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Implementation of Numerical Simulation Activities in Automotive Development Processes

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Outline

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- Introduction
- Current trends and targeted goal
- Lessons learnt over 20+ years
- What are the root causes
- Comparison with the physical process
- Example for conducted emissions of a HV on-board charger
- Take aways

Introduction

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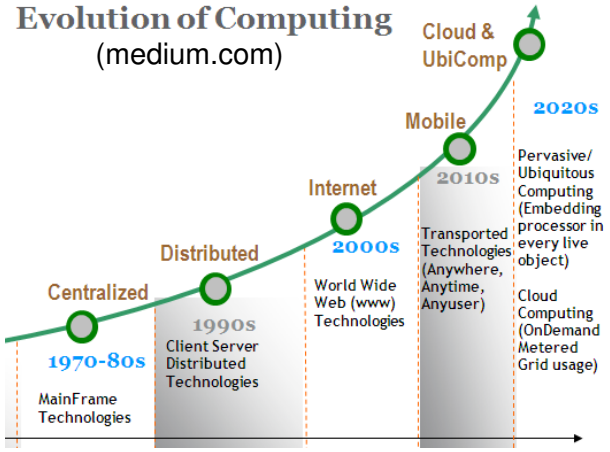
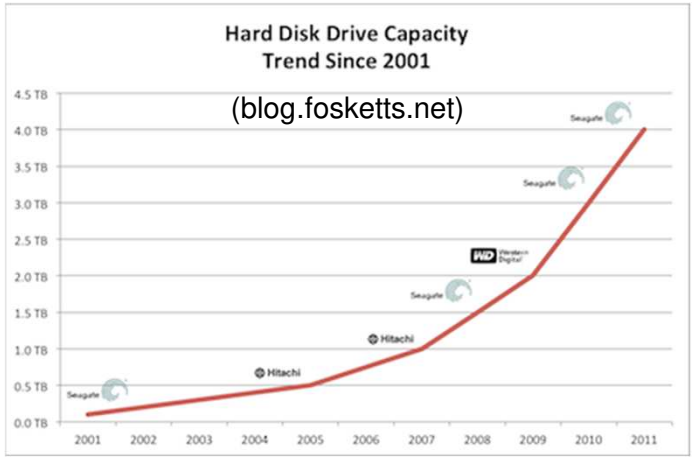
- Numerical simulation tools for EMC activities have improved significantly (features, speed, size) over the past 30 years





- The use of such tools for full-system EMC(*) simulations has not progressed proportionally
- Often not related to the capabilities of the simulation tools themselves
- Mainly due to technical and industrial difficulties
- Not much hope for the next 10 years if nothing changes

(*) Not the case for RF and antenna simulations

Current trends and targeted goal

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- Focus on cost efficient numerical simulation in EMC tasks/activities to enhance performance and productivity, globally reducing development and production costs

• What will be done …	… it's cost and time saving, giving equal or better quality persecution and/or customer satisfaction
• What could be done …	… it's possible but gain has to be confirmed
• What won't be done …	… it has been proven that there are no benefits
• What can't be done …	… because it's industrially unrealistic

Lessons learnt over 20+ years (1)

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Reasons why EMC numerical simulation have not been so successful up to now

1) Not defining correctly and exhaustively the purpose of the simulation
   - What decision should be taken at the end
2) Not delivering the conclusions on time
   - Not choosing the appropriate level of modeling, not knowing the input data, not choosing the right solver, underestimating the duration of simulation
3) Not producing trustful results
   - Measurements are still necessary at the end
4) No time or cost savings
   - Another approach (experimental) would have been faster, better and cheaper
5) Not having understood the product development process
   - Results and conclusions have a very low impact on the decision making

Lessons learnt over 20+ years (2)

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6) Having hoped for a too precise model
   - The model is not limited to the strict representation of the EMC problem
   - Simulations were not run on time
7) Bad measurements have contradicted correct simulation results
   - Numerical simulation was discredited because measurements are still the reference
8) Simulation engineers having very little knowledge in physics and electrical engineering (education in applied mathematics)
   - Results don’t make sense and contradict fundamental properties
9) Not knowing what should be expected as result
   - Results cannot be validated without a cross-check (true also for measurements)
10) Cannot demonstrate cost effectiveness
   - Not knowing how much can be saved, or how much non-compliances costed on a previous project

What are the root causes

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The capabilities of the simulation suite are seldomly the principal reason

However, we often hear *“Oh, but if we would have had … we could have …”*

Main reasons:

1) Technical reasons

    Industrial difficulties

    Incompatible expectations

2) Organizational reasons

    Process compatibility

    Technical policy

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Industrial difficulties (1)

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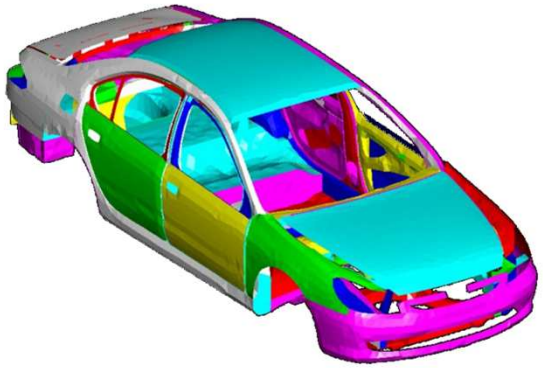
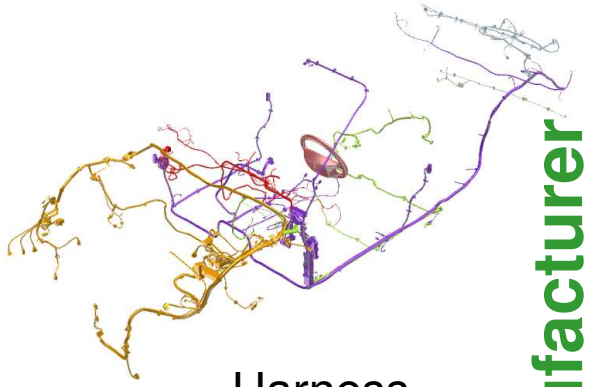
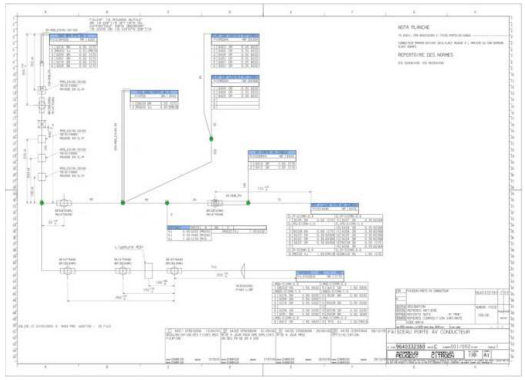
- The general automotive EMC modeling scheme



Metallic parts



Harness



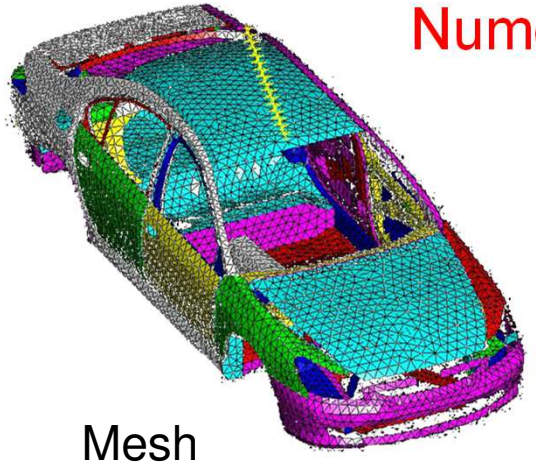
Harness schematic

CAD virtual models

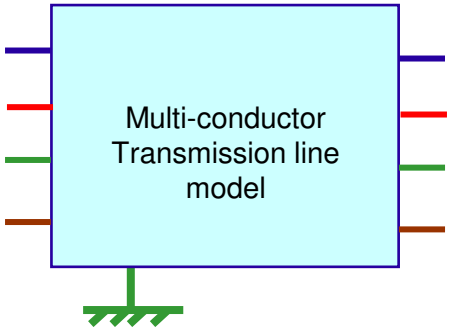
Numerical models

Car manufacturer

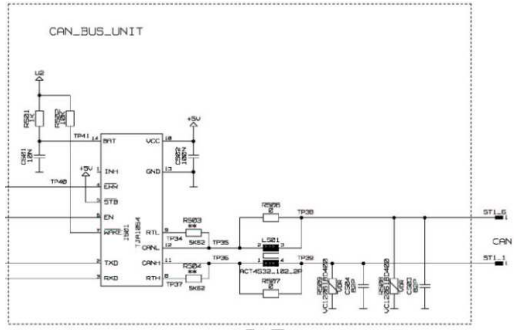
Component supplier



Mesh



Harness model



Electrical schematic

Industrial difficulties (2)

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- Intellectual property protection
  - The suppliers are not willing to provide their numerical model to the integrator
  - The integrator is not willing to distribute his numerical model to the suppliers
- Large system simulation
  - Computational time, memory size
  - The integrator has to support the global model (number of clusters, CPU + memory, licenses…)
- Multi-scaling issues
  - System, subsystem, components, devices and chips (uP)
  - Currently a 2-level context (car manufacturer / component suppliers, component suppliers / chip suppliers)

Industrial difficulties (3)

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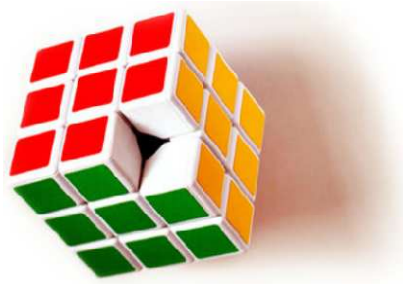
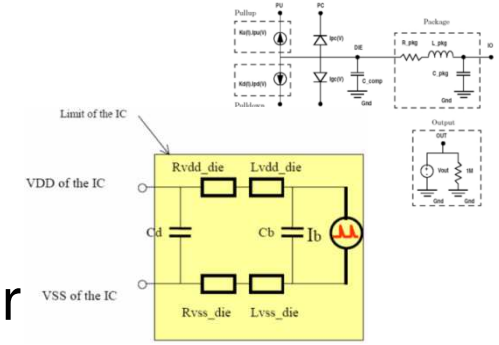
- Completeness issues
  - Numerical simulation can only be run if all the parts of the EEA are present in the global model
  - EMC numerical simulation of the EEA is impossible without the contribution of all the component suppliers
  - Diversity of the system must be taken into account
- Equivalent model issues
  - Representativeness or lack of data
  - Unable to relate voltage levels to susceptibility levels by the integrator on a large scale
  - Loads are not often imposed by the integrator (functional specifications rather than electrical design specifications)
  - Important number of pins
    - Pin-to-pin characterization by measurements is not feasible
    - Parasitic impedances between pins are not modeled





Industrial difficulties (4)

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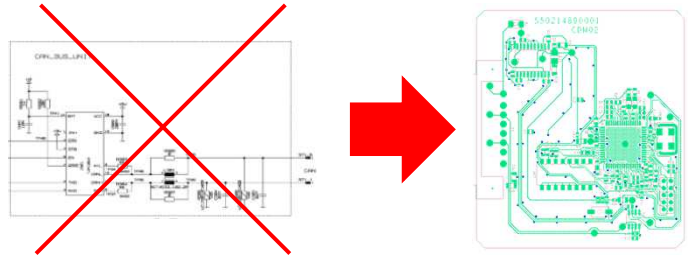
- Model issues
  - Suppliers and integrator do not have the same numerical simulation platforms
  - Universal import/export formats can be used (Catia, Nastran, STEP, etc.) models could be exchanged but requires (re-)meshing
  - Time to (re-)construct the models
- Models change during the development phases
  - Obsolete models at a given milestone
  - Requires updating the models
- Transparency of results
  - No sharing of results (the integrator may not communicate the results to the suppliers)
- … and more depending on the car manufacturer



Industrial difficulties (5)

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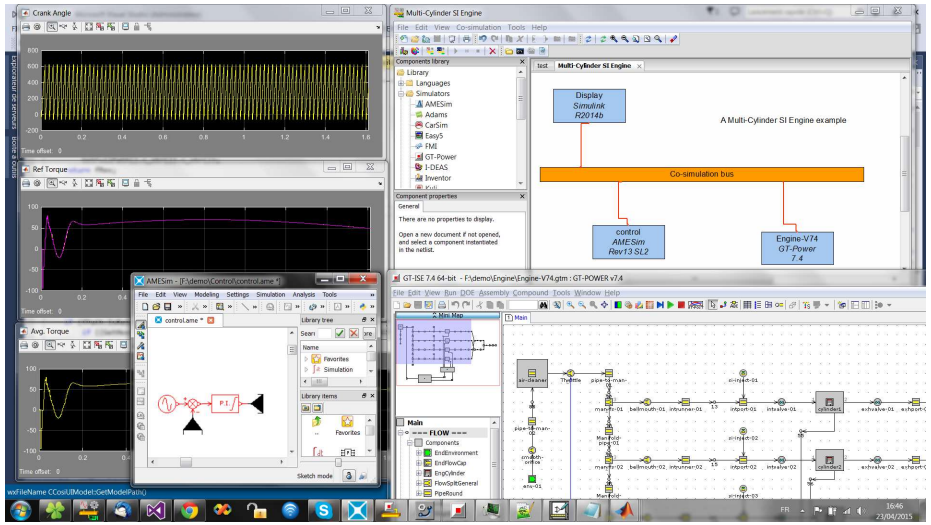
- A possible future solution: Co-simulation over Internet Protocol(*)



(Courtesy of Chiastek)

(*) M. Klingler: *Online EMC Numerical Simulation - Towards a Collaborative French or European Project* – 16th International Symposium on Electromagnetic Compatibility "EMC Europe 2017", Angers, France, 4-8 September 2017.

What are the root causes

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Main reasons:

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    Process compatibility

    Technical policy

Incompatible expectations (1)

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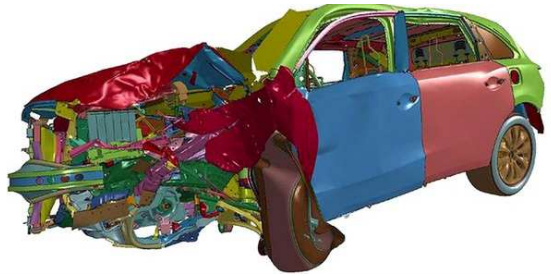
- **Question from management:** *"Why can't you do what is done for crash or aero?"*

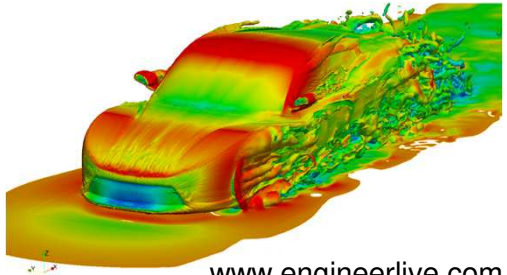
Crash

www.computerhistory.org



No electrical function considerations !!!

Aero (CFD)



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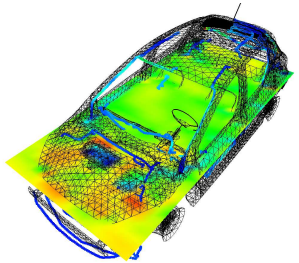
Equivalent level of complexity as …

Electromagnetic fields (radiation)

Car body

Threshold levels (J, E and H fields)



Incompatible expectations (2)

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- **Answer to management:** *"EMC requires much more than simple Pass/Fail status based on primary quantities (J, E and H fields)"*
  - Optimization of vehicle/project electrical validation plans
  - Replacement of physical electrical EMC tests (Pass/Fail)
  - Replacement of physical EMC investigations (better/worse, partial tests)
  - Risk assessments and justification of electrical design rules
  - Replacement of general EMC measurements
- **and** *"EMC activities cover a combination of at least 3 different topics (8 cases)"*
  - Immunity, emission
  - Conducted, radiated
  - On table, on vehicle

A specific model for each combination (8)

Incompatible expectations (3)

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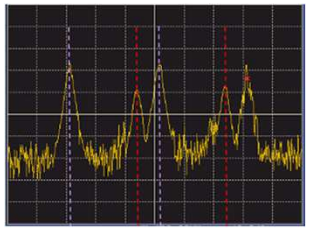
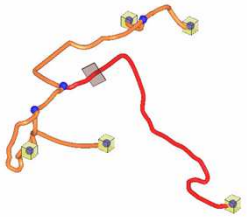
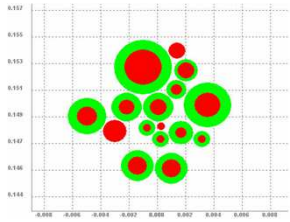
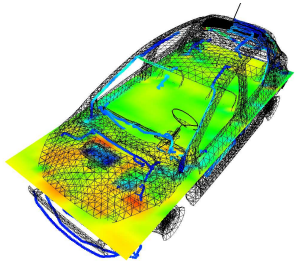
- Levels of difficulties in modeling in EMC

Model	Level		Criterion	
Functional (scenarios, algorithms, cycles…)	System		Pass / Fail	
Signals (waveforms, spectrum)	Components		Threshold levels (Voltage and currents)	
Propagation (conduction)	Harnesses		Coupling (S-parameters)	
Electromagnetic fields (radiation)	Car body		Threshold levels (J, E and H fields)	

Incompatible expectations (4)

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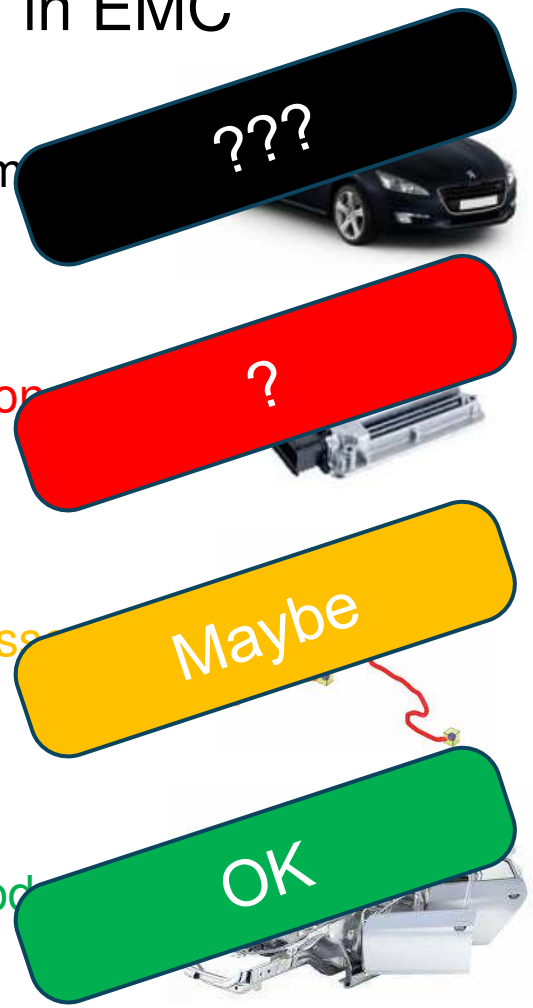
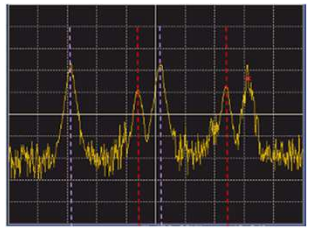
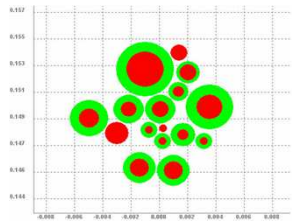
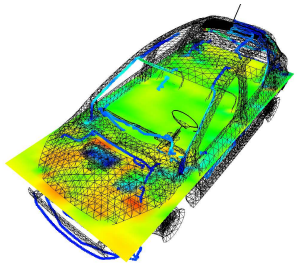
- Levels of difficulties in modeling in EMC

Model	Level	Criterion
Functional (scenarios, algorithms, cycles…)	System	Pass / Fail
Signals (waveforms, spectrum)	Compon	Threshold levels (Voltage and currents)
Propagation (conduction)	Harnes	Coupling (S-parameters)
Electromagnetic fields (radiation)	Car bod	Threshold levels (E and H fields)









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Process incompatibilities

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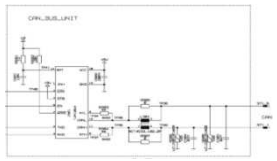
Numerical simulation milestones?

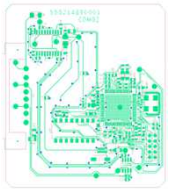
Vehicle specifications | Component requirements | Vehicle design | Vehicle validations | Homologation | SOP(*) | Production

Component specifications | Component design | Component validations

(*) Start Of Production

Schematic | PCB | Prototypes | Final product





Uncertainties on EMC models

Relevance of EMC simulation results

Antagonist situation

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Technical policy (1)

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Numerical simulations are sometimes, or often:

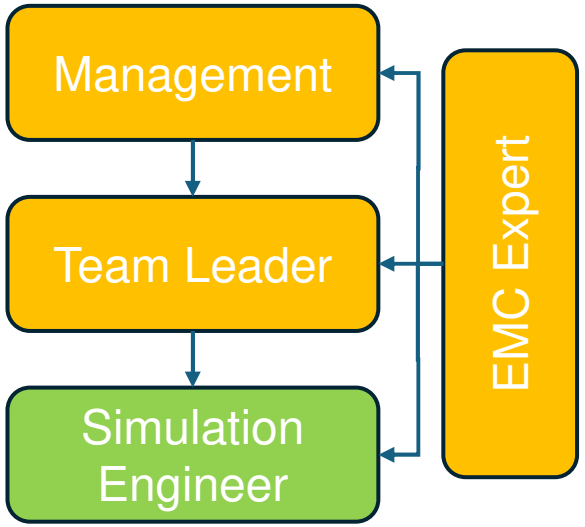
- Trial approaches *"Let's see if numerical simulation can help"*
- Ad hoc attempts at moments when an EMC issue or a question occurs under stress *"Help us with numerical simulation, we're in trouble!!!"*

A modeling and numerical simulation suite can only solve an electric or electromagnetic problem

It cannot address an **EMC** issue ; this is up to the EMC engineers considering different possible options (measurements, simulation, mixed, etc.)

And cannot address an **industrial and commercial** problem ; this is up to the managers considering time, cost and customer impact/satisfaction

So, numerical simulation activities require at least **2 more hierarchical layers** than only modeling, simulation and post-processing



Technical policy (2)

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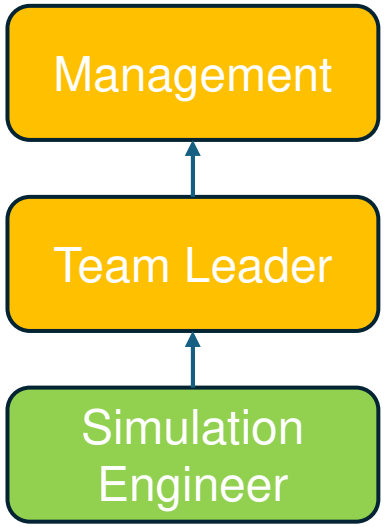
Hierarchical layers from bottom up *(what is often done)*

- At simulation engineer level:
  - Tries to convince the team leader that his results are sufficiently appropriate to address the questions and contribute to a decision within time and cost limits
- At team leader level:
  - Convinces management that numerical simulation can replace or complement the conventional physical approach
- At management level:
  - Asks *"What will be the development and production cost reductions?"*
- At team leader level:
  - Replies *"Difficult to say…"*



Technical policy (3)

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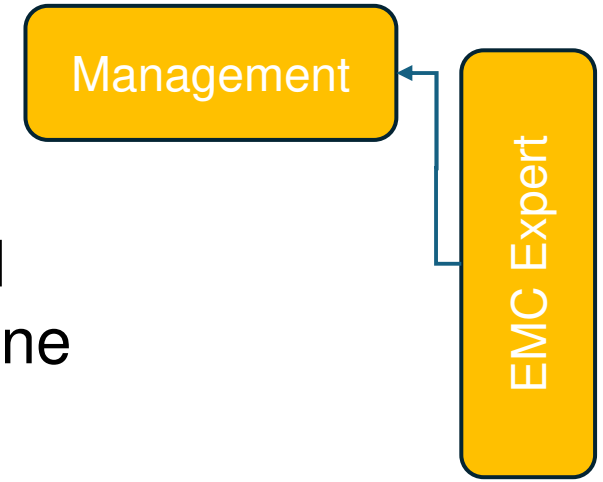
Hierarchical layers from top down *(what is not often done)*

- At management level: Define the numerical simulation strategy and deployment plan
  - When do we simulate what?
  - Similar to the full physical development plan, numerical milestones should be defined and justified on an industrial/economical basis
  - Decide between physical tests, numerical simulation and hybrid physical/simulation options at the different milestone
  - Ensure the budget for the EMC simulation activities and charge financially the vehicle projects (like for testing)



Technical policy (4)

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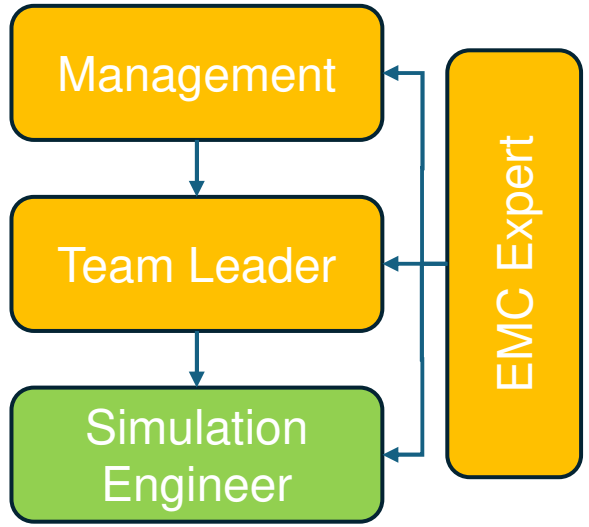
- At team leader level: Define the numerical simulation activities and milestones
  - What is the question that has to be addressed?
  - With what input data? With what uncertainties?
  - What are the physical/numerical schemes?
  - Arbitration between physical, numerical simulation and hybrid physical/simulation options for specific cases
- At simulation engineer level: Define and execute the simulation schemes in the details
  - The models, pre-processing, simulation, post-processing activities in themselves



(Note: Management, team leader and engineer can be the same person in some cases)

Comparison with the physical process

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- The physical development process is based on phases and milestones
- The expected levels of maturity at each milestone are realistic and sufficient
- Goals are specific to each milestone taking into account the level of maturity
- Budget and resources are planned and allocated for each phase between milestones
- The validation plan is perfectly defined
  - Type of tests to be applied (on components and on vehicle)
  - Configurations to be tested
- Each test has an uncertainty budget
- Validation and verification of test facilities and setups, quality audit, accreditations

No doubt on results

Numerical simulation opportunities

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• Proof of concept of new technologies	OEM	supplier
• Vehicle specifications	OEM	
• Supplier consultation	OEM	
• Component specifications		supplier
• Design and risk analysis	OEM	supplier
• Validations on table		supplier
• Validations on vehicle	OEM	
• Troubleshooting and crisis	OEM + supplier	
• Homologation (maybe in the future R10 annex)	OEM	
• Commercial life (shortage, sourcing, …)	OEM	supplier

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Example for conducted emissions of a HV On-Board Charger

Why this choice of example?

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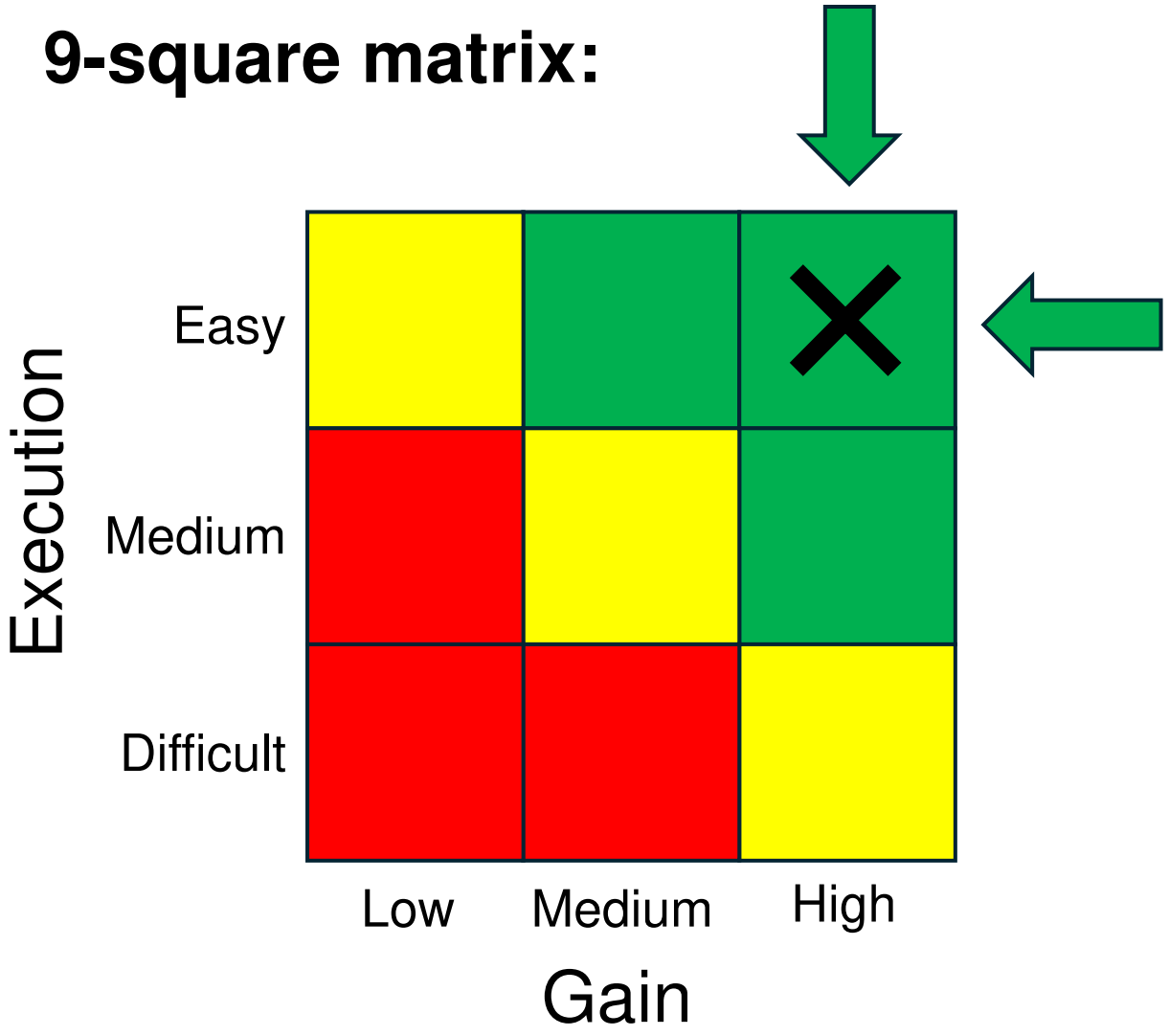
9-square matrix:



High impact:

1) A given OBC can be deployed on many different vehicle projects and car bodies
2) A vehicle project can include different OBCs
3) Up to 4 charging modes (4 tests)
4) Late modifications are a nightmare
5) Compliance is mandatory for homologation

Easy implementation of simulation:

1) Relatively low frequencies (< 30 MHz)
2) Sizes are small compared to the wavelength
3) Conducted phenomenon (electrical)
4) Reasonable levels of difficulties

Numerical simulation opportunities

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• Supplier consultation	OEM	
• Component specifications		supplier
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• Troubleshooting and crisis	OEM + supplier	
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• Commercial life (shortage, sourcing, …)	OEM	supplier

Proof of concept of new technologies phase

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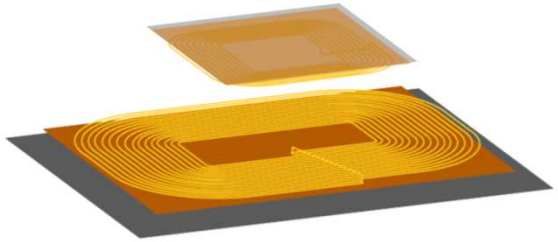
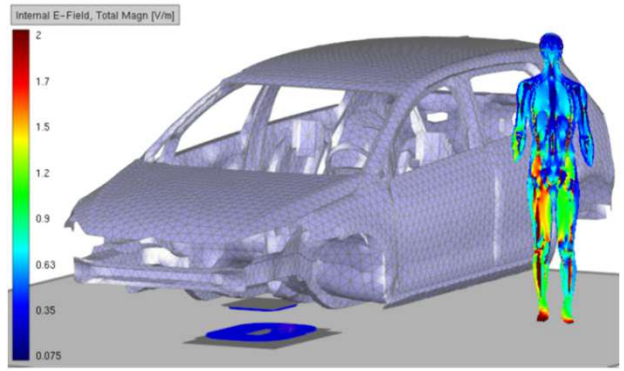
- **Goal:** Avoid prototyping, understand the impact of parameters and optimize the new technology
- No real industrial pressure (no SOP defined)
- Cost is not the main concern, because only a few samples will be produced from TRL3 to TRL6(*)
- Time is not a main concern either, because time-to-maturity depends mainly in the degree of innovation, the financial support, the partners, etc.
- High levels of skills are usually involved (experts, laboratories, universities, etc.) and specific tools / methods are developed
- No EMC mandatory development requirements at this stage
- Mainly numerical simulations of electrical and EM phenomena



Courtesy of EMCoS



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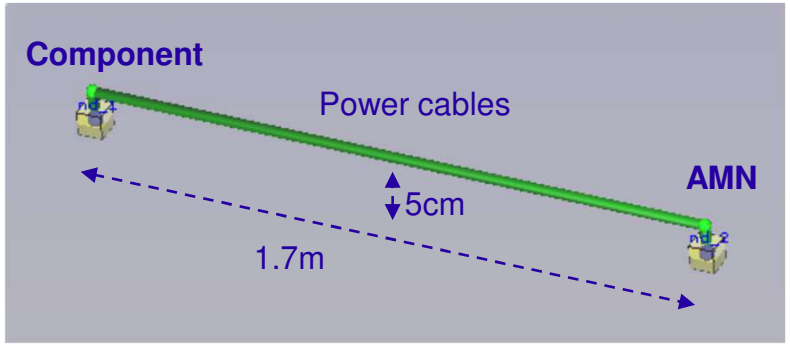
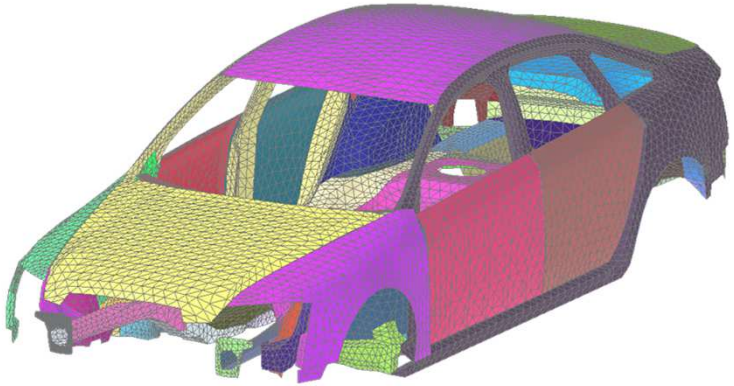
(*) Technology Readiness Level: Estimation scale of maturity

During vehicle specification phase

EMC Expert Consultant

- **Goal:** Adapt conducted level requirements on table and verify that they will lead to compliance on vehicle
- Design golden rule: The EMC of electrical architectures should not be configuration-specific
  - Many different configurations and options for a vehicle project
  - Only few configurations will be validated at the end
  - That means that it should also comply on a previous models
- Model the generic test setup on table that will be specified to the supplier in the RFQ
- Model the typical implementation and harness routing on similar previous vehicle models





Courtesy of EMCoS

During supplier consultation phase

EMC Expert Consultant

- **Goal:** Ensure that the supplier develops the component with state-of-the-art technics and skills
- Insert supplementary requirements and deliverables in the request for quotation (RFQ)
- Define design review milestones based on numerical simulation assessments before first component prototype
- Only focus on critical parts of the component, such as filter interfaces known for high risk of EMC non-compliance
- **Deliverable n°1:** Worst-case equivalent black-box model (multiport S-parameters files) at last milestones
- Prototype only filters in the housing and validate simulation model
- **Deliverable n°2:** Measurement results (multiport S-parameters files)

Functional schematic

Implementation

Housing

EMC electrical schematic

PCB layout

Radiated coupling

Grounding

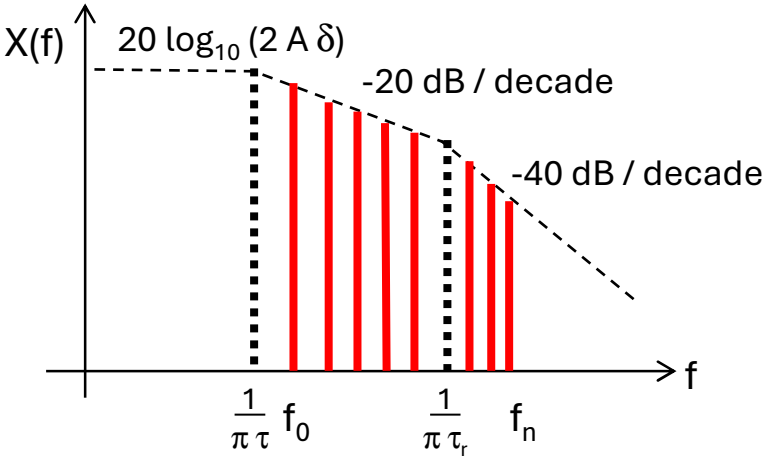
During component specification phase

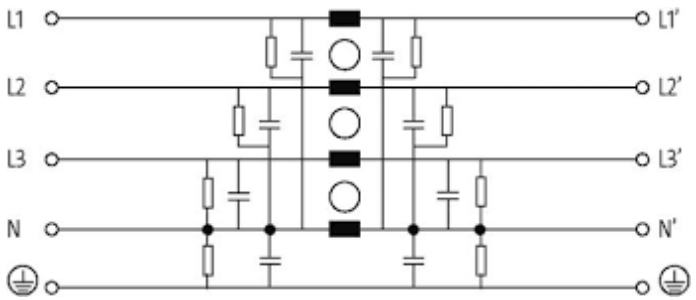
EMC Expert Consultant

- **Goal:** Ensure that the design of the component will meet the requirements on table and on vehicle
- Design golden rule: The EMC of the component should not be architecture-specific
- Define the clock frequencies to satisfy performances and minimize filtering efforts
- Define the filtering performances depending on the powers involved, the clock frequencies, etc.
- Define the filter structure
- Define the specific test setup on table according to implementation scenarios on vehicle (indicated by the OEM), e.g. connection to chassis
- Validate test setup with OEM (sometimes not done)

Design rules

Component requirements

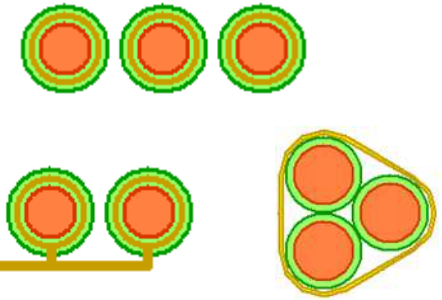


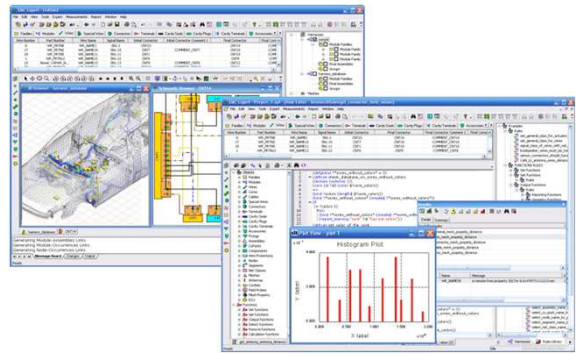


During OEM design phase (process)

EMC Expert Consultant

- **Goal:** Avoid having to run numerical simulations for frequent or systematic electrical architecture configurations
- Design rules always have an additional cost
  - Either they are necessary (cost is justified) or they were unnecessary (loss)
  - Rules that are applied but unnecessary have a cost (in production)
  - Rules that are not applied but were necessary have also a cost (in corrective solutions during development)
- Design rules have a huge impact on cost
  - 1€ saved can lead to 100k€+ on a vehicle project
- Use of numerical simulation to define the optimal design rules in the internal EMC design guidelines document
- Use machine learning possibilities for parametric rules



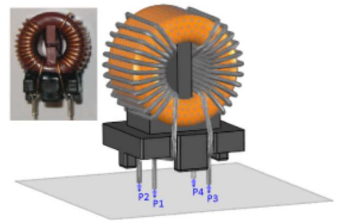


Courtesy of EMCoS

During supplier design phase (process)

EMC Expert Consultant

- **Goal:** Avoid having to run numerical simulations for frequent or systematic PCB routing verification and device implementation configurations
- Same cost considerations as for the OEM
- Constitute models of off-the-shelf systematic devices (capacitors, inductances, etc.). Some suppliers even use often the same devices
- Using numerical simulation to define best practice PCB design rules
- Define numerical simulation methodologies to design filters with minimum information on the exact characteristics of the devices



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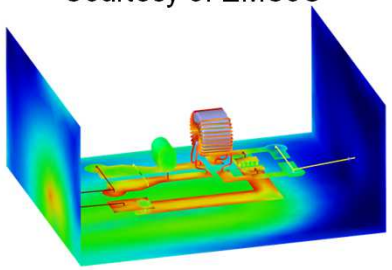

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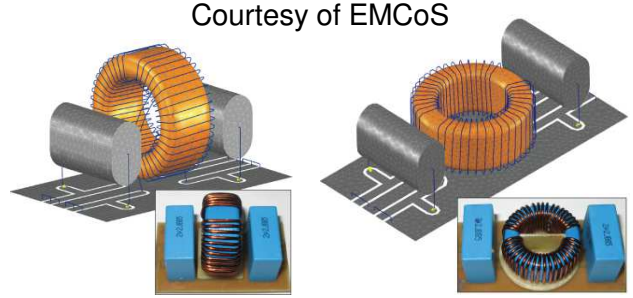

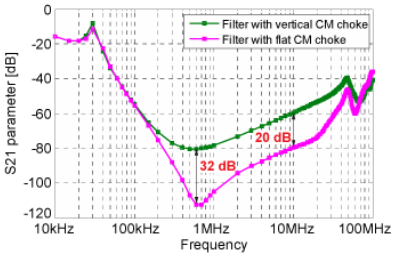

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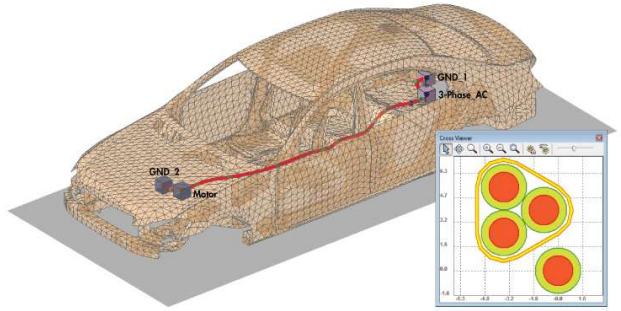
During OEM design phase (project)

EMC Expert Consultant

- **Goal:** Minimize EMC risks and production costs, and keep on schedule
- EMC risk analysis on project specific violations of design rules (physical impossibilities, conflict with another non-EMC design rule, etc.)
- Model the typical implementation and harness routing on similar previous vehicle models
- Do not wait for supplier's model because it might not be complete and component might not be compliant on table
- Base assessment criteria just on the 2 first levels of difficulties (J, E and H fields, S-parameters, linear loads, etc.)
- Create typical vehicle models of the project that will be used
  - During the validation phase
  - For the specifications of the next project



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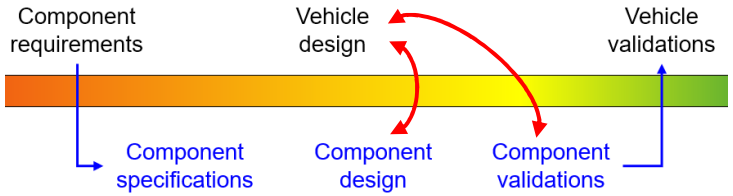

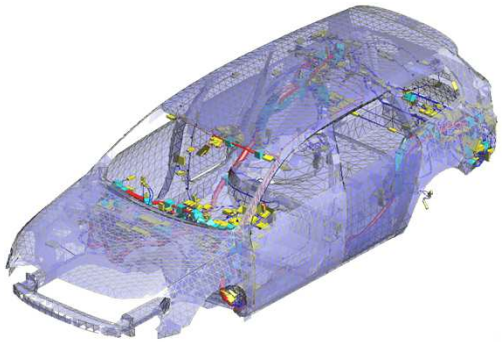

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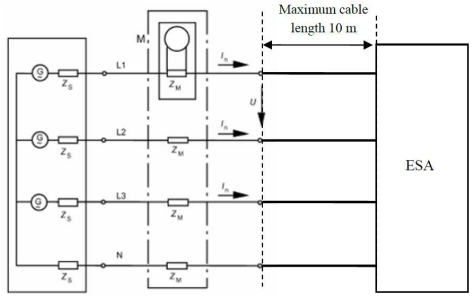
During supplier design phase (project)

EMC Expert Consultant

- **Goal:** Minimize EMC risks and production costs, keep on schedule, and avoid an architecture-specific EMC design
- Execute design reviews according to milestones in RFQ
- Model the specific test setup on table between component interfaces and AMN inputs to obtain multiport S-parameter equivalent black-box
- Validate the design of the filter by numerical simulation at each milestone using the equivalent black-box (including uncertainties and tolerances of devices)
- OEM supplies equivalent worst-case black-box models (multiport S-parameter files) of numerical simulations performed during vehicle specification or design phase
- Simulate and validate the component interfaces with OEM's worst-case equivalent models



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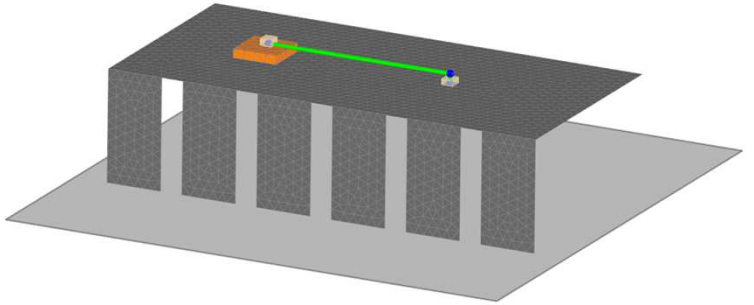

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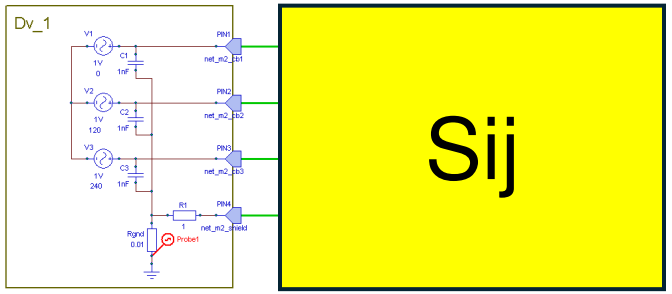

During component validation phase

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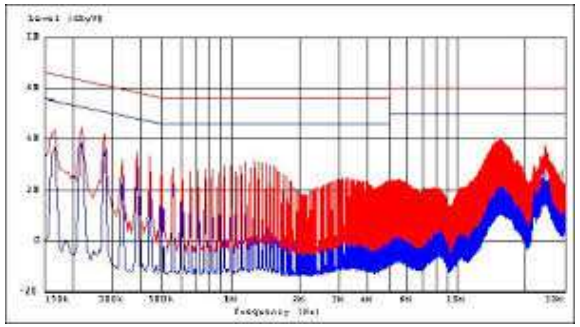
- **Goal:** Provide the OEM with an equivalent model of the component based on real measurements
- Only once the component is close to conducted emission compliance
- Use the multiport S-parameter equivalent black-box (or multiport S-parameter measurements of the test bench if possible)
- Apply de-embedding technique to AMN output measurements to obtain equivalent noise sources at component interfaces
- Simulate or measure component interface impedances
- Combine equivalent noise sources and interface impedances to create equivalent frequency-domain model of real component
- Provide the component equivalent model to OEM



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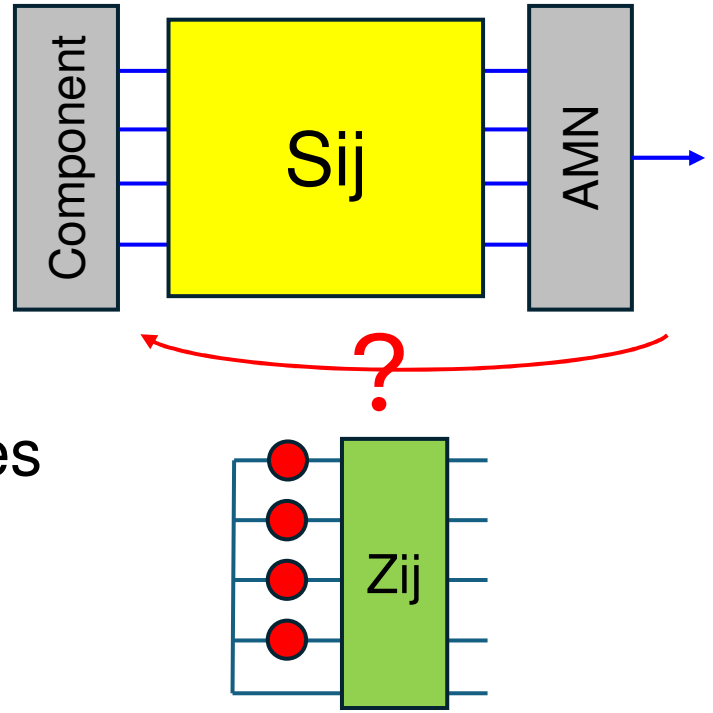
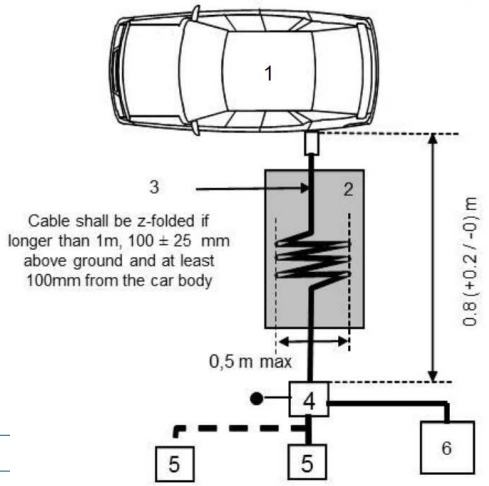


During vehicle validation phase

EMC Expert Consultant

- **Goal:** Reduce the number of physical validation tests needed to cover model and configuration diversities
- Run first measurements on reference vehicle
- Introduce component equivalent model in vehicle models
- Run first simulations on model of reference
- Verify that similar results are obtained (don't expect perfect matching)
- Run simulations for other vehicle models and/or configurations
- Calculate difference Δ between simulation results
- Add (+/-) difference to reference measurement results
- Validate that AMN output levels are below the limit with sufficient margin for each model / configuration



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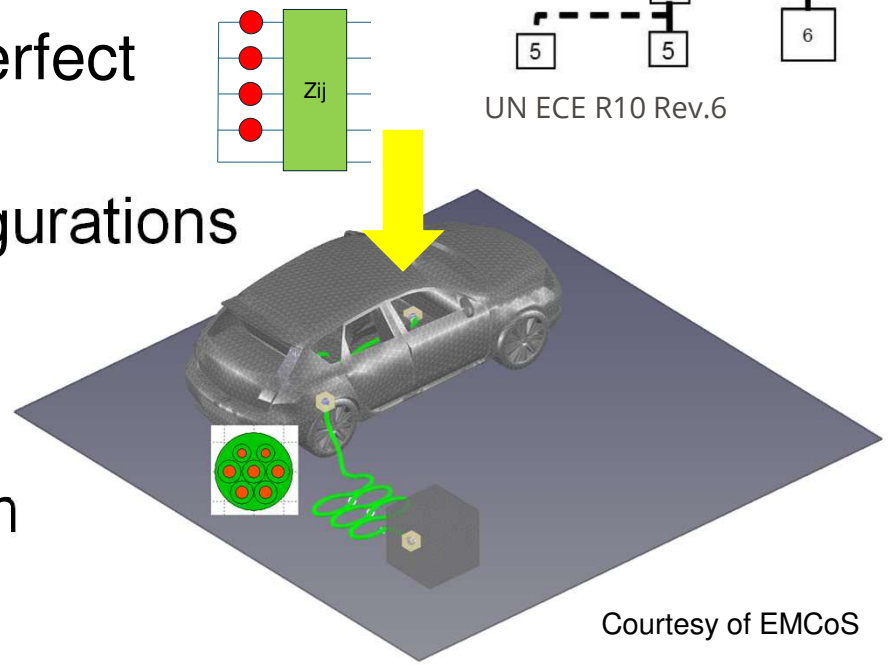

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EMC crisis and firefighting before SOP

EMC Expert Consultant

- **Goal:** Solve the crisis as fast as possible, with the most cost-effective solution, and avoid trial-and-error endless iterative random tests
- If everything has been followed correctly, this will be unlikely, but just in case …
- No need to panic anymore !!!
  - Component supplier already has the latest updated models of the component interfaces that have been validated
  - OEM already has the latest updated models of his vehicle project
- Modifications can be easily and efficiently done by numerical simulation to
  - Understand what is happening
  - Identify the parameters that impact the results (especially resonances)
  - Define the different physical configurations and solutions to be tested in priority for the next day

Take aways

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- Your might have one of the best RF/EMC simulation suites in the world, but this is not sufficient
- Numerical simulation in EMC is weakened for technical and organizational reasons
- To overcome these blocking points, these tasks should become part of the Product Lifecycle Management
- A global technical policy has to be established if one expects to obtain cost efficient numerical simulations, enhancing the performance and productivity by globally reducing development and production costs
- A methodology to define a technical policy and to process EMC matters should be developed and adapted specifically for each OEM and component supplier, for short-, medium-, and long-term prospectives
- The example given in this presentation is purely imaginative and is only meant to show how one could define the different simulation activities of a given vehicle feature throughout a development process

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Thank you for your attention

Questions?

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