

# **Virtual Modelling of Unintentional and Intentional Electromagnetic Emissions from Electric Vehicles**

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## **Summary**

This paper describes virtual testing of Plug-in Electric Vehicles (PEVs) according electromagnetic compatibility (EMC) requirements for the unintentional emissions and according the radio frequency spectrum allocation for the intended emissions of communications systems. It includes numerical model creation and related validation with real-life measurements. As a consequence, performing simulation approaches can save significant development cost and accelerate notably PEVs Time-To-Market.

*Keywords: simulation, EMC, prediction, communication, optimization*

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## **1 Introduction**

Future vehicle electronic systems will provide advanced safety related functions to aid and protect the driver and passengers. Thus, electromagnetic compatibility (EMC) and Connectivity performance represents an increasingly significant challenge for the function, safety and reliability of modern vehicles.

The electromagnetic environment created by unintentional and intentional sources, when sufficiently strong, may interfere with the operation of vehicle electronics sub-systems which degrades the performance of the whole system. Reciprocally, when not tested and/or not qualified, an EV may create interference with its surrounding environment. In addition EVs are particularly taking advantage of the rise of advanced connectivity solutions like for example enabling interaction with the car from distance, localizing the next charging station in the vicinity, checking remotely the batteries status or climate control.

Today comprehensive electromagnetic (EM) simulation software are indispensable tools for the design and analysis of EMC and Connectivity solutions in the automotive industry for the two following reasons:

1. Legislation on car safety, performance, EMC and radio communications standards varies significantly across the world. As a consequence, vehicle manufacturers and suppliers are making use of EM simulation tools to get new vehicles and components developed as quickly and economically optimized as possible while making sure their newest models meet these standards.
2. Optimizing EM performance virtually give designers' greater control as they can simulate the system behavior during concept and development phases before being able to measure any real prototypes.

A Plug-in Electric Vehicle (PEV) is any motor vehicle that can be recharged from an external source of electricity, such as wall sockets. Typically the electrical energy is stored in rechargeable battery. PEV is a subgroup of electric vehicles that includes "pure" battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs) where both a conventional internal combustion engine and an electric motor coexist as illustrated

in Figure 1. In this paper, simulation of EM emissions of Plug-in Electric Vehicle (PEV) is thoughtfully considered.

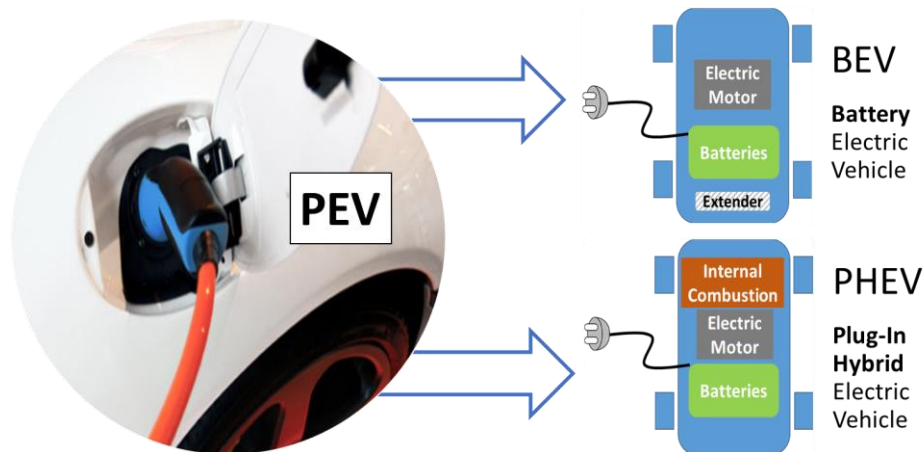


Figure 1: Difference between BEVs and PHEVs

The discussion will cover both aspects of PEV electromagnetic radiations:

- Unintentional Emissions: EMC immunity/emissions and Coupling to the Power Grid
- Intentional Emissions: Connectivity and Communications Systems

## 2 Unintentional Emissions and EMC requirements

The concept of EMC is to protect both the communications channels and the electrical circuits used in charging and operating the vehicle. The effort is essentially on limiting or controlling EM emissions by both the vehicle and charging station devices in order to keep those quantities within tolerable limits for other nearby devices.

This paragraph gives an overview of the specific EMC testing for PEVs and presents an example of radiated emissions and immunity test case according UNECE R10 legislation [1]. A detailed list of standards applied for proving legal compliance is given in Annex 1 for Immunity and Annex 2 for Emissions.

Then a real life test case situation is assessed and confronted to the results of its equivalent virtual model.

### 2.1 Overview of specific EMC testing for PEVs

Figure 2 give an overview on the additional PEVs testing cases required in comparison to a vehicle without plug (conventional combustion- or eventually electric powertrain-equipped). Those specific EMC requirements help to maintain the integrity of the EV system as a potential disturber of the electric power grid, as well as to protect the vehicle and charging station from other disturber eventually found on the grid. This is necessary to maintain the safety and interoperability of the PEV within its charging environment. Therefore influence and impact of the conductive charging supply equipment on the overall EMC performance of the PEV must be checked.

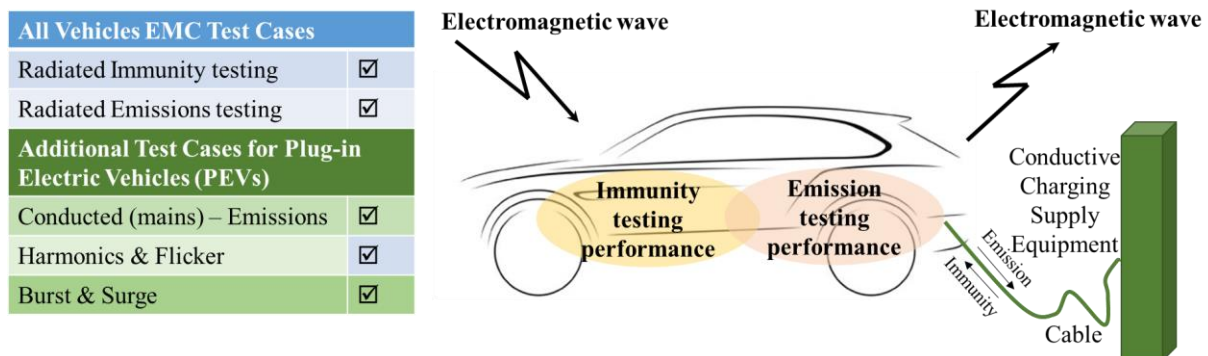


Figure 2: EMC test cases and setup for Electric Plug-in Electric Vehicles (PEV)

## 2.2 Example of unwanted radiated emissions – Measurements

An example of EMC radiated emissions performance is given in Figure 3. Typically vehicle-level radiated emissions test requirements specify broadband and narrowband emissions measurements over the band 30–1000 MHz using an antenna at a fixed point relative to the vehicle. The most common test configuration is a semi-anechoic chamber (SAC), with an antenna mounted 3 m high at a distance of 3 m or 10 m from the side of the vehicle and aligned with the center of the engine hood.

Having connected the PEV to the power grid through the charging cable, measurements are performed and radiated electric field values must not exceed specified CISPR 12 limits along the measured frequency range. According to the results of Figure 3, this EMC test is passed and consequently the measured PEV fulfills EMC legal requirements of UNECE R10's regulation. Nevertheless an emission peak is observed around 35 MHz which could potentially lead further to non-compliance situation when the radiating mechanism may not fully controlled and/or understood.

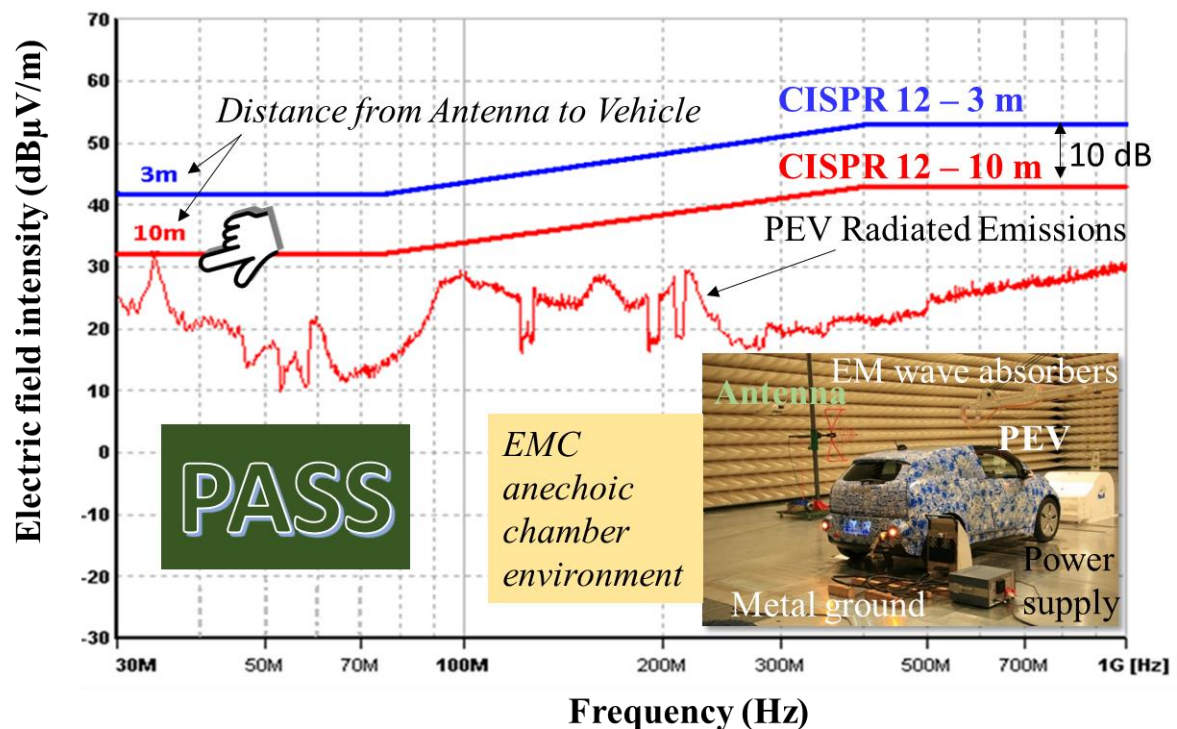


Figure 3: Electric field intensity received by the measurement antenna

## 2.3 Confrontation real measurements and simulation

A three dimensional (3D) EM simulation model helps to recreate the EMC testing scenario described in Figure 4 and understand the related radiation propagation phenomenon. In particular for the test case given in the previous paragraph, simulation results give a deep insights on EM field and current distributions and determine why at this particular frequency range around 35 MHz a radiation peak is observed. Indeed a 35 MHz-external plane wave creates a system resonance not visible for the rest of frequency spectrum: 10 dB stronger electric field intensity are numerically observed according the first color plot of the Figure 4 and therefore confirms the measured peak value. Any modification of the PEV chassis characteristics like grounding concept change or new cable harness positioning may affect positively or negatively the radiated EM field intensity and may shift the frequency resonance. A project-required modification of those parameters can be quickly performed thanks to the simulation model and eventual performance impact may quickly and surely verified.

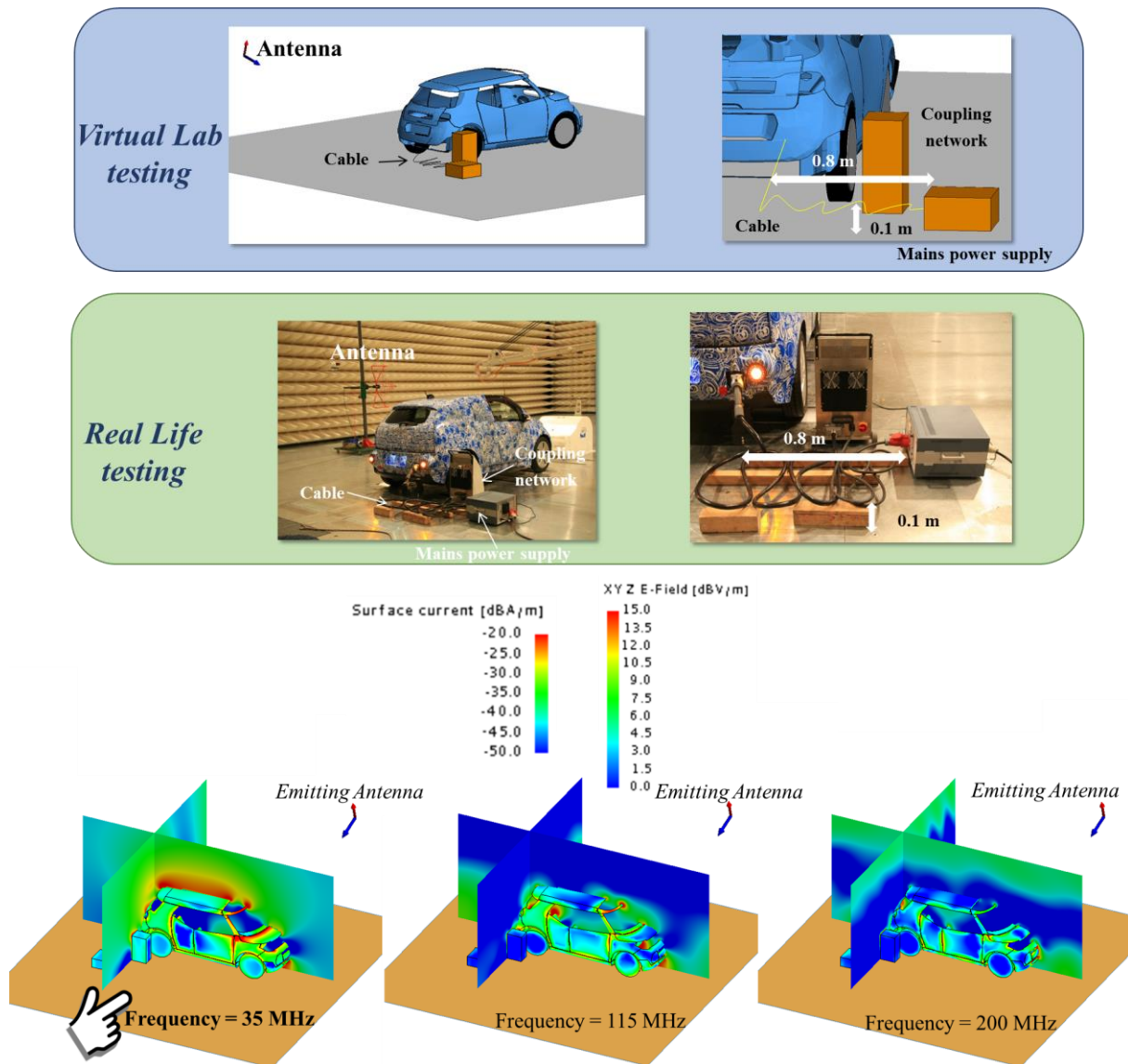


Figure 4: Virtual laboratory and Electric Field distributions

### 3 Intentional emissions (Over-The-Air) and Connectivity requirements

Driven by consumer demand for increasingly advanced services, embedded vehicle connectivity proliferates across all OEMs platforms. Considering an EV, the main threat is posed by the frequency noise generated by its electric or hybrid powertrain which could potentially interfere with communications channels.

Over-The-Air (OTA) testing method provides formal means of verifying that a PEV integrating either cellular communication (2G-GSM/3G-WCDMA/4G-LTE) or non-cellular communication (ITS, Car-to-X, Wi-Fi, Geolocalization) systems fulfills the End-User's performance expectations and comply to Radio Standards [2].

#### 3.1 Connected Car Ecosystem

In general, the ability of EVs to directly communicate with one another and with infrastructure is a key element of integrating the vehicle into a smarter and safer environment. This allows vehicles to gather and transmit information that will lead to fewer accidents, less traffic and greater energy efficiency. Likewise ongoing technological developments toward automated driving feature make electrification of the powertrain and vehicle connectivity an indivisible whole.

Most common wireless communications technologies and radio-based services implemented in modern vehicles are illustrated in Figure 5.

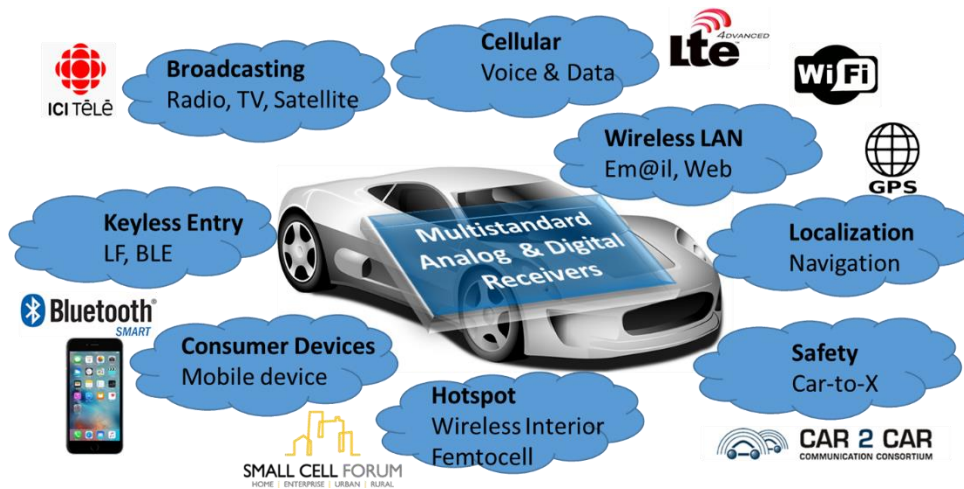


Figure 5: Connected car ecosystem

### 3.2 Over-The-Air Testing setup

The PEV telematics system is connected to a base station emulator simulating network protocols as shown in Figure 6. Particularly the measurement environment is very similar to CISPR12 EMC test case of Figure 3 with notably similar constraints on the absorbing walls conditions and distance from antenna to vehicle.

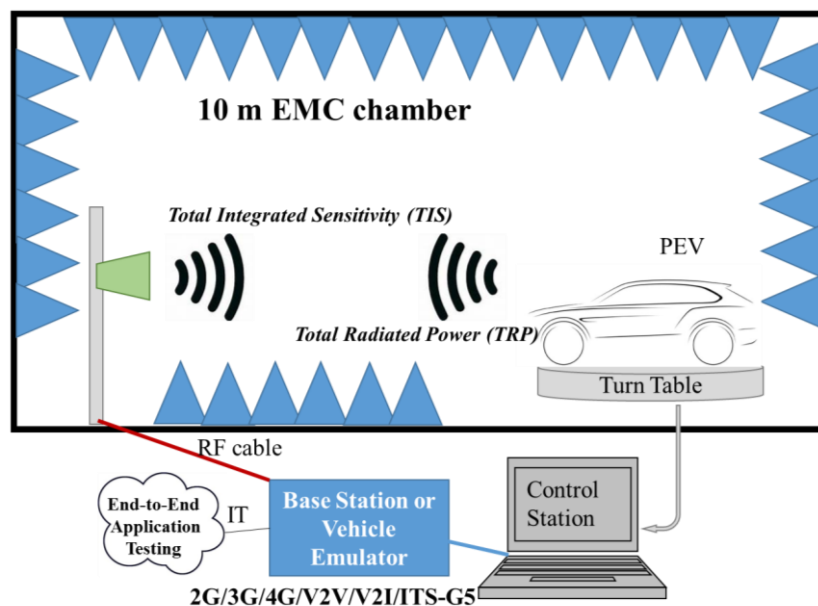


Figure 6: OTA testing setup

### 3.3 Confrontation virtual and real OTA testing

A simulation model is built according the real OTA test scenario (cf. Figure 7). A good agreement between measurement and simulation is obtained for a 4G-LTE radio protocol link testing. The polar plot of Figure 6 represent the radiating pattern performance in all the directions of the horizontal or azimuth plane of the PEV. The measured and simulated total integrated sensitivity (TIS) includes all cables losses and integration effects. After having validated the virtual vehicle model, the antenna parameters can be quickly optimized in order to get the most isotropic radiation pattern maximizing the coverage area performance. Furthermore no severe sensitivity degradation of the radio link (average TIS equal to -120 dBm) could be noticed: in this

particular testing case, the electric powertrain parasitic noise does not impact the quality of cellular LTE communication channel.

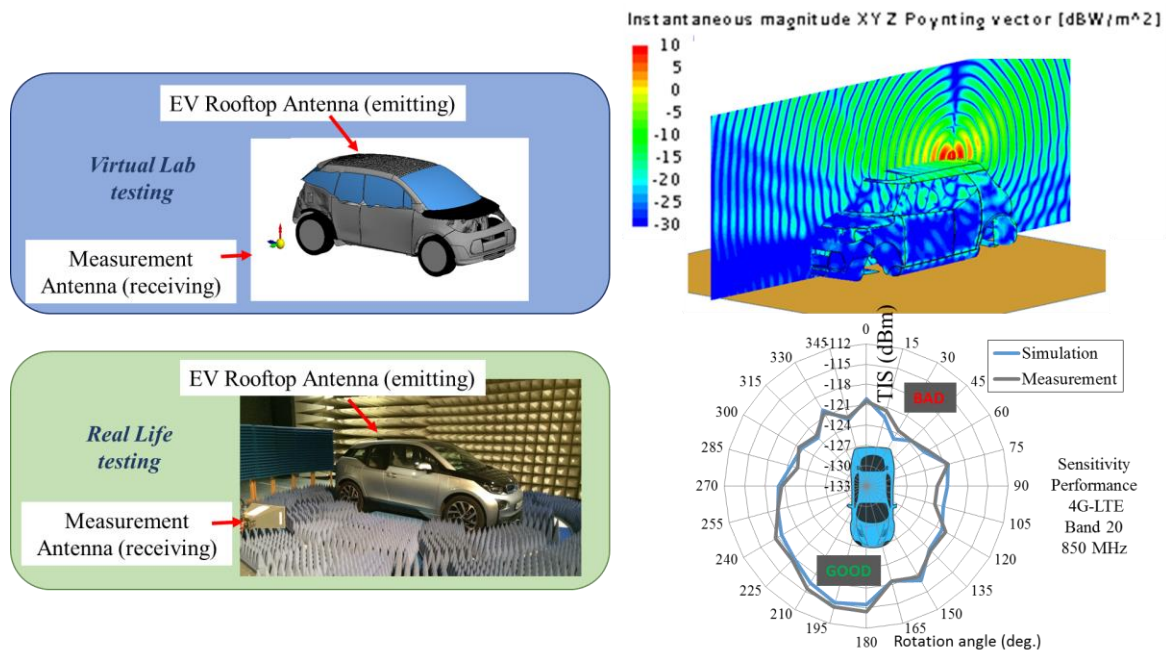


Figure 7: OTA virtual and real life assessment

## 4 Conclusions - Virtual Modelling opportunity

The transportation trend toward packed electronics, high voltage systems, along with the ever present desire to reduce costs, might have an impact on the EMC and Connectivity performance to electromagnetic interference. The addition of internal radio transceivers and antennas can further increase the possibility of disturbance both from internally generated signals, as well as external signals or noise detected by the antenna and coupled into the Electric Vehicle. Maintaining solid EMC performance without degrading the wireless communication channel quality becomes ever more challenging as the density of radio communications systems increases while those systems occupy wider electromagnetic spectrum range.

Developing an electric vehicle can be a long development process with many iterations at the design, build, and testing stages. To perform simulation, rather than building and testing prototypes, can phase out of the loop unnecessary steps and accelerate the learning curve of the product performance and behavior as illustrated in Figure 8.

Moreover, virtual modelling assesses level of details that will be never available with real measurements. Simulation methodologies represent very attractive propositions saving considerable amount of resources when thoughtfully integrated into overall EV project development planning.

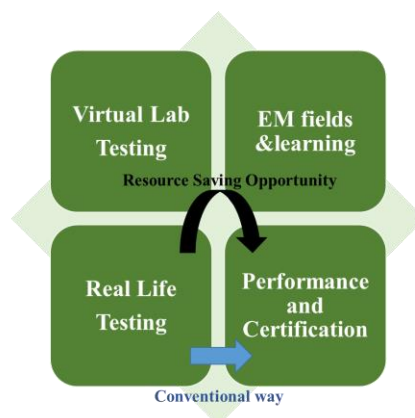
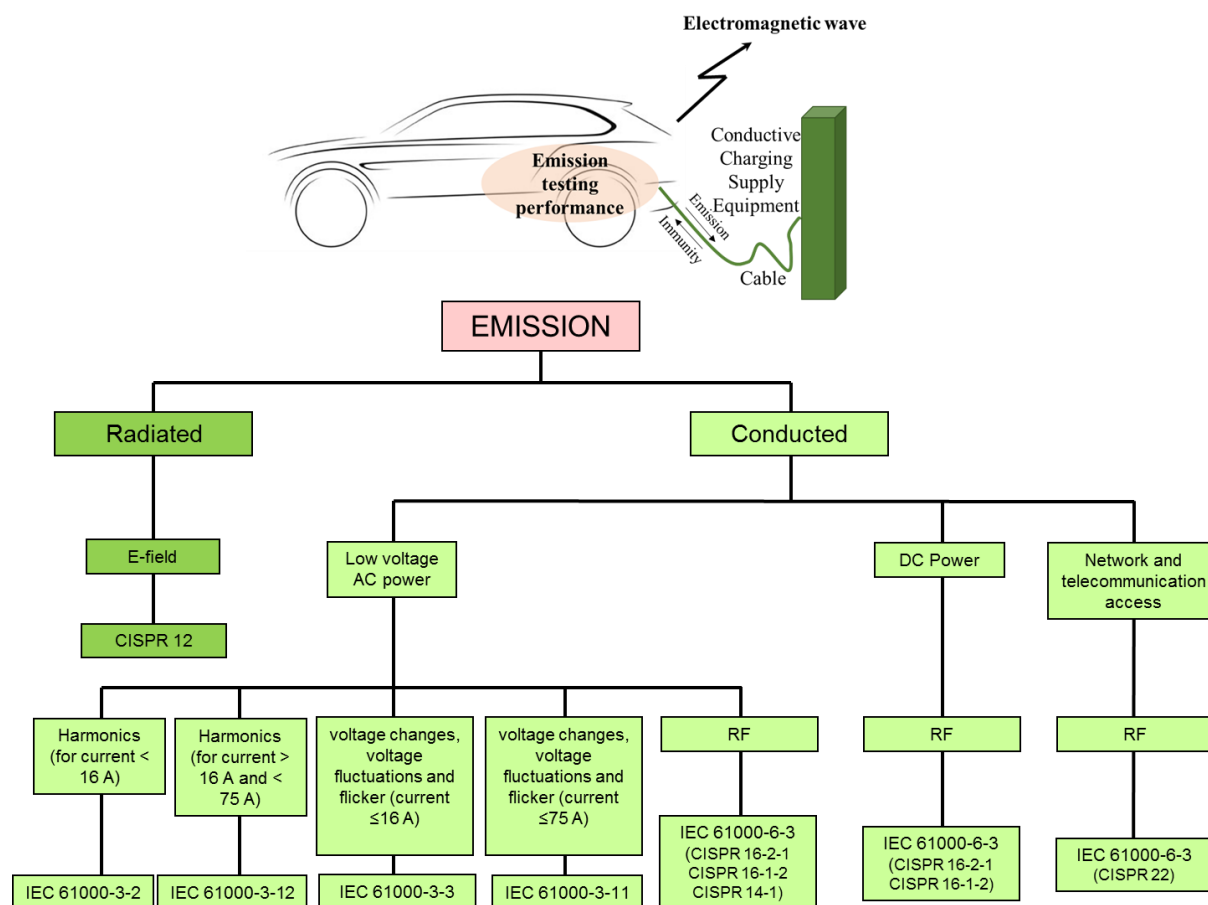


Figure 8: Virtual Modelling opportunity

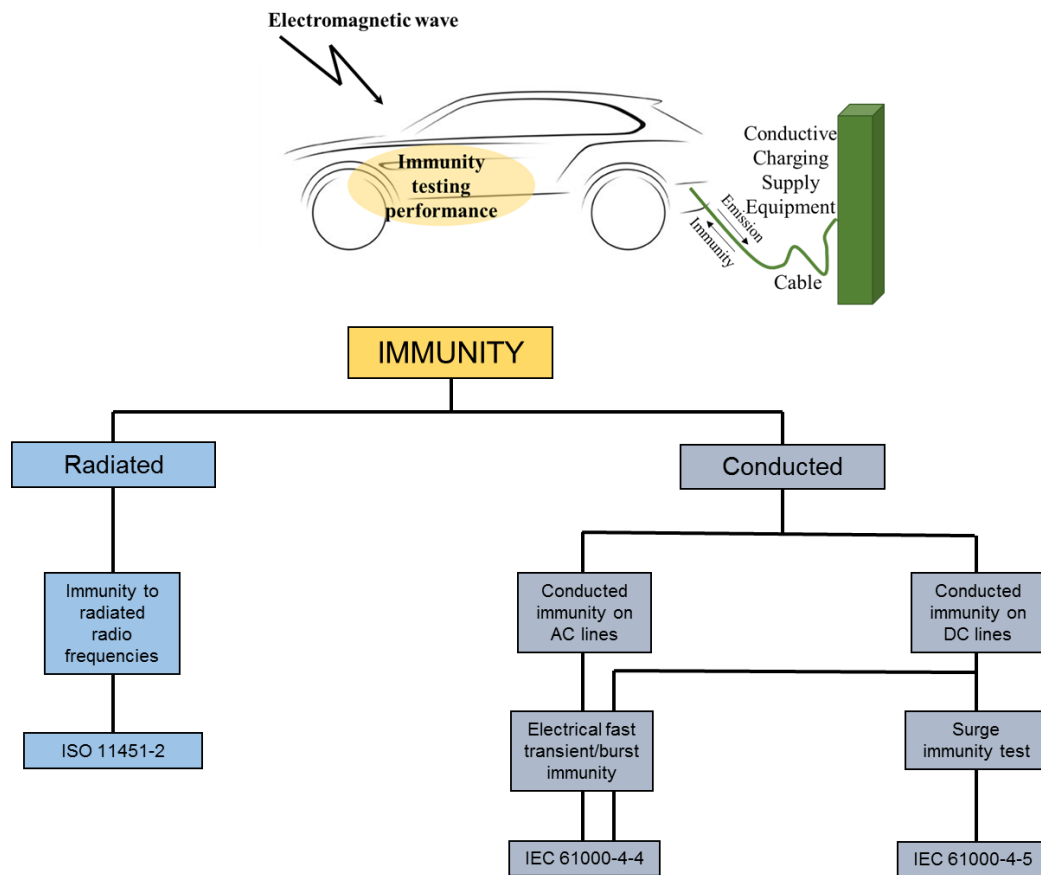
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## Annex 1: Overview of UNECE R10 Rev5 EMC requirements for Emissions



## Annex 2: Overview of UNECE R10 Rev5 EMC requirements for Immunity



### Author



Pascal Hervé is graduated from the National Institute of Applied Sciences in Rennes (France) where he earned a Ph.D. in electrical engineering. He also holds a Master's degree in Business Administration from the University of Applied Sciences in Munich (Germany). At Alcatel, Sony, BenQ-Siemens and Nokia, he gained international experience in Europe and Asia as Product Developer for the Consumer Electronics branch. He was responsible for leading in the research, design and development of mobile/portable device radio-frequency subsystems for handheld/portable battery-operated devices such as smartphones & data-enabled terminals. Since having joined CSA Group in 2011 as R&D Manager, he delivers EMC Consulting and Simulation services to Automotive OEMs for the next generation of embedded telematics.