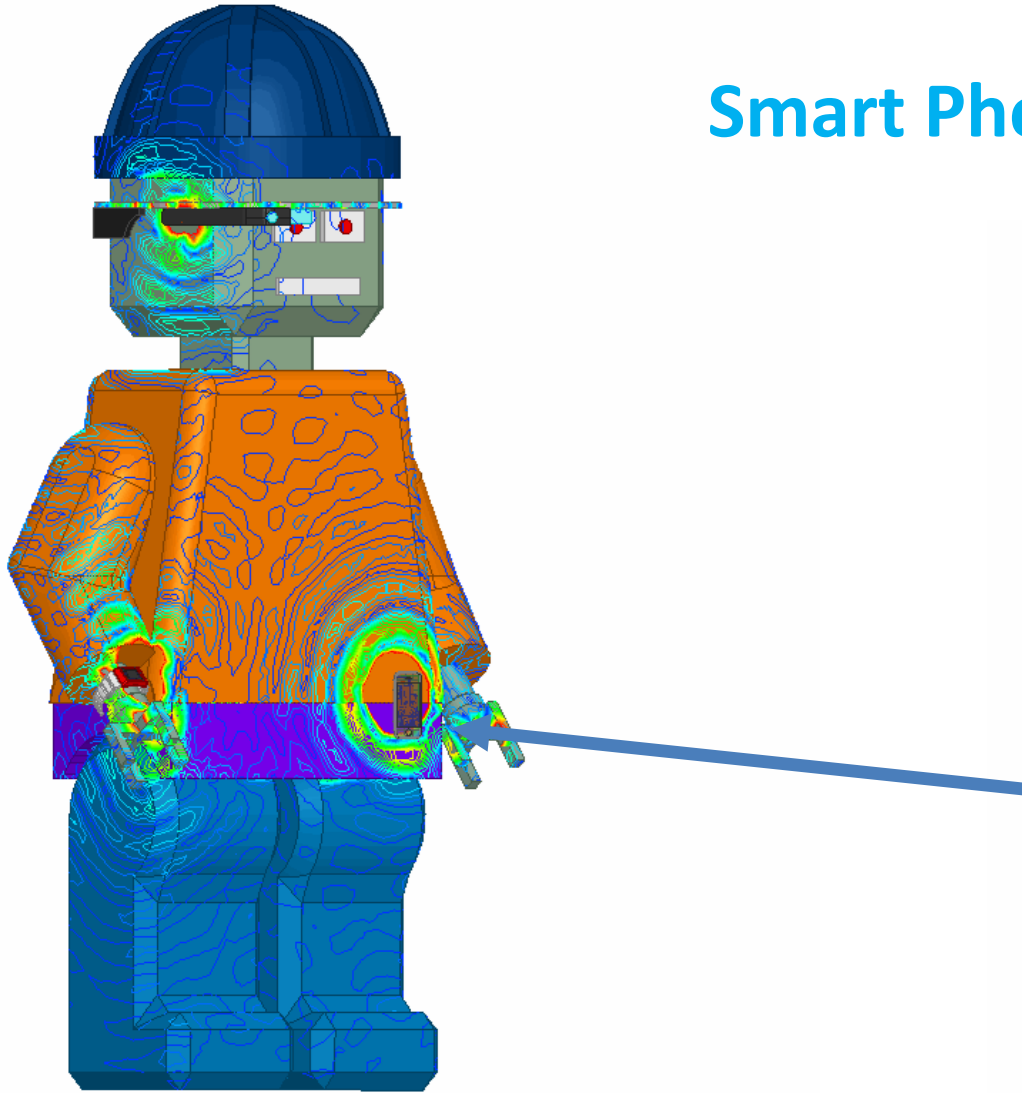
Investigation of MRI @300MHz interference on implanted pulse generator device.



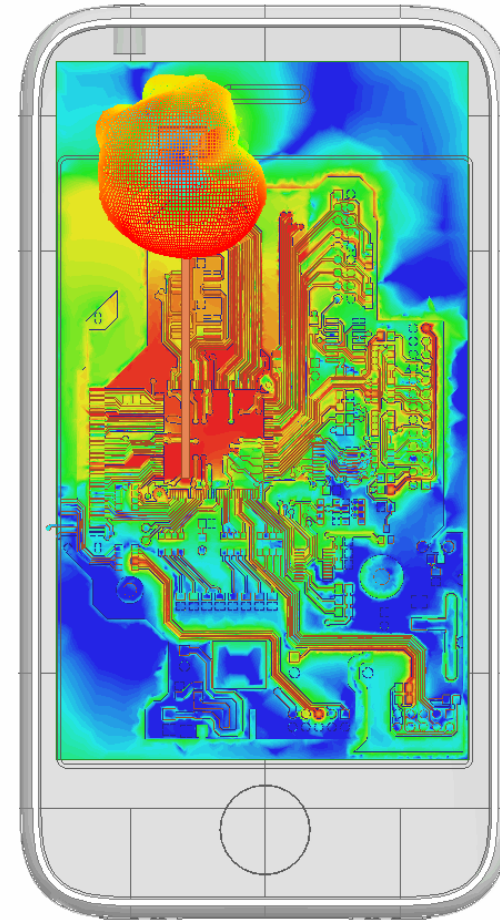
EMI on Pulse Generator

Noise is only induced on the device when the body is completely inserted in the MRI

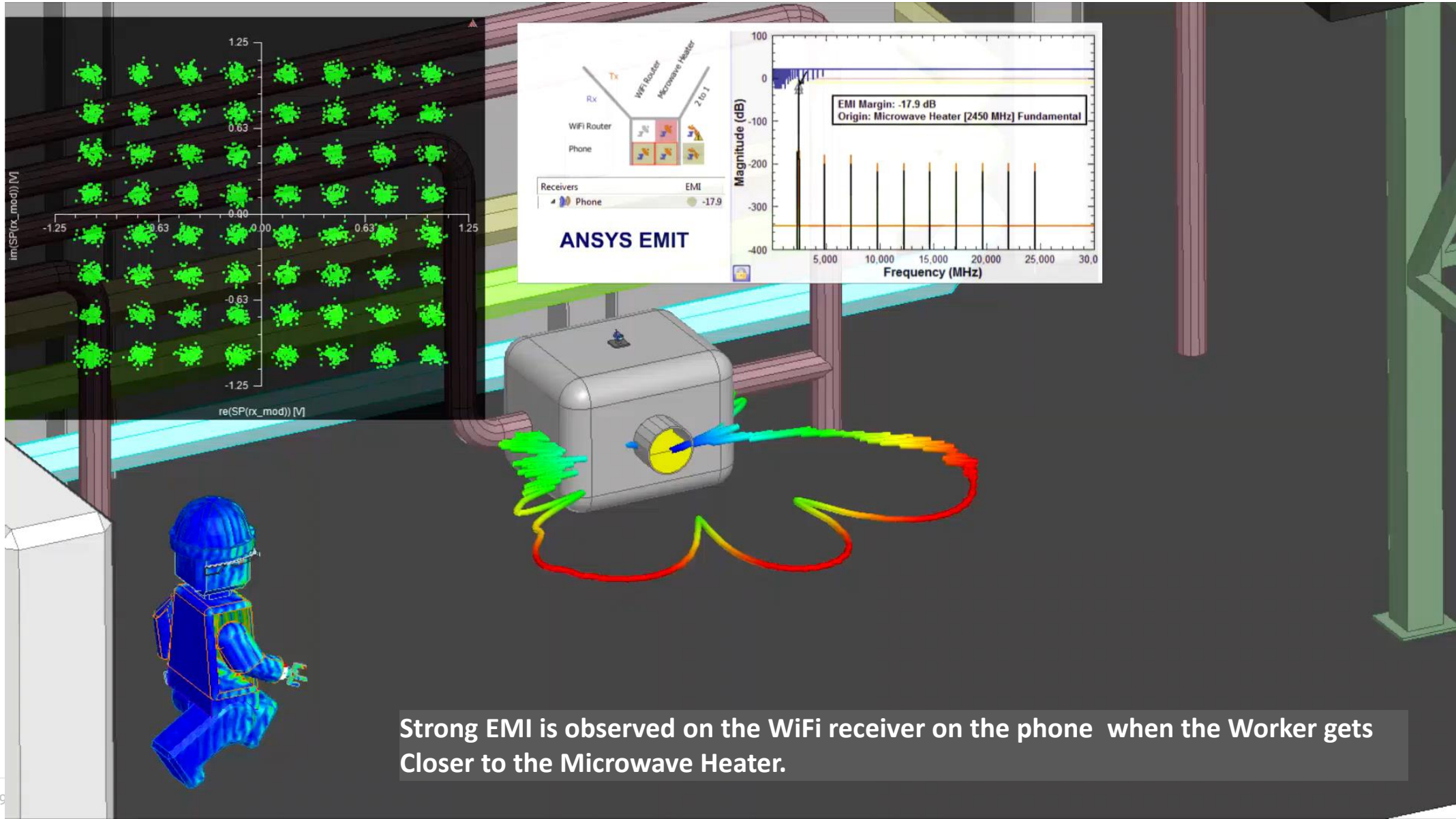




Smart Phone with WiFi



EMI from Microwave Heater

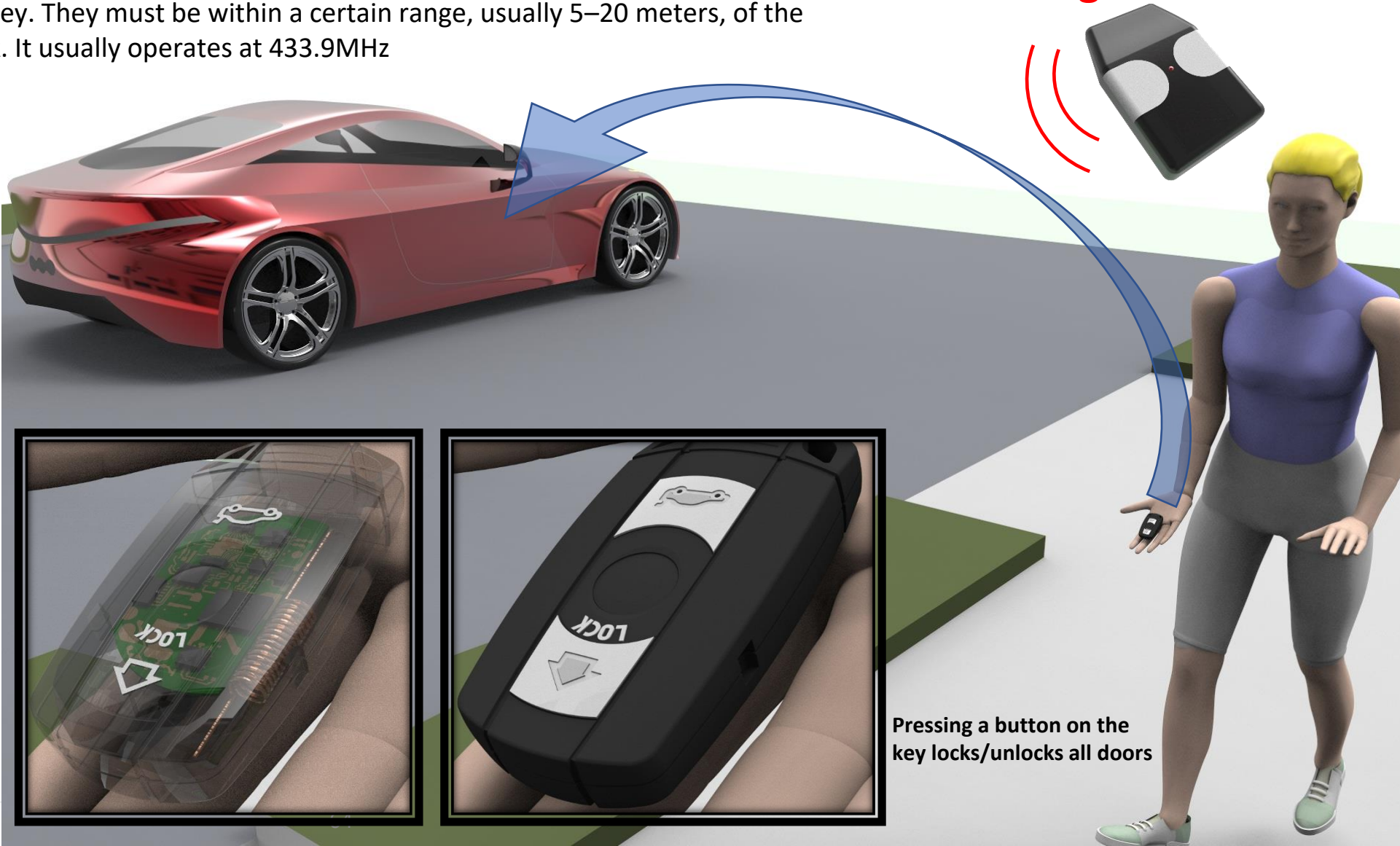


GENERAL EMI - RKE

RKE EMI

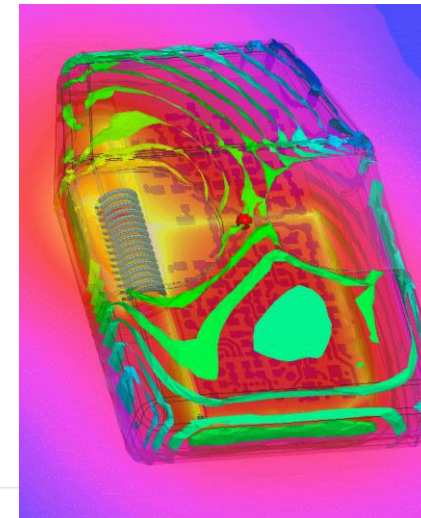
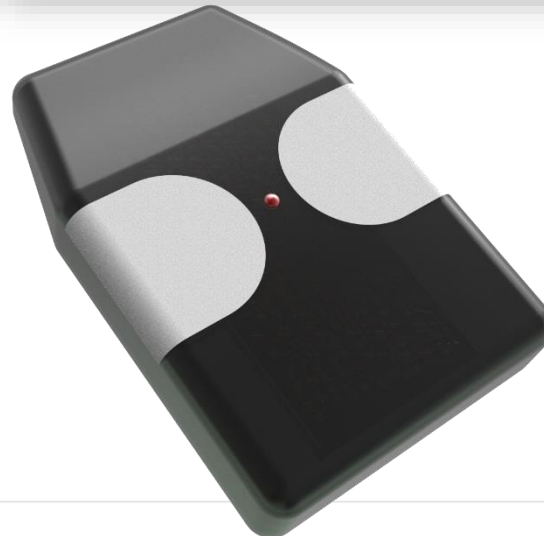
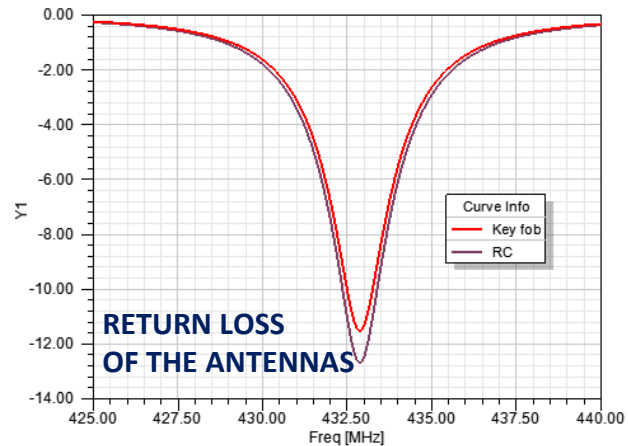
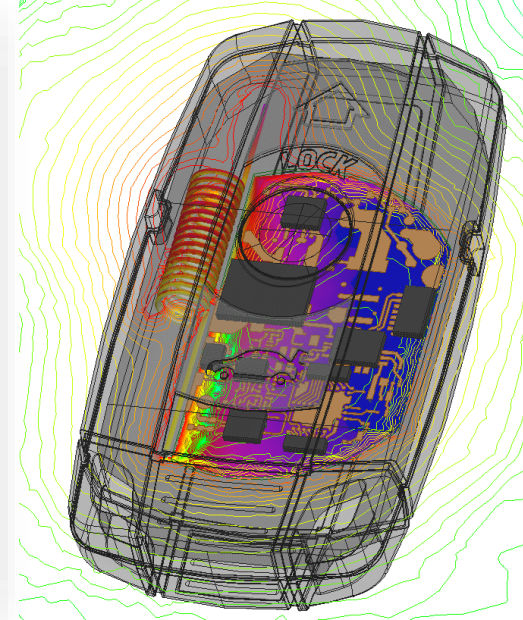
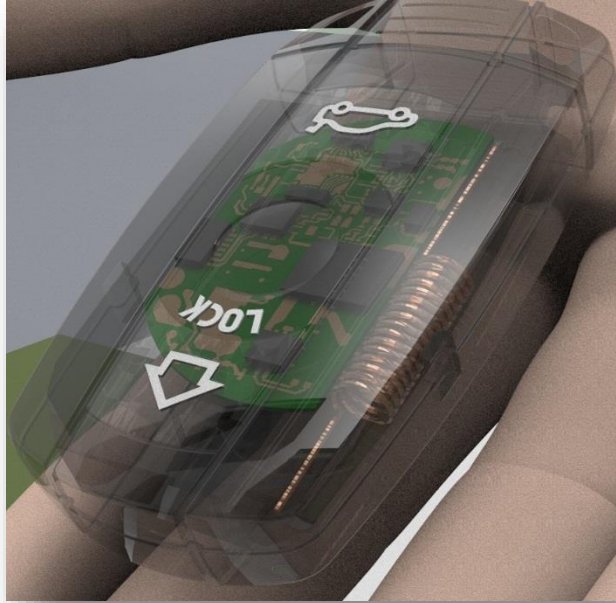
A keyless entry system is an electronic lock that controls access to a vehicle without a key. They must be within a certain range, usually 5–20 meters, of the car to work. It usually operates at 433.9MHz

RF Signal Jammer:



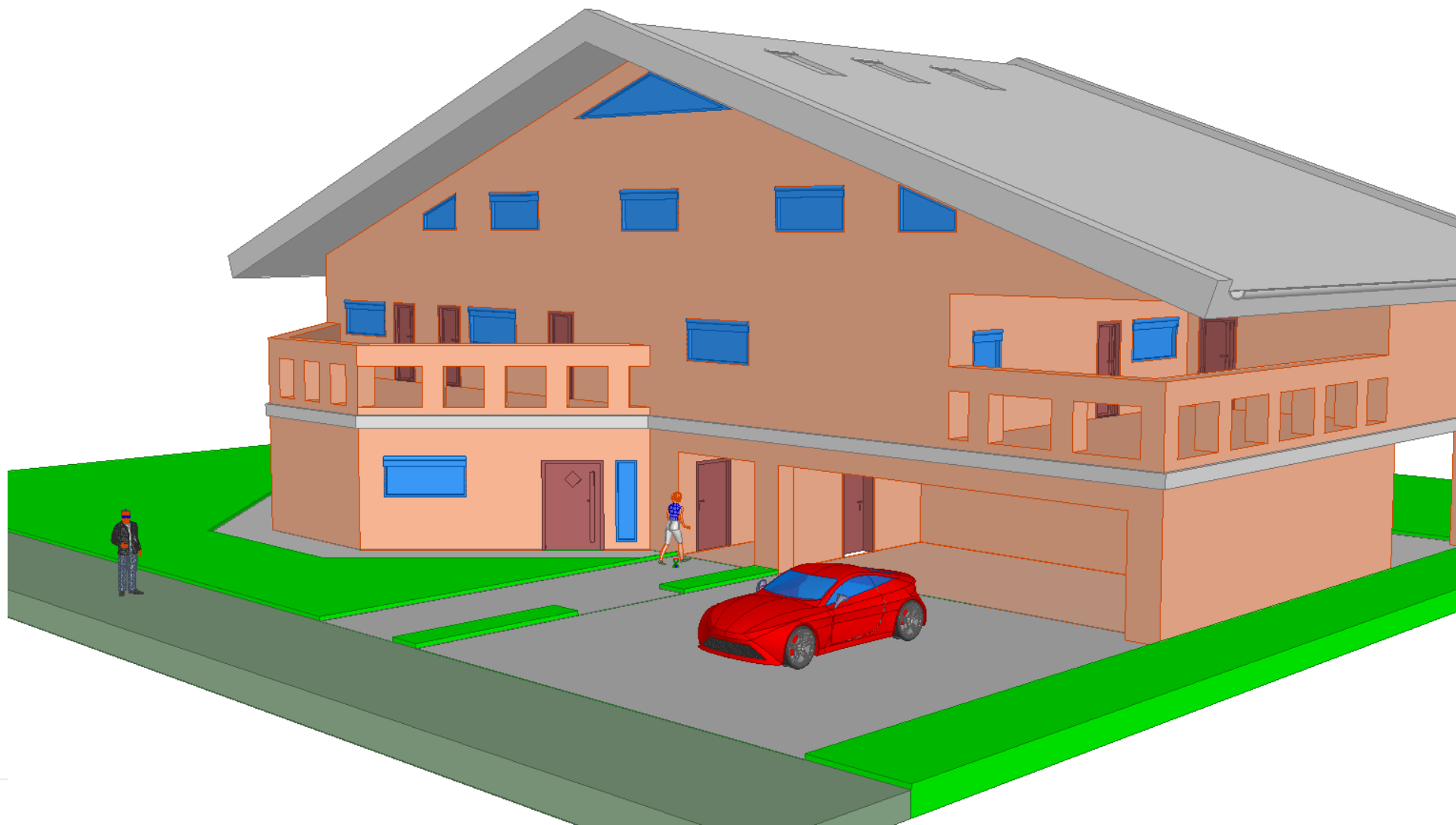
GENERAL EMI - RKE

In order to reproduce this EMI scenario, a RKE controller was designed in HFSS using a 433MHz coil antenna and a common gate opener RC was also designed in HFSS using a 433MHz coil antenna.

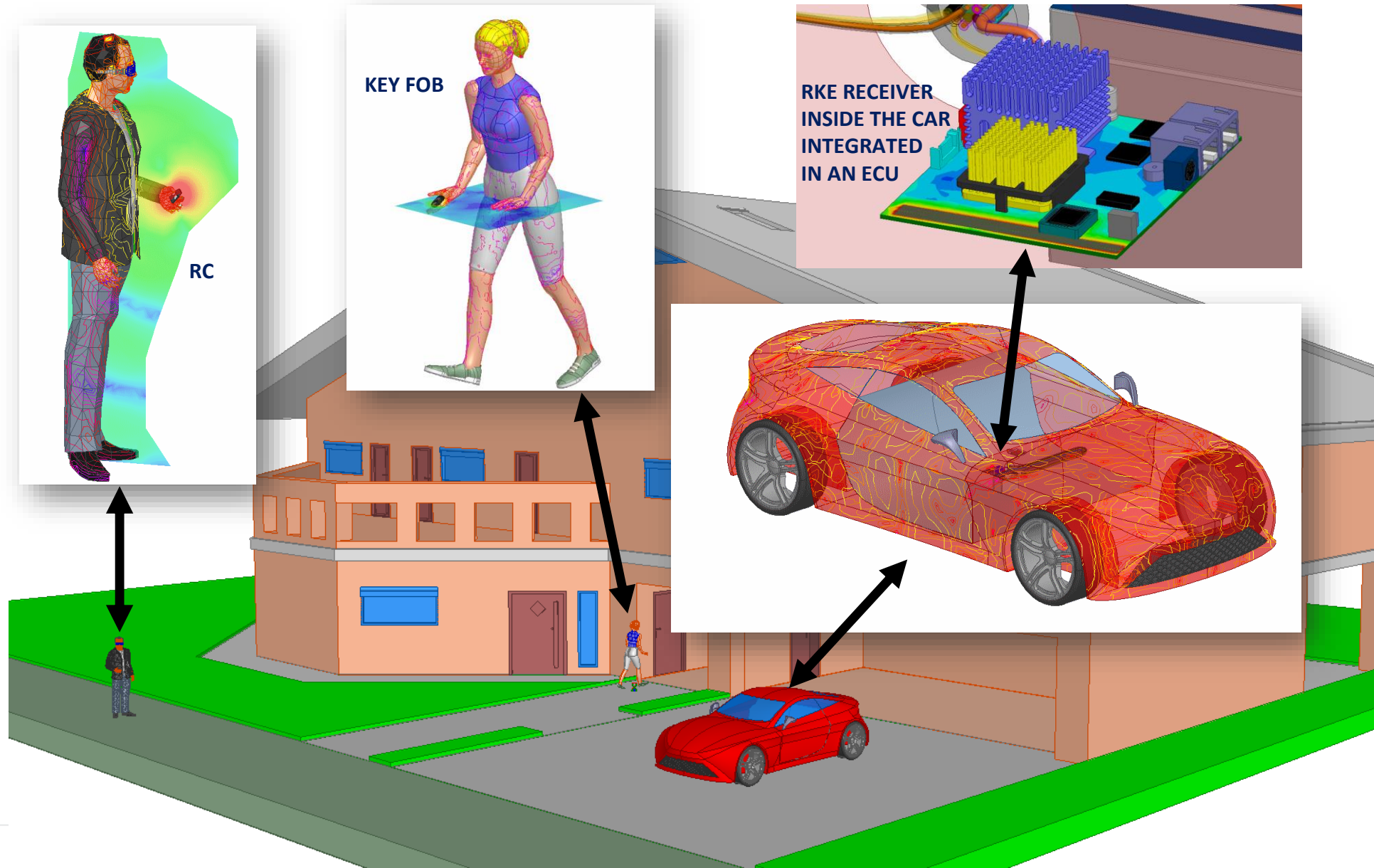


GENERAL EMI - RKE

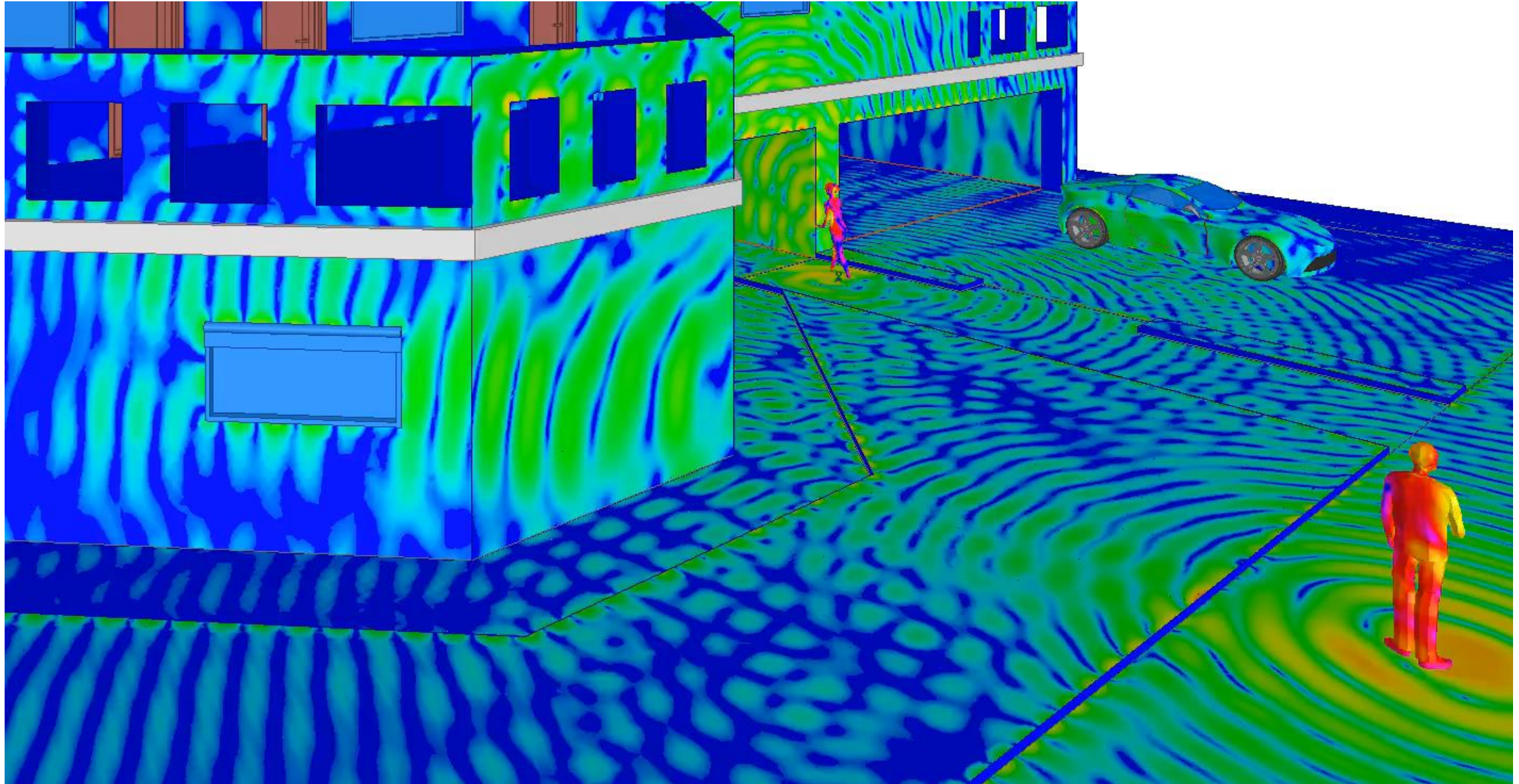
ANSYS HFSS Hybrid Solutions were used to solve a very large design. In this case the RKE system is activated by a woman to lock the red car, and the man on the side walk is activating a RC to interfere in the RKE communication



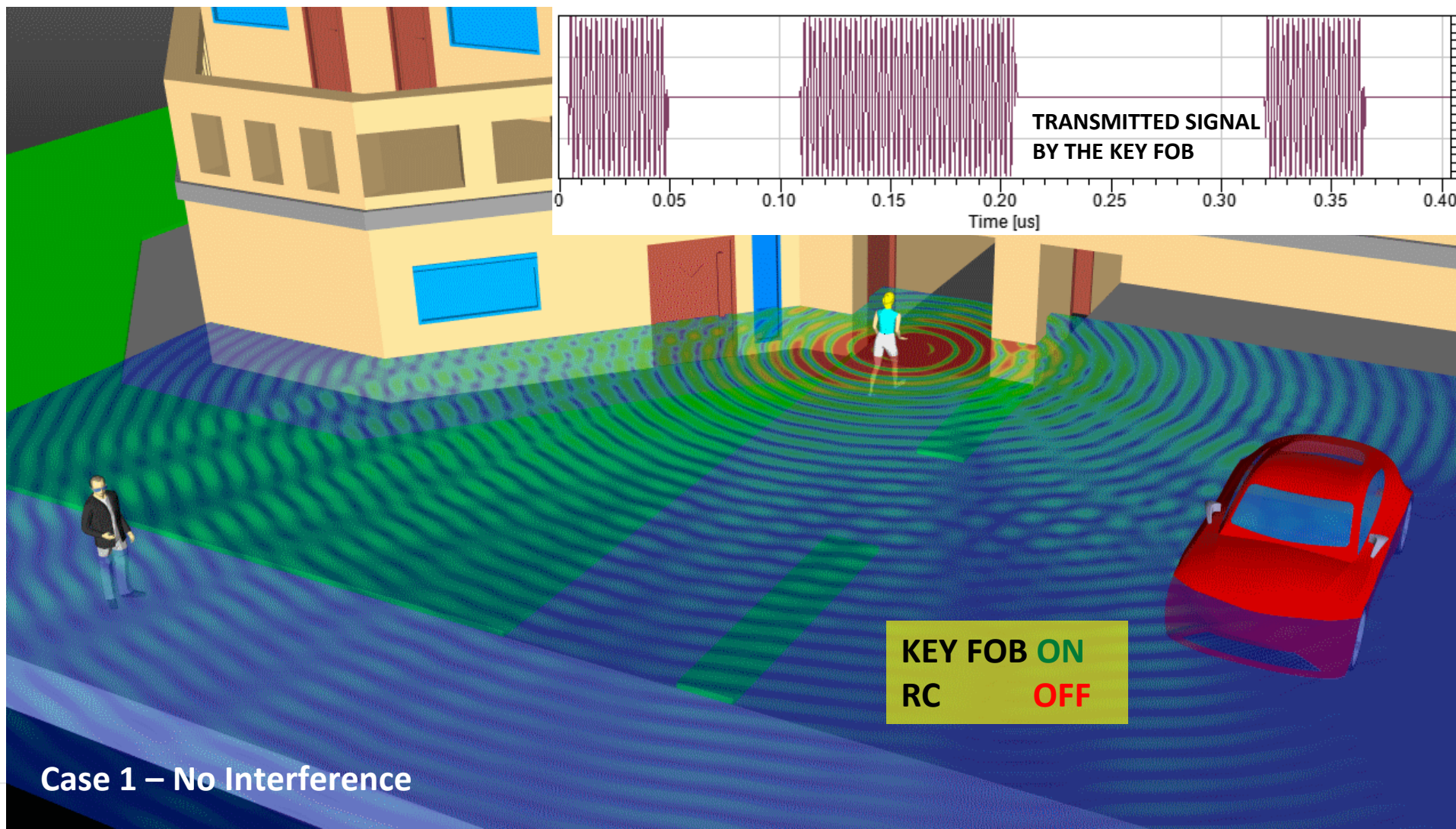
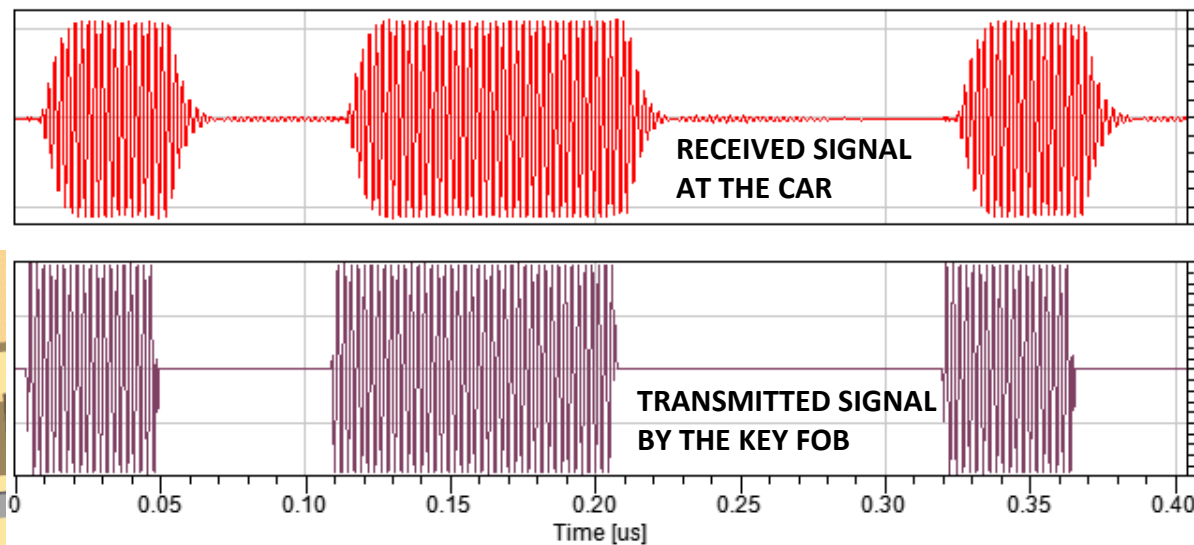
GENERAL EMI - RKE



GENERAL EMI - RKE



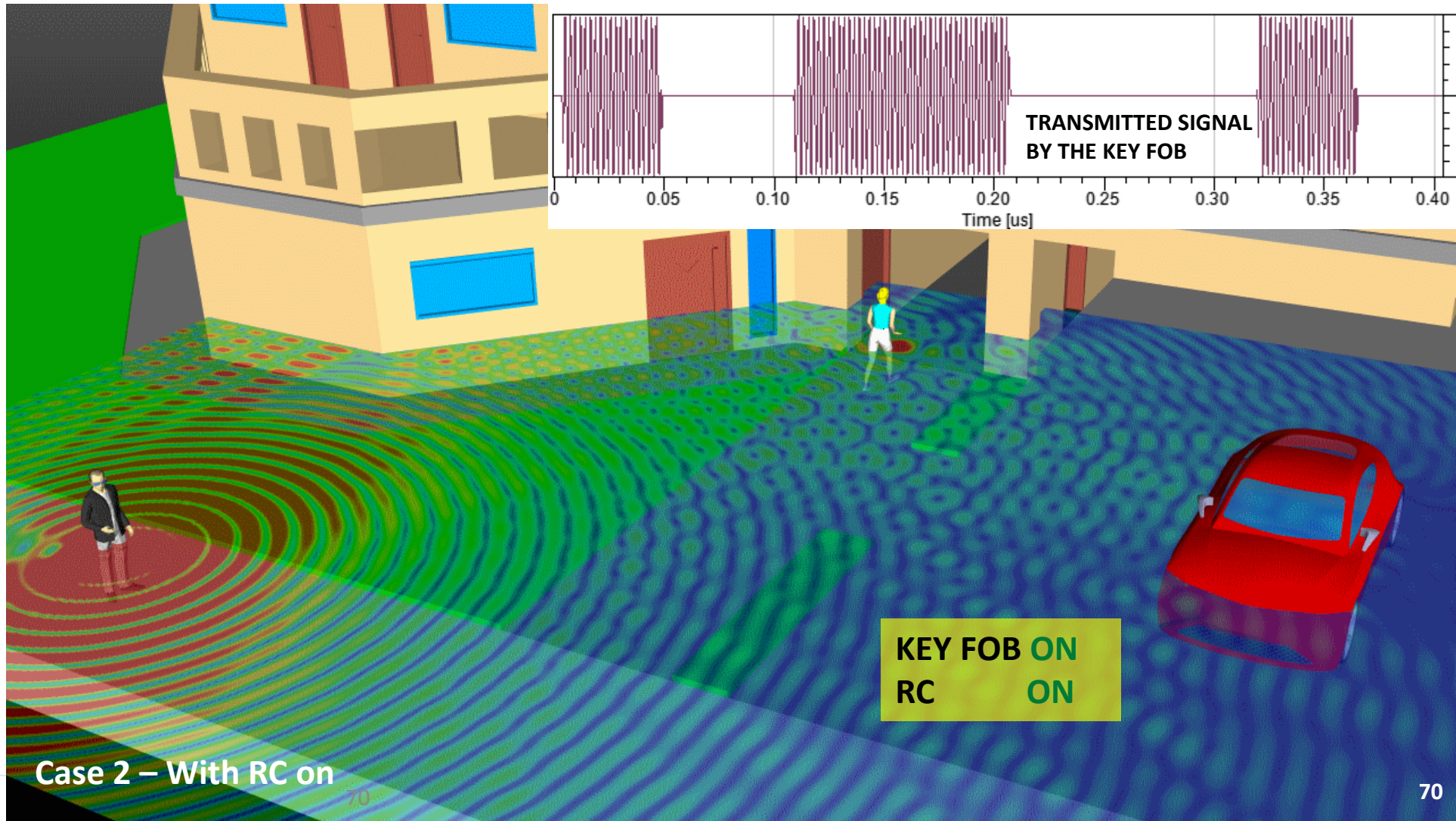
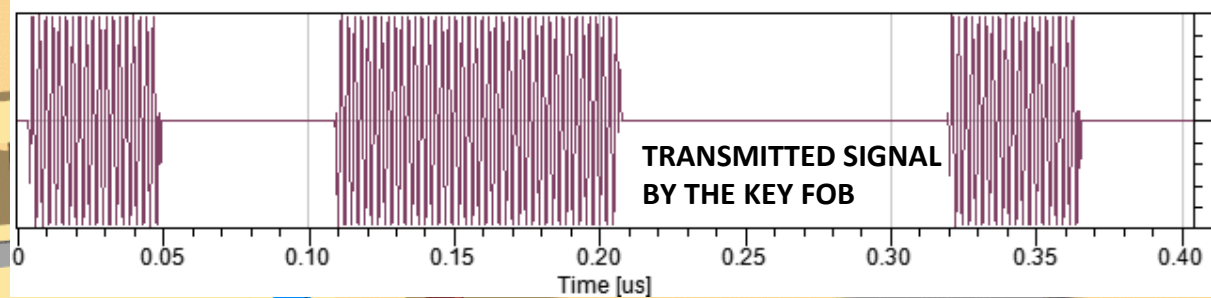
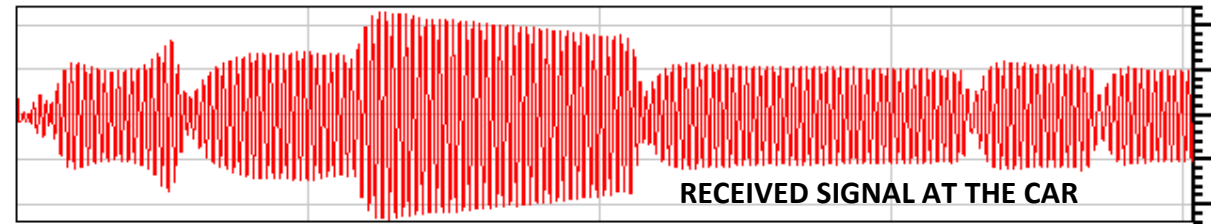
GENERAL EMI - RKE



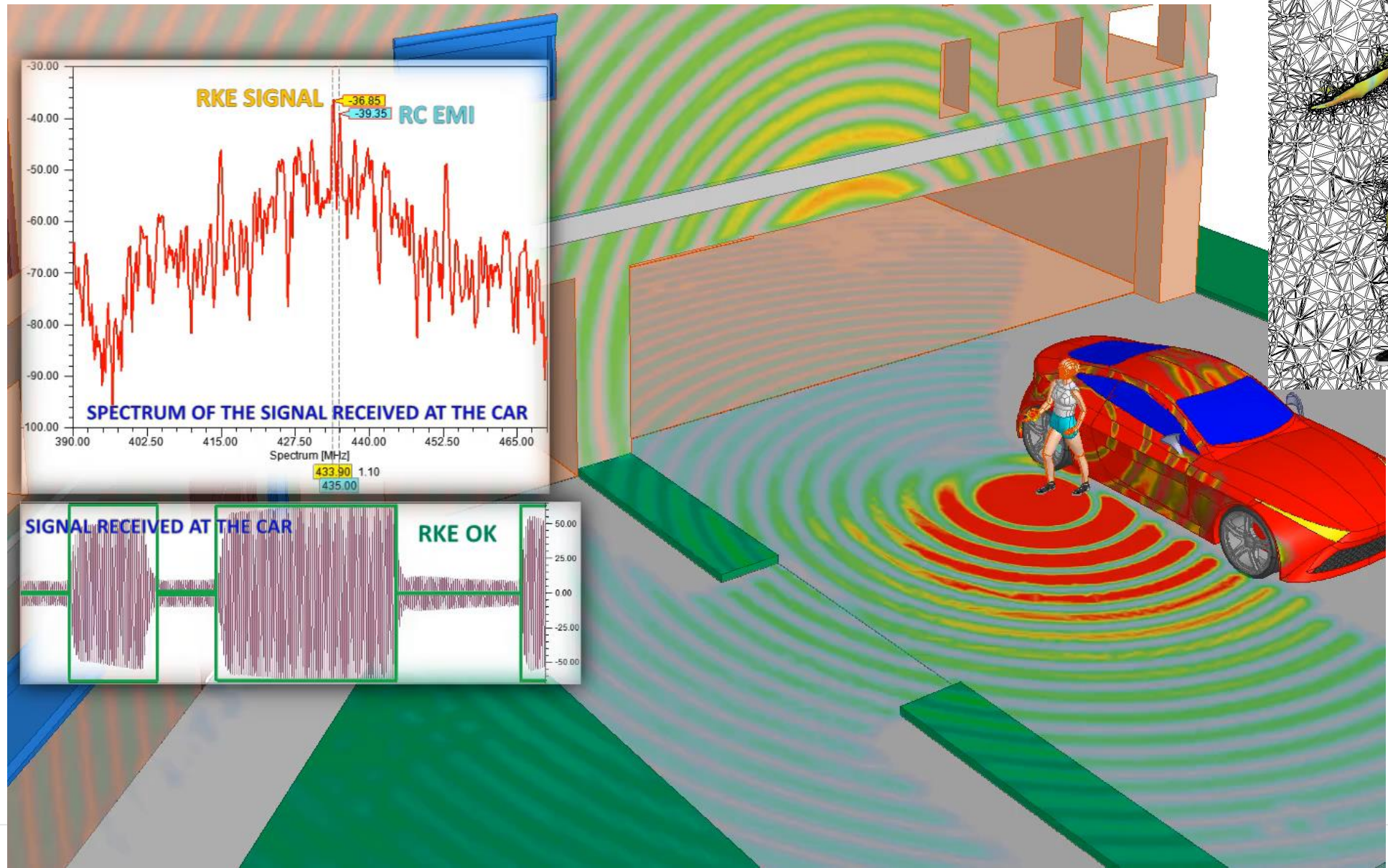
Case 1 – No Interference

GENERAL EMI - RKE

When the RC is turned on a significant interference is observed in the received signal. In this case key fob buttons can be pressed but the doors won't lock.



GENERAL EMI - RKE



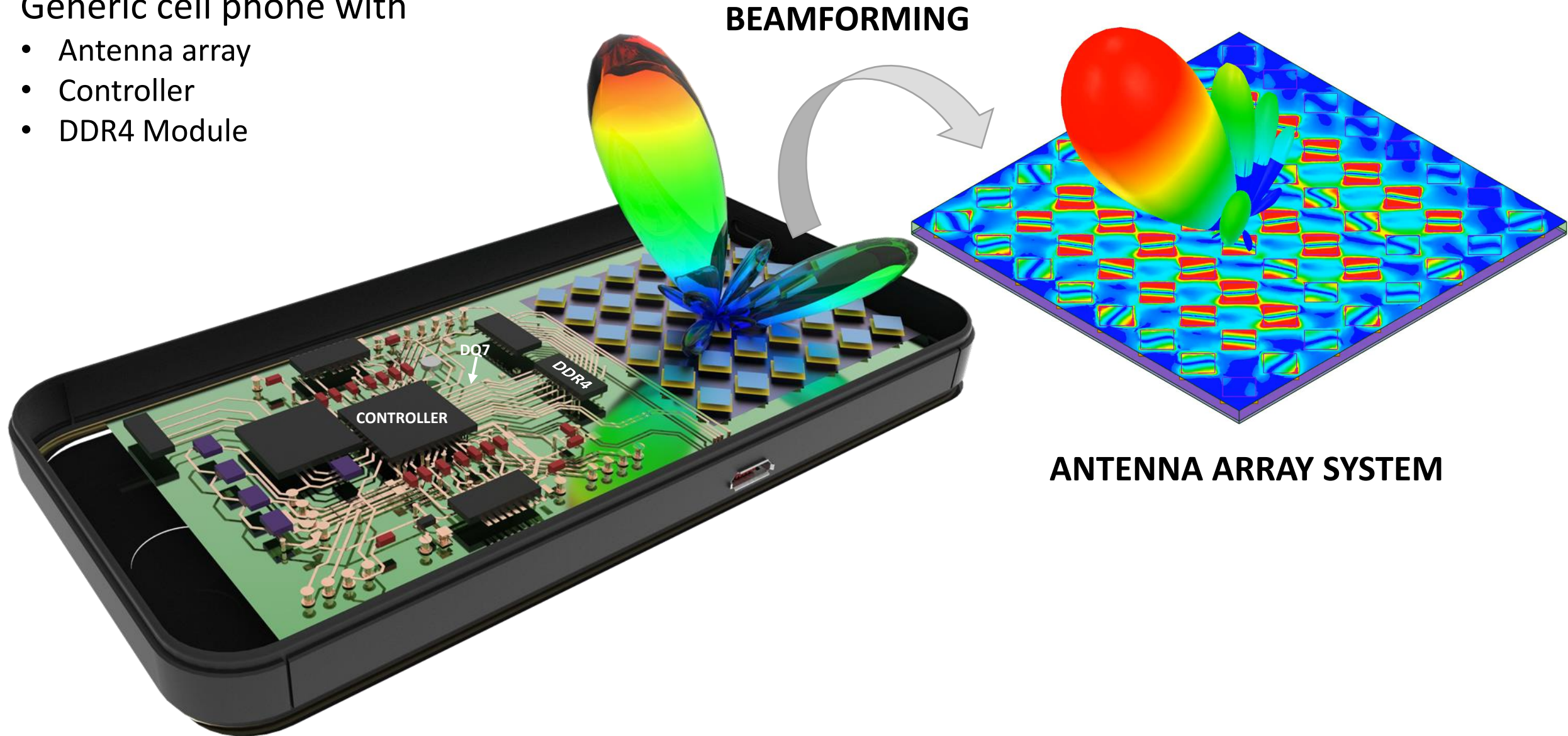
5G Generic Cell Phone Model



5G Generic Cell Phone Model

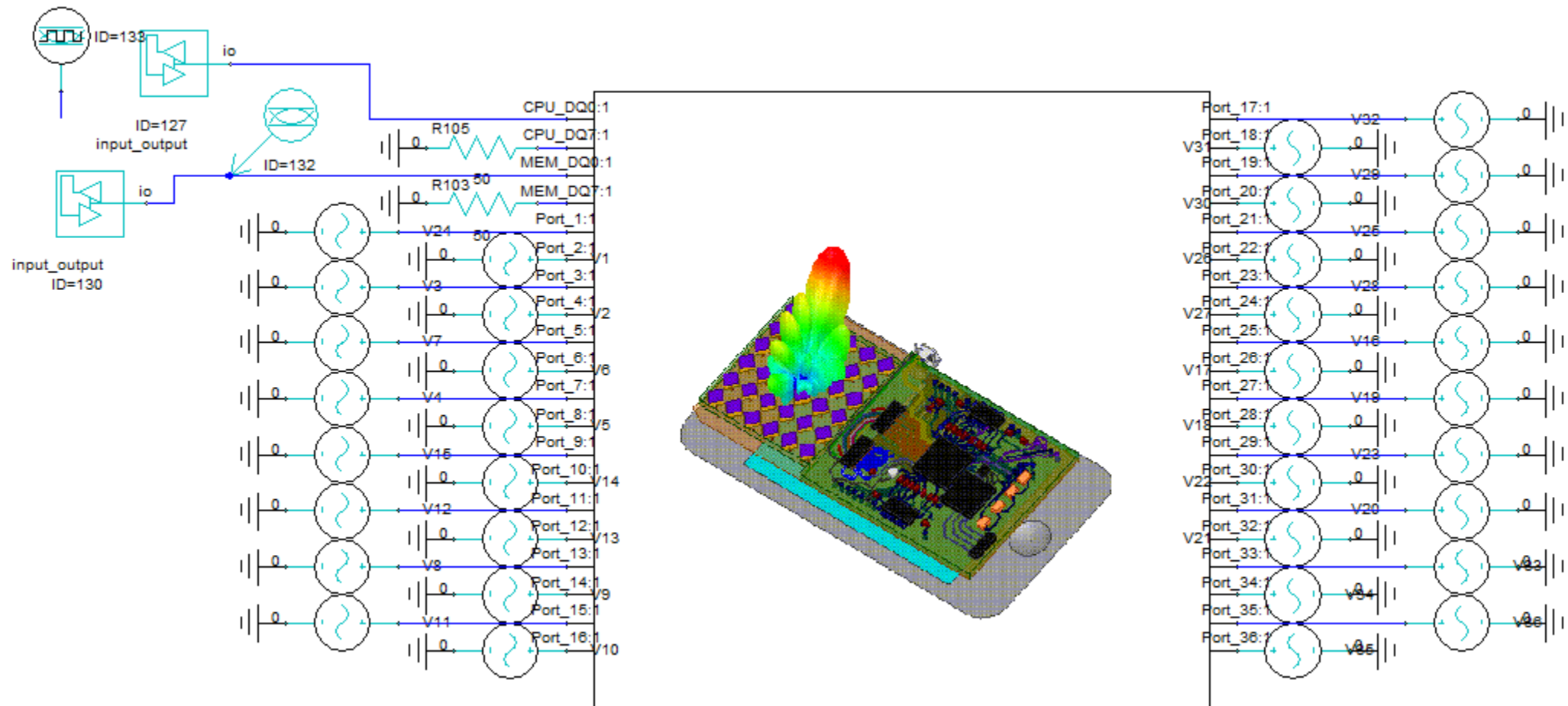
Generic cell phone with

- Antenna array
- Controller
- DDR4 Module



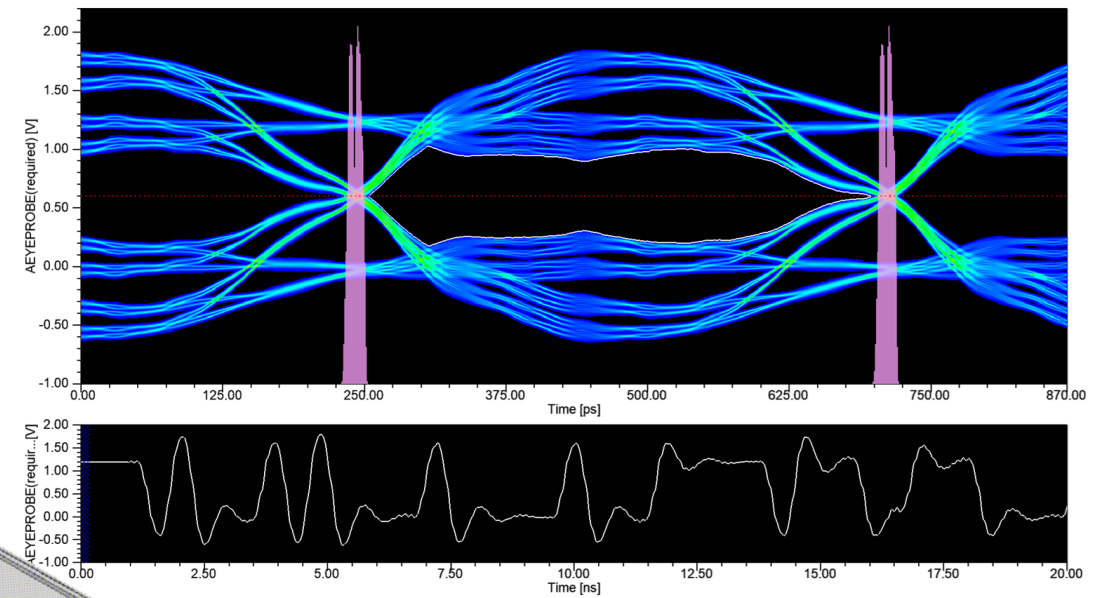
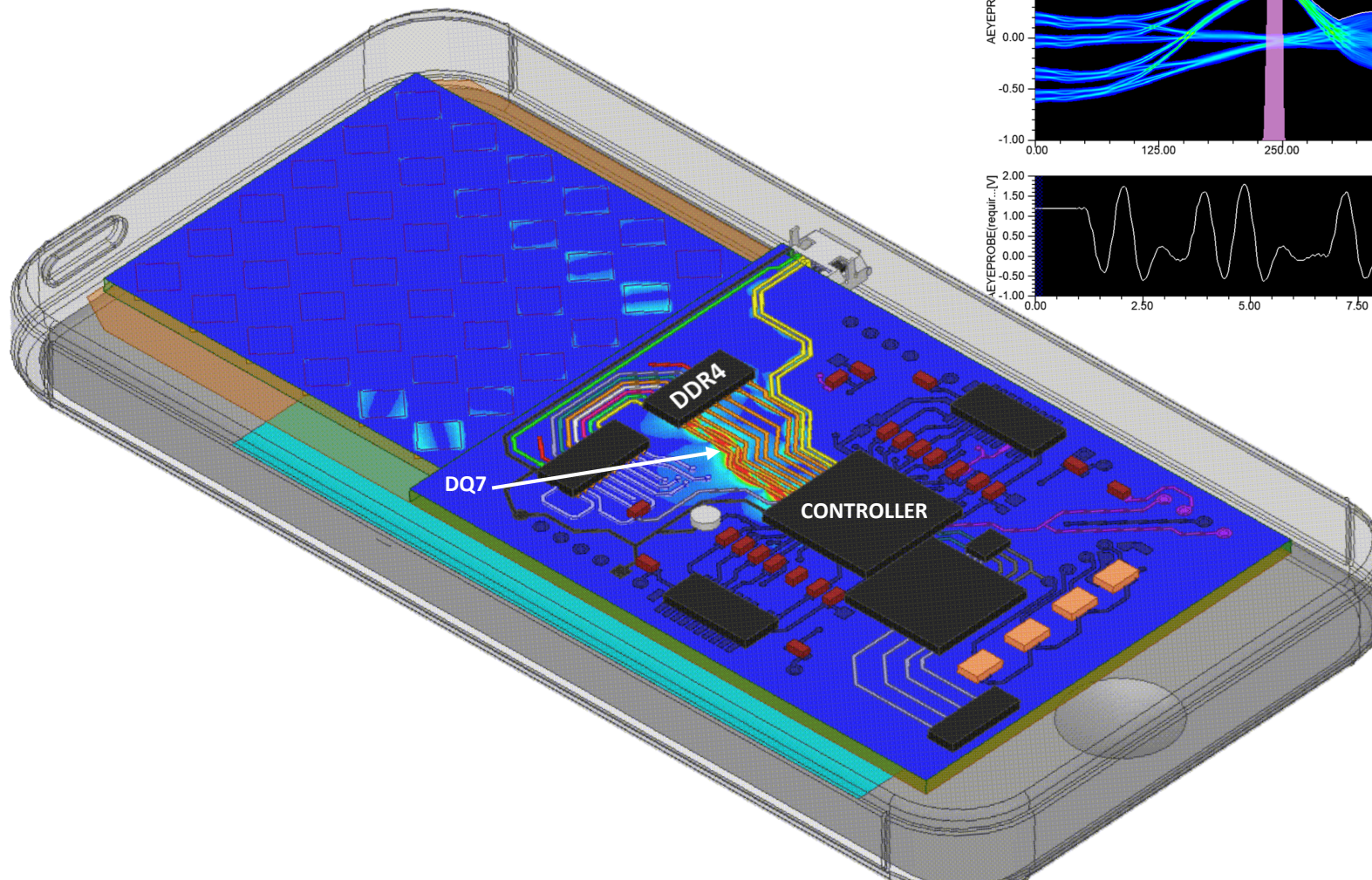
Dynamic Link

Schematic with IBIS models for the controller and DDR4 module (DQ7 only) and CW sources (mag and phase controlled by variables) for antenna excitation.



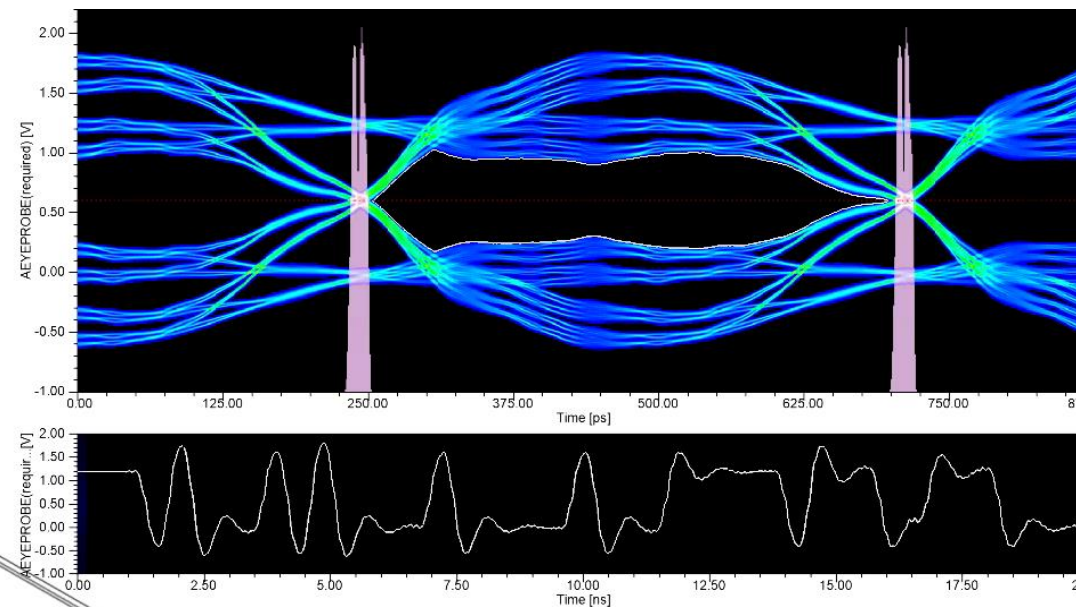
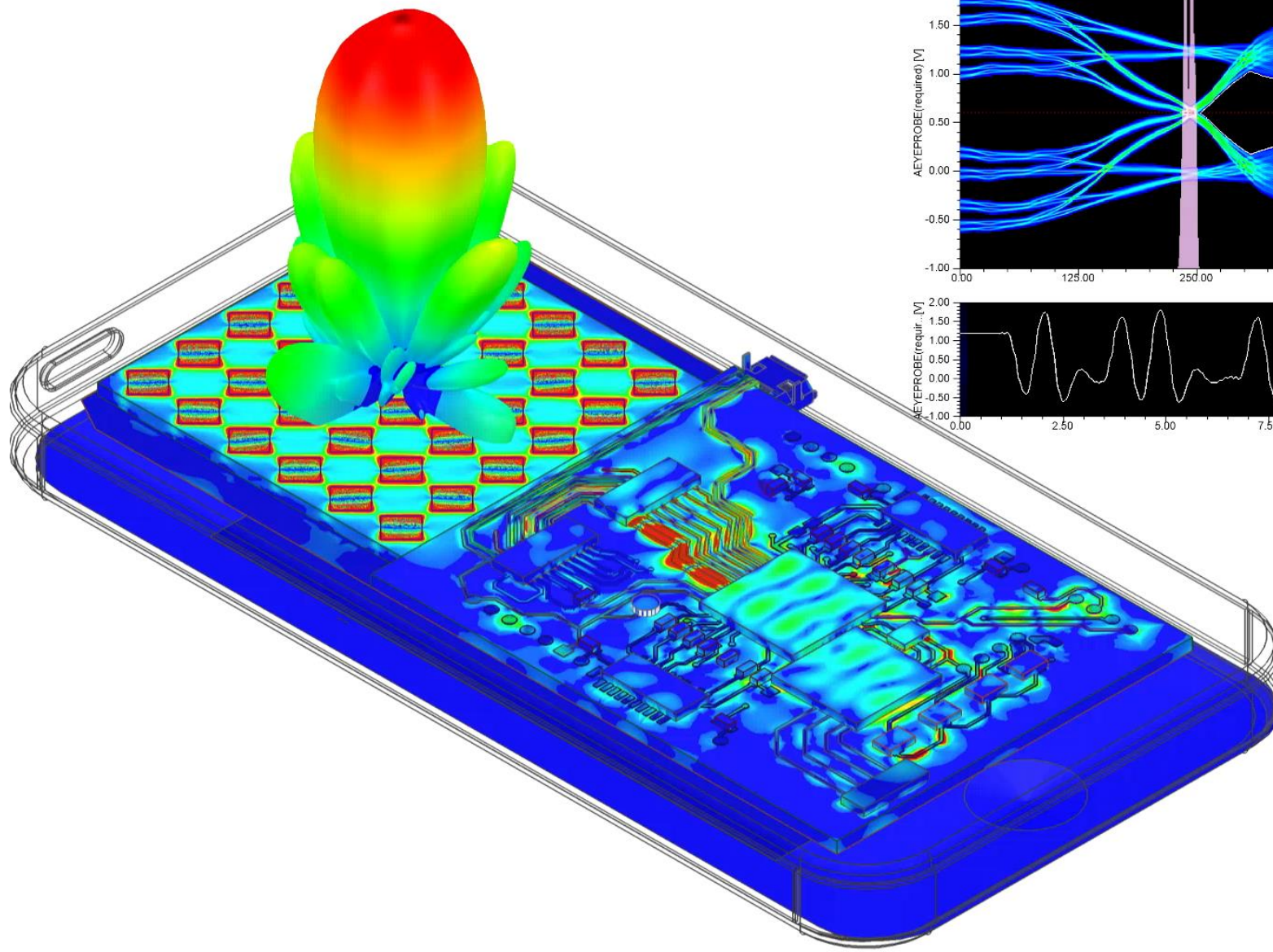
DQ7 Eye Diagram

DQ7 Eye diagram when antenna array is off



DQ7 Eye Diagram

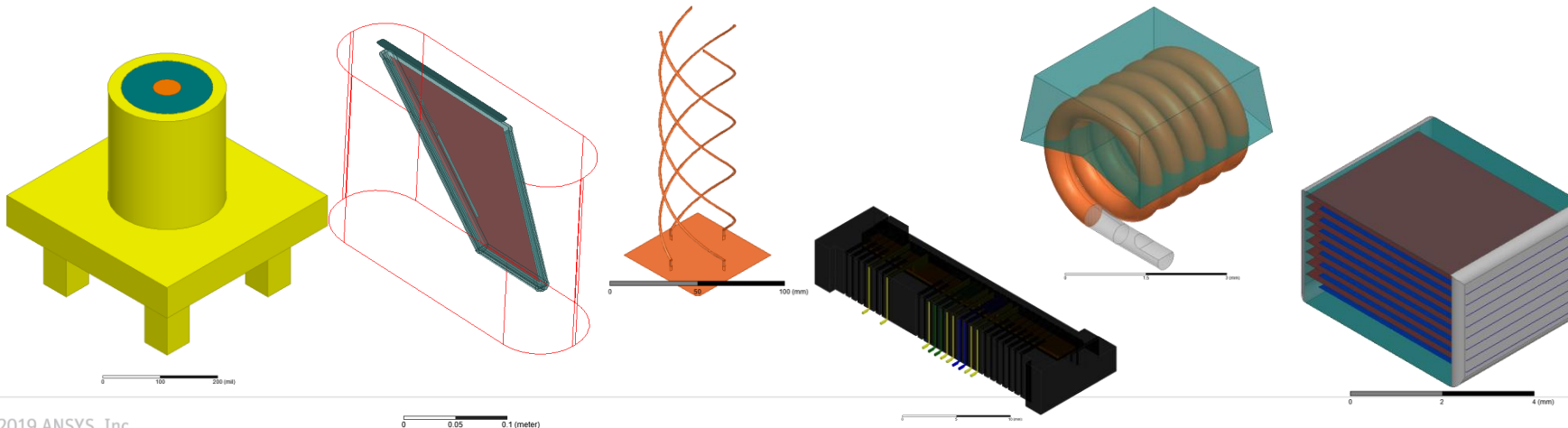
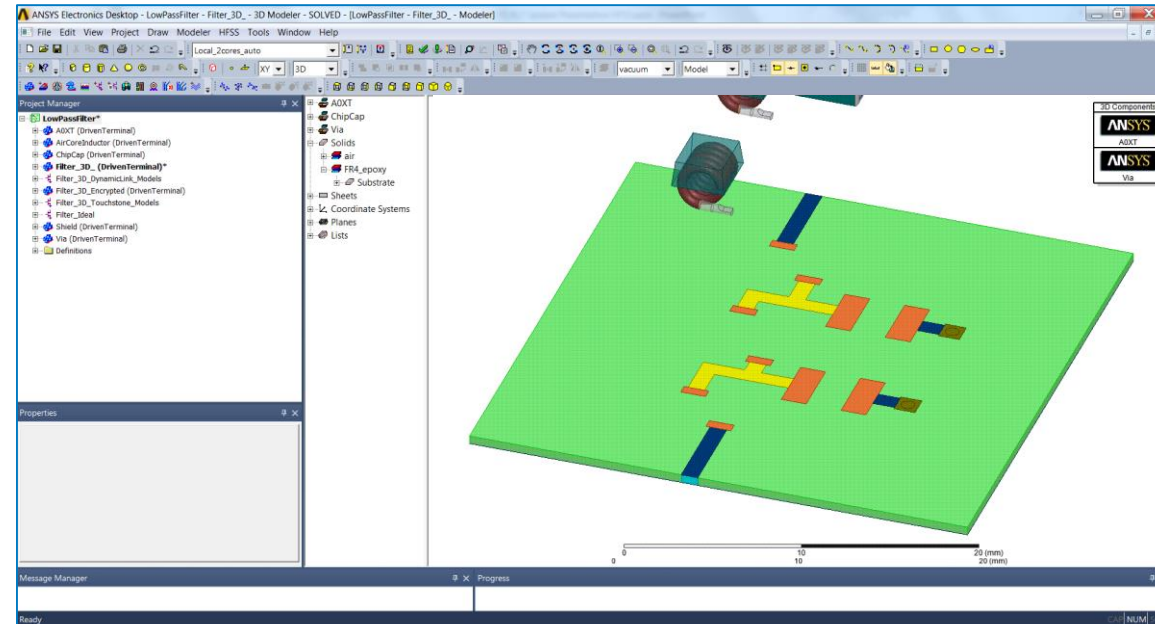
Beamforming EMI Effects



DQ7 Eye Diagram

3D Components

- **3D Components**
 - Password Protected
 - Independent mesh on Hybrid Designs
 - Hide content (IP)
 - Save and reuse designs
 - Share with partners, vendors and companies

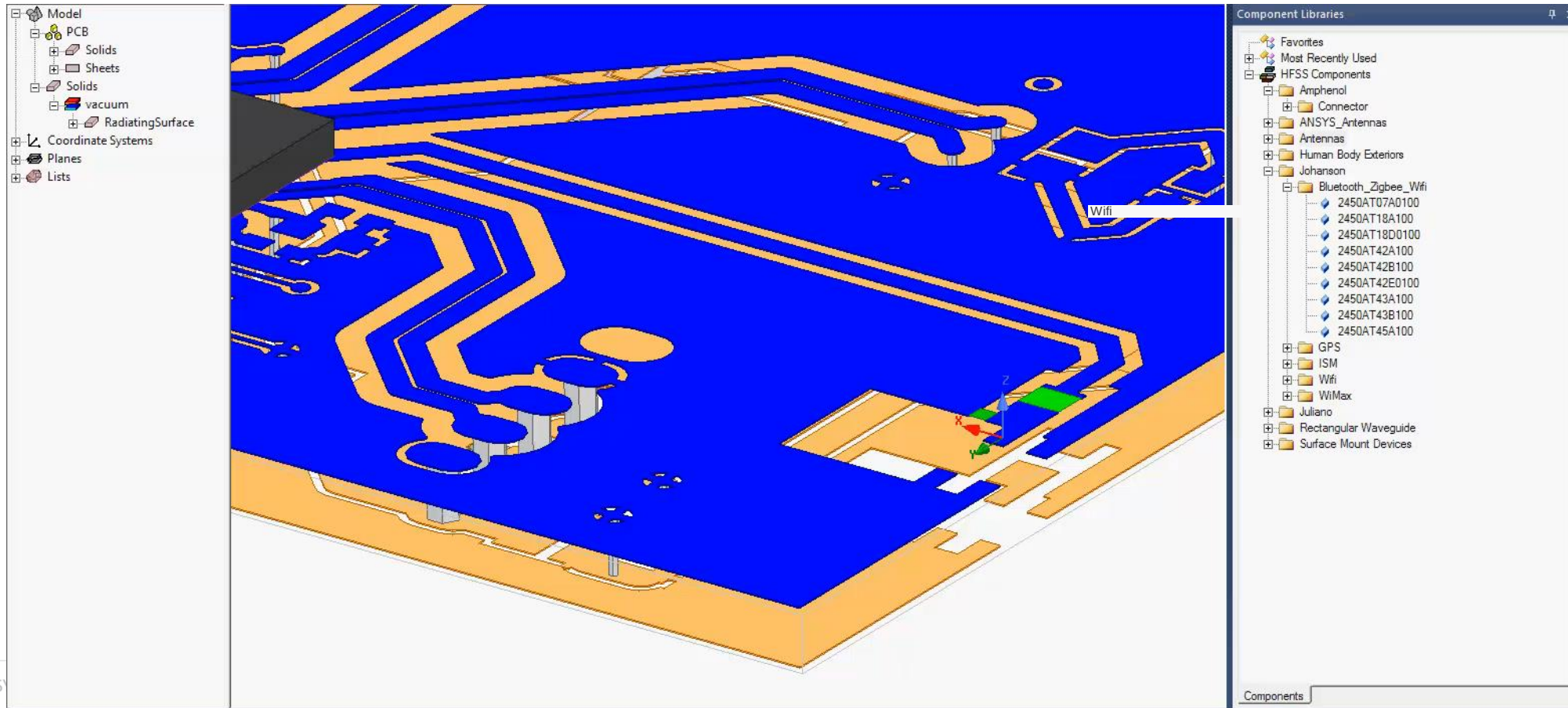


3D Components

Encrypted 3D Components - Johanson

XTALK between a diff clock into WiFi Antenna

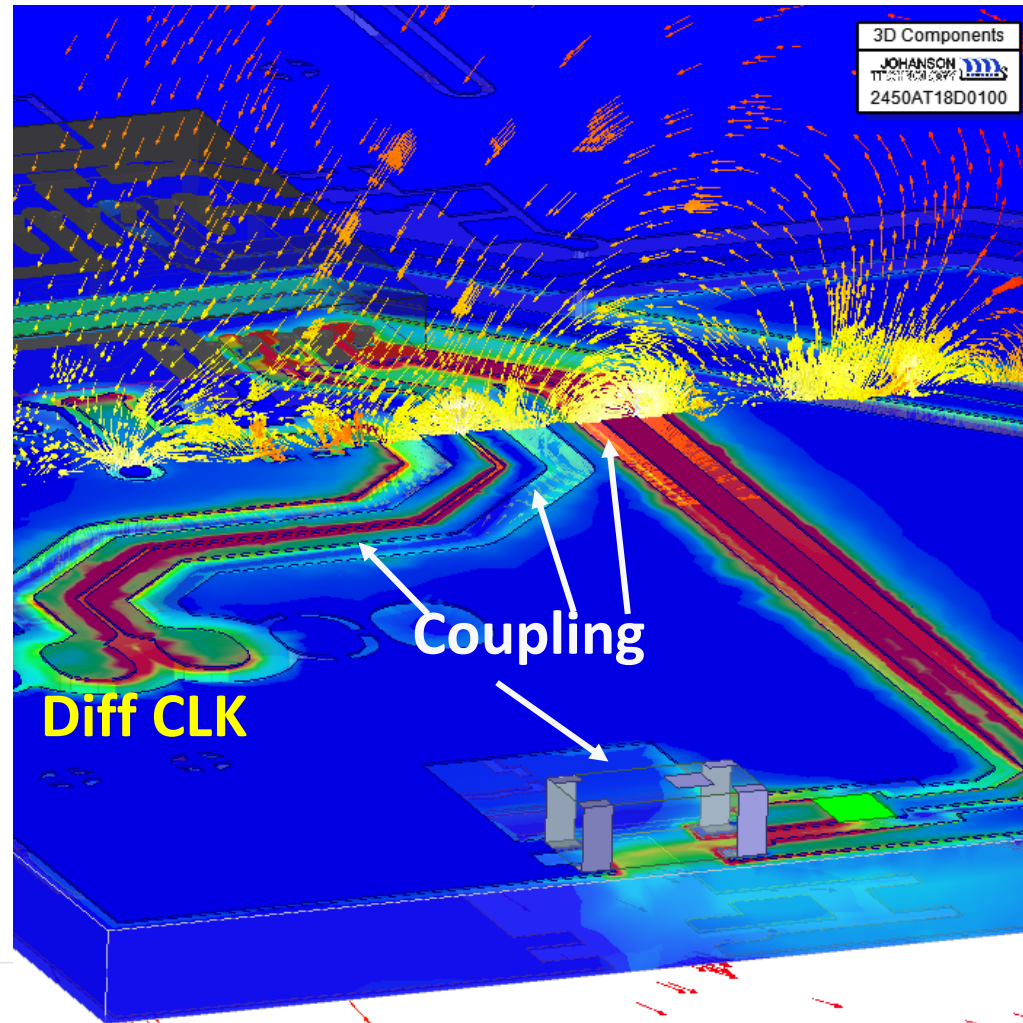
With the 3D antenna model we can accurately calculate not only the radiation pattern and tune the components for best matching, but also EMI from several signals in the PCB since the antenna is connected to the trace (data linking wouldn't work in this case). Note that only the antenna pads are visible, including the fields so the IP is protected.



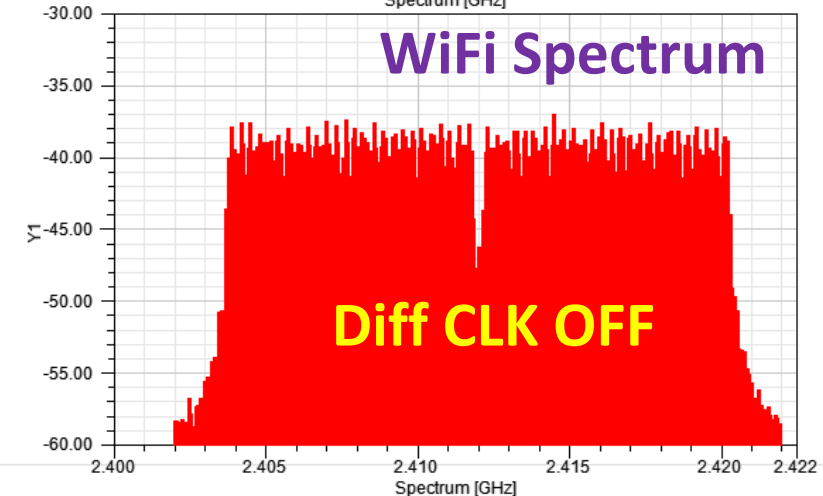
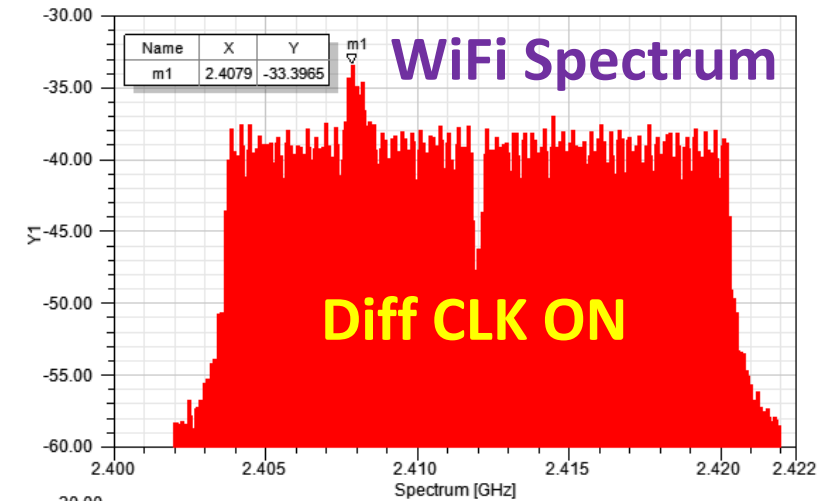
3D Components

XTALK between a diff clock into WiFi Antenna

Differential clock causes significant EMI. SSCG, capacitors can be applied to the CLK or a different WiFi channel could be used

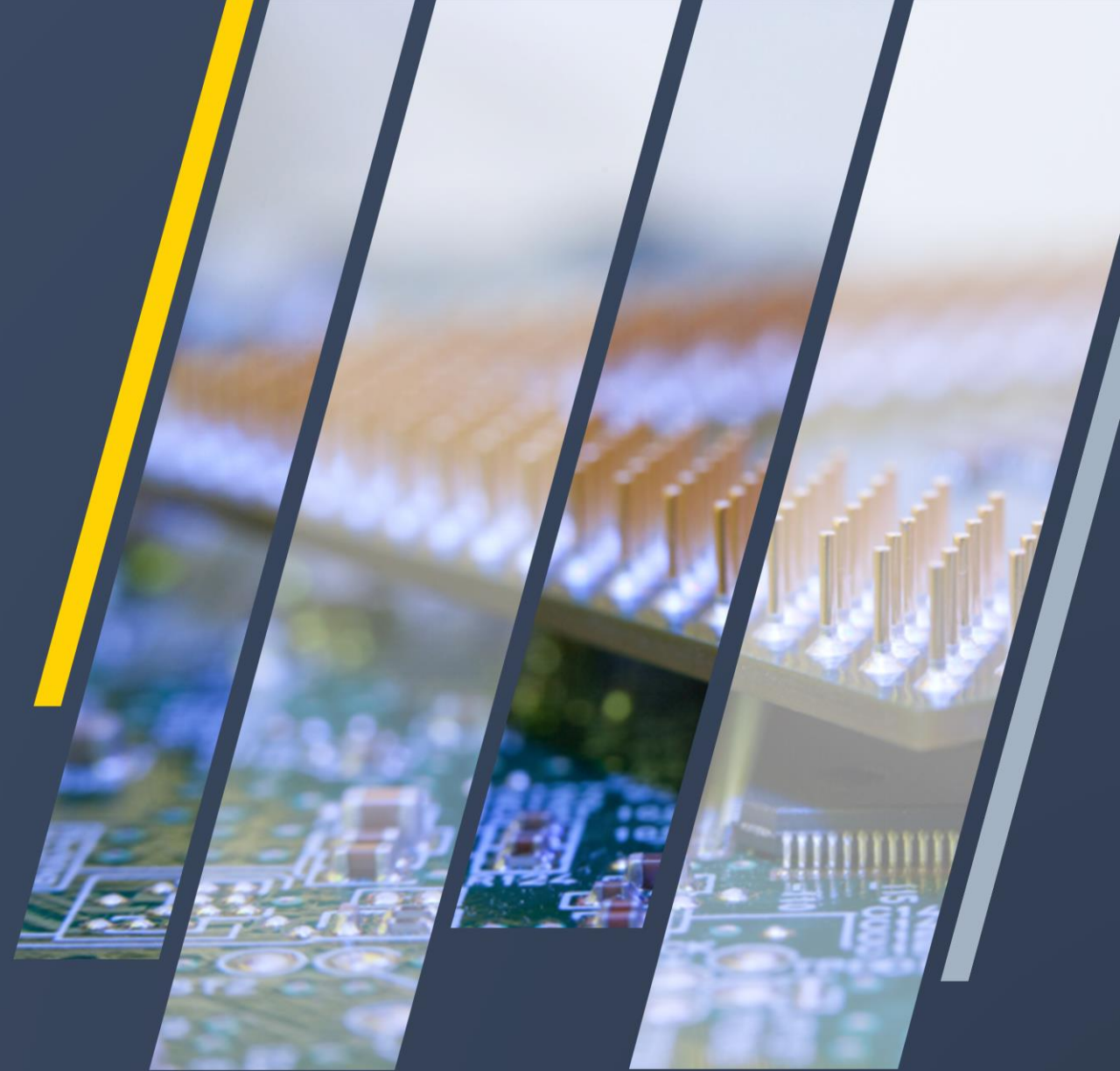


Encrypted 3D Components - Johanson





EMP, Lightning and EFT



FEM – TIME DOMAIN

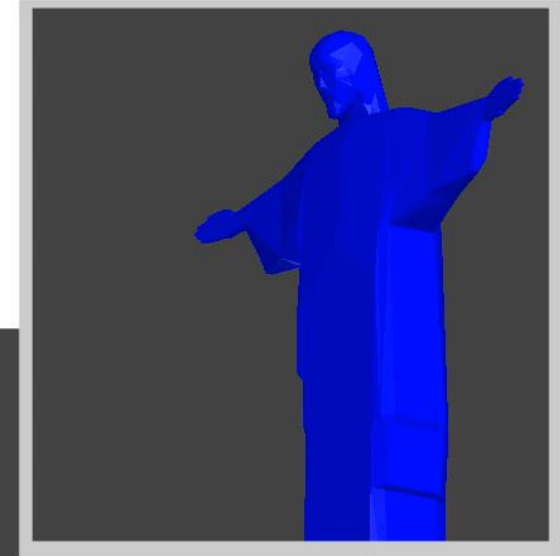
LIGHTNING STRIKE ON CHRIST THE REDEEMER IN RIO DE JANEIRO

The fingers of the Christ statue was damaged by lightning. A preventive system using lightning rods are now placed along the arms down to the hands. The total cost of the lightning rod system is about U\$1 million and the implementation is going to take 4 months until it is finished. ANSYS HFSS Simulation below shows the FEM transient implicit solver in R16 solving the complete model in 7 minutes. A comparison with the real lightning caught on camera is shown on the left.



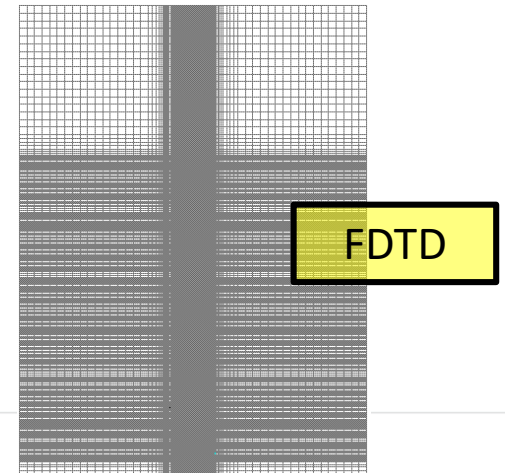
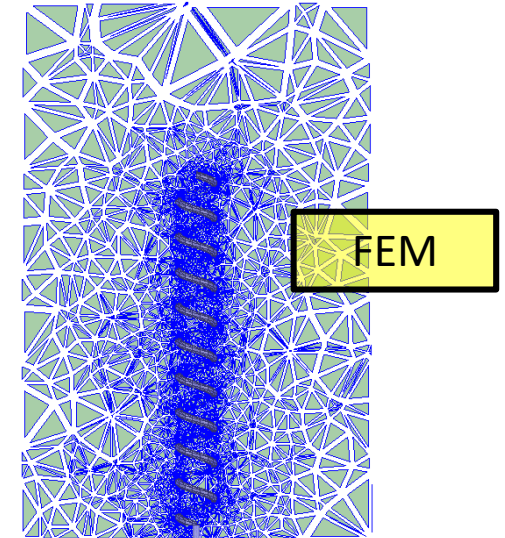
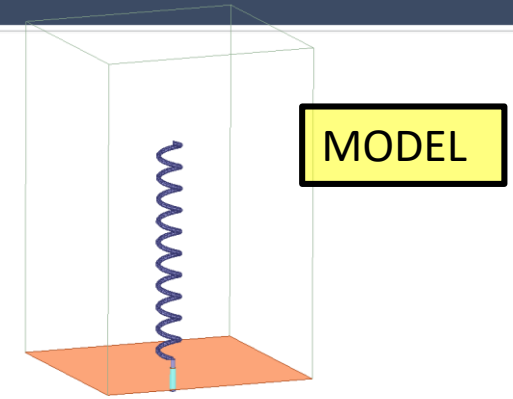
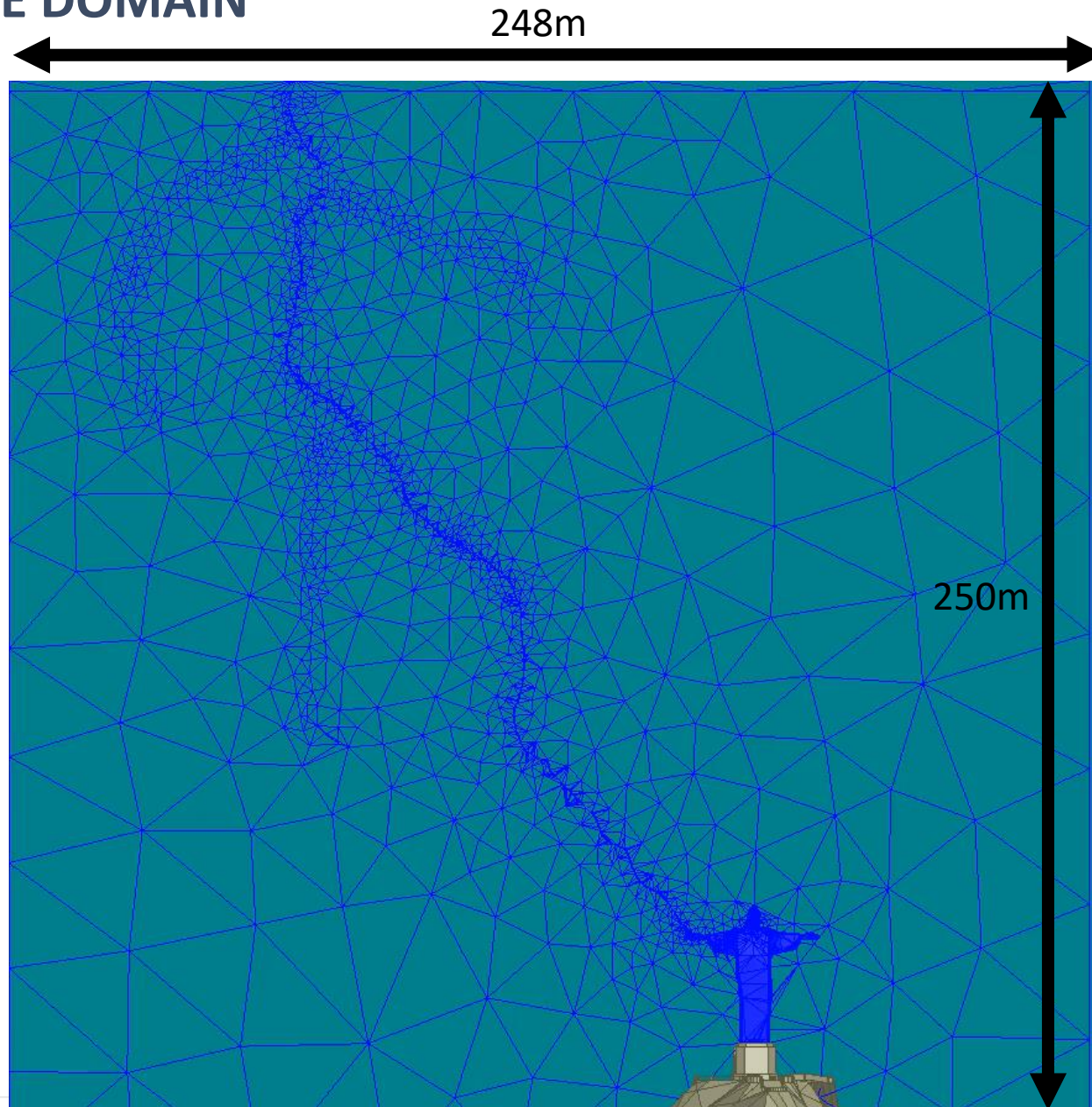
SOURCE:

<http://g1.globo.com/fantastico/noticia/2014/02/tecnico-vai-passar-3-meses-trocando-para-raios-do-cristo-redentor.html>



ANSYS HFSS TRANSIENT
Solved in 7min with 4GB of RAM

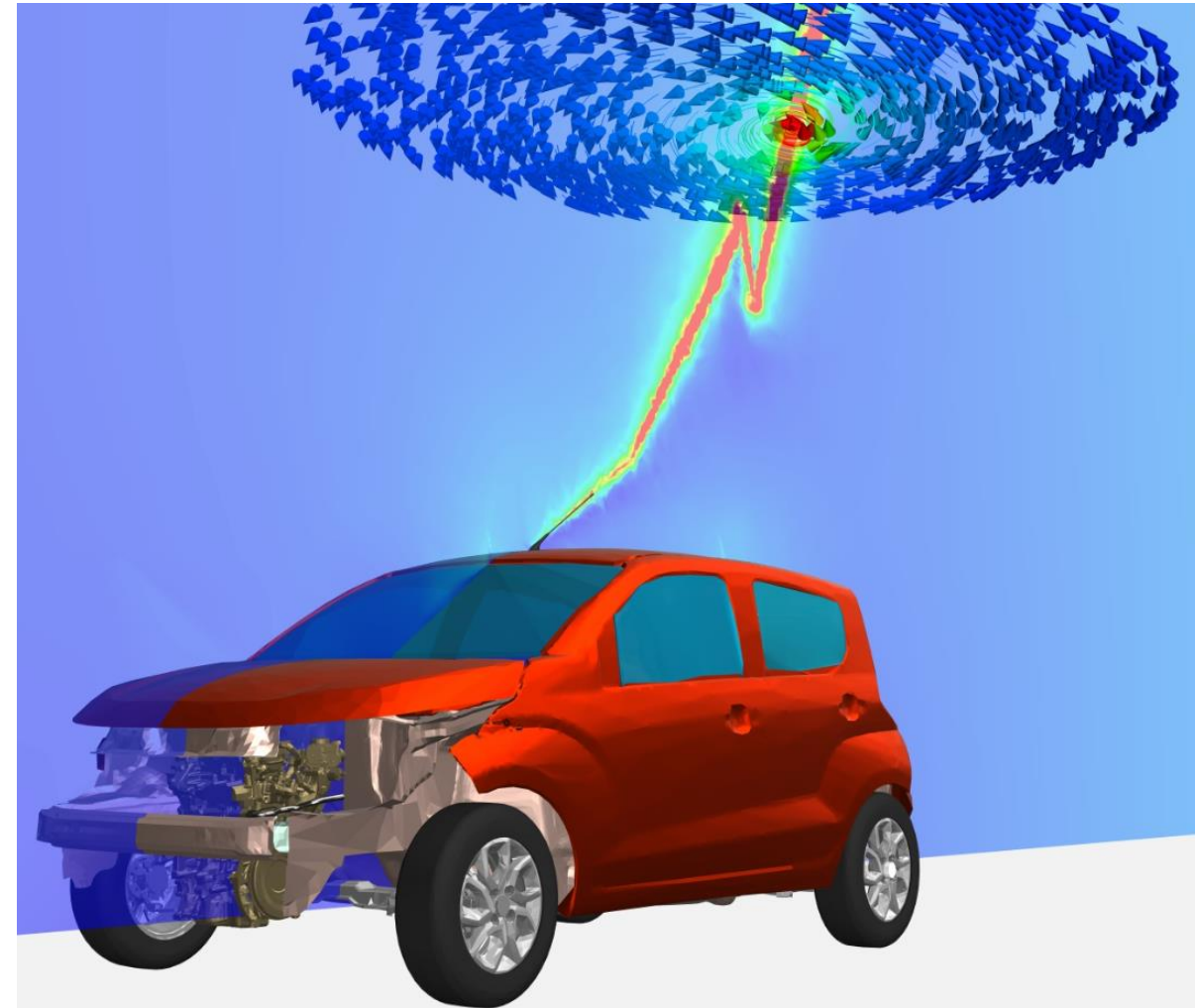
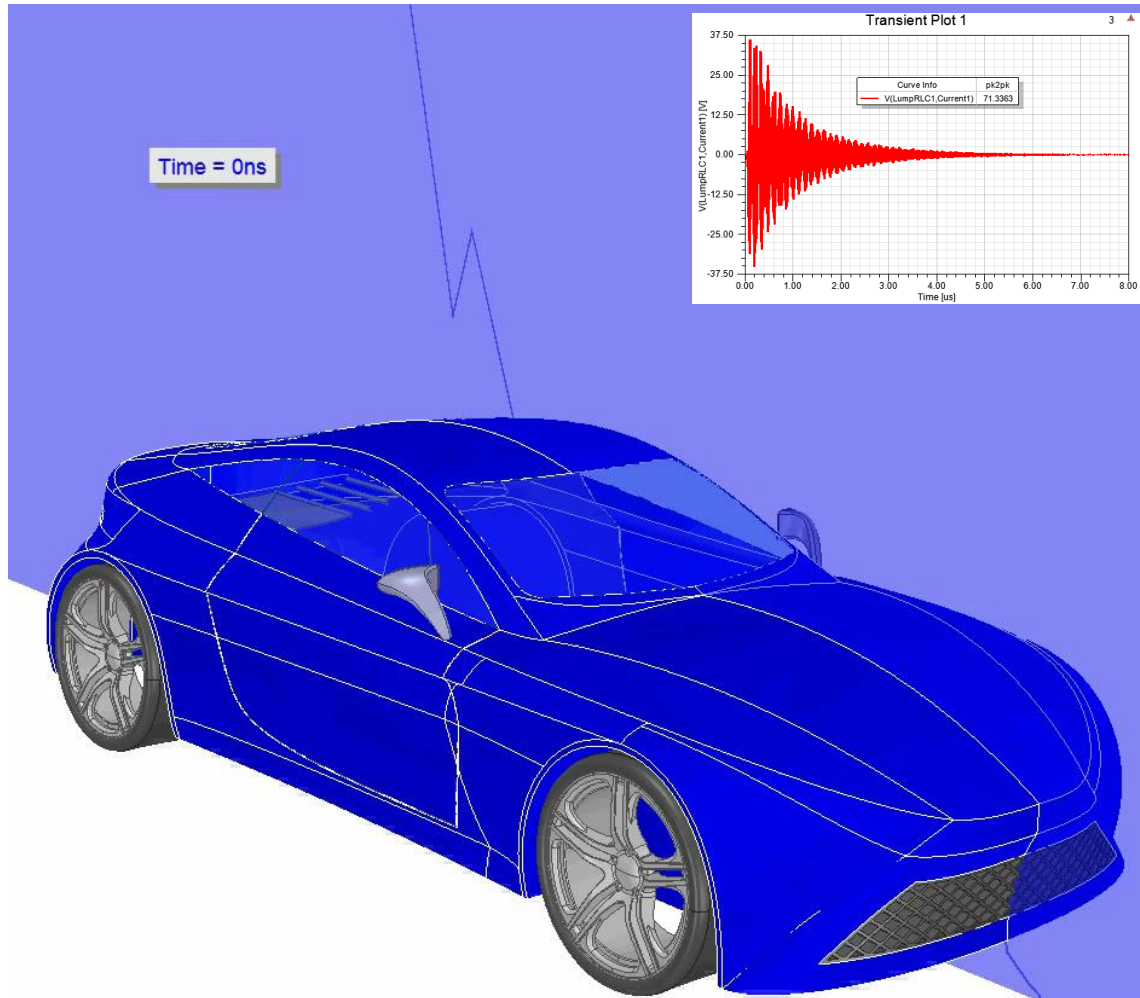
FEM – TIME DOMAIN



LIGHTNING STRIKE

- Lightning strike on vehicles (not a standard yet)

Courtesy FCA



MIL-STD-464 HEMP

Requirement Rationale (A5.5): High-altitude EMP (HEMP) is generated by a nuclear burst above the atmosphere which produces coverage over large areas and is relevant to many military systems. The entire continental US area can be exposed to high-level fields with a few bursts. MIL-STD-2169, a classified document, provides detailed descriptions of the components of the threat waveforms (E1, E2, and E3). Figure A2 provides an unclassified version of the free-field threat developed by the International Electrotechnical Commission (IEC). In a nuclear war, it is probable that most military systems will be exposed to HEMP.

Requirement Guidance (A5.5): EMP protection should be implemented for selected military systems. Many systems do not have a specific need expressed in their operational requirements for the EMP environment. In these instances, EMP requirements should not be imposed, since protection and verification can merely add unnecessary acquisition costs.

HEMP is propagated as a plane wave. The direction of propagation with respect to a system is determined by line of sight from the system to the burst point. Therefore, for systems located directly beneath the burst, the electric field is horizontally polarized (parallel to the earth's surface), whereas for systems located near the tangent to the earth from the burst point, the fields are essentially vertically polarized. Also, the fields vary in a complex manner in amplitude and polarization with respect to direction and angle from the burst point. Since it is generally unknown where a system will be located with respect to the burst point, a prudent design approach is to harden against the maximum threat-level field.

The prompt gamma HEMP (E1) couples well to local antennas, equipment in buildings (through apertures), and to short and long conductive lines. E1 contains strong in-band signals for coupling to MF, HF, VHF and some UHF radios. The most common protection against the effects of E1 is accomplished using electromagnetic shielding, filters, and surge arresters. E1 can temporarily or permanently disrupt the operation of fixed, mobile, and transportable ground-based systems, aircraft, missiles, surface ships, and electronic equipment and components.

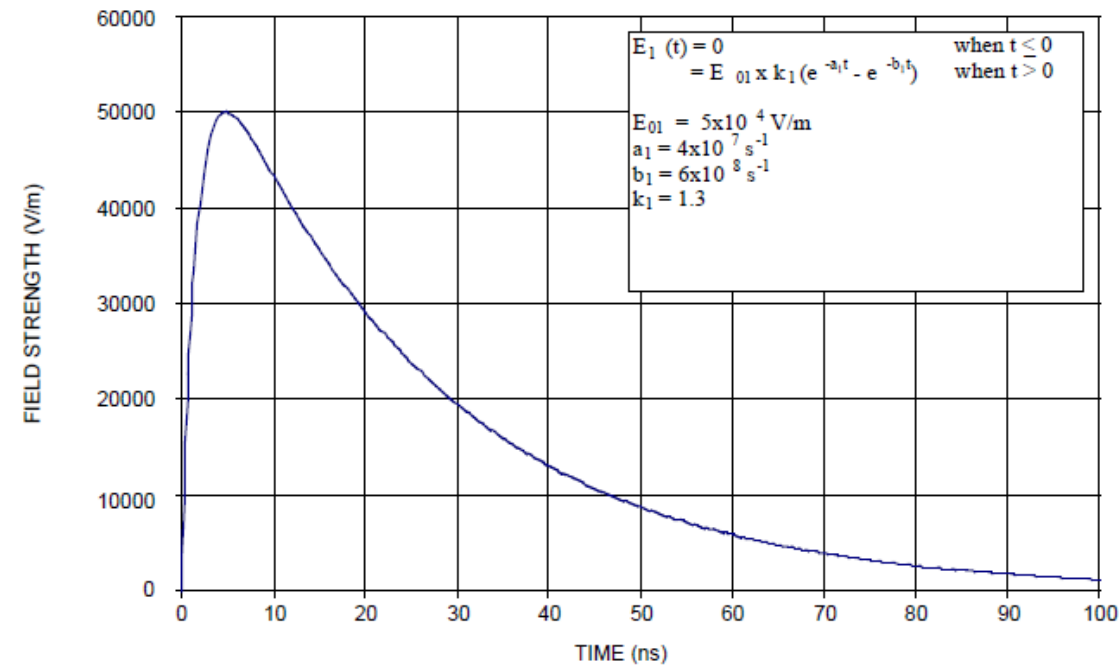
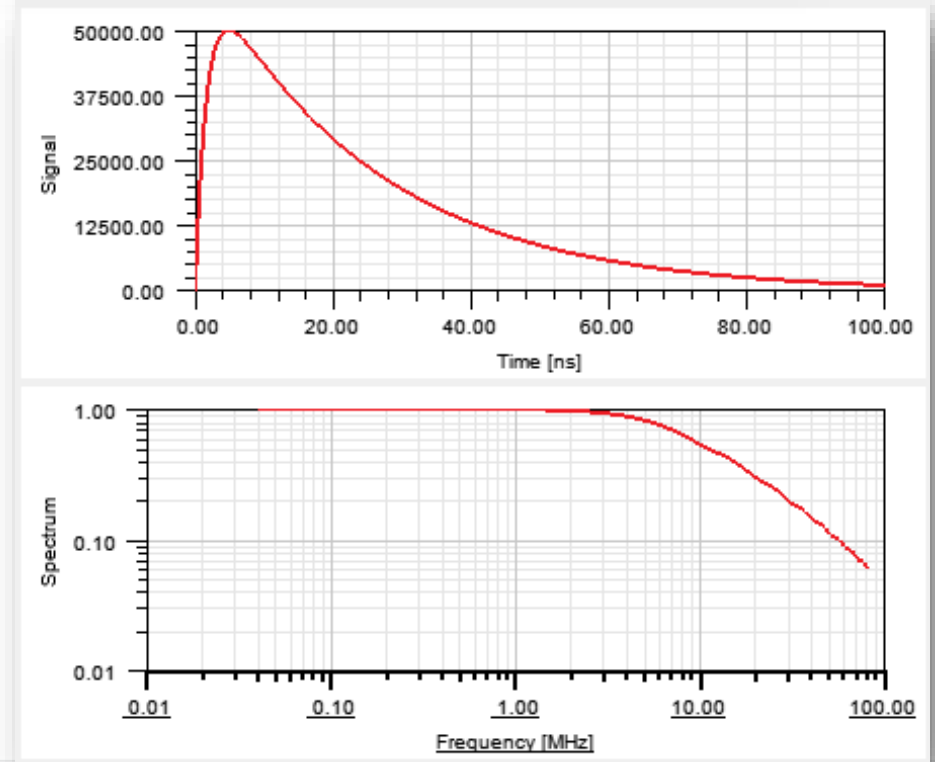
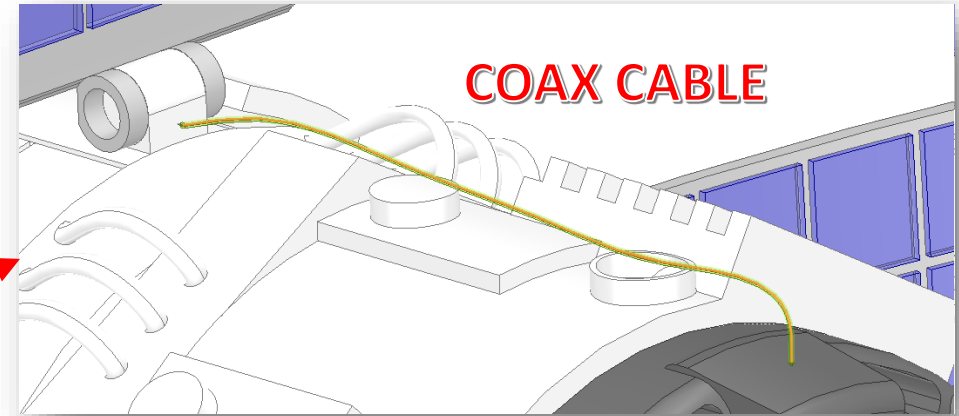
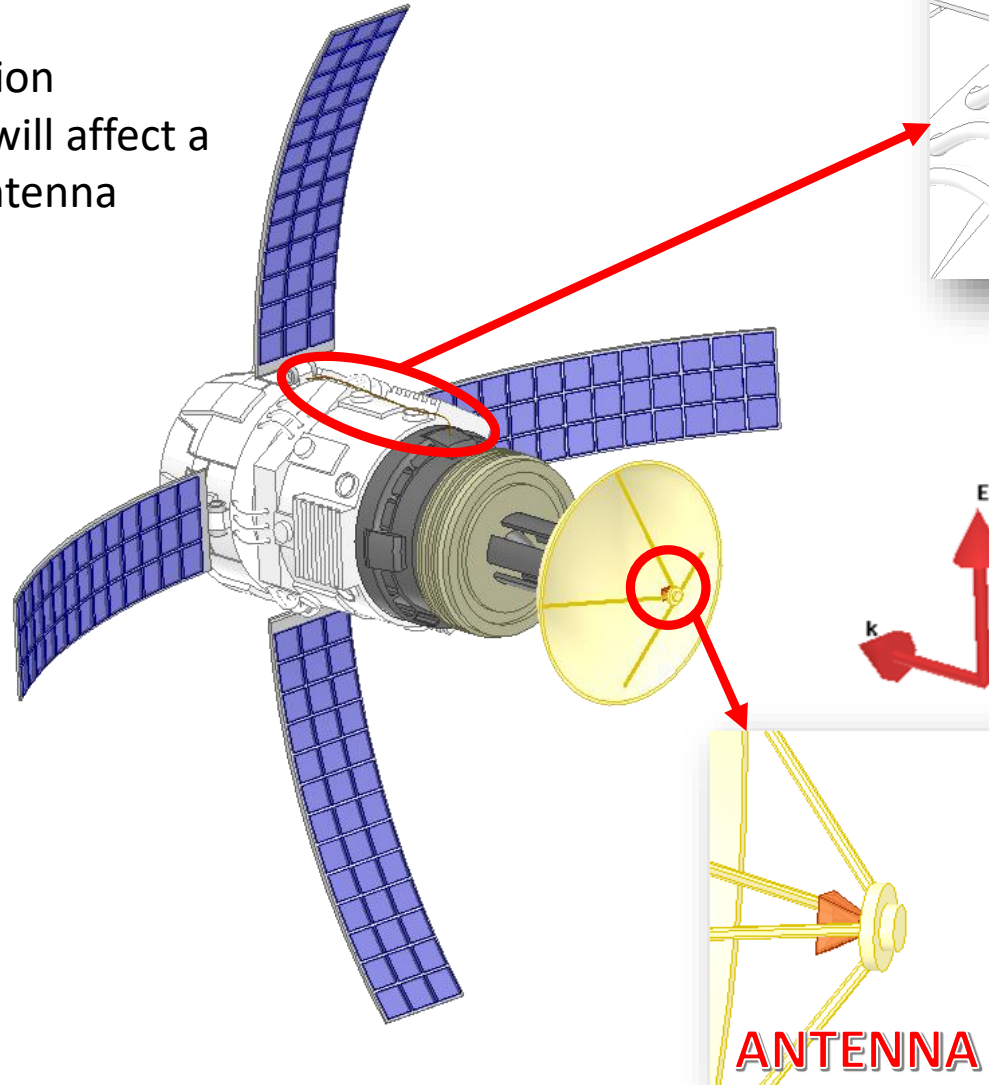


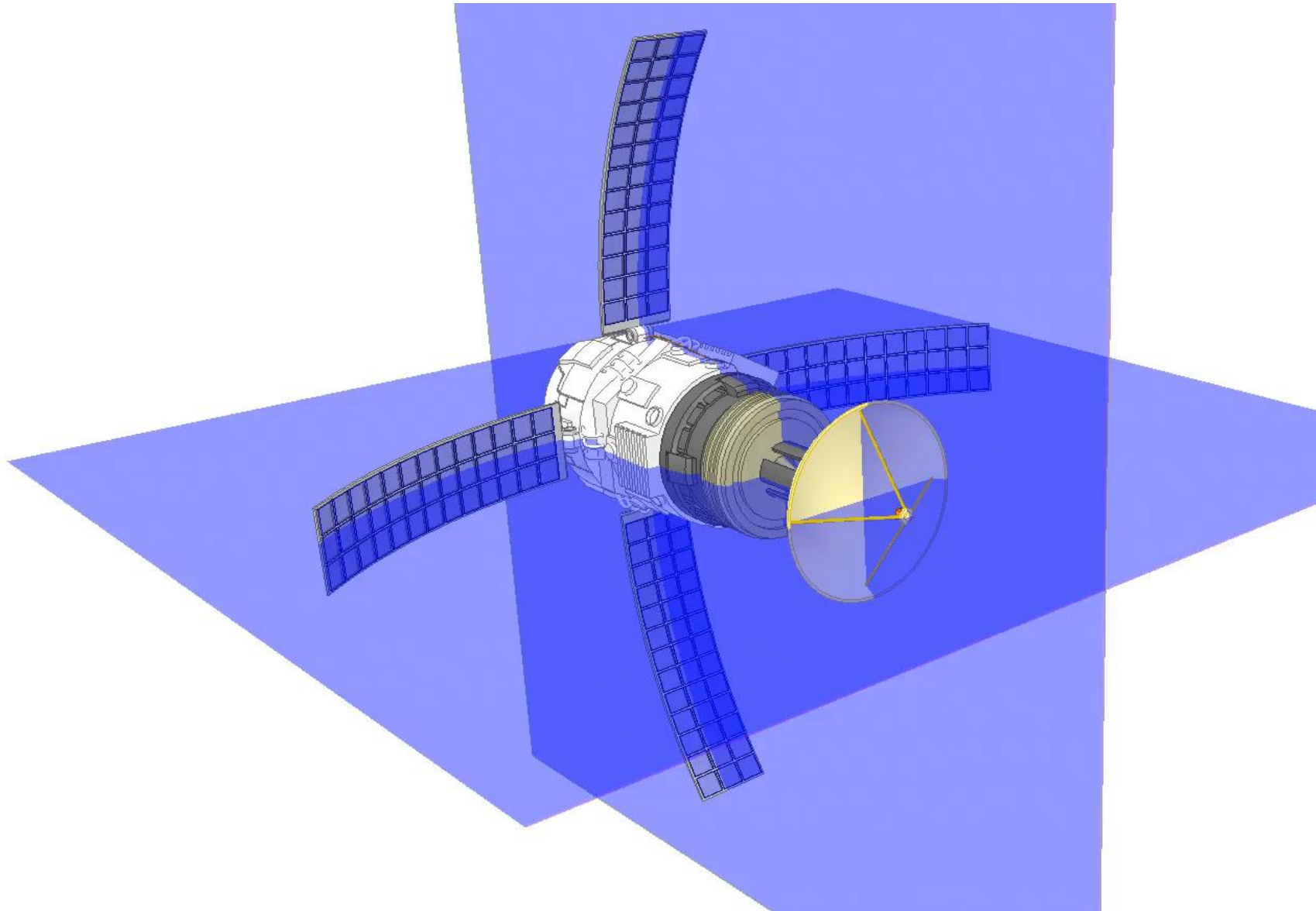
FIGURE A2. Unclassified free-field EMP environment (IEC 61000-2-9)

MIL-STD-464 HEMP

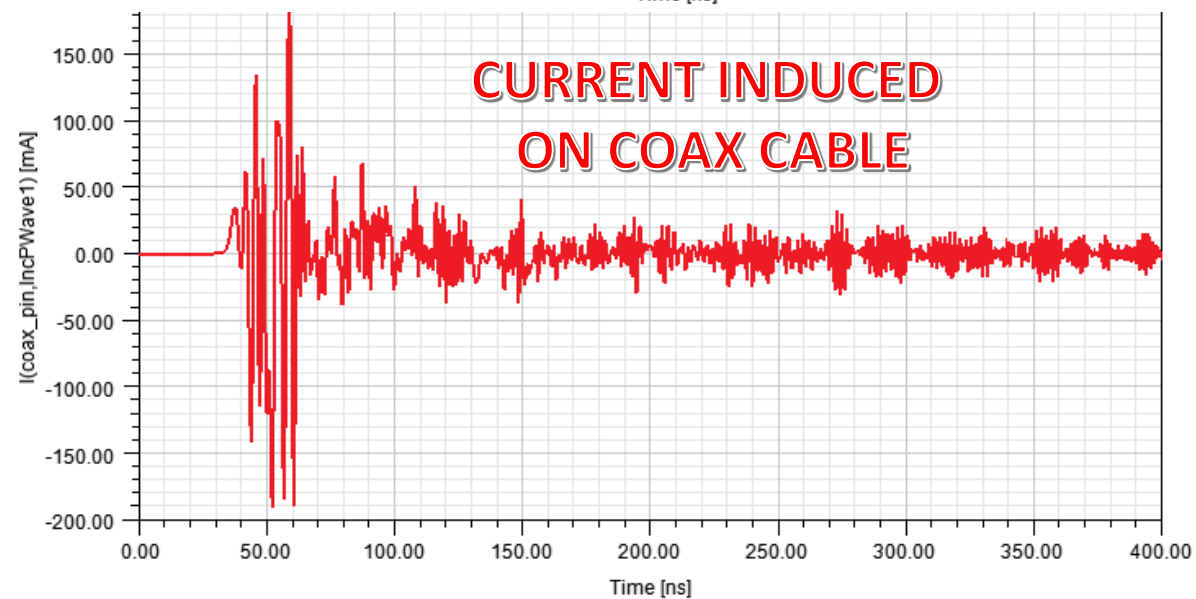
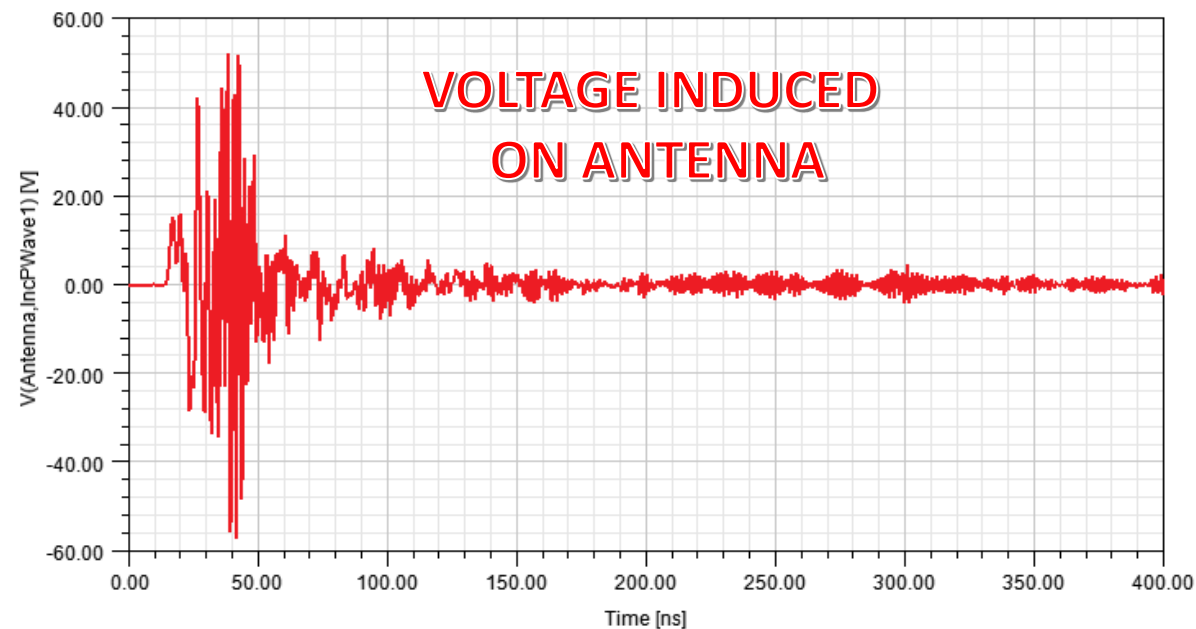
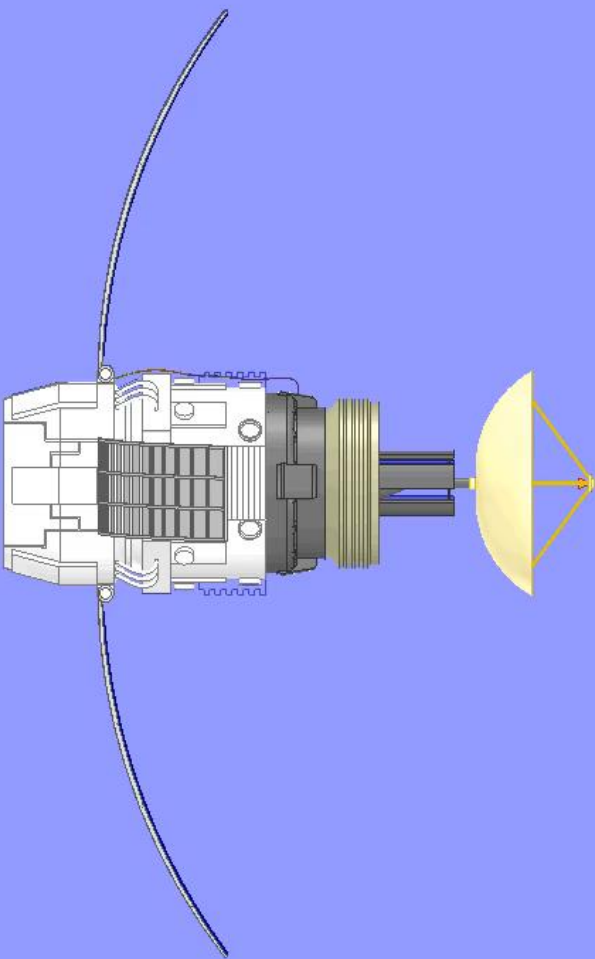
HFSS Transient simulation showing how a HEMP will affect a coaxial cable and an antenna placed on a satellite



HFSS: ElectroMagnetic Pulse



HFSS: ElectroMagnetic Pulse



HFSS: ElectroMagnetic Pulse

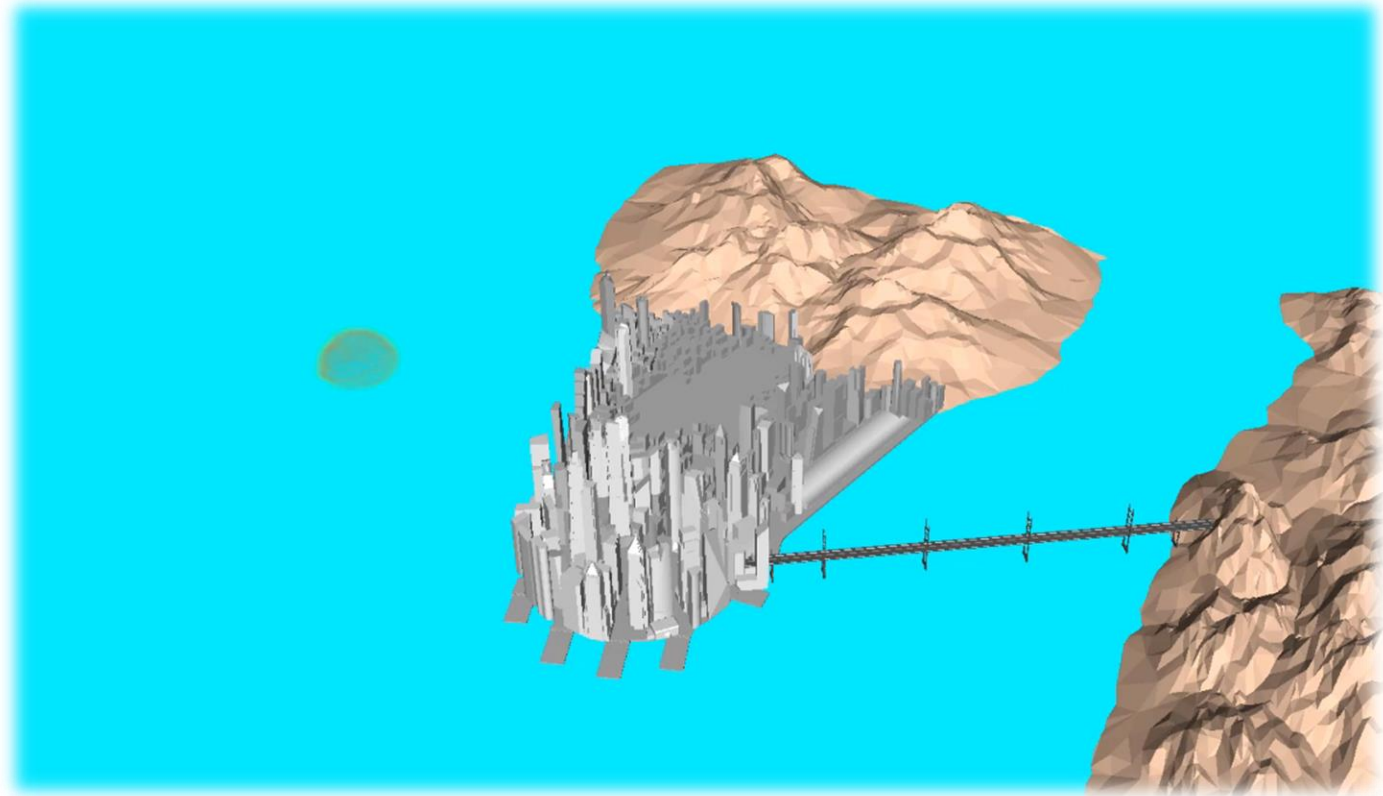
Executive Order on Coordinating National Resilience to Electromagnetic Pulses

— INFRASTRUCTURE & TECHNOLOGY | Issued on: March 26, 2019



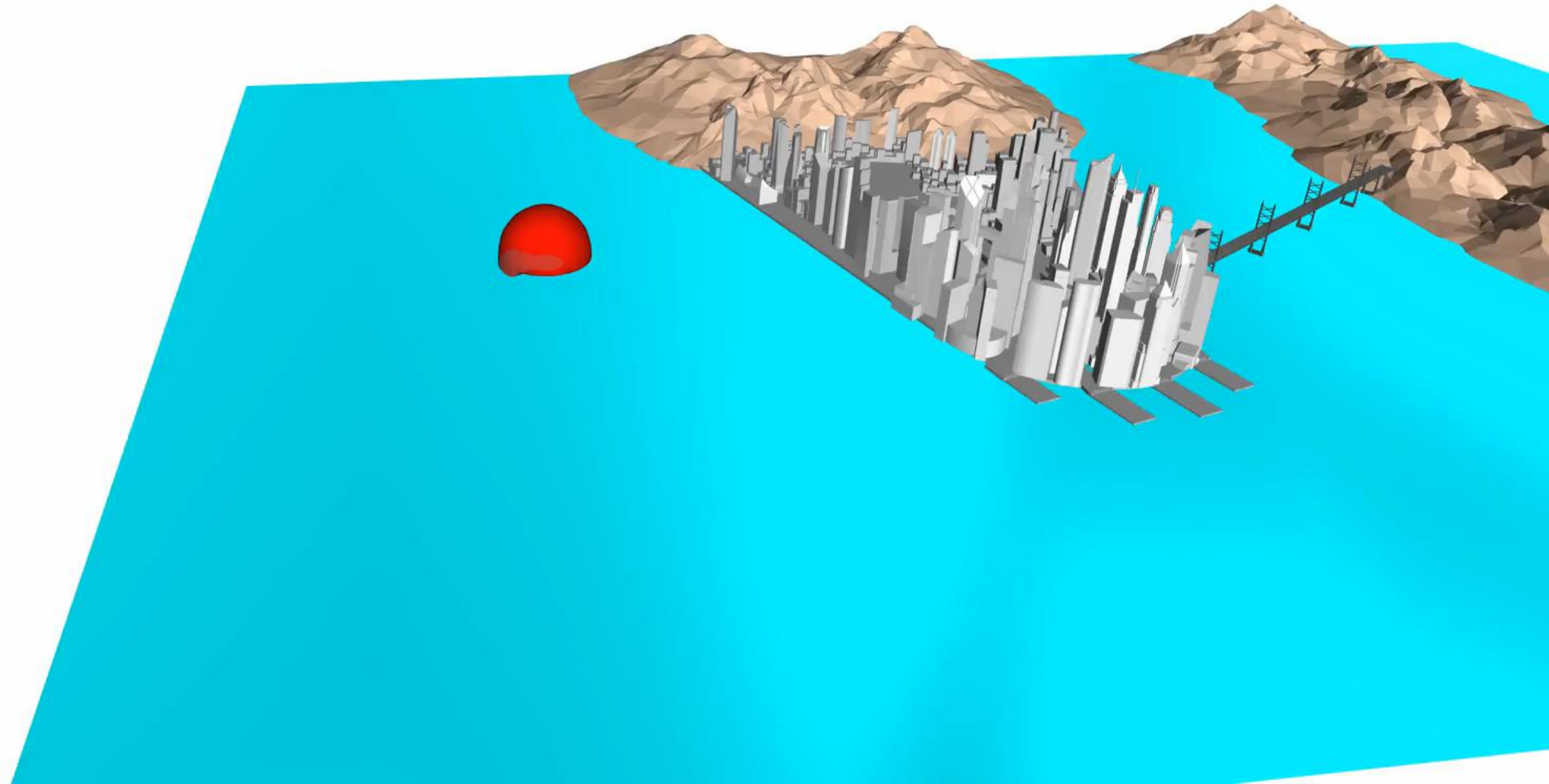
By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. Purpose. An electromagnetic pulse (EMP) has the potential to disrupt, degrade, and damage technology and critical infrastructure systems. Human-made or naturally occurring EMPs can affect large geographic areas, disrupting elements critical to the Nation's security and economic prosperity, and could adversely affect global commerce and stability. The Federal Government must foster sustainable, efficient, and cost-effective approaches to improving the Nation's resilience to the effects of EMPs.

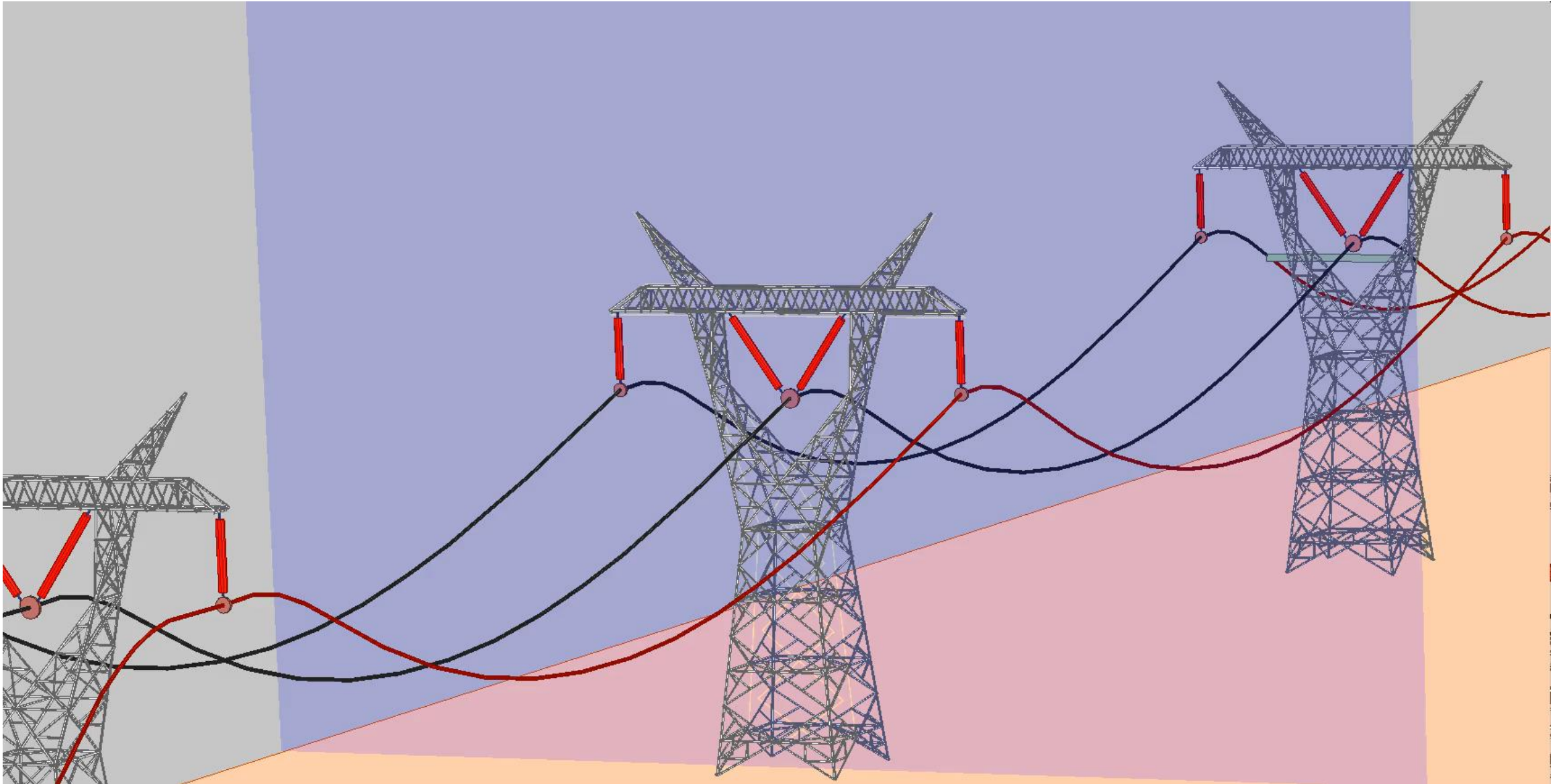


<https://www.whitehouse.gov/presidential-actions/executive-order-coordinating-national-resilience-electromagnetic-pulses/>

HFSS: ElectroMagnetic Pulse



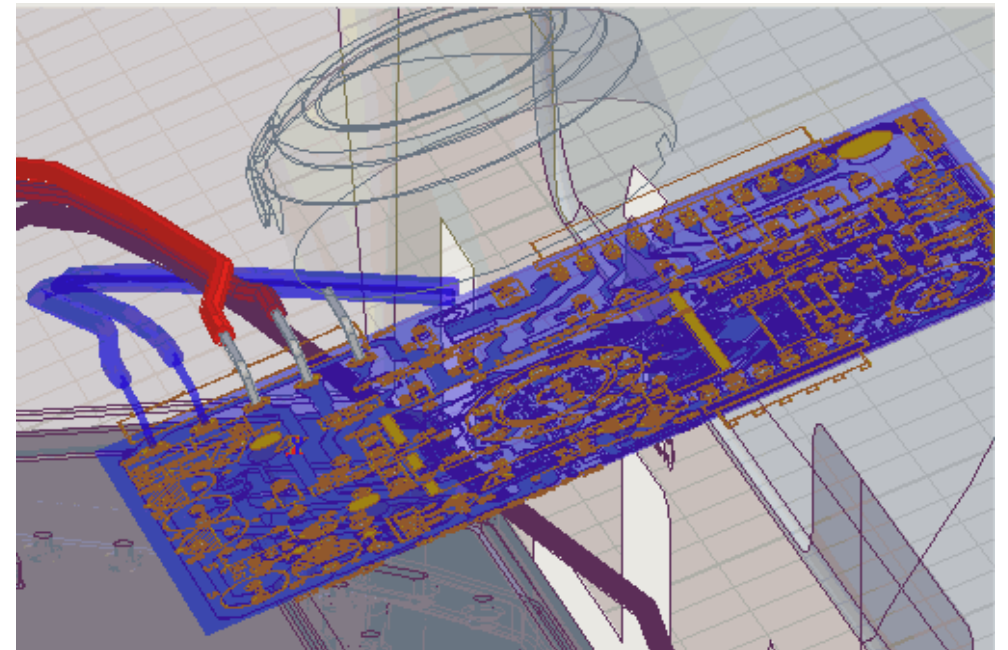
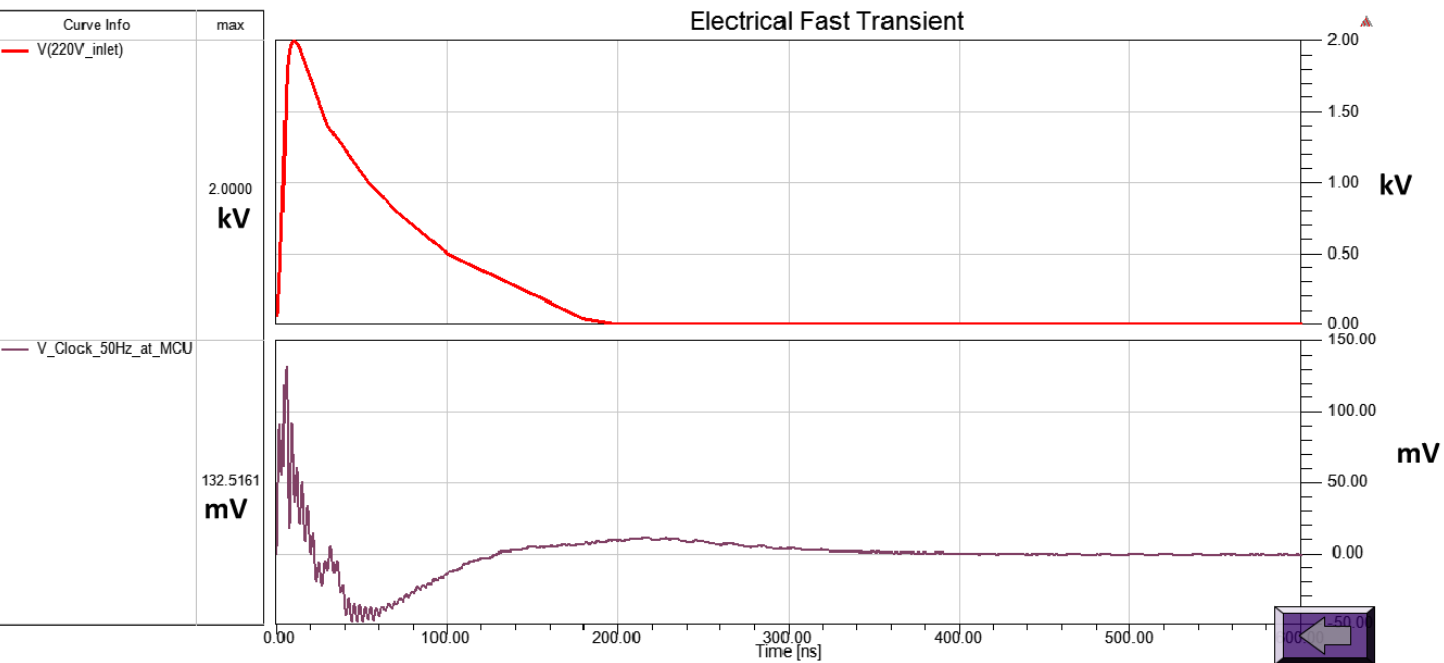
HFSS: ElectroMagnetic Pulse



ELECTRICAL FAST TRANSIENT

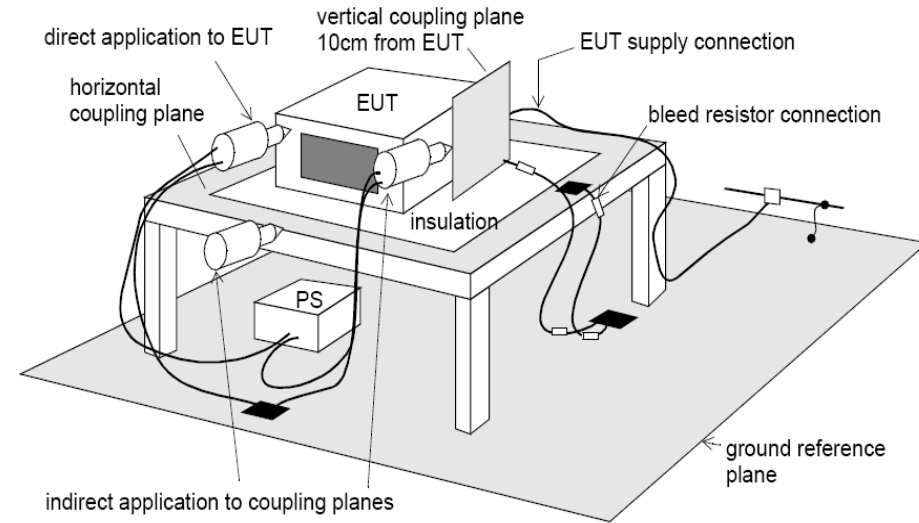
Courtesy
Electrolux

- IEC 61000-4-4

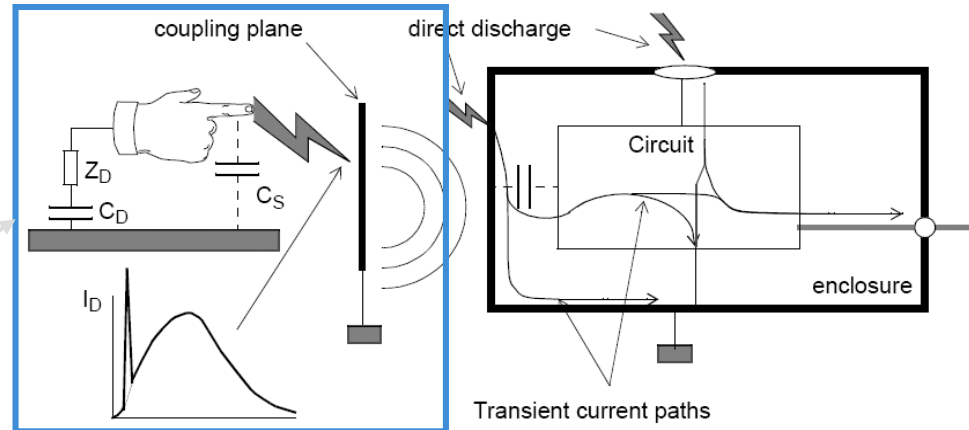


Standardized ESD Test Setup IEC61000-4-2

- Test simulates a case where static discharge hits to EUT (Equipment Under Test) directly or indirectly
- EUT tested by series of ESD discharges
 - Pulse shape 0.7ns/60ns
 - Base standards voltages from $\pm 0.1\text{kV}$ up to $\pm 15\text{kV}$
 - In automotive environment up to $\pm 30\text{kV}$
- Coupling mechanisms
 - Direct, air discharge
 - Direct, contact discharge
 - Indirect discharge, vertical coupling plane
 - Indirect discharge, horizontal coupling plane
- EUT can damage in test



This simulation demo

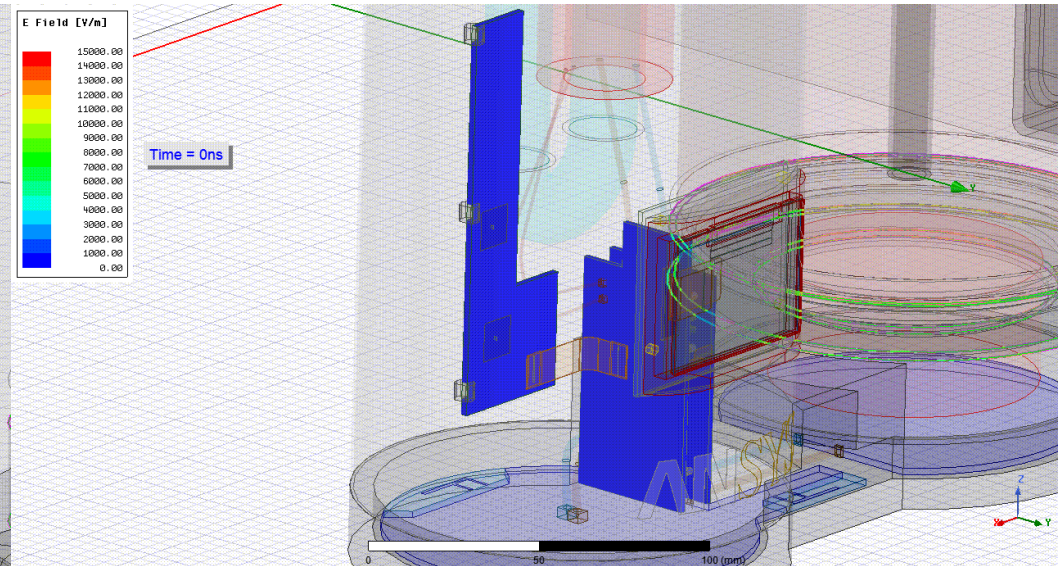
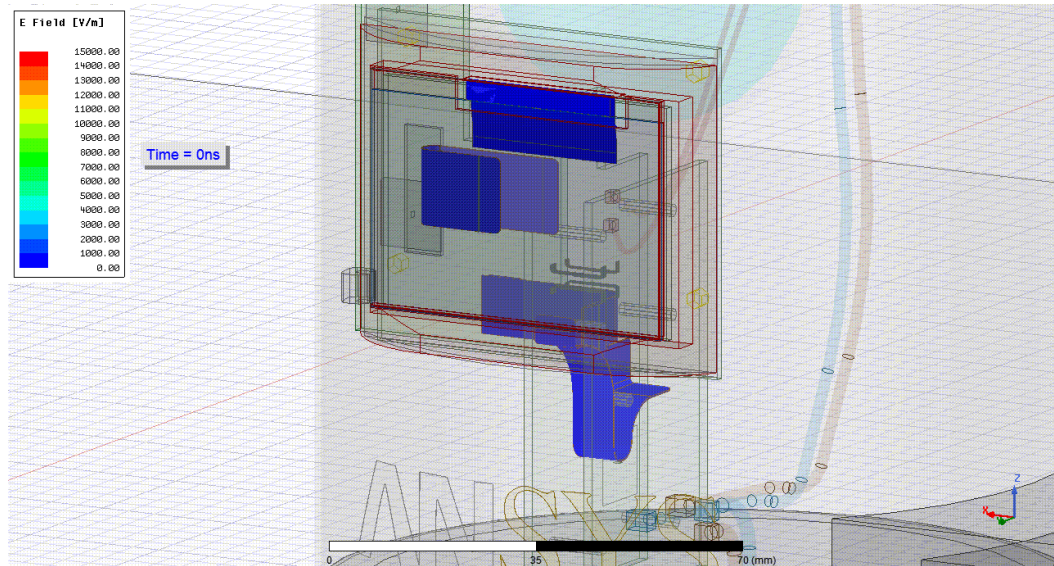
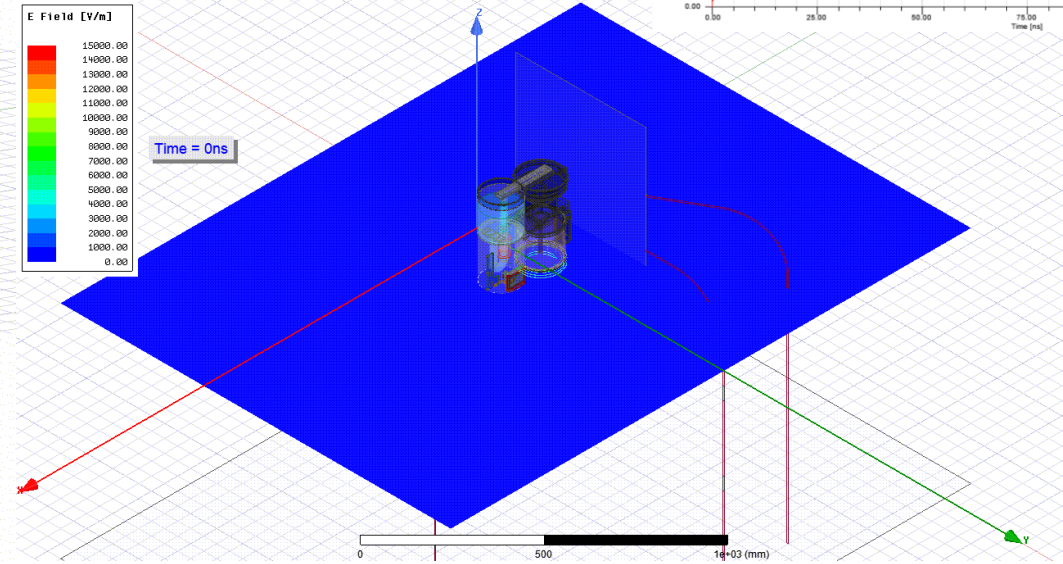
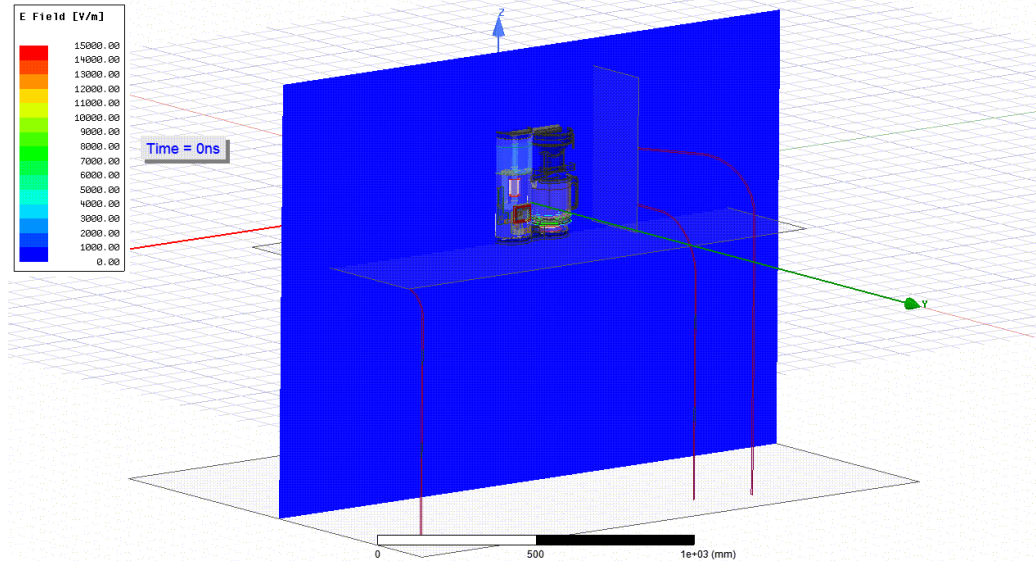


Contact Discharge		Air Discharge	
Level	Test Voltage kV	Level	Test Voltage kV
1	2	1	2
2	4	2	4
3	6	3	8
4	8	4	15
X ^{Note 1}	Special	X ^{Note 1}	Special

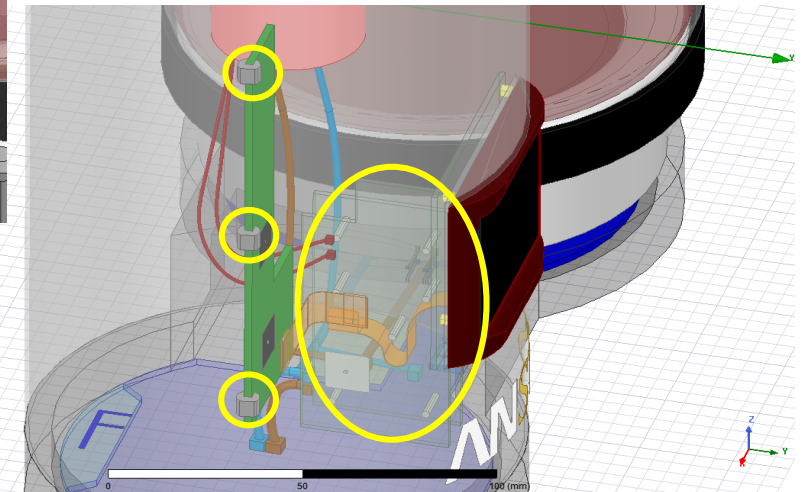
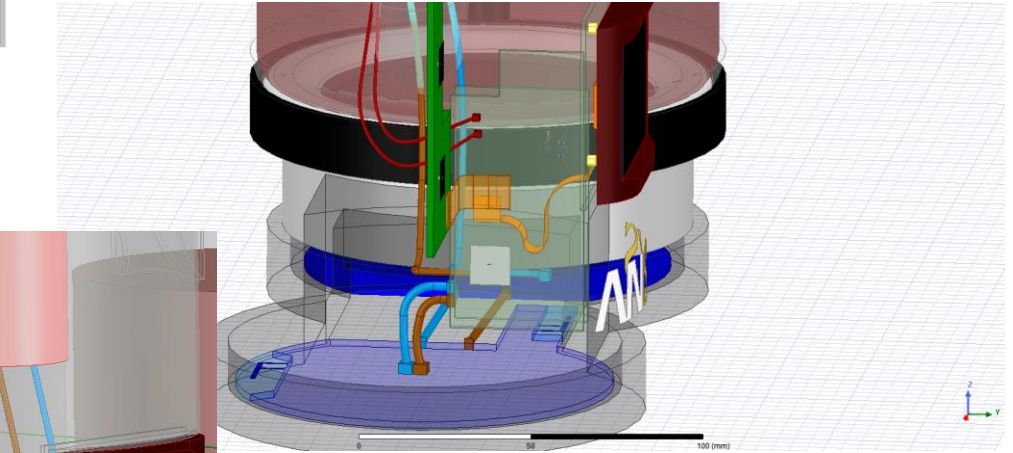
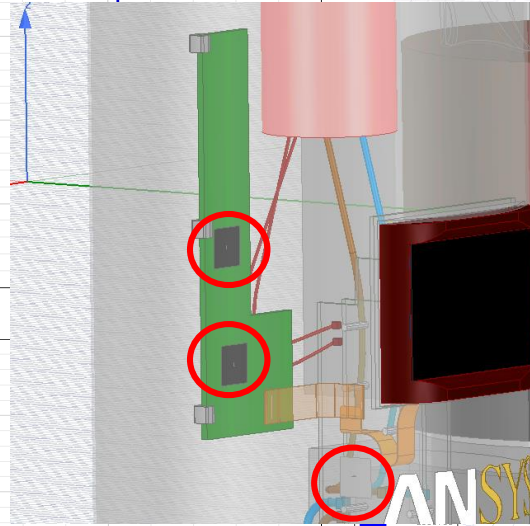
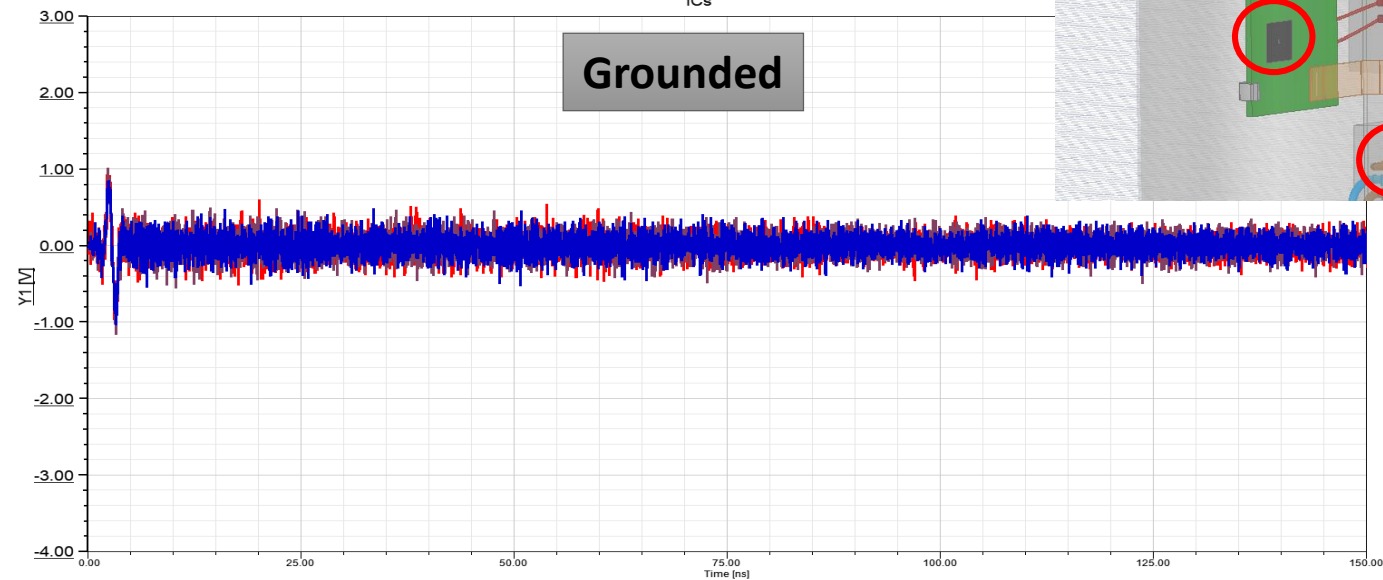
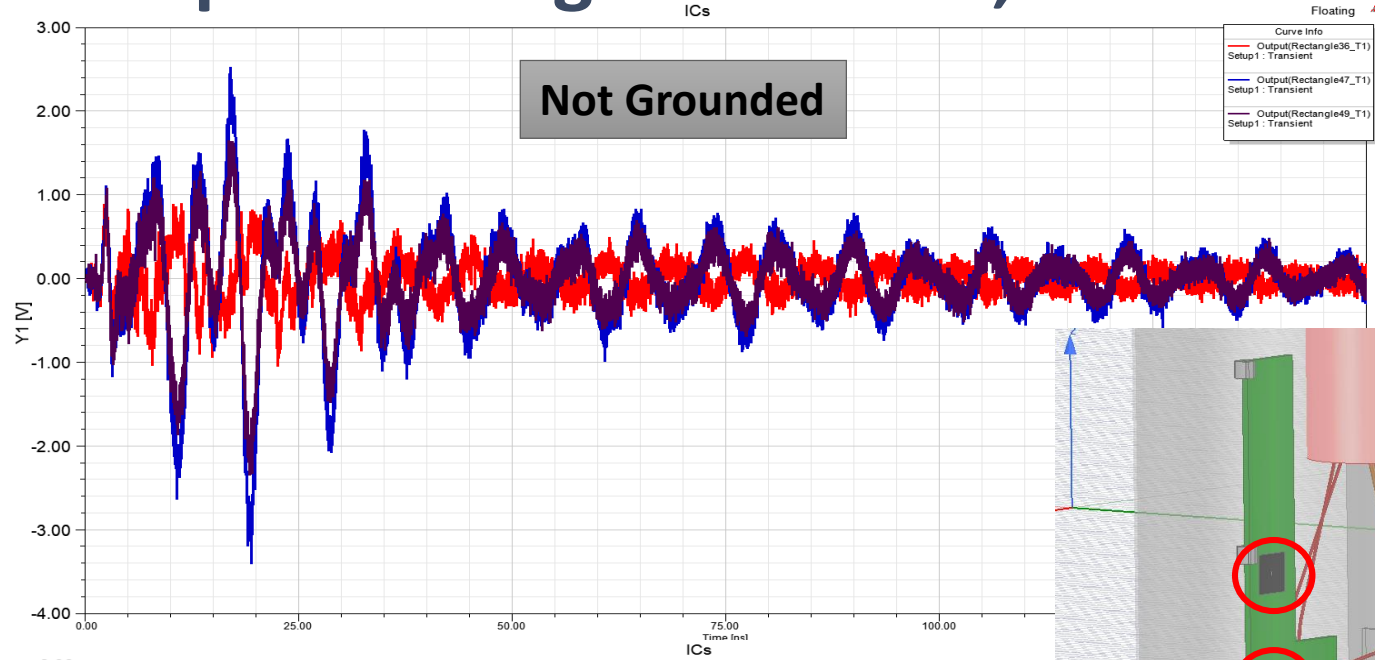
ESD Simulation Example, Indirect Discharge



Animated E-Field Distribution, Indirect Discharge

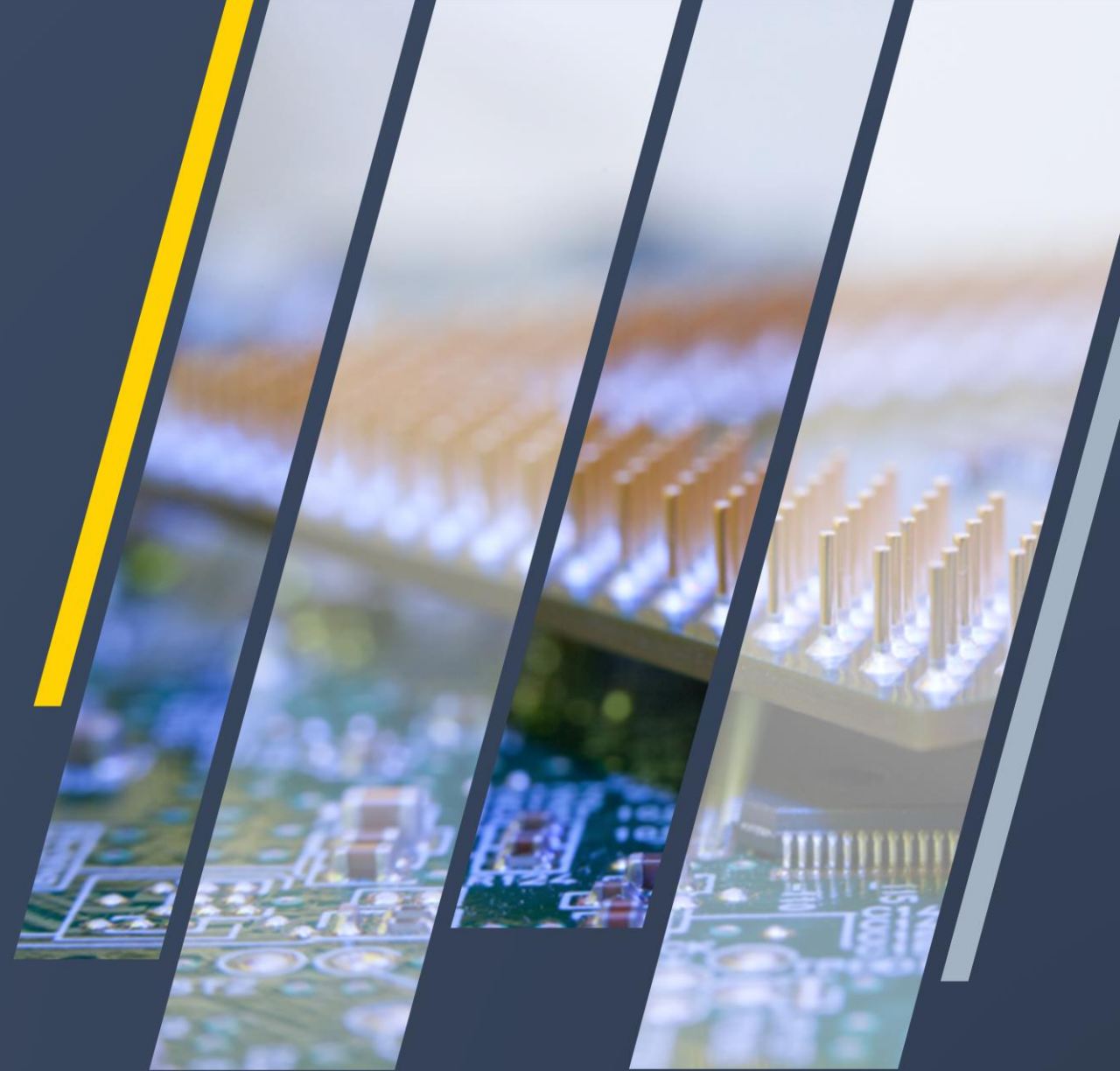


Coupled Voltage to IC area, Relative Difference



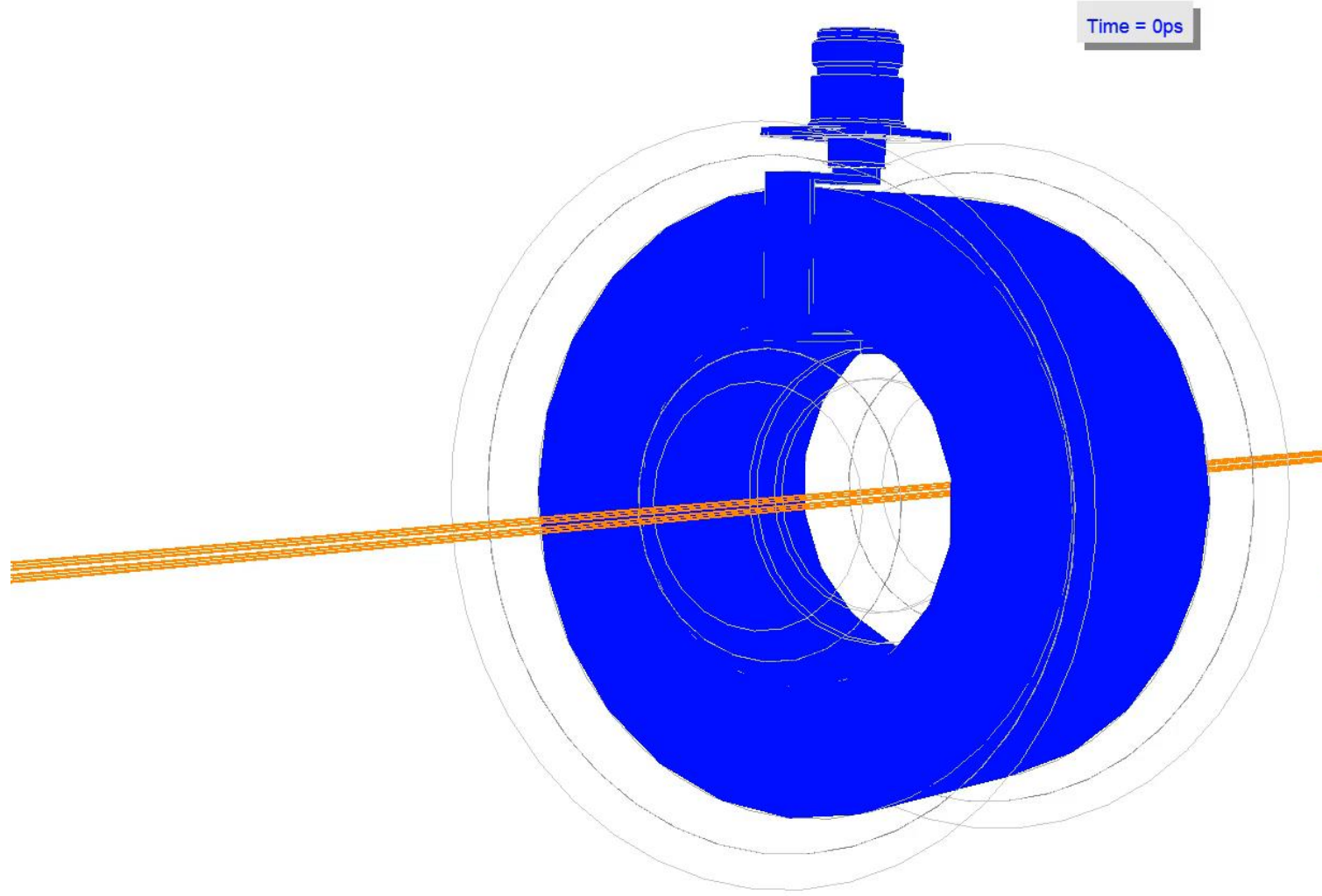


Bulk Current Injection ISO 11452-4



BCI TEST

The Bulk Current Injection Probe provides a means of applying a controlled RF stress level to an EUT through cables without requiring a direct connection to the conductor(s) of interest. The BCI is simply clamped around the test conductors which then becomes a one turn secondary winding, with the current probe forming the core and primary winding of an RF transformer.

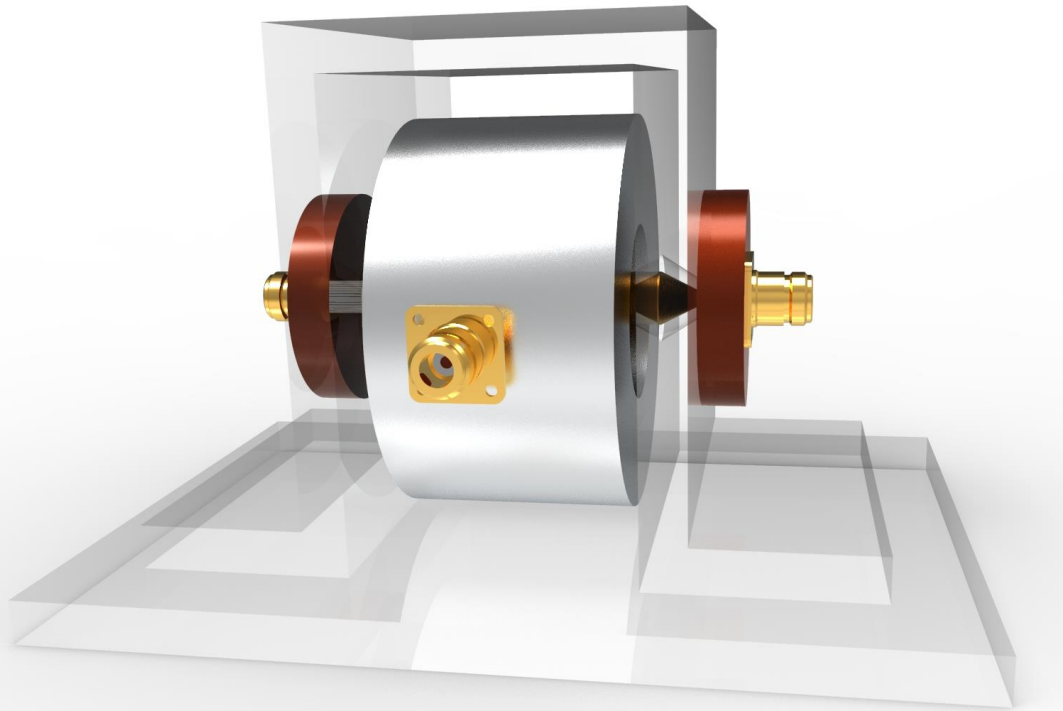


ISO 11452-4

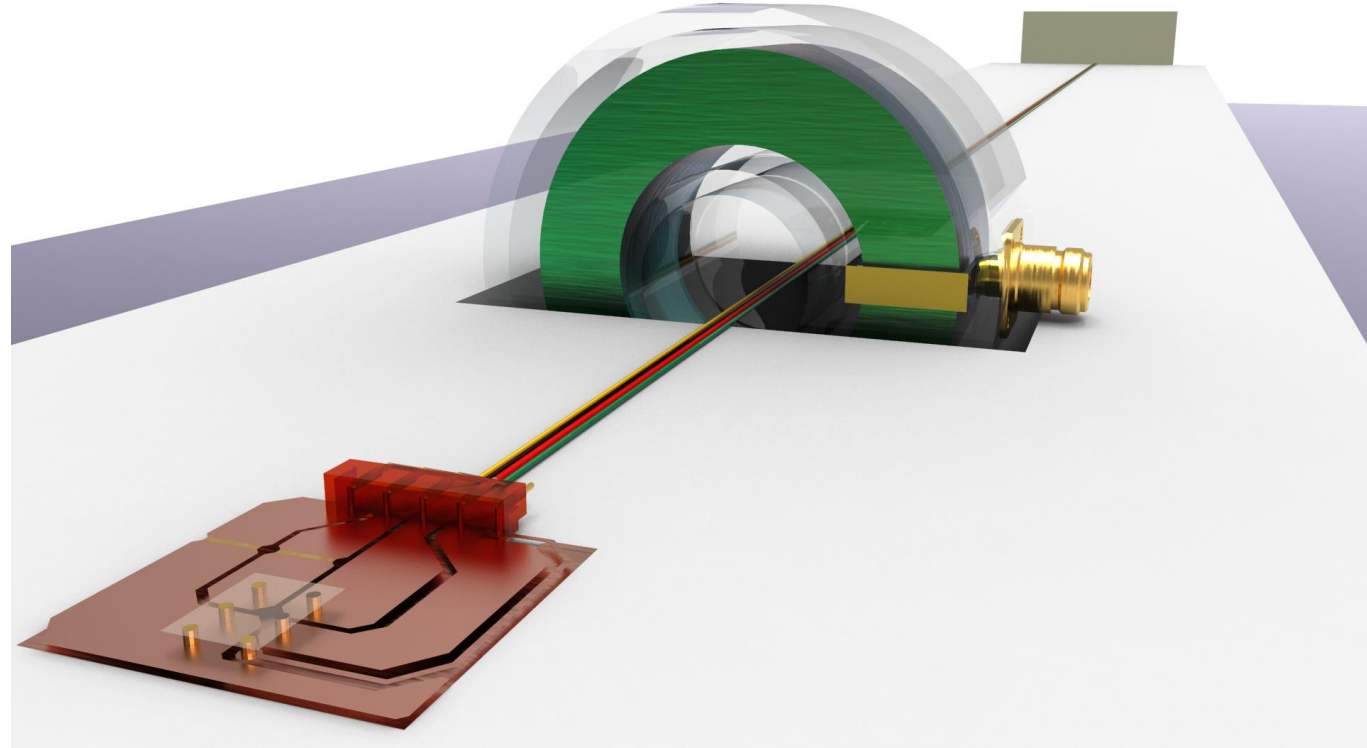
Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy

The ISO11452-4 standard methods consist of two phases:

1. Calibration using a Calibration Test Fixture

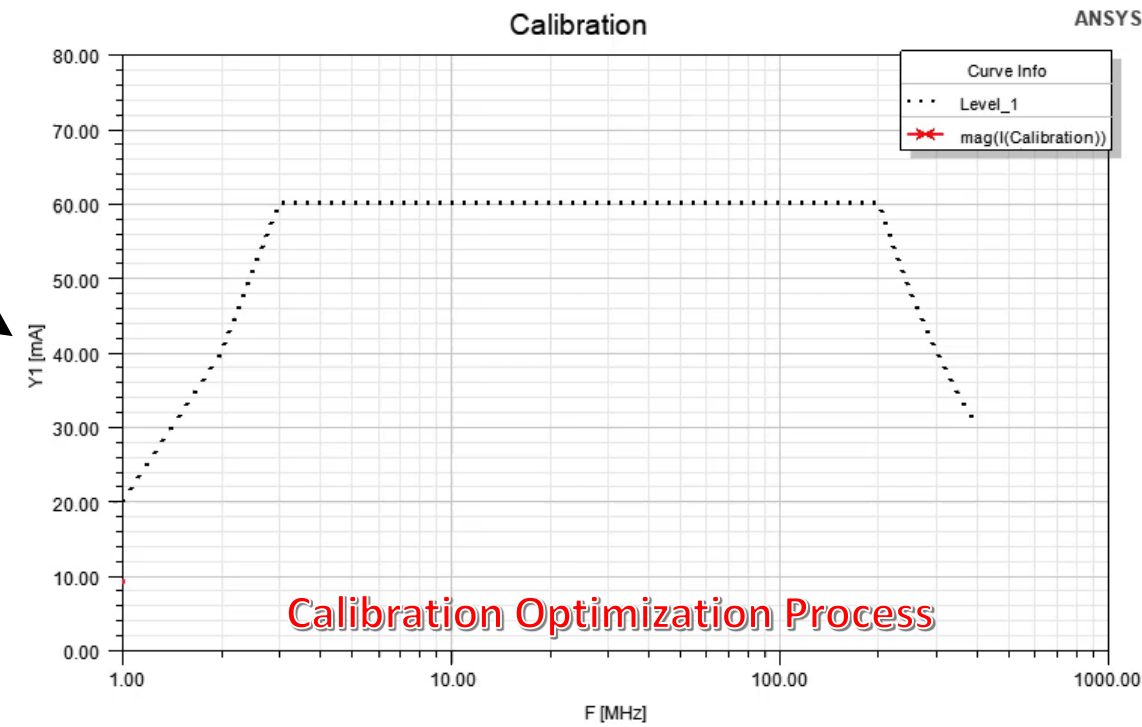
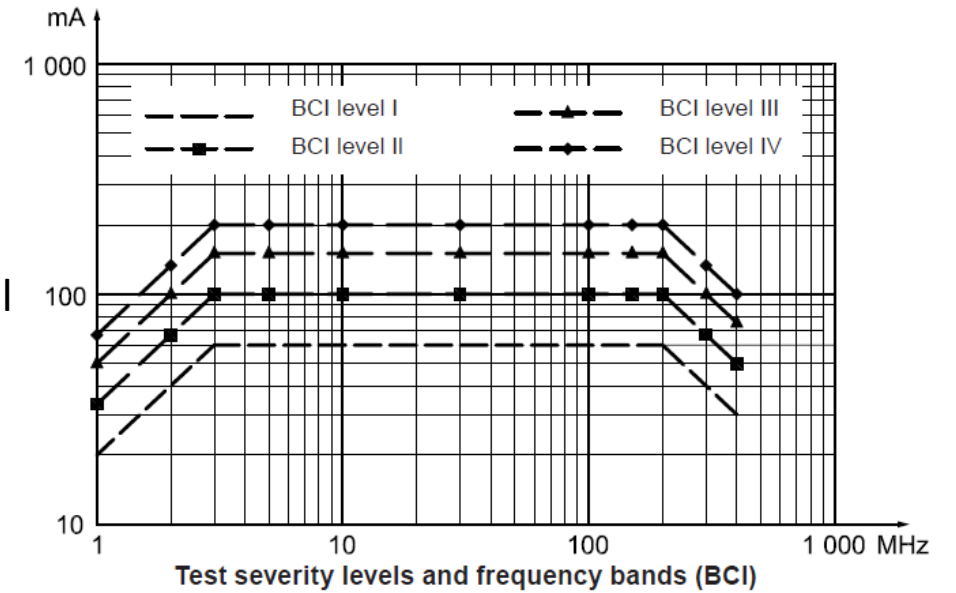
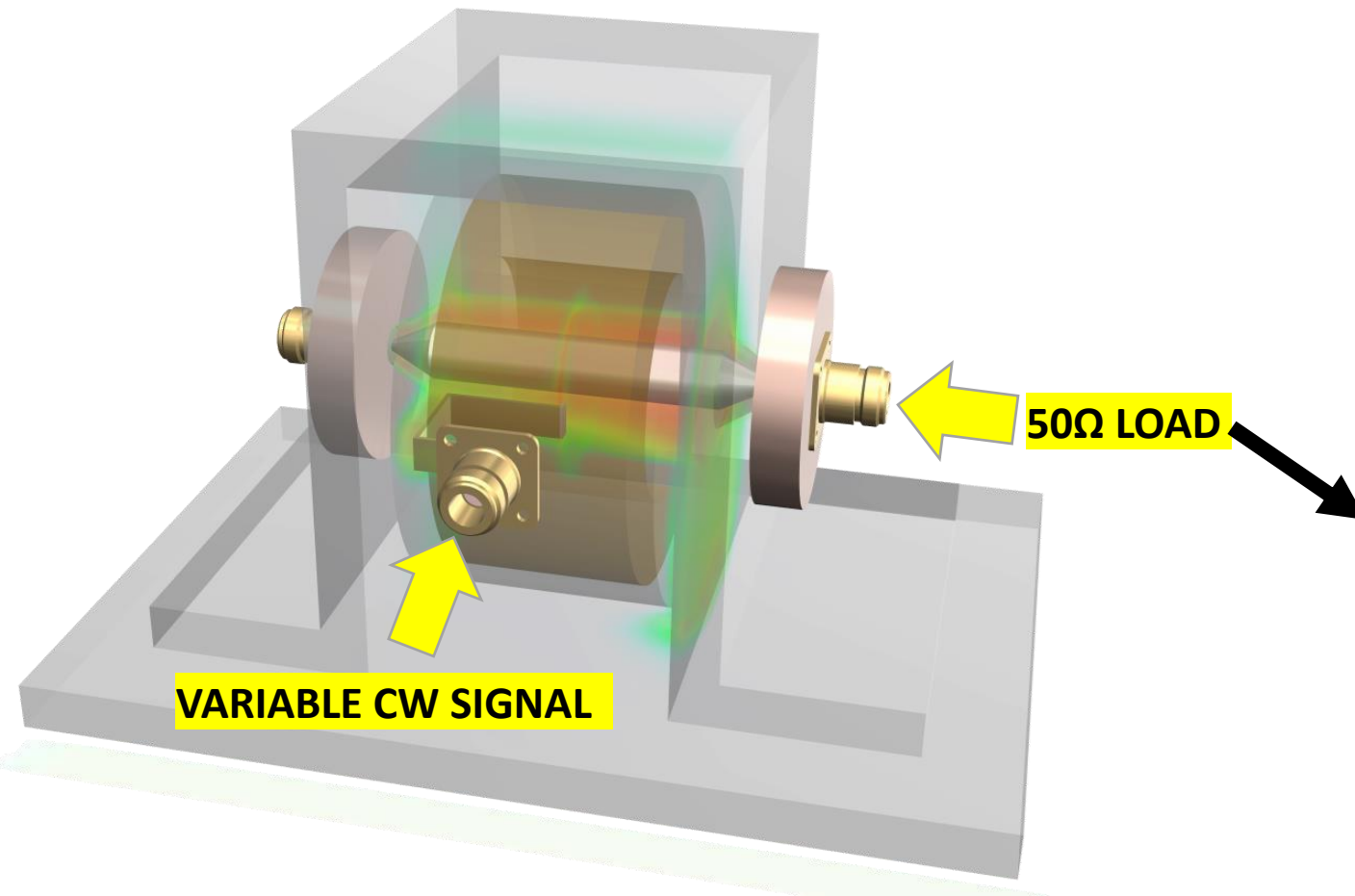


2. BCI Test Procedure



1. Calibration using Test Fixture

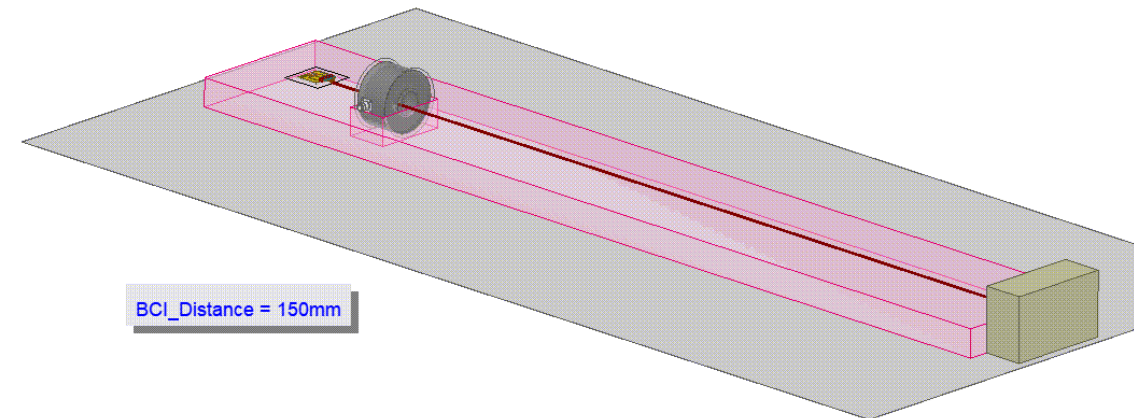
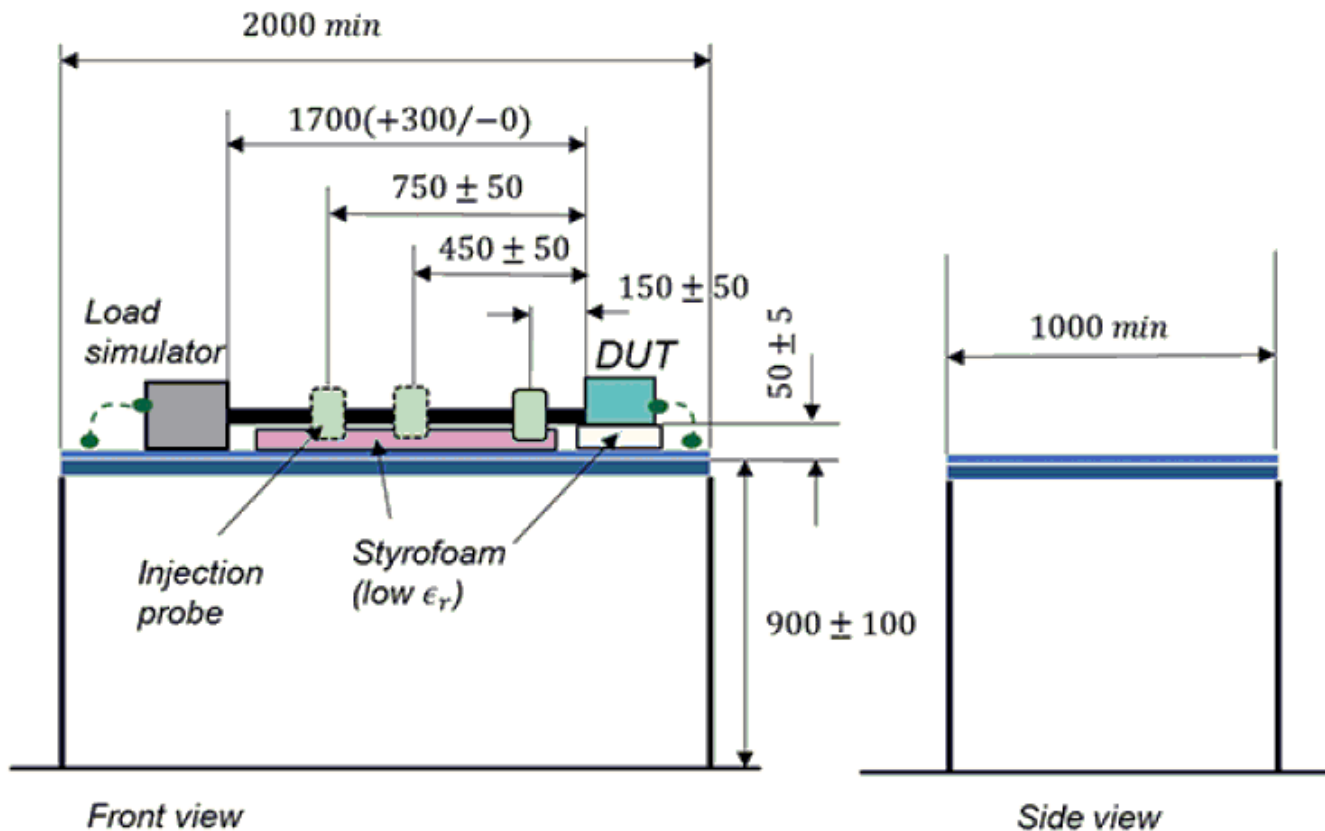
During the calibration procedure a variable input CW signal is injected into the BCI creating the required current level in the 50 Ω load over the required frequency range (1 –400 MHz). The level of the CW input signal used during the calibration is later used during the actual testing.



2. BCI Test Procedure - CW

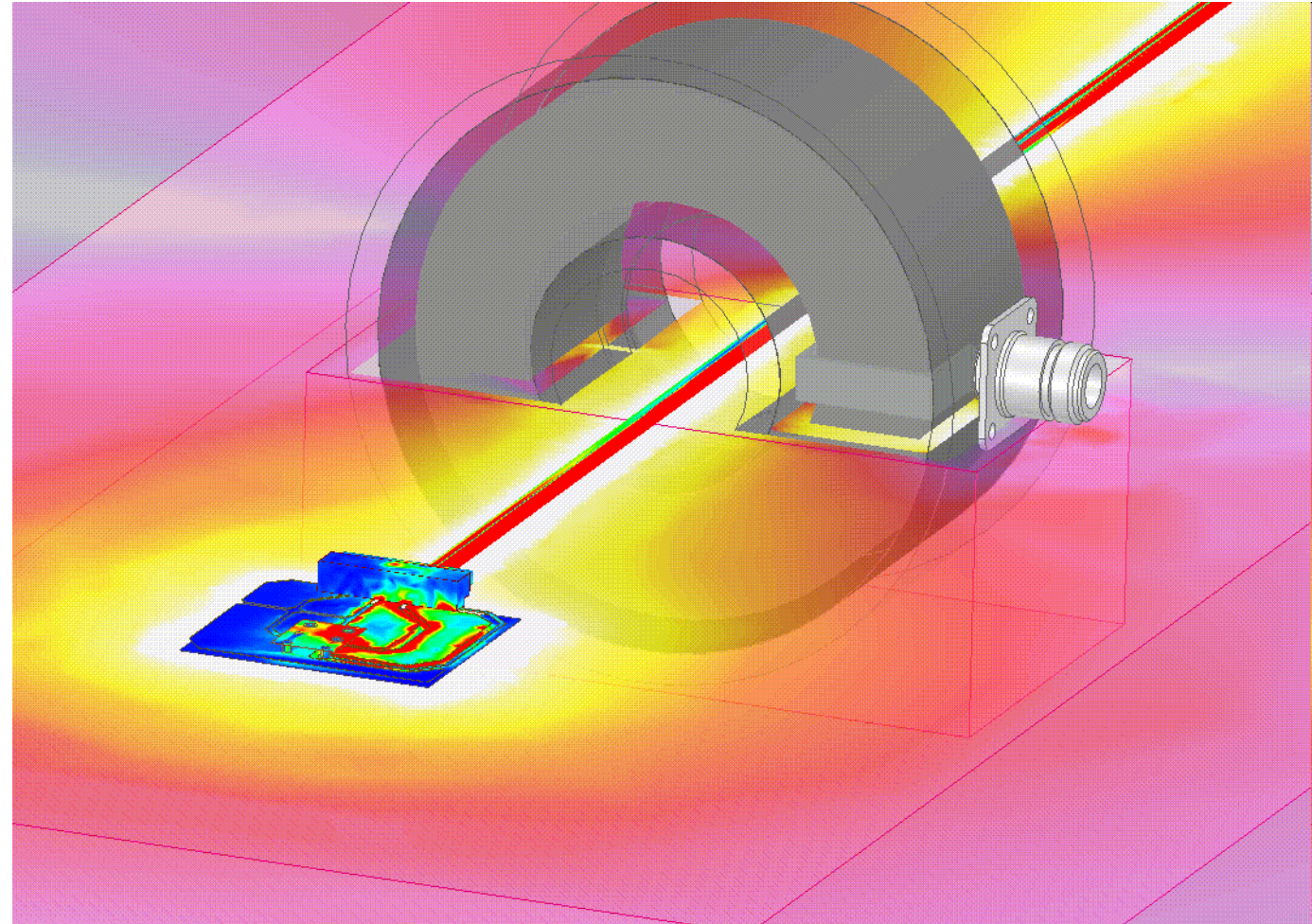
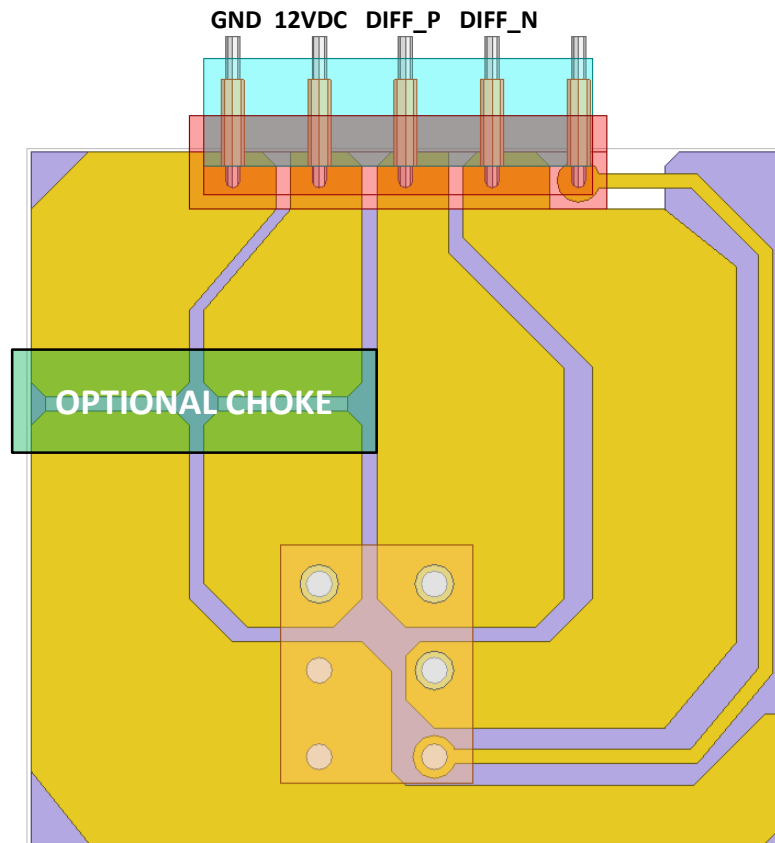
The test is conducted by injecting the input CW signal (recorded during the calibration procedure) into the current probe clamped over the harness connected to the DUT. The DUT shall be operated as required in the test plan.

HFSS Fully Parametric Model



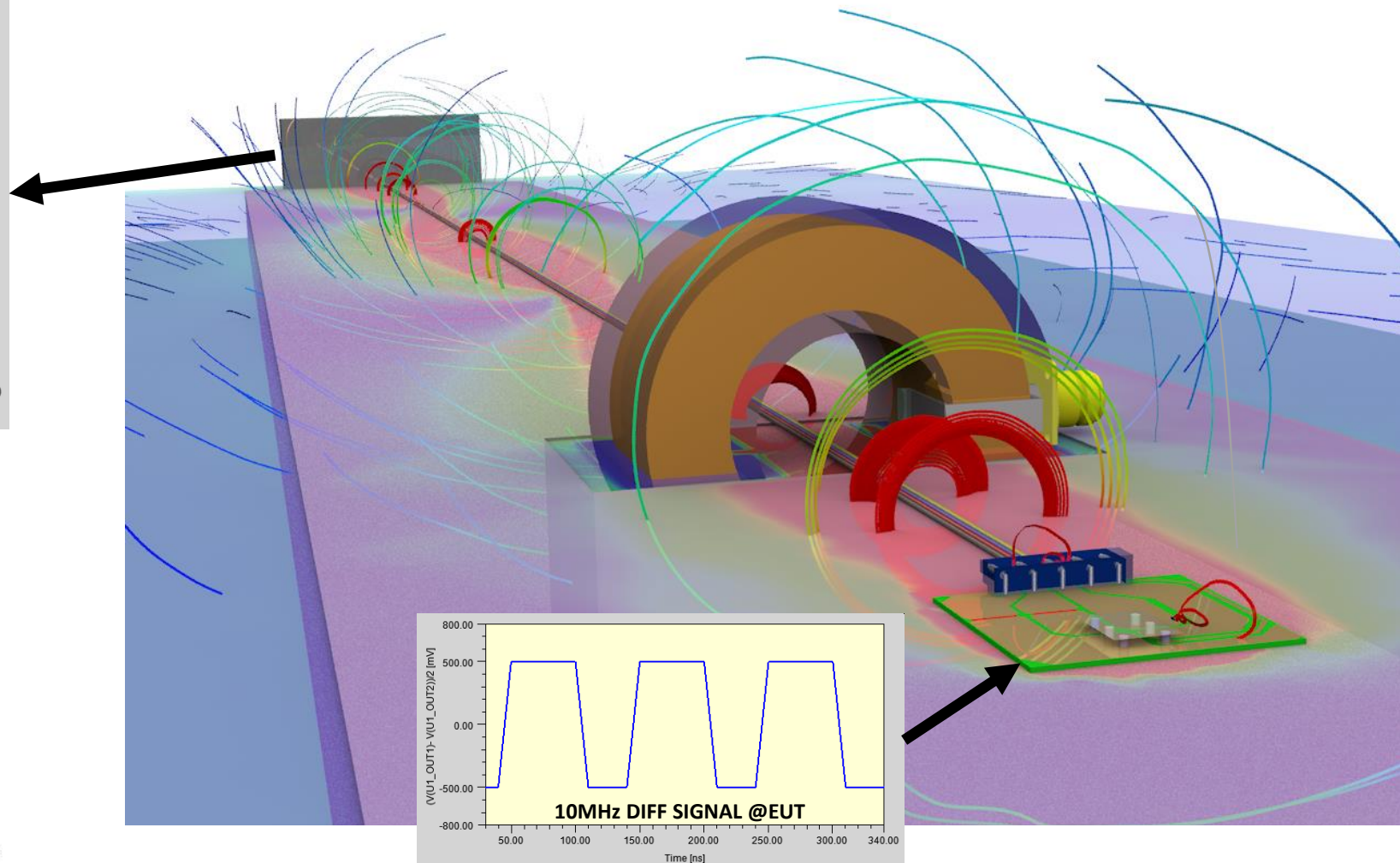
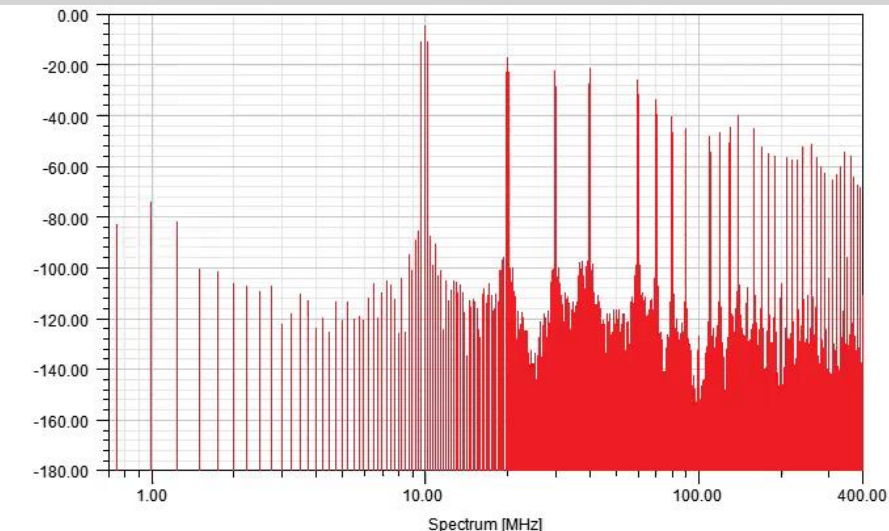
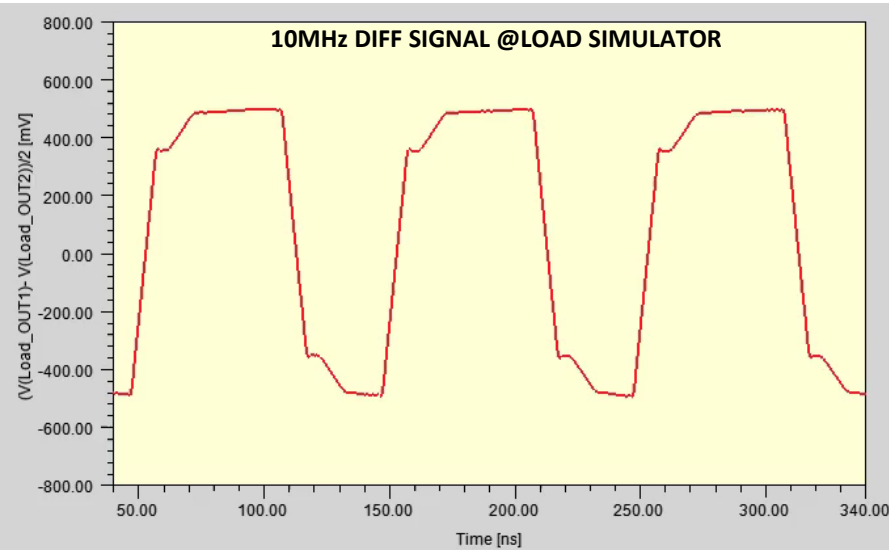
2. BCI Test Procedure - CW

A simple EUT is used where a 12VDC from battery is used to power the EUT and a 10MHz differential signal is transmitted by the EUT to the Load Simulator. An optional choke can be placed on the EUT to suppress noise.



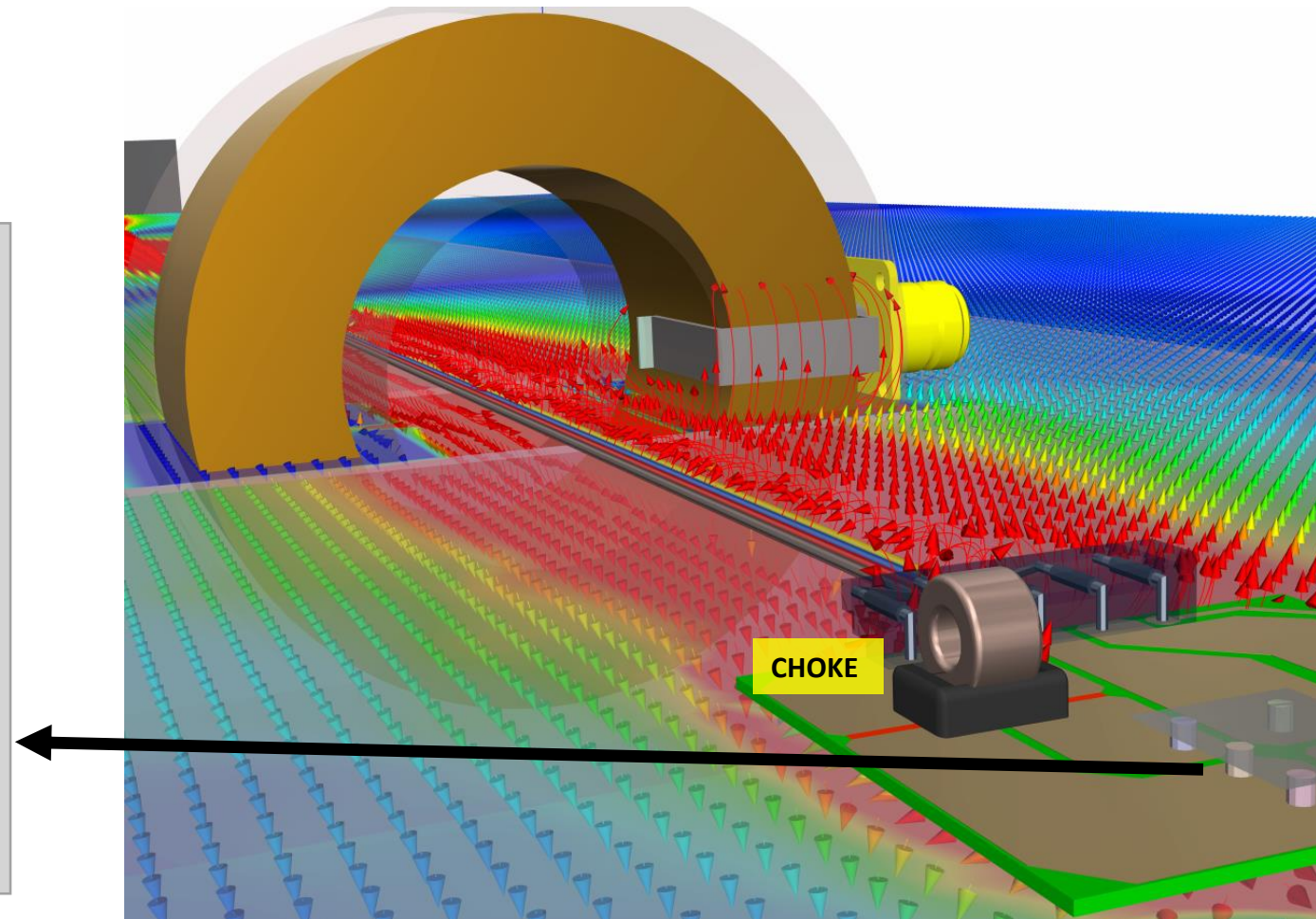
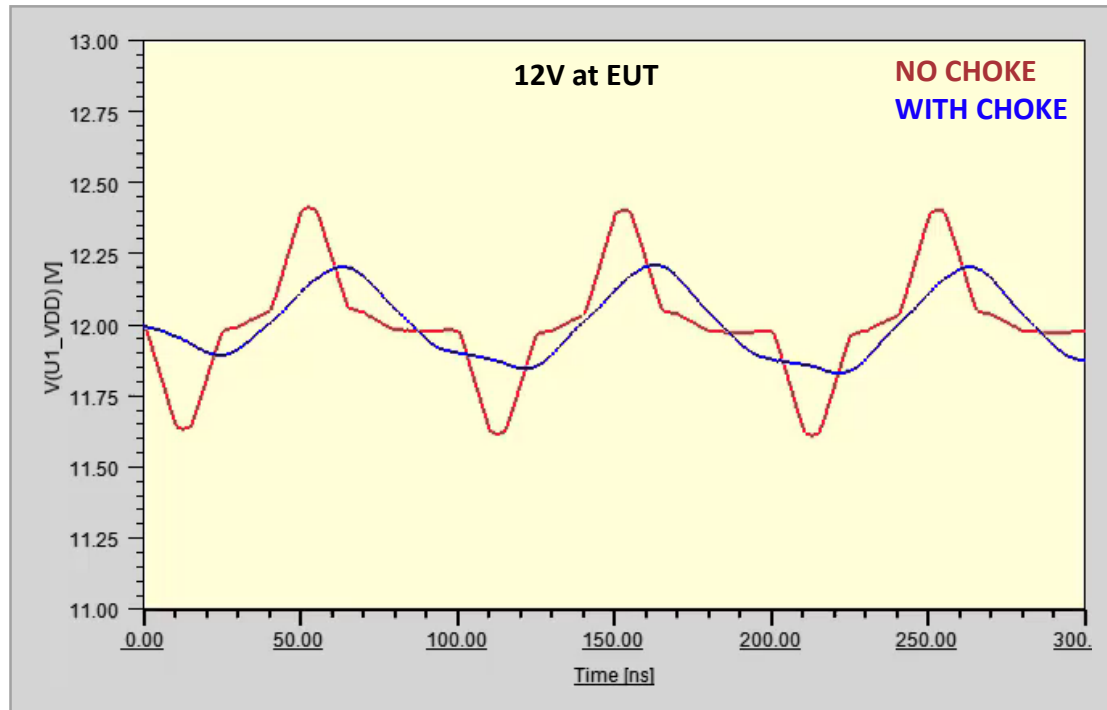
2. BCI Test Procedure - CW

Plot below shows how the differential signal is affected by the BCI as we change the input CW signal according to the calibration step (frequency range 1 to 400MHz).



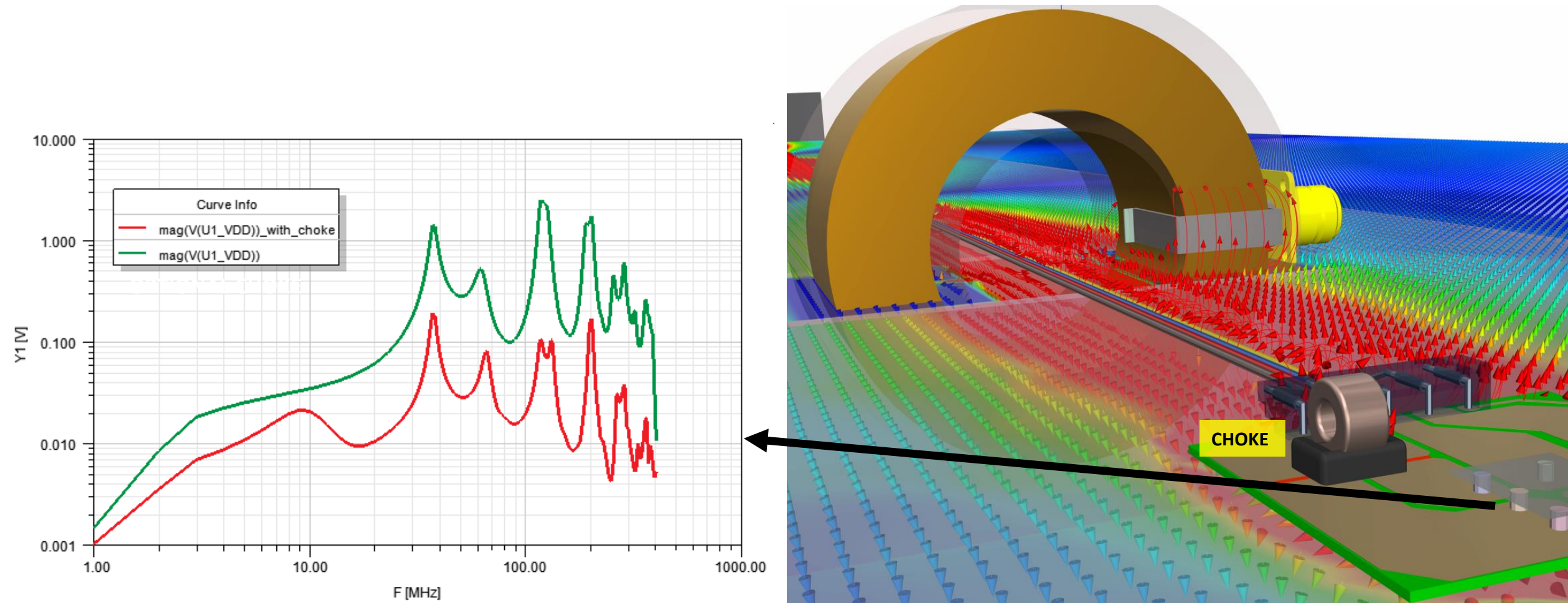
2. BCI Test Procedure - CW

Plot below shows the noise on the 12VDC at the EUT as we change the input CW signal according to the calibration step. The noise coupled from the BCI decreases if we add a choke.



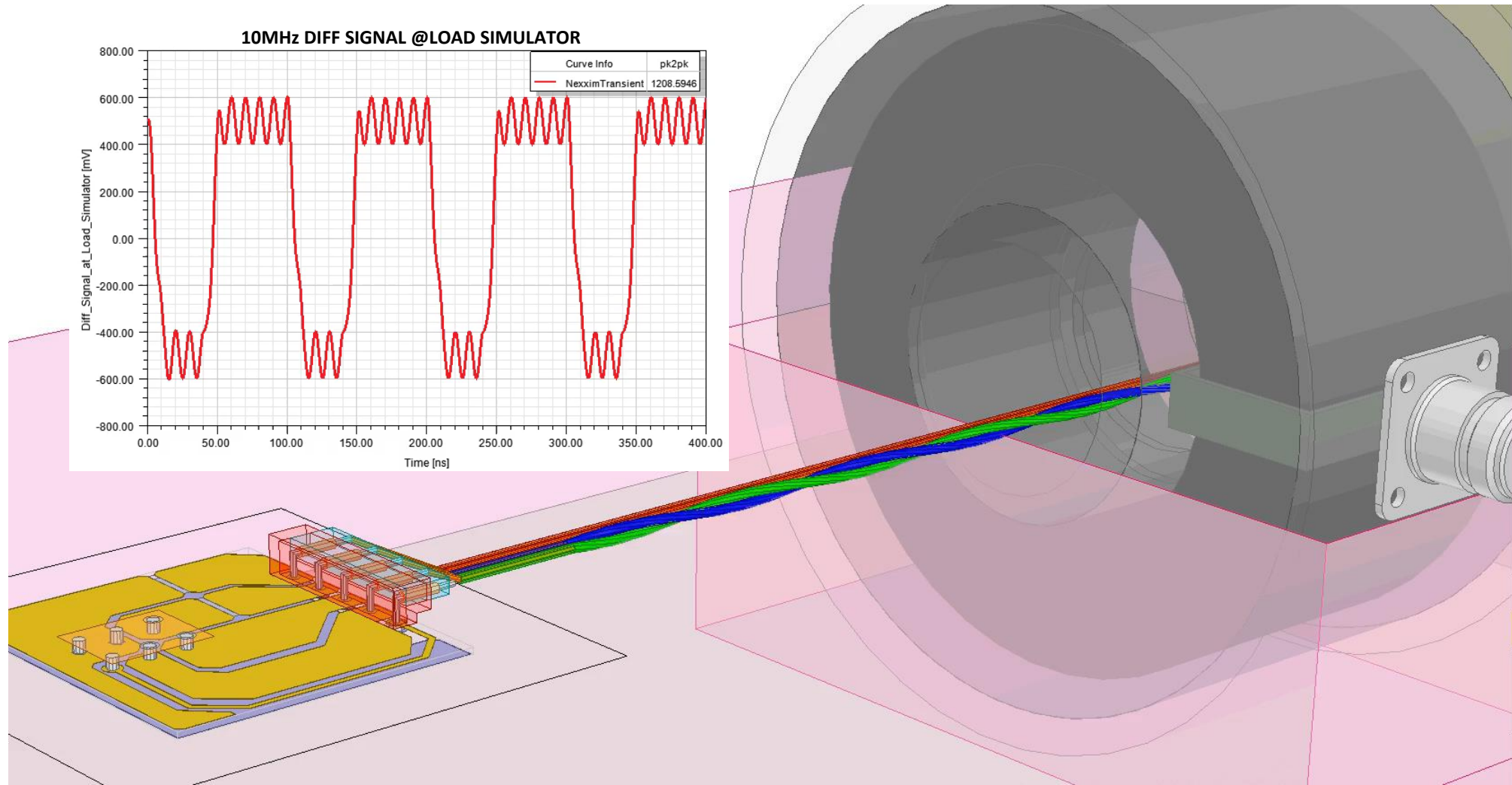
2. BCI Test Procedure - CW

We can also evaluate the results in frequency domain. In this case the 12VDC battery is turned off, so only the noise generated by the BCI is measured at the 12V pin on the EUT. Plot below shows that induced voltage in frequency domain with and without the choke.



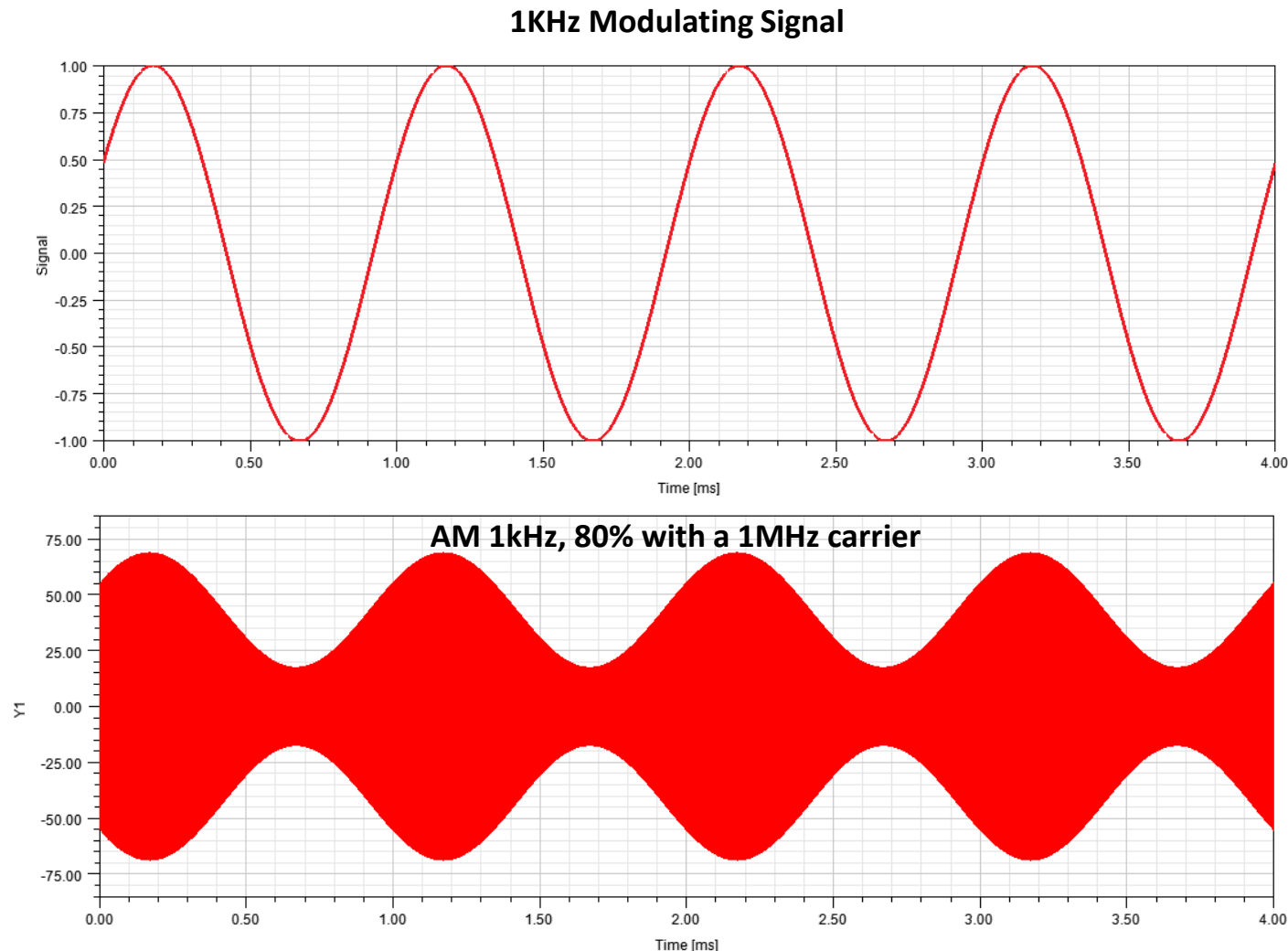
2. BCI Test Procedure - CW

The conductors for the differential signals are now twisted. Near the EUT, a segment of the conductors is kept in parallel and it is not twisted. By changing the length of this segment, it is possible to observe the noise induced in the differential signal.



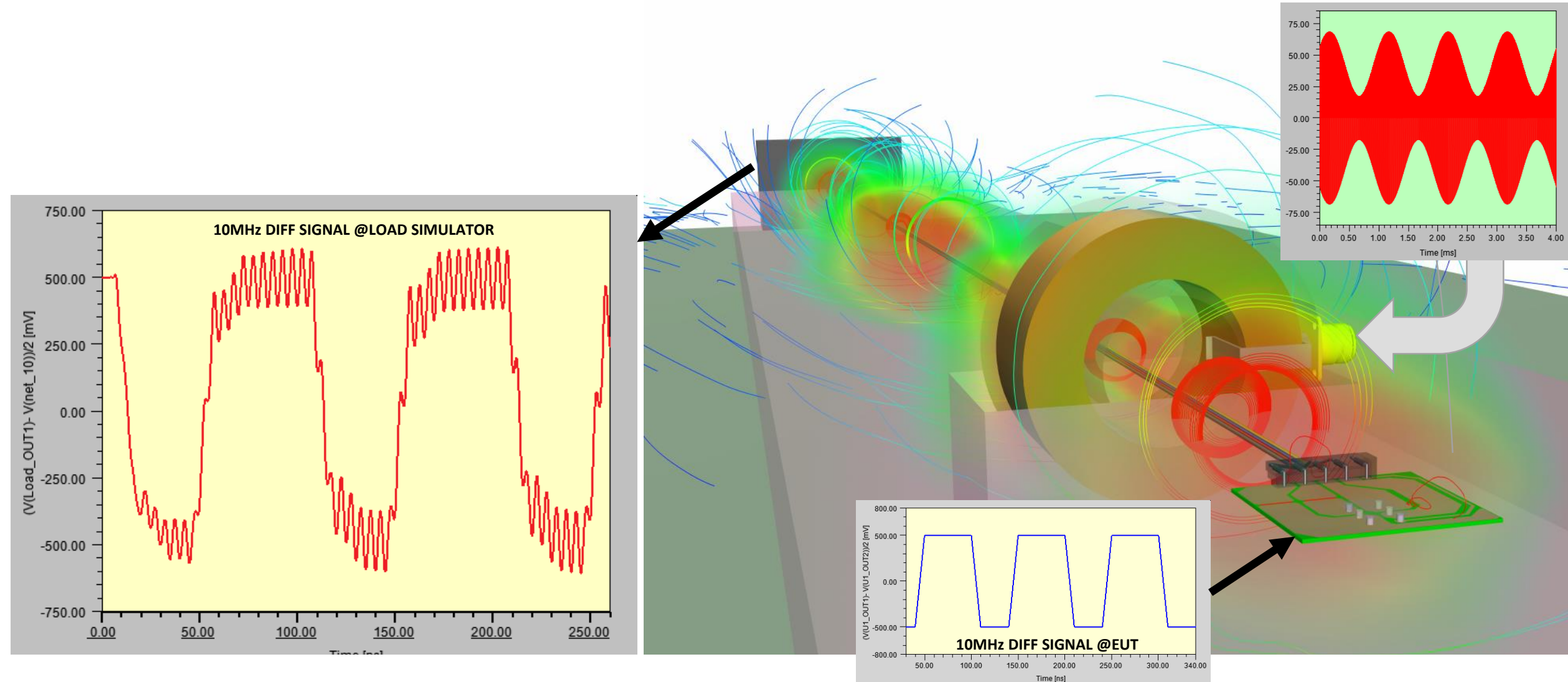
2. BCI Test Procedure – AM 1kHz, 80%

During the testing, besides CW, an AM modulated signal is used with the carrier frequency, f , varied from 1 to 400 MHz. A modulation index of 0.8 is used as well as a CW modulating signal of 1kHz.



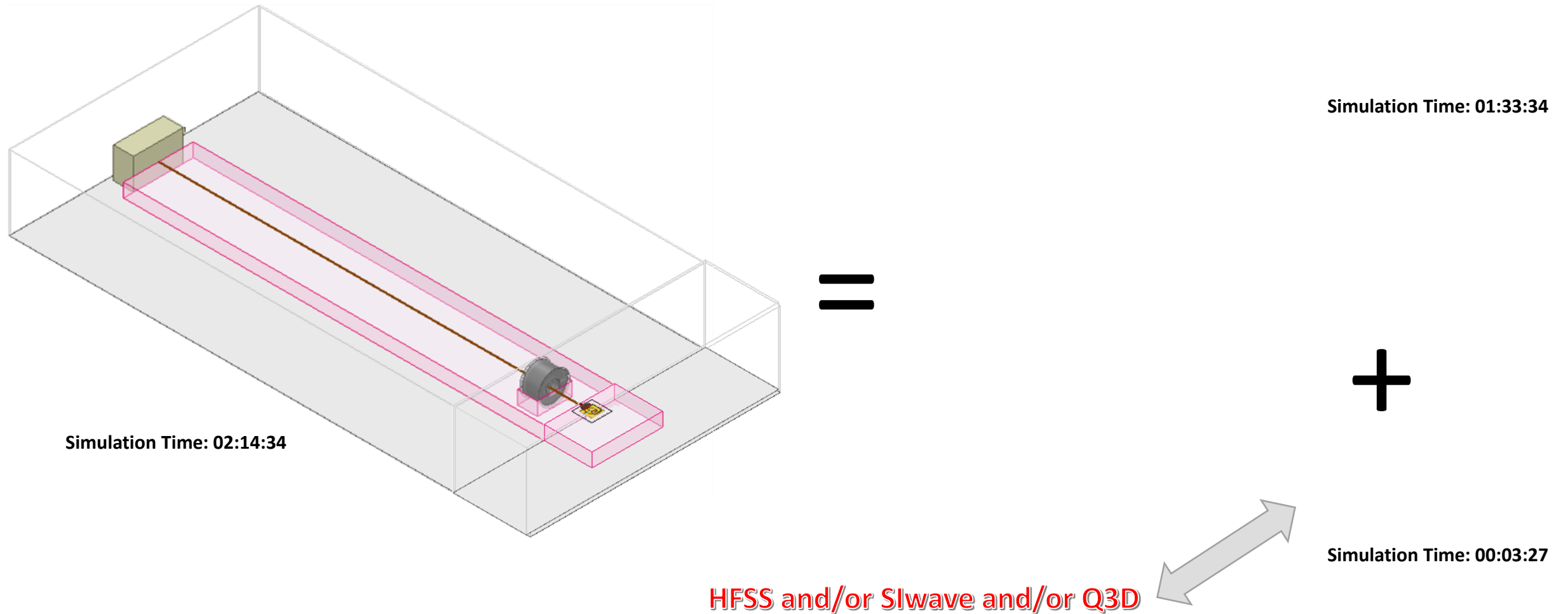
2. BCI Test Procedure – AM 1kHz, 80%

In this test the AM 1kHz, modulation index of 80% using a 200MHz carrier is applied to the BCI



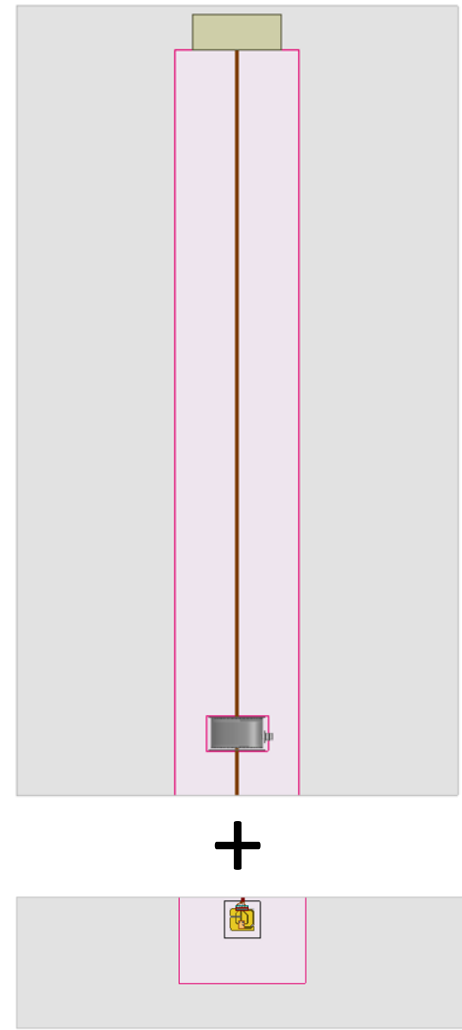
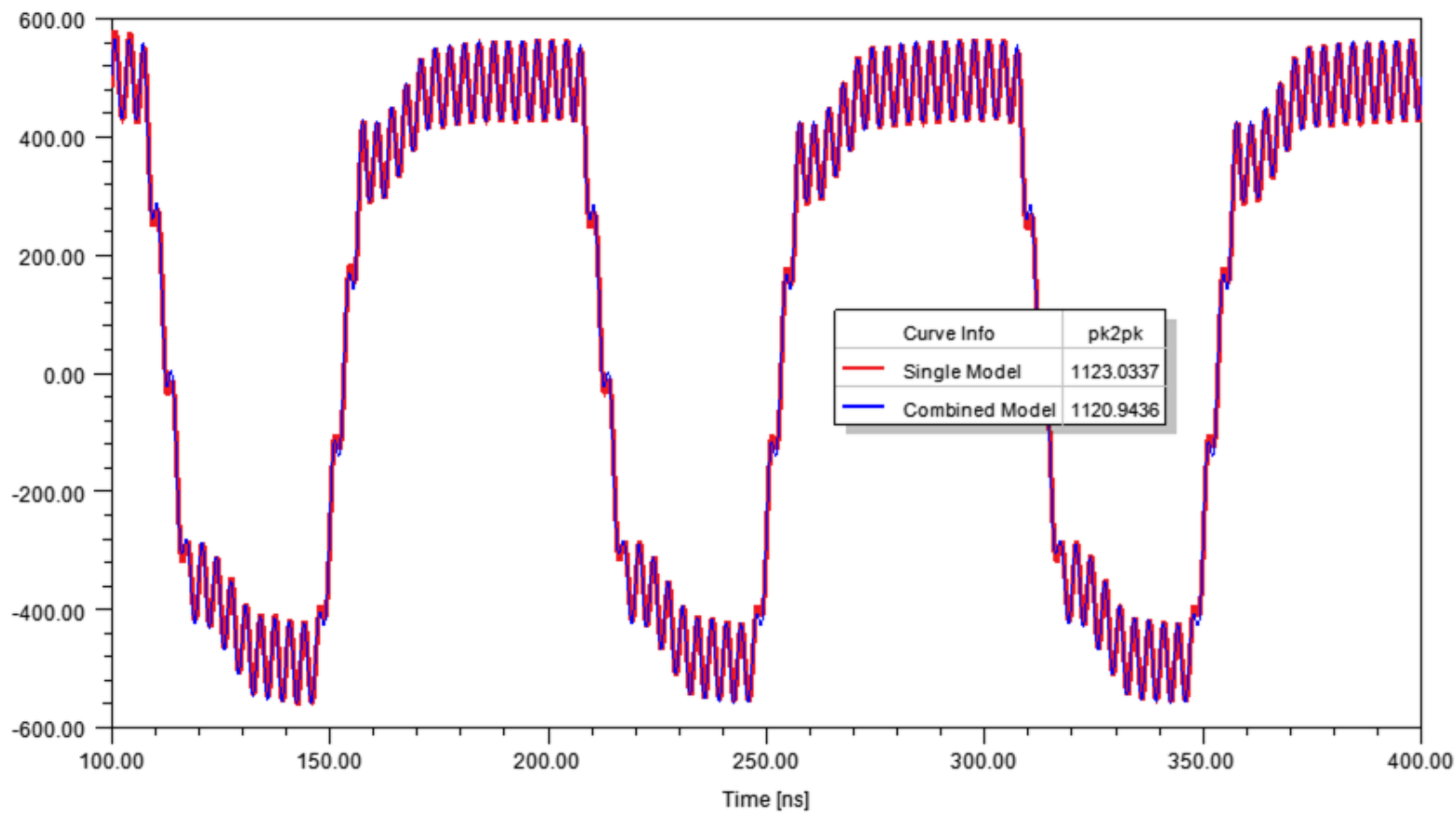
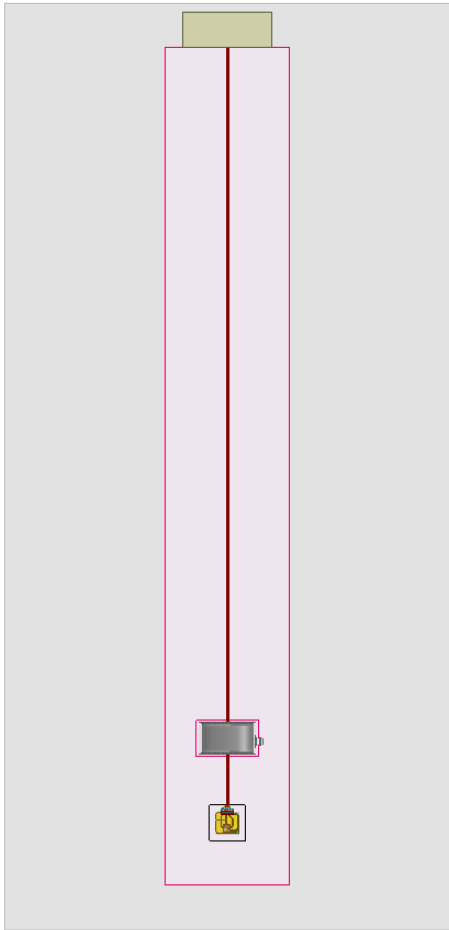
Approach for Complex EUT

The time to simulate complex EUT can be really large. A “divide and conquer” approach can be used: the 3D model can be divided into 2 separated models to accelerate the simulation process.



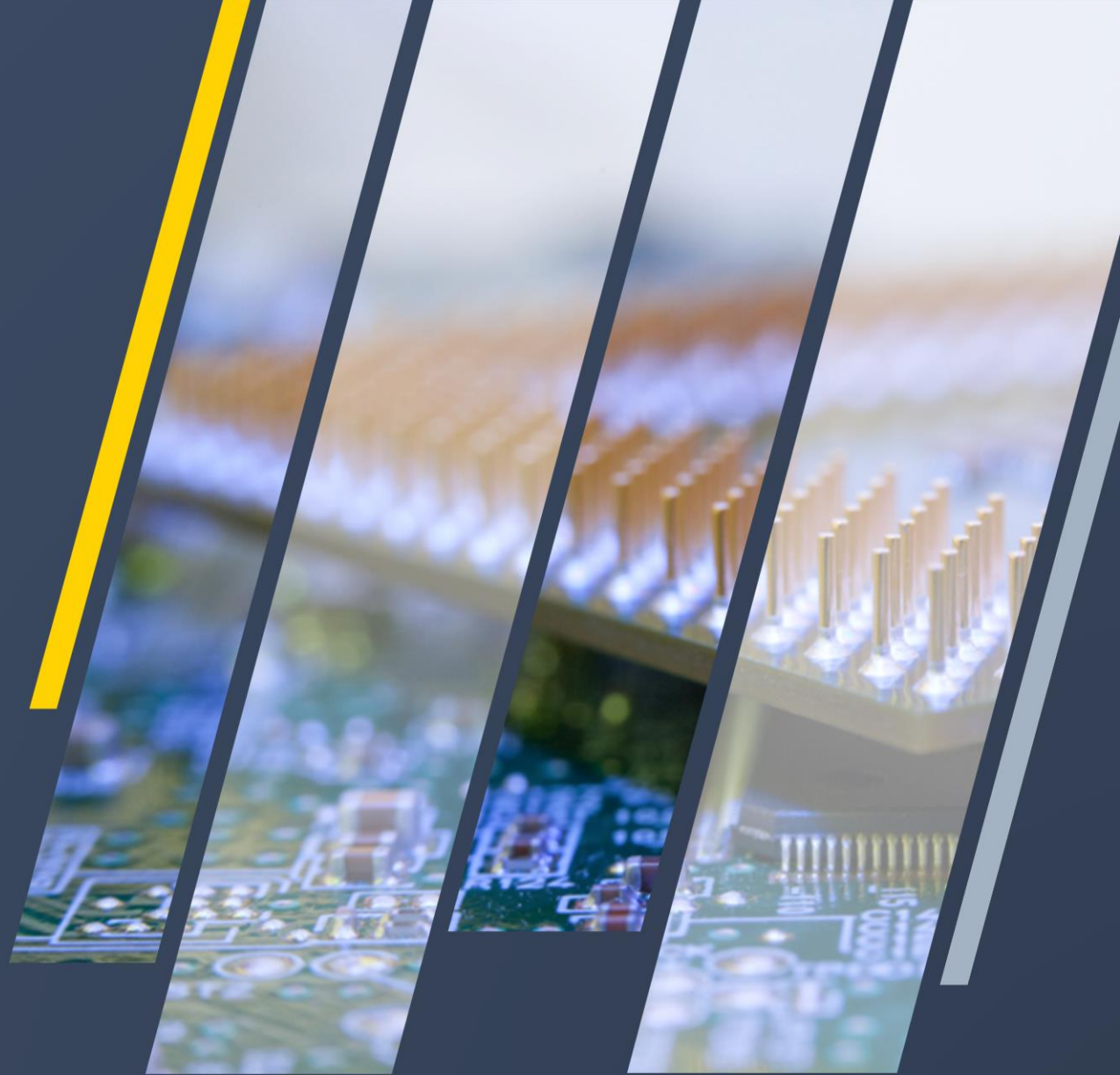
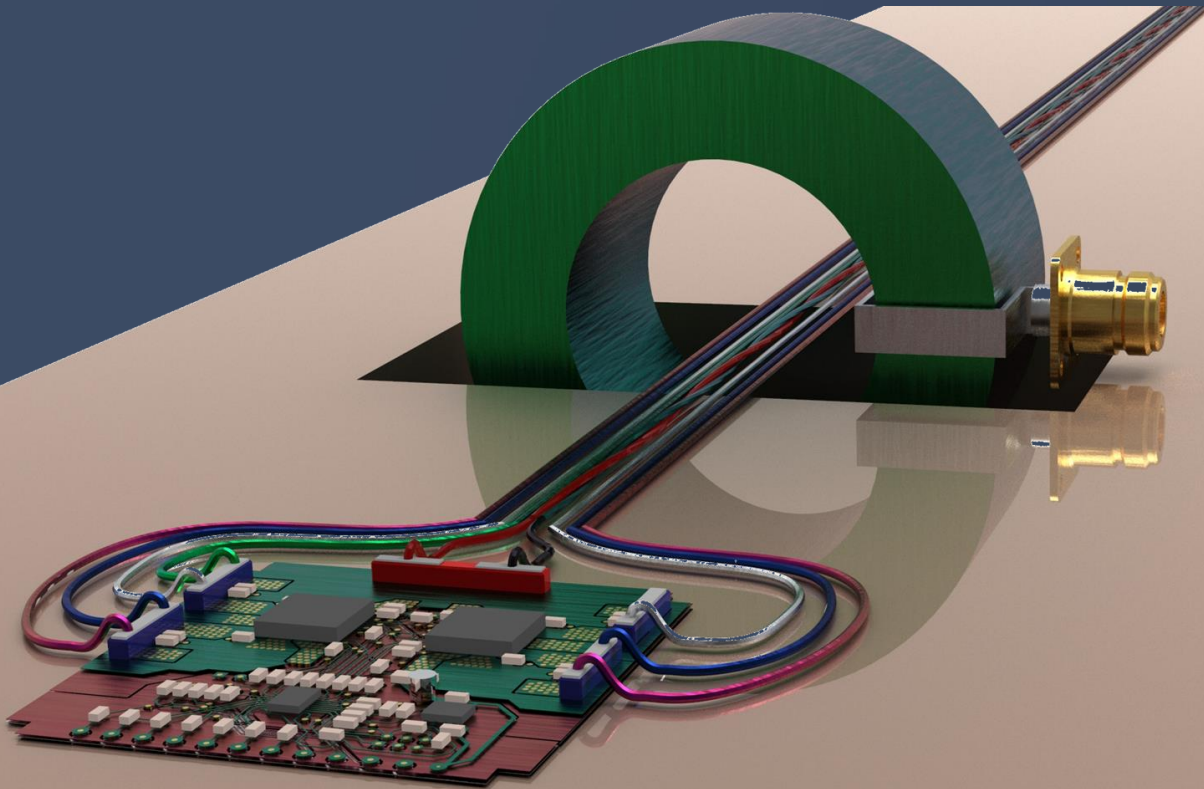
Approach for Complex EUT

As observed below, the waveform at the load simulator is virtually the same for a single model and for the combined two separated models



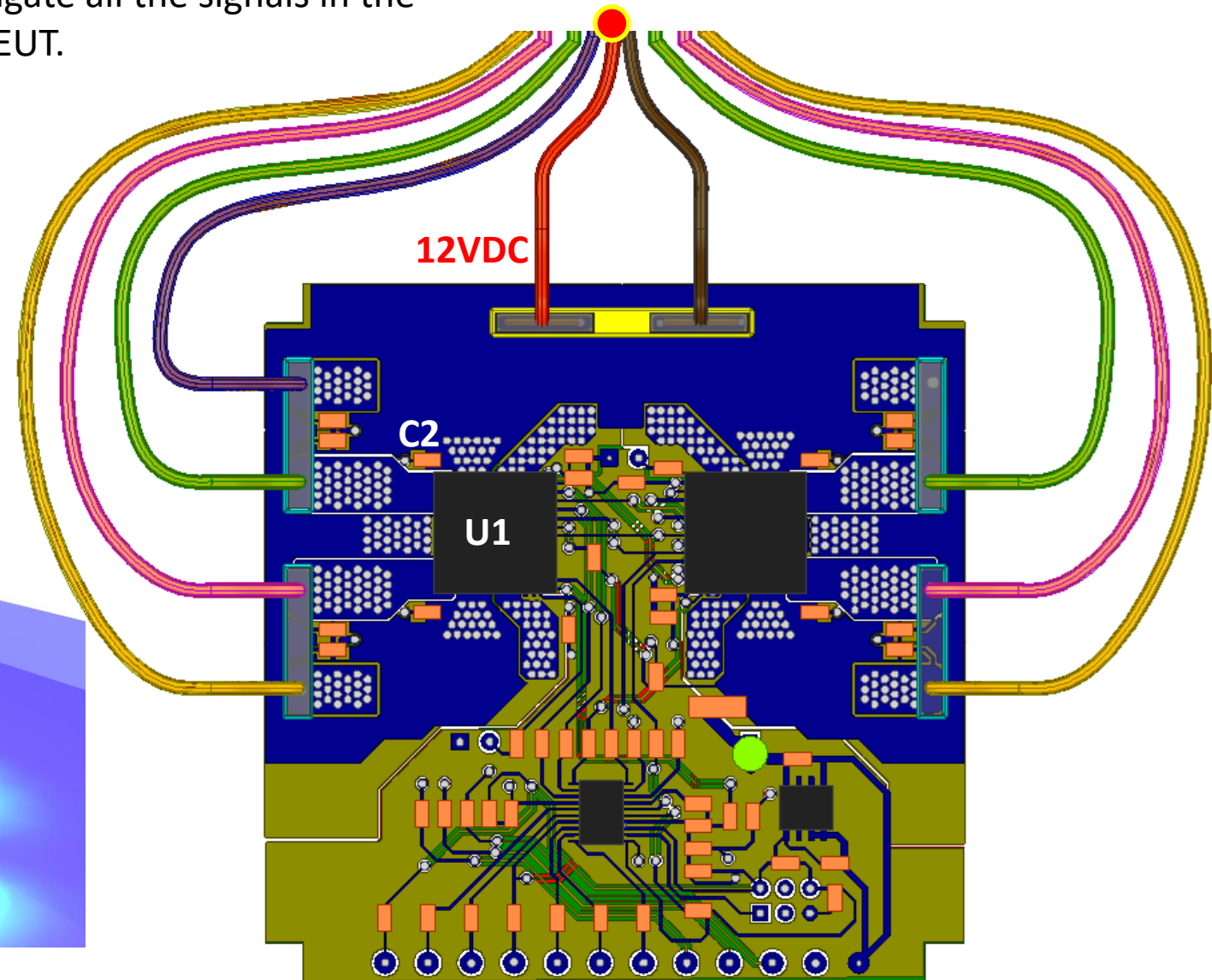
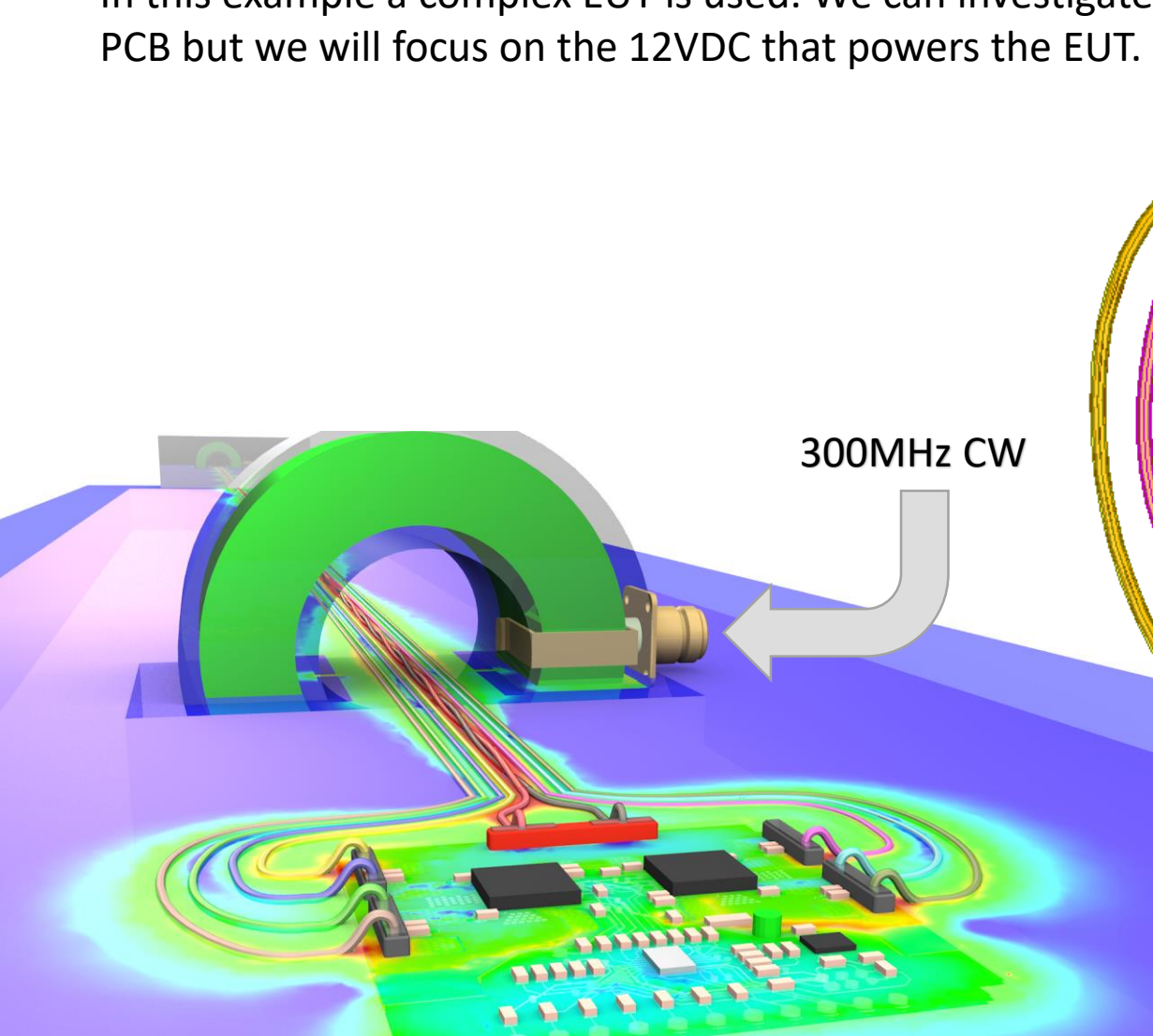
ANSYS®

BCI A Complex EUT



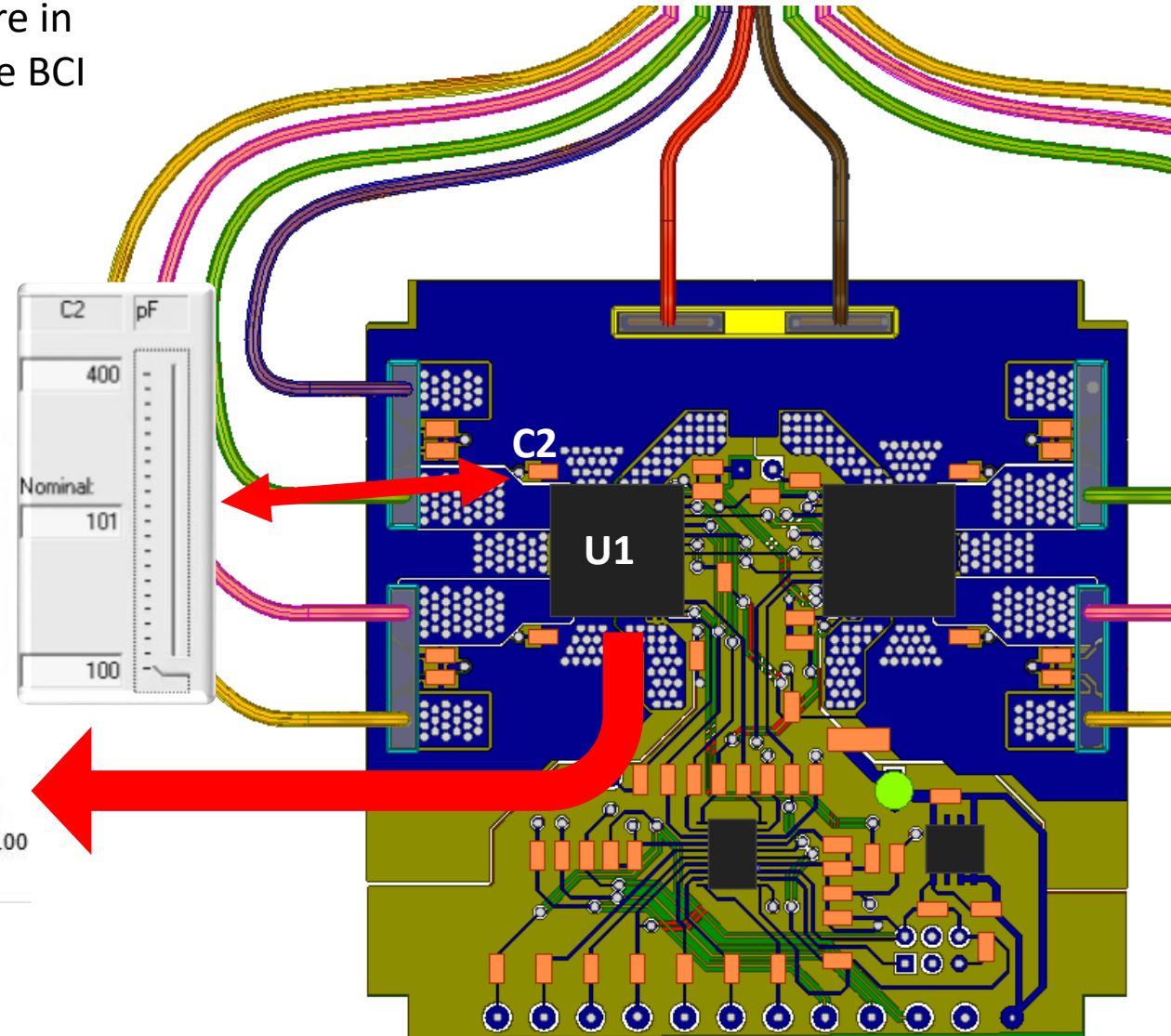
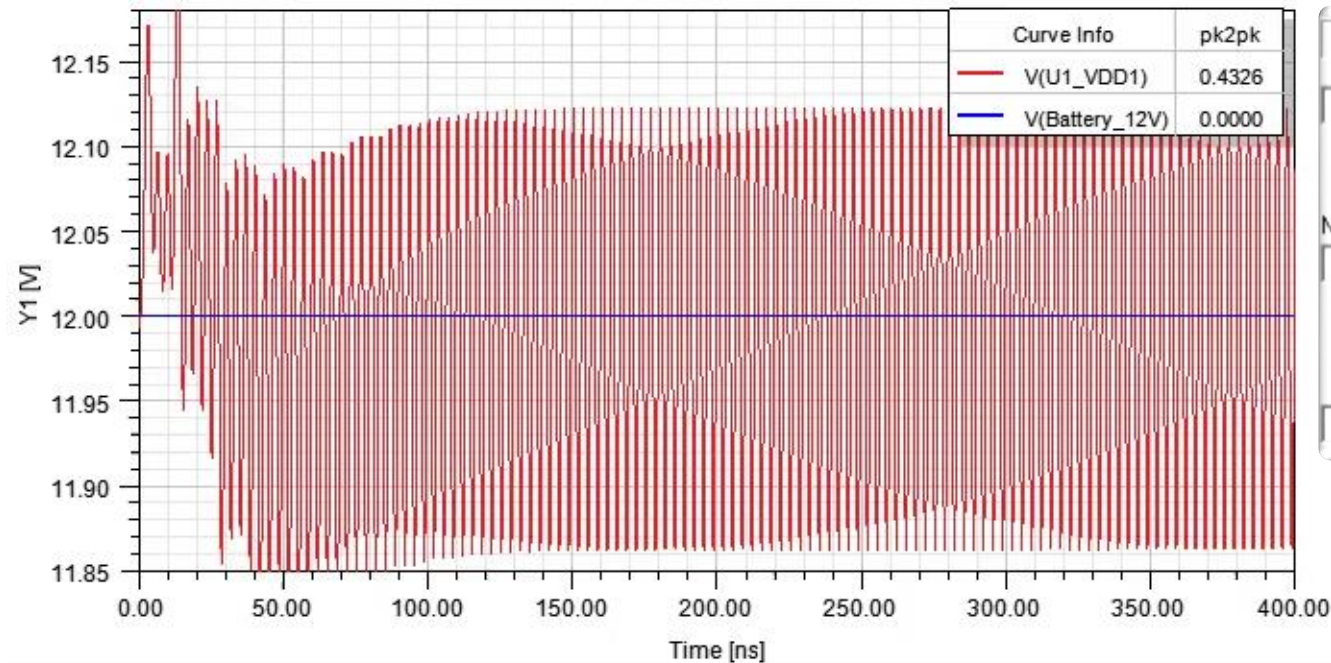
Complex EUT

In this example a complex EUT is used. We can investigate all the signals in the PCB but we will focus on the 12VDC that powers the EUT.



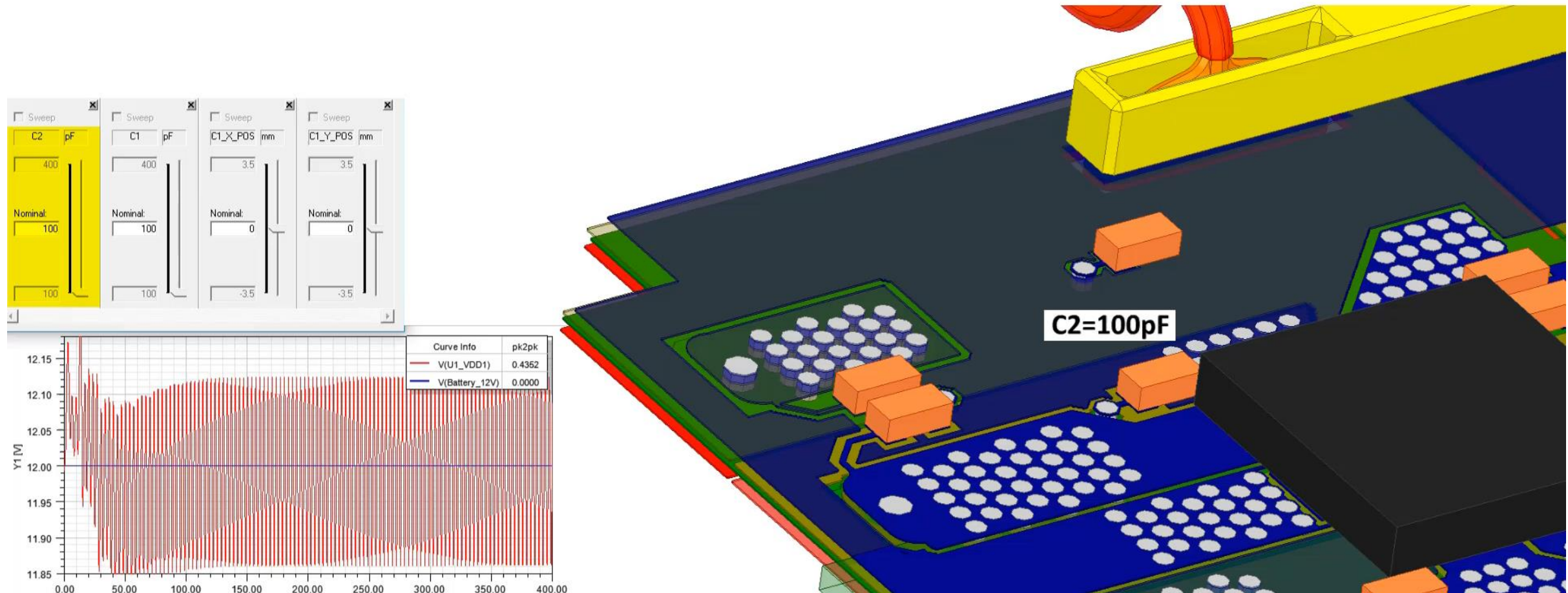
Complex EUT

After the 3D simulation is done, one can easily change the values of components and see the impact on the waveform anywhere in the PCB. Here we see how C2 filter the noise generated by the BCI on the 12V signal at the U1



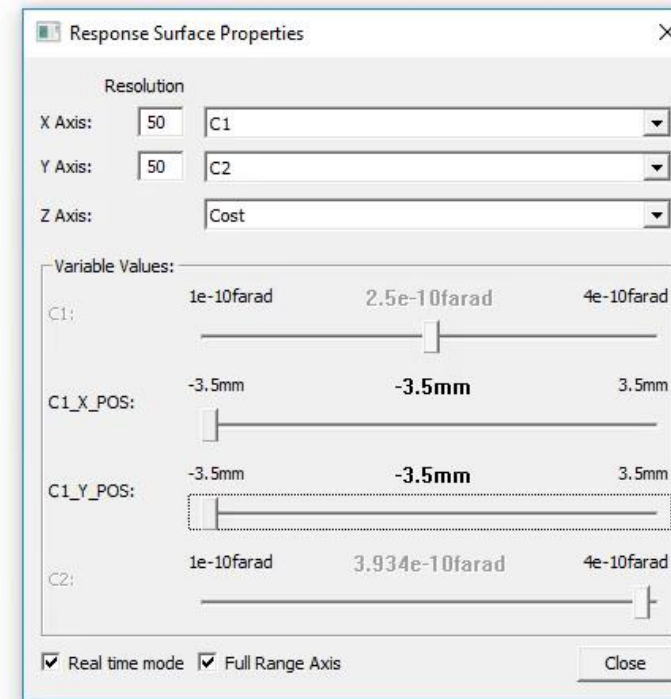
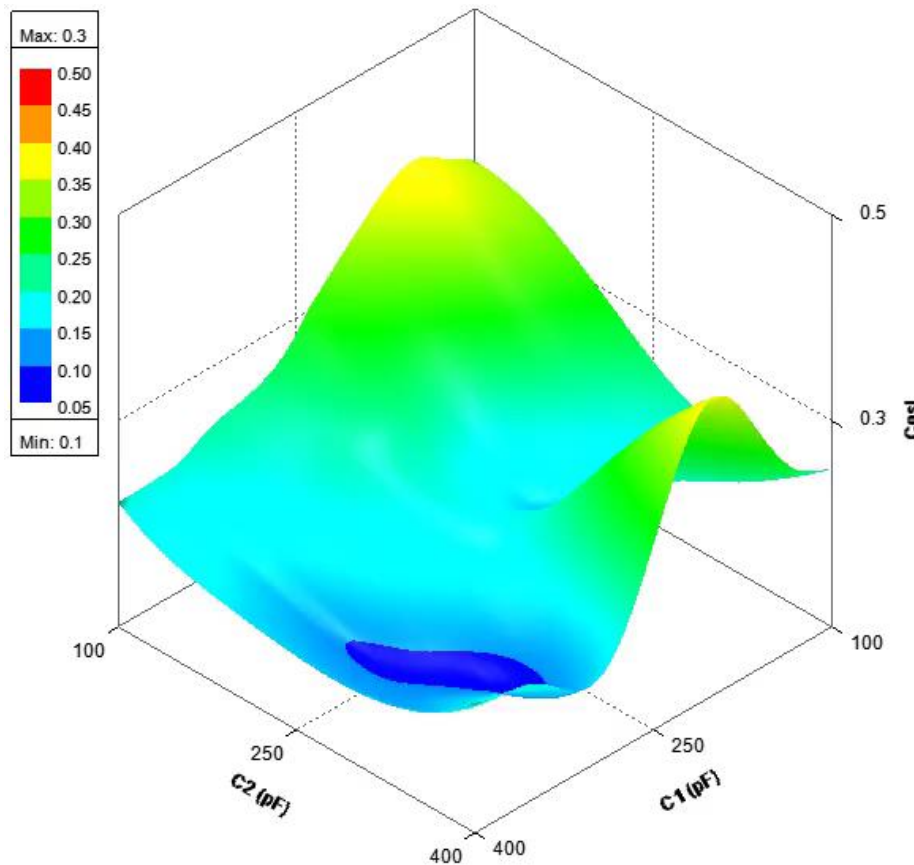
Complex EUT

Not only component values can be changed on the fly. 3D geometries or in this case the layout of the PCB can be tuned in real time to improve the performance of the EUT against external noise. In this case a capacitor C1 was added to the PCB.



Complex EUT

A DOE can run in seconds to determine the impact of the variables on the pk2pk noise and understand the contribution of which component value or 3D geometric change in the overall performance of the EUT under the BCI test



Response Surface Properties

Resolution

X Axis: 50 C1

Y Axis: 50 C2

Z Axis: Cost

Variable Values:

C1: 1e-10farad 2.5e-10farad 4e-10farad

C1_X_POS: -3.5mm -3.5mm 3.5mm

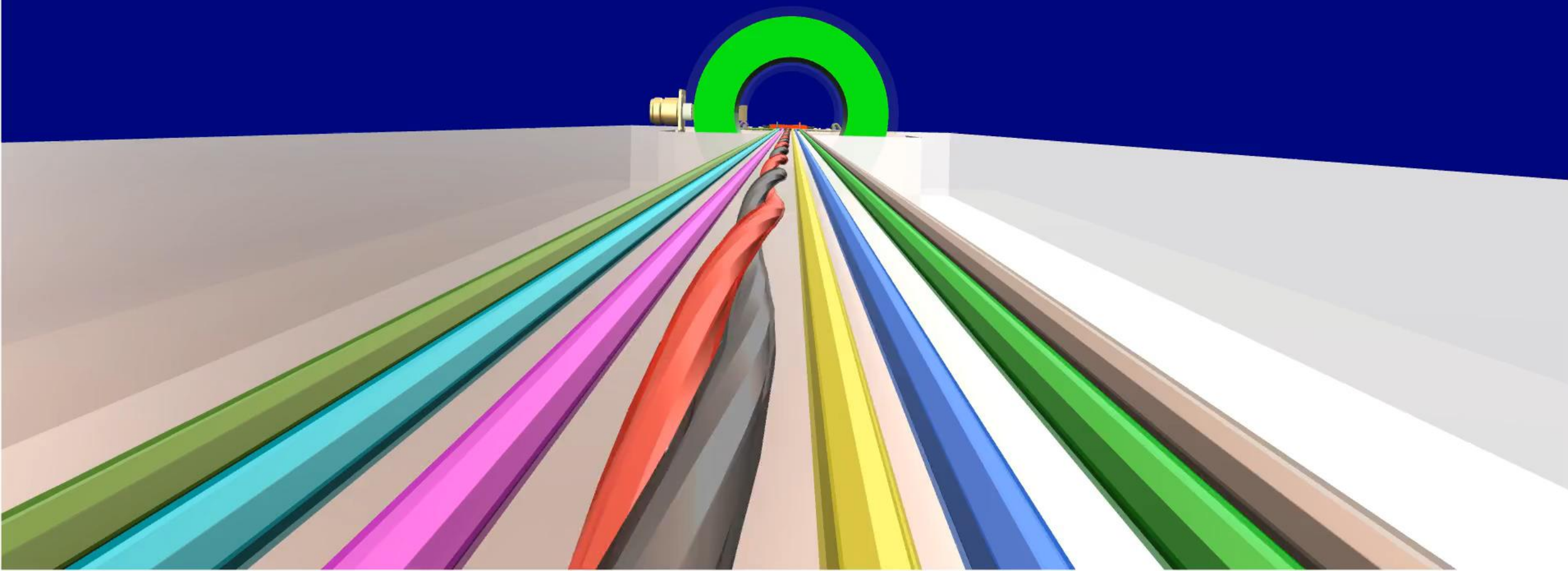
C1_Y_POS: -3.5mm -3.5mm 3.5mm

C2: 1e-10farad 3.934e-10farad 4e-10farad

☒ Real time mode ☒ Full Range Axis

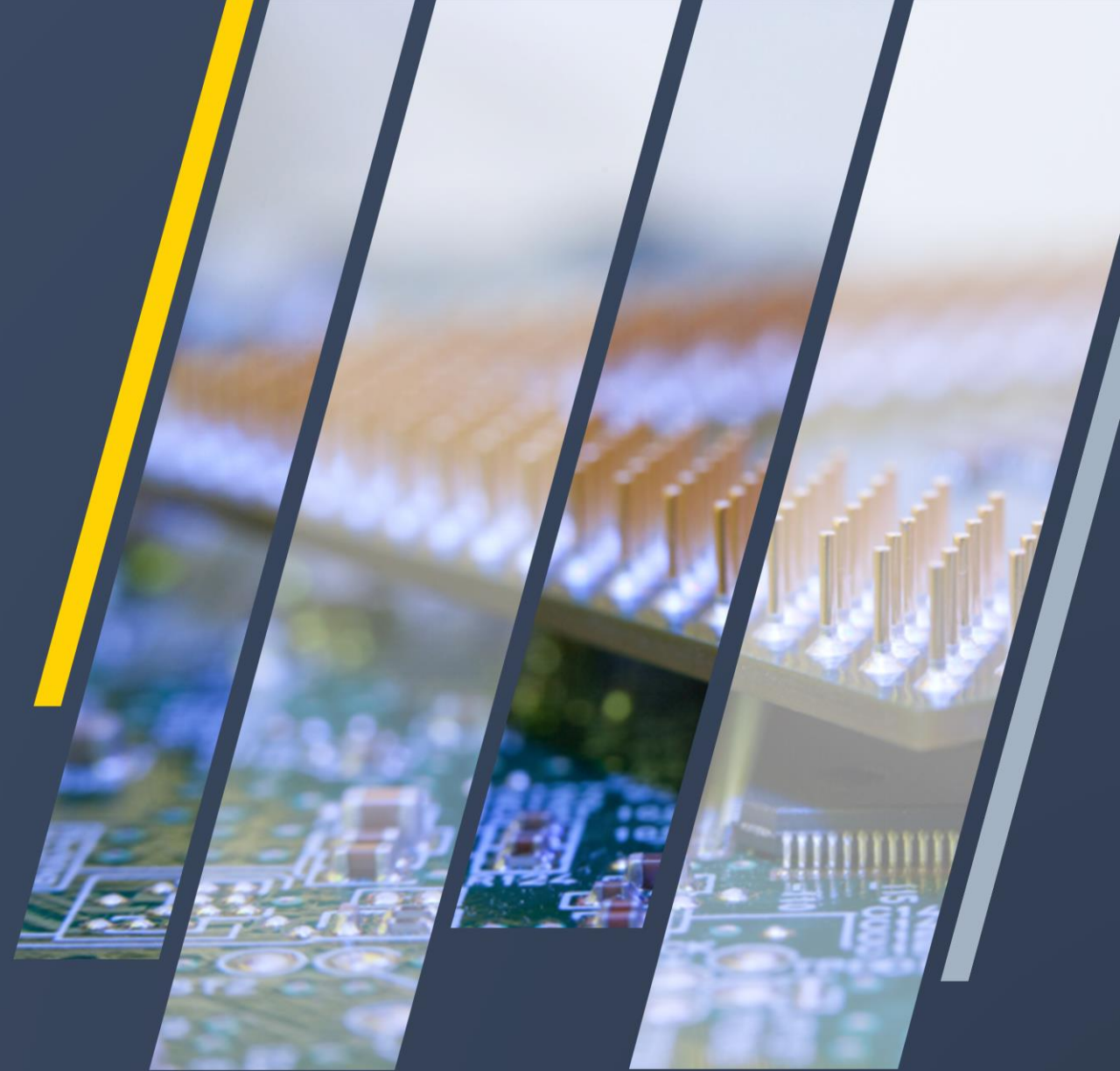
Close

Complex EUT



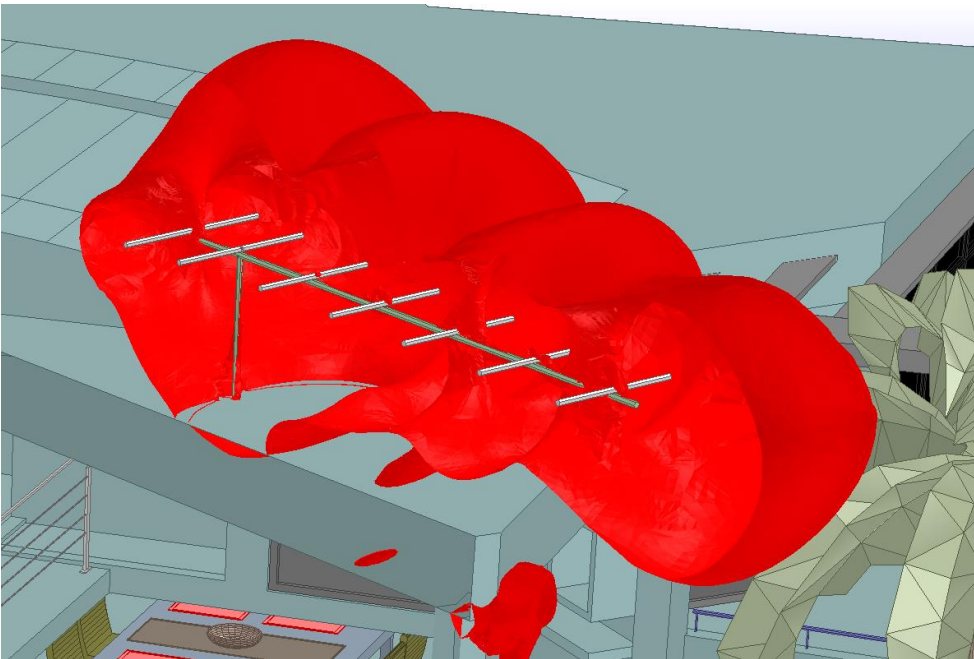


Radiation Hazard



Radiation Hazard

Radiation hazards have to be within standard limits for many different hazard applications, e.g. human safety (HERP), fuel (HERF) and ordnance (HERO). Most radiation safety standards define maximum limits for field strength in frequency bands and form an equivalent exposure level in cases where multiple transmitters are active in any particular environment.



ICNIRP:

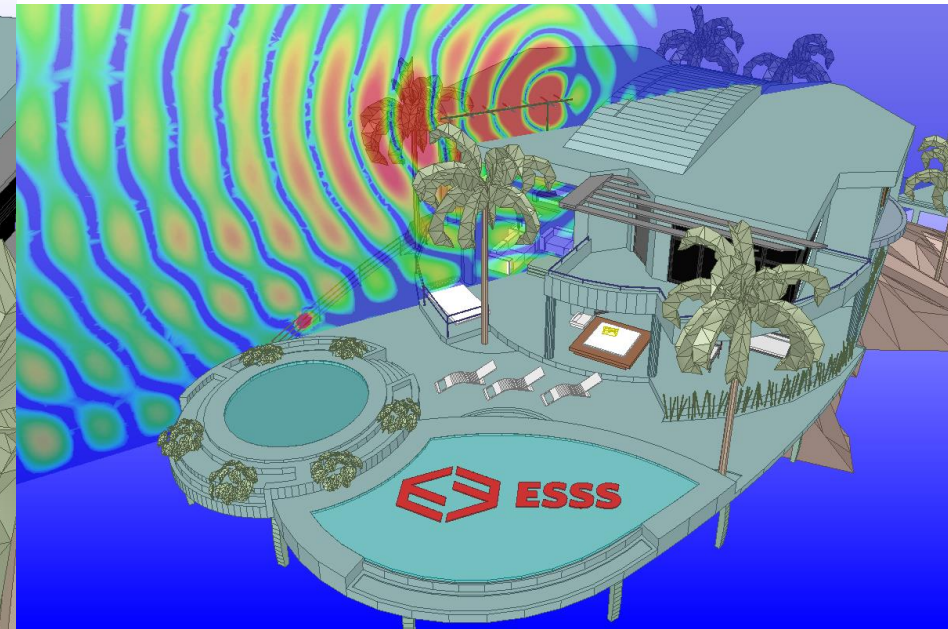
Occupational levels

International Commission on Non-Ionizing Radiation Protection (ICNIRP)

Frequency range	E-field strength (V m ⁻¹)	H-field strength (A m ⁻¹)	B-field (μT)	Equivalent plane wave power density S _{eq} (W m ⁻²)
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20,000	$1.63 \times 10^5 f^{1/2}$	$2 \times 10^5 f^{1/2}$	—
8–25 Hz	20,000	$2 \times 10^4 f$	$2.5 \times 10^4 f$	—
0.025–0.82 kHz	$500/f$	$20/f$	$25/f$	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	$1.6/f$	$2.0/f$	—
1–10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10–400 MHz	61	0.16	0.2	10
400–2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2–300 GHz	137	0.36	0.45	50

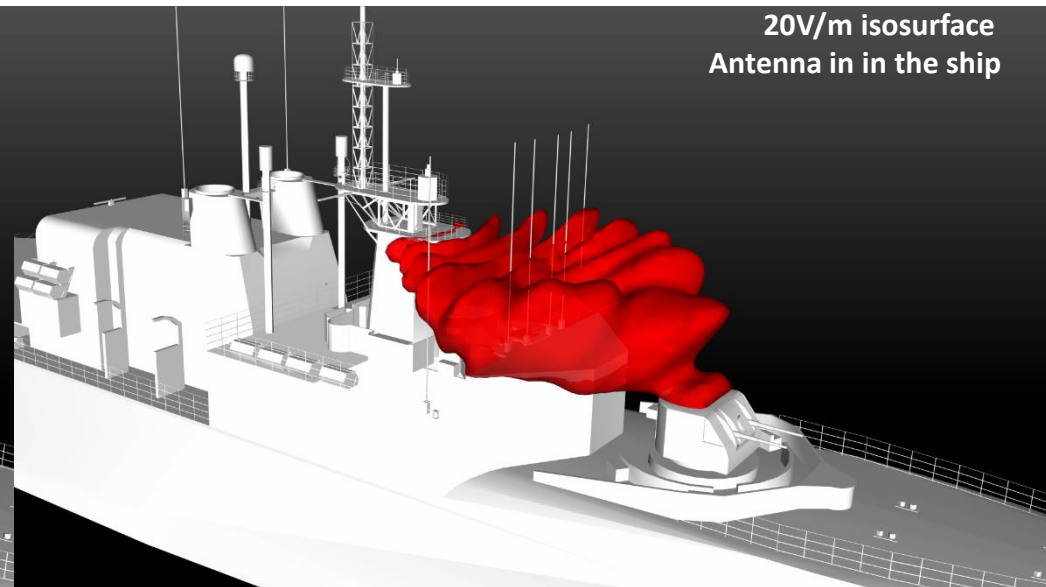
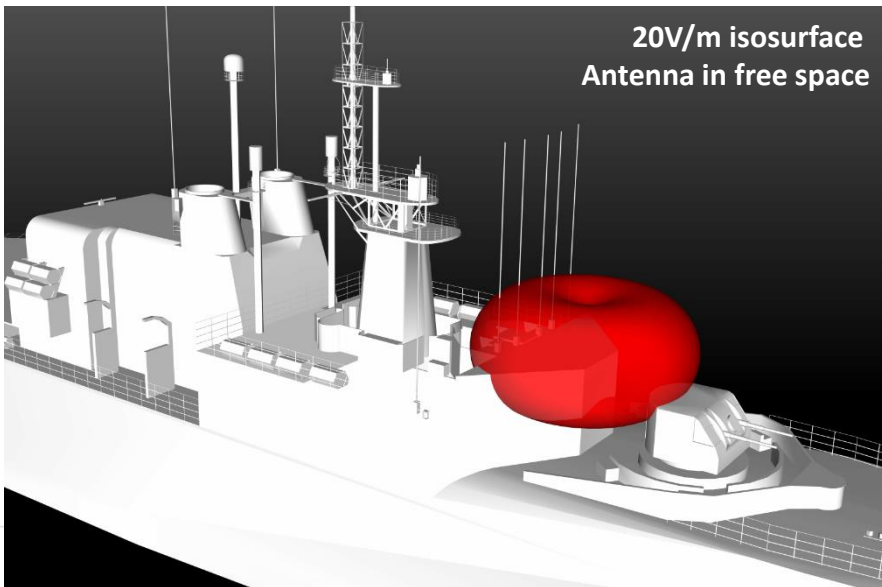
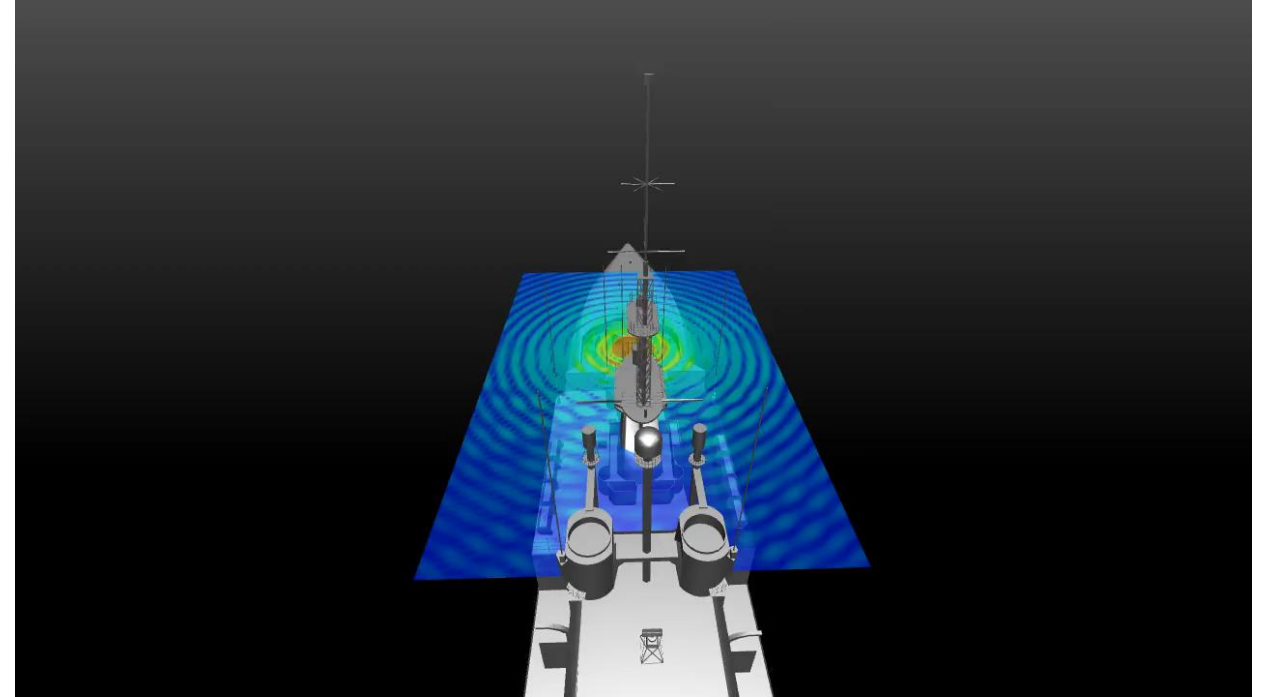
Public levels

Frequency range	E-field strength (V m ⁻¹)	H-field strength (A m ⁻¹)	B-field (μT)	Equivalent plane wave power density S _{eq} (W m ⁻²)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4 f^{1/2}$	$4 \times 10^4 f^{1/2}$	—
8–25 Hz	10,000	$4,000/f$	$5,000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10



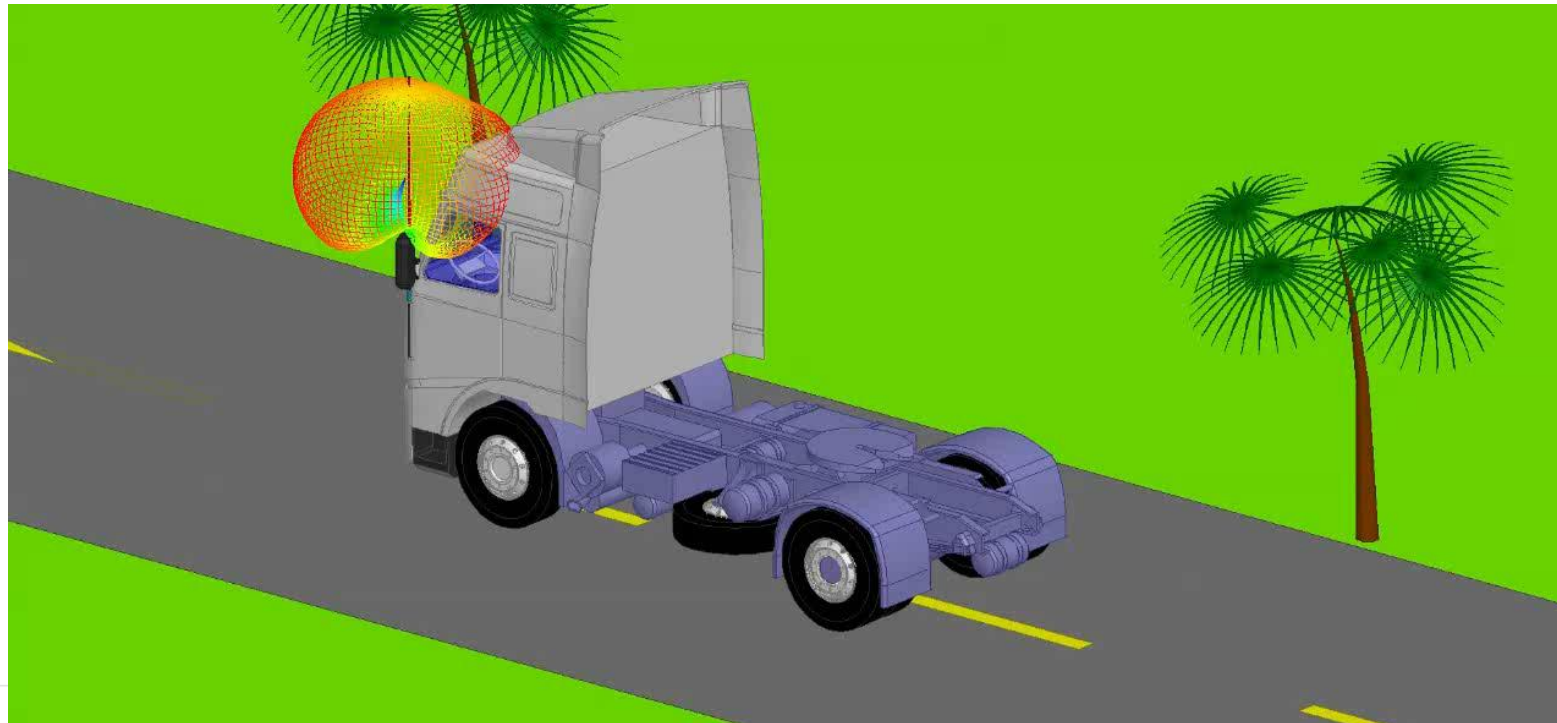
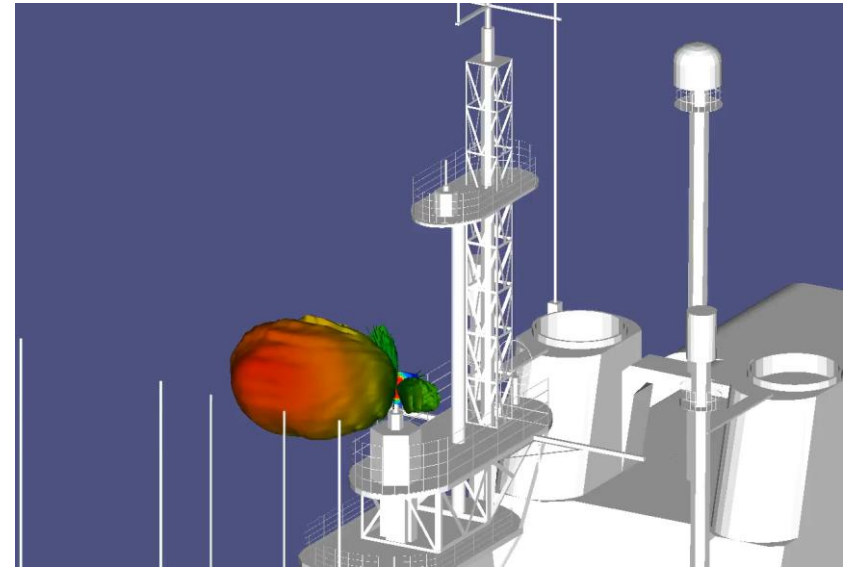
Radiation Hazard

IEC 60533-199 [5] and MIL-STD-461C standards establish limits for electric field and/or power density due to hazards of electromagnetic radiation to avionics (HERA), equipment (HERE), fuel (HERF), ordnance (HERO) and personnel (HERP). Usually engineers consider a free space approach (e.g. Friis equation) to estimate these values. Figure below shows the difference of the electric field when the antenna is considered to be in free space and when it is actually installed in the ship. The areas where equipment cannot be installed (HERE) changes due to the geometry of the ship.



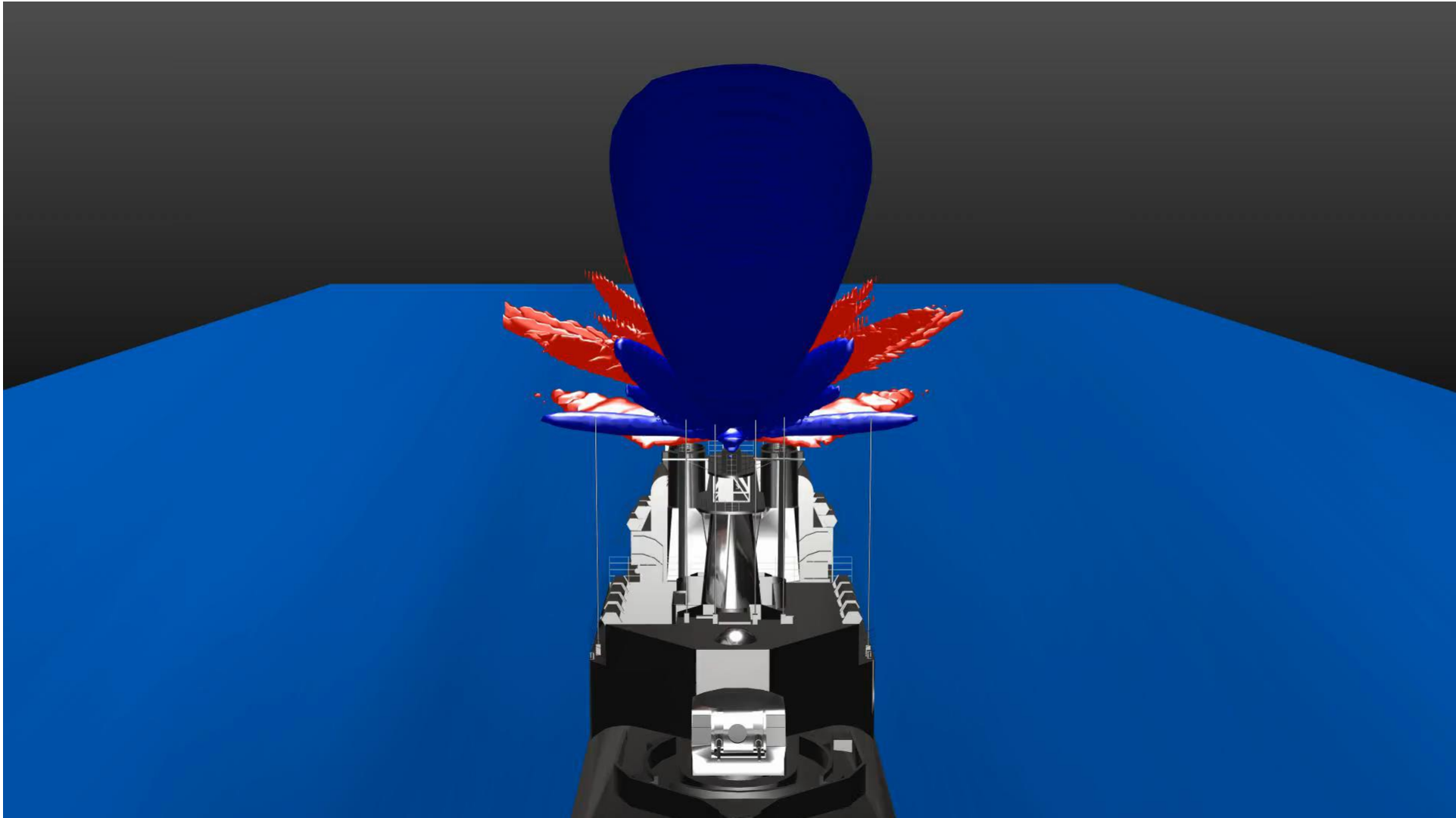
Radiation Hazard

Animation shows the radiation pattern of a phased array radar comprising of 256 elements in a hybrid FEM/SBR+ simulation. The radar operates at 4GHz. When the radar is rotated towards the front of the ship, there is no obstruction and the radiation pattern is slightly affected by the geometry of the ship. Nevertheless, when the same radar rotates 180 degrees in the horizontal plane, the main radiation suffers a lot of interference from the mast and other objects from the ship. This strongly affects the electromagnetic field distribution

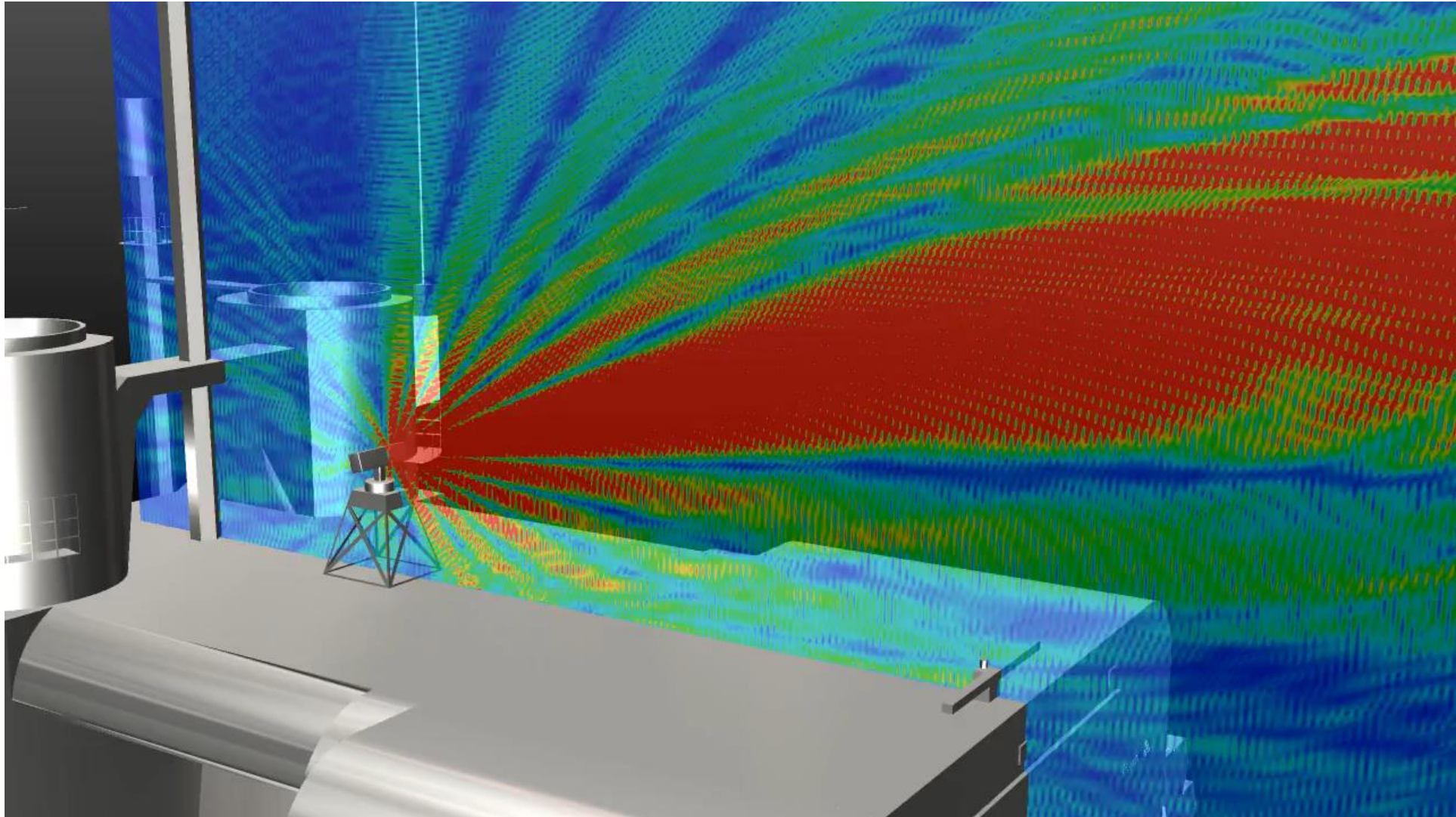


Radiation Hazard

20V/m isosurfaces when the radar is rotated towards the mast (red isosurface) and towards the front of the ship (blue isosurface) considering the ship geometry



Radiation Hazard HERA



ANSYS®

Thank You

