Electromagnetic Simulation of Antennas Installed Inside Vehicles
An Automotive EMC Approach

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- Recent technology implementations in the automotive industry have increased the requirement for antenna system expertise.
  - Digital FM radio broadcasting
  - Remote keyless entry (RKE) and tire pressure monitoring systems (TPMS)
  - Global position systems (GPS)
  - Satellite digital audio radio service (SDARS)
  - Bluetooth and Wi-Fi

- Automotive EMC standards can now be virtually applied from chip level up to vehicle level due to advance in numerical simulation.
  - More ECUs
  - Higher OBDII data rates
  - CAN lines
  - More electronics is brought into the car
  - More mounting locations

INCREASE OF EMI
ANSYS Solutions to the Electronics Industry

ANSYS Multiphysics Solutions

Electromagnetic Simulation
- Low Frequency and EM
  - Maxwell
  - RMxpert
  - Simplicer
  - Q3D
- High Frequency
  - HFSS
  - SIwave
  - Designer
  - Redhawk
  - PowerArtist
  - Pathfinder
  - Sentinel

Mechanical Simulation
- Implicit
  - ANSYS Mechanical
  - ANSYS Structural
  - ANSYS Professional
- Explicit
  - ANSYS AUTODYN
  - ANSYS LS-Dyna

Computational Fluid Dynamics (CFD)
- Electronics cooling
  - ANSYS Icepak
- General CFD
  - ANSYS CFD
HFSS – Premier 3D Electromagnetic Analysis Tool

Test case from ACES: The Applied Computational Electromagnetics Society
Automobile with GPS Patch Antenna

GPS (1.575 GHz) mounted at roof center

10 adaptive passes to 0.0020 delta S convergence

• Some distortion from pattern of ideal groundplane
Automobile with GPS Patch Antenna

GPS mounted near front edge

10 adaptive passes to 0.0016 delta S convergence

- Some distortion from pattern of ideal groundplane
Automobile with GPS Patch Antenna

GPS (1.575 GHz) mounted at roof center

9 adaptive passes to 0.0084 delta S convergence

- more distortion of pattern

- ~12 RAM in ~ 1hr
  - 4X core processor
  - Includes adaptive passes
Induced Noise on FM Antenna

FM Antenna on PT Cruiser

Spark Plug Fields on PT Cruiser

ANSYS Maxwell to ANSYS HFSS link.

Voltage induced on FM antenna

FM Antenna on PT Cruiser

Spark Plug Fields on PT Cruiser

ANSYS Maxwell to ANSYS HFSS link.
HFSS model incorporates:

- shell of entire vehicle
- vehicle frame, motor
- window mounted antenna
- full DC motor geometry

Close up of window mounted AM antenna

Close up of DC Motor

Motor Noise/EMI in AM Receiver
Motor Noise/EMI in AM Receiver

AM Modulated Signal generating sub-circuit

HFSS model with motor as noise source

Speaker output

Motor noise waveform

AM modulated waveform

Audio signal

AM receiver circuit
Motor Noise/EMI in AM Receiver

Audio Signal Only

AM Signal and Activated Motor

Audio Signal Only

Ansoft LLC

AMRecvrwithNoiseSrc

XY Plot 2

Curve Info

V(AudioOutput)

Transient

Audio Signal Only

AM Signal and Activated Motor

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Motor Noise/EMI in AM Receiver

Audio Signal Only

AM Signal and Activated Motor

Audio Signal Only
In-Vehicle GPS Reception
A GPS telematics ECU receives the signal broadcasted by satellites at L1 frequency (1.575 GHz), calculates the actual position of the vehicle and send this information through a data network (usually an EDGE or GPRS network).

How can we evaluate the GPS reception to chose the proper placement of the ECU?
Intuitively one can use a transient solver, having a incident plane wave coming from above, RHCP polarized at 1.575GHz, flowing normally towards the vehicle surface to simulate a GPS signal.

The electric field can be visualized anywhere in time, showing the reflections due to vehicle’s structures which will cause multipath and also the attenuation and phase shift.
In-Vehicle GPS Reception

A GPS signal is received by numerous incident angles. Transient analysis for numerous waves becomes very time consuming. One alternative is to use **Radiation Efficiency** by having the GPS antenna of the ECU transmitting a L1 signal instead of receiving.

**Radiation Efficiency** is the ratio of the radiated power to the accepter power. Radiating Power is the amount of time-averaged power (in watts) exiting a radiating antenna structure through a radiation boundary (the lateral walls of the airbox).

\[
e = \frac{P_{\text{rad}}}{P_{\text{acc}}}
\]

where

- \( P_{\text{rad}} \) is the radiated power in watts.
- \( P_{\text{acc}} \) is the accepted power in watts.

\[e=83\%\]
Radiation Efficiency can give us fast results in frequency domain indicating the best candidates for GPS antenna placement inside the vehicle. The example below shows a comparison between the ECU installed in the current position (position 1) and a new position (position 2) under the dashboard near the throttle.

Near field plots are shown (3D polar plot and radiation pattern) as well as the radiation efficiency.
Automotive EMC Standards – ISO 11451-2

Picture taken at INPE. Courtesy of Volvo Brasil.
The international standard ISO 11451-2 is applied to road vehicles and describes a vehicle test methods 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.
The antenna illuminates the vehicle and two simulations are performed:

1- The ECU is placed inside the vehicle without wiring harness and a clock signal is applied to the connector and goes to the uprocessor through a PCB trace.

2- The same ECU is now connected to the wiring harness and the same clock signal is now applied to the end of the harness near the motor that is connected to the ECU through the connector.
This simulation shows that when the ECU is connected to the wiring harness the EMI is higher for a given bandwidth. Bit Error Rate (BER) for 165MHz is 1E-3 when the ECU is connected to the cable harness and it is 1E-17 when there is no cables and the clock is applied directly to the connector.
Full Vehicle EMC tests

Domain Decomposition Method
HPC – High Performance Computing

DOMAIN DECOMPOSITION TECHNIQUE ENABLES THE SIMULATION OF VERY LARGE FIELD PROBLEMS BY SHARING THE ORIGINAL MESH INTO SUB DOMAINS USING PARALLEL PROCESSING COMPUTING

Distributes mesh sub-domains to networked processors and memory
Full Vehicle EMC tests

Domain Decomposition Method

- 200MHz
- 900MHz
- 3 GHz
Full Vehicle EMC tests

FEBI – Finite Element Boundary Integral
Full Vehicle EMC tests

**FEBI – Finite Element Boundary Integral**

DDM

310 min and 75 GB RAM

FEBI

28 min and 6.8 GB RAM
EMC ON AUTOMOTIVE COMPONENTS

Printed circuit board (PCB) with multiple package chips

MCU: Chip inside wire-bond package
EMC ON AUTOMOTIVE COMPONENTS

Increasing Accuracy through Chip Power Model - CPM

Traditional Model

Simplifying assumption of all gates switching at same time

Chip Current

Triangular

Peak value

Triangular+Trapezoidal

Average value

Freq

T=500ps

Apache CPM

Chip Power Delivery Network

Current signature represented as PWL sources

Current drawn through supply pins

Pin 1

Pin 2

Pin 3

Pin 4

Pin 5

Pin 6

Pin 7

Pin 8

Pin 9

Pin 10

Pin 11

Pin 12

Pin 13

Pin 14

Pin 15

Pin 16

Pin 17

Current drawn through ground pins

Time (in S)

< 1e-7

CPM includes all die parasitics

Estimated Cdie

Missing Rdie, Ldie

Single Lumped Model

Power-grid RLC

Intrinsic De-cap

Intentional De-cap

Instance Load Capacitance

Well Capacitance
EMC ON AUTOMOTIVE COMPONENTS

- Operation of safety (airbag) and infotainment systems depend on MCU speed
- Operating speed of MCU depends on quality of power supply it receives
- Poor PCB design can cause 100+mV drop
- Can reduce MCU performance by more than 40-60MHz
- Must design PCB considering MCU and impact on its performance

Chip (IC)

Yellow ~ voltage at MCU with pkg/PCB
-100+mV drop from PCB
Red ~ voltage at MCU/pkg but no PCB
- MCU speed lower by 40MHz
EMC ON AUTOMOTIVE COMPONENTS

- **IC level**: EMC of active and passive components
- **Module level**: EMC behavior of components and PCB
- **System level**: System EMC behavior in standardized test setups
- **Vehicle level**: Complex antenna structures in ‘real emc world’

Currently EMI checks done here only

EMI needs to be improved in all of above levels
The proposed simulation framework allows to predict the true post-silicon EMC behavior vs. increasingly aggressive EMC targets dictated by marketing, customers, and international standards.

Dr. Davide Pandini, ST Agrate
CISPR25 STANDARD

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Radio disturbance characteristics for the protection of receivers used on board vehicles, boats, and on devices – Limits and methods of measurement

Figure 1 – Method of determination of conformance of radiated/conducted disturbance
An entire anechoic chamber can be simulated, including the absorber elements, DUT, antennas and the complete environment. This chamber can be used for simulating radiated emissions and immunity analysis.
RADIATED EMISSIONS

In this example the radiated emissions (Quasi Peak detector) are captured by the biconical antenna for every angular position of the DUT.
Radiated Emissions

3 meter sphere

Simulated results show very good agreement with measurements
Bigger environments can be simulated using different solvers. This example uses the Far Field data of a FEM antenna array model as a source to a bigger model solved using Physical Optics.
Physical Optics solver gives fast results of Far Fields by approximating the current density on surfaces and considering $J$ equals to zero in “shadow regions”.

No S-Matrix though
GSM Communication Using FEBI and IE Regions

S-Matrix can be calculated using FEBI and IE Regions.
GSM Communication Using FEBI and IE Regions
GSM Communication Using FEBI and IE Regions

The complete vehicle was simulated considering all geometries
We can couple the 3D HFSS model to ANSYS Designer and run a complete system level analysis of GSM communications. ANSYS Designer has complete libraries of system levels such as Wi-Fi, Bluetooth, WCDMA, GSM, etc... Results including eye diagrams, frequency and time domain, BER can be plotted for the whole system.
GSM Communication Using FEBI and IE Regions
GSM Communication Using FEBI and IE Regions

We can also use signals measured on lab on our simulations. This case an actual song was used as excitation for our model and the EMI caused by GSM can be seen in time and frequency domain.
Summary

i. Simulation examples of antenna placement in vehicles and automotive EMC were shown using realistic models and Automotive Standards.

ii. Electronics content in car are increasing exponentially and numerical simulation is required to reduce time to market and reduce costs through virtual prototyping. *Simulation Driven Product Development.*

iii. Automotive EMC depends on every component, including chip level, so a Chip Package System (CPS) was presented allowing to predict the true post-silicon EMC behavior vs. increasingly aggressive EMC targets dictated by marketing, customers, and international standards.

iv. Comparison between simulations vs. measurements has shown the effectiveness and the accuracy of ANSYS electromagnetic simulation tools.

v. With the acquisition of APACHE, ANSYS provides a unique capability to accurately simulate EMC from Chip level up to a complete System Level fully integrating 3D full wave models with circuit/system solvers.