From Radar Traps to Navigation Systems - How Simulations Can Help Reduce Cost and Improve Efficiency

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Overview

Trends in Automotive Industry

- Added value of electronics
- High frequency applications in automotive applications

Examples

simulation challenges: Ansys solutions

- FEBI
- Satellite systems
- Radar Traps

Summary
Two Trends in Automotive Industry

1) **Added Value of Electronic components in Automotive production (M. Wissmann, VDA Pres; IAA 2011)**:

   - 1990: 16%
   - 2011: 30...40%

2) **Statistic of Automotive Breakdowns shows major contributions of electric and electronic parts in automotive**


High Frequency applications for Automotive

**Car Entertainment**
- FM /Radio
- SDARS
- DVBT

**Mobile Communication**
- GSM
- UMTS
- Bluetooth

**Telematics**
- ETC (Electronic Toll collection)
- C2C (Car to Car Communication)
- C2I (Car to infrastructure / Traffic guidance systems)
- Ecall (obligatory f. 2015)

**Positioning**
- GPS / Navigation
- Stolen vehicle tracking
- Asset tracking / fleet management
- Car sharing systems

**Car Safety**
- TPM Tire pressure monitoring
- Keyless Entry
- Proximity / collision avoidance radar
GPS Reception in-Vehicle

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 choose the proper placement of the ECU?
GPS Reception in-Vehicle

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.
GPS Reception in-Vehicle

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.
Domain Decomposition Method

HPC – High Performance Computing

Domain Decomposition Technique enables the simulation of very large field problems by sharing the original mesh into subdomains using parallel processing computing.

Animations performed by ESSS.
Full Vehicle EMC tests

Domain Decomposition Method

Animations performed by
Full Vehicle EMC tests

**FEBI – Finite Element Boundary Integral**
Hybrid IE-Regions

- Metal objects can be solved directly with an IE solution applied to surface
  - Removes the need for air box to surround metal objects
- Homogeneous dielectric objects can be replaced with IE-Region
  - Dielectric is solved using IE to surface

Assignment:
- Select Objects
  - HFSS → IE Regions → Assign As IE Region

IE-Regions shows ~70% RAM reduction vs. ABC
Full Vehicle EMC tests

**FEBI – Finite Element Boundary Integral**

- **DDM**: 310 min and 75 GB RAM
- **FEBI**: 28 min and 6.8 GB RAM
Case study in HFSS: car body with remote keyless entry (RKE) system

• Overall Project geometry

550cm

Control console with receiving antenna

RKE antenna working at 433MHz

Key transmitter
DDM: car body with RKE

Automatic separation to domains

Parallel simulation of seven domains

1x Master
7x Domains (on dual CPU, Quadcore machine)

<table>
<thead>
<tr>
<th>Task</th>
<th>Start Time</th>
<th>Elapsed Time</th>
<th>Disk</th>
<th>Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix Assembly/Solve</td>
<td>00:20:24</td>
<td>00:14:58</td>
<td>1.46 G</td>
<td>2514 KB/44347 tetrahedra</td>
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<tr>
<td>Distributed Solve for</td>
<td>00:21:10</td>
<td>0:01:38</td>
<td>0 K</td>
<td>Maximum domain memory: 1.859 GB, Average domain memory: 1.417 GB, Total memory for all domains: 3.916 GB</td>
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Case study: car body with RKE

- Field solution (433 MHz): E-Field from transmitting key-circuit in the hand of a person near a car
Tire Pressure Monitoring System (TPMS)
TPMS - Mesh Generation

- Geometrically conformal mesh automatically created and adapted for each iteration
  - Engineer not required to create each mesh
  - E-field at IP vs. rotation angle
Roof Mounted GPS

- GPS antenna mounted on roof
  - Circular patch
- Volume = 2500 $\lambda^3$
EMI/EMC: Shielding Enclosure Standard

EMC standard from ACES (Applied Computational Electromagnetic Society)
- Shielded enclosure
- Good test for accuracy
Wire Harness

- common mode signal on wire harness at 50 MHz
- “Bundle of wires” simulated as one “wire” with single ended common mode excitation ports.
Mobile Phone in Auto: an antenna in a Faraday cage

- What if radiator not connected to enclosure
  - E.g. mobile phone in auto
- Solve mobile device alone and impress fields from this solution into simulation car 900 MHz
- HFSS to HFSS link.
Hybrid Solution for Antenna Placement Analysis Using IE-Regions: Results

No need to solve space in between antenna and car body

<table>
<thead>
<tr>
<th>Solution Type</th>
<th>Total RAM (GB)</th>
<th>Elapsed Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEM w/ DDM</td>
<td>160G</td>
<td>8</td>
</tr>
<tr>
<td>Hybrid Solution</td>
<td>11</td>
<td>2.7</td>
</tr>
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</table>

15X Less 3X Faster
Fields from DVD Player

Source Locations
Slwave continued

• electromagnetic analysis tool for Complex PCBs
• How does it work?
  – application of full-wave solvers breaks a complex problem into a collection of simpler problems.
  – Radiated fields included.
• Radiated fields from PCB can be impressed into an HFSS simulation → the Slwave - HFSS link
Power Integrity with SIwave

Low $|Z|$ at 50 MHz

High $|Z|$ at 137 MHz
More on SIwave

SIwave linked data:
Radiated source fields from DVD at 125 MH
Back to problem size: **Reflector Antennas**

- Design of large structures
- Efficient in memory, simulation time

**81% Less RAM: Enhanced IE-Region vs. FEM**
Satellite Systems

- Simulation of satellite systems
- Efficient in memory, simulation time

733 λ

47 GB RAM
Simulation time: 57 mins
ca. 4.4 Mio $\lambda^3$
Radar trap problem

\[ f_{\text{radar}} \sim 25 \text{ GHz} \Rightarrow \lambda \sim 12 \text{ mm} \]

\[ 40.5 \text{ Mio} \lambda^3 \]

\(~ 7000 \times 5000 \times 2000 \text{ mm} \)
Leveraging High Performance Computing Hardware

- Spectral Domain Method
  - Distributed Frequency Sweeps
- Multi-Threading
- Distributed Parallel Solvers
  - HFSS-Transient
- Robust Design
  - Distributed Solve Option (DSO) *
- HFSS-Hybrid DDM
  - Hybrid HFSS/HFSS-IE Domain Solver
- HFSS-IE DDM
  - Matrix based Domain Solver
- HFSS Periodic Domains
  - Finite Array Domain Solver
- HFSS DDM
  - Mesh based Domain Solver

*Distributed Solve Option is a separate license and is not included with HPC
Back to Radar Traps: What are Metamaterials?

- A Metamaterial is essentially a material whose bulk electromagnetic properties arise from the interaction of structures, or structural voids, that are placed in arrays that are spaced on the order of a wavelength.
  - Therefore, the design of the individual structures/periodicity can be used to modify the properties.
  - Gives possibility for many opportunities as the limitation of electrical properties of natural materials is well known.
What are Metamaterials?

- On left, see how natural materials behave in a bulk manner when an external field is incident. In actuality, the effect is due to the superposition of many very small induced atomic or molecular dipoles.

- On right, a metamaterial uses a periodically spaced array of structures to induce a similar bulk effect, but via structure design. Note that the periodicity of the structures is smaller than the wavelength.

\[ n_1 \rightarrow n_2 \rightarrow n_1 \]

Incident Field \( E_{\text{ext}} \)

Incident Field \( E_{\text{ext}} \)

\[ n_1 \rightarrow n_{\text{eff}} \rightarrow n_1 \]
What are Metamaterials?

- It is of note that reflection is related to the Relative Permittivity and the Relative Permeability

\[ \tilde{n} = \sqrt{\tilde{\varepsilon}_r \tilde{\mu}_r} \]

- What do the signs of the real parts of \( \tilde{\varepsilon}_r \) and \( \tilde{\mu}_r \) mean?
  - If both real parts are greater than zero, or if both real parts are less than zero, a propagating wave is allowed
  - If either of the real parts are less than zero with the remaining being greater than zero, only evanescent fields are allowed
Implementation of MIN into Macro-simulation

- Note that the PEC (Red) scatters strongly in many directions
- The Cloaked PEC (Blue) has nearly no backscatter
HFSS results

PEC = ideal

NIM-material

Einfallende Welle

Gestreute Welle
„Solutions for 40 Mio $\lambda^3$„
Summary

- HPC scaling
- ANSYS HFSS → quick & efficient simulation solution
- Large structures
- Whole systems