Overview of FEKO for Efficiently Solving EMC Problems with Numerical Simulations

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Introduction: What is FEKO?

- FEKO is a global leading electromagnetic simulation software suite that uses multiple frequency and time domain techniques with true hybridization to analyse and solve a broad spectrum of problems.

Introduction: Applications

- Antenna Design
- Antenna Placement
- Electromagnetic Compatibility (EMC)
- Scattering
- Others

Multiphysics Analysis and Optimization
FEKO Applications

Antenna Design, Placement and RCS

Antennas for wireless communication devices and systems (FM, GPS, 3G, TV, LTE, MIMO and many others), reflector antennas, antennas for radars, antennas with radomes, ….

Placement of antennas on vehicles, aircraft, satellites, ships, cellular base-stations, towers, buildings, including radiation patterns, co-site interference and RADHAZ analysis, …

Arrays of microstrip patches, waveguide-based elements, reflect arrays, …

RCS analysis and studies for aircraft, vehicles (e.g. tanks), ships, buildings and wind turbines …

EMC Türkiye 2015, Istanbul, 3rd September 2015

FEKO Applications

EMC and Cable Coupling

- EMS and EMI analysis and design cases, which involve cables, which either radiate through imperfect shields and cause coupling into other cables, devices or antennas, or which receive (irradiation) external electromagnetic fields (radiated from antennas or leaked through other devices) and then cause disturbance voltages and currents potentially resulting in a malfunctioning of the system.

- Electric and magnetic shielding for metallic or dielectric enclosures of arbitrary shape with arbitrary opening cuts into them.

- Near fields for radiating hazard analysis.

- Electromagnetic pulses (EMP), lightning effects and High Intensity Radiated Fields (HIRF).

EMC Türkiye 2015, Istanbul, 3rd September 2015
Introduction: Main industries

Aerospace
Defence
Automotive
Healthcare
Communications
Consumer Electronics
Energy

Solvers in FEKO – Simulation Map

Asymptotic Methods (high-frequency approximation)
Full-wave Methods (physically rigorous solution)
Hybridization to solve large and complex problems
General study Cycle

Circuit Design → Antenna Design → Antenna Integration

PCB or circuit connection → Cables analysis

Antenna Placement and RCS analysis

EMC aspects: HIRF, Lightning, Interferences,…

Radiation Hazards
Solution Scaling: SAAB JAS-39 Gripen

- Doubling the solution frequency, requires that the triangle mesh size is halved

- This increases the number of mesh elements, resulting in an increase in the computational requirements

- This benchmark illustrates how computational resources scale with frequency, comparing requirements for MLFMM and PO methods
### Electrical Size of the Aircraft

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Electrical Size of Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length</td>
</tr>
<tr>
<td>300 MHz</td>
<td>15 λ</td>
</tr>
<tr>
<td>600 MHz</td>
<td>30 λ</td>
</tr>
<tr>
<td>1.2 GHz</td>
<td>61 λ</td>
</tr>
<tr>
<td>2 GHz</td>
<td>101 λ</td>
</tr>
<tr>
<td>10 GHz</td>
<td>504 λ</td>
</tr>
<tr>
<td>20 GHz</td>
<td>1009 λ</td>
</tr>
</tbody>
</table>

### Computation Resource Scaling

- **Memory and runtime scaling for the SAAB JAS-39 Gripen:**
  - The results are normalized (300 MHz, MLFMM = 1) to highlight the factor increase in requirements as a function of increasing frequency.
  - Furthermore, the graphs highlight the difference between requirements in the MLFMM and PO methods. PO can solve the problem at 20 GHz where the plane is 1000 λ long.
Comparison of Results: MLFMM and PO

1.2 GHz

MLFMM  PO

2.0 GHz

MLFMM  PO
Simulating Composite Material Airframes

- **F5 aircraft with carbon fibre construction**
  - Fibre:
    - Conductivity = $4 \times 10^4$ S/m
    - Relative permittivity = 3.4
  - Epoxy (orthogonal to fibre):
    - Conductivity = 50 S/m
    - Relative permittivity = 3.4

- **Compute**:
  - Monostatic RCS
  - Surface current distribution

- **Excitation**:
  - Linearly polarised plane wave

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Simulating Composite Material Airframes

Elevation RCS at 50 MHz

Azimuth RCS at 50 MHz

Surface current distribution
Why FEKO for lightning?

- **Frequency-domain analysis**
  - Time-domain codes need too many time steps due to the low frequency components of the lightning spectrum

- **Exceptionally low noise floor**
  - Inherent stability of MoM formulation
  - Ability to simulate reliably down to a few Hz

- **Efficient analysis of cable bundles**

- **Schematic capability**
  - Add sources, components, terminations and probes

- **Time-analysis capability in POSTFEKO**
Cables in aircraft

Initially cables are just modelled as conductors → easy to reproduce in measurement

Currents with and without shielding

- Lightning-induced currents observed at the shorted ends of the three unshielded cables
- Up to 1400 mA for unshielded cables
- Up to 21 mA for shielded cables

Important to know how much shielding is enough.
Don’t want to add too much weight and don’t want to lose flexibility.
Study: interference between HF and VOR system
Study: interference between HF and VOR system

Interference between HF and VOR system

Interferences on the VOR system when the HF antenna is used

Study: Cable analysis

2 Coaxial channels VOR 1 & VOR 2

HF antenna
Study: Cable analysis

Spurious currents induced on the VOR cables

Adding shields around the coaxial bundle
Study: Cable analysis

Spurious currents level attenuated
Interferences was noticed between HF and VOR system
Cable analysis was performed to identify the interference phenomenon
Strong spurious currents are induced on the coaxial VOR cables.
Additional shield around VOR coaxial cables reduced significantly the spurious currents (more than 15x)

Perspectives: Lighting strike on Helicopter platform
Perspectives: Lighting strike on Helicopter platform

- Lightning strikes aircraft

- Investigate:
  - Antenna coupling
  - Coupling to cables in aircraft

- Impressed current sources for strike and exit points

- Broad-band characterisation of frequency response of platform
  - 1 kHz to 1 MHz in current example
  - Double exponential pulse form
  - Fast computation using AFS technology in FEKO
  - Surface meshing efficiency using MoM/MLFMM
Perspectives: Lighting strike on Helicopter platform

- Special shielding materials can be specified in FEKO
  - E.g. carbon fibre, low conductivity composites

- Such materials can be arbitrarily applied to any body panel

- Perspectives:
  - Comparative simulation runs will test whether such materials improve shielding performance.
  - Study of different cable shield configurations
Antenna Placement on Vehicles

- Evaluate communication blind spots for vehicle antennas.
- Radiation hazard studies for personnel next to or inside vehicle.
- Antenna coupling

 Radiation Hazards of Multiple Transmitters (1)

- FEKO example (3 x monopole mounted on vehicle):
  - Compute radiation levels for each transmitter

- POSTFEKO Lua scripting:
  - Compute percentage contributions for each monopole
  - Sum percentage contributions
  - Render isosurfaces of maximum exposure boundaries
  - Render field planes where colouring represents exposure levels
Radiation Hazards of Multiple Transmitters (2)

- Combined radiation hazard: 3 transmitters simultaneously transmitting

ICNIRP Radiation Hazard Zones

- ICNIRP radiation hazard zones for TETRA vehicle mounted radio
  - Yellow - Public safety zone
  - Red - Occupational safety zone
Naval Antenna Placement

Determine effect (patterns and isolation) of positional changes

Effect of slanting

Antenna mounting options

Effect of shielding-disc size
Complex PCB geometries (ODB++ or Gerber formats) can be imported into FEKO for board level analysis, including:

- Noise interference with antenna feeds and sensitive components
- Coupling between traces and layers
- Component placing and shielding analysis

Case study related to board level noise coupling

- The goal of the study was to investigate noise coupling from various noise sources to the antenna feed port
- CMA was chosen due to the insight obtained through modal analysis and modal currents
- A modification was purposed which successfully reduced the coupling issue
Incremental Detail Effect on Modal Current

The dominant modal behaviour is determined by the larger details on the board, and the antenna, the incremental detail has a negligible effect on the modal current distribution.

Reduced Coupling on Modified Design

Modal current, mode #3, 1.7 GHz - original geometry  
Modal current, mode #3, 1.7 GHz – modified geometry

S_{12, partial} Coupling mode #3 - original geometry  
S_{12, partial} Coupling mode #3 - modified geometry
After problematic noise coupling was identified at 1.7 GHz, a design modification to the problematic area alleviates the interference.

The CMA investigation was verified with an S-parameter simulation: the coupling between the noise sources and the antenna feed was calculated. The S-parameter data also verifies that the design modification will reduce the coupling.
Shielding Effectiveness

Shielding effectiveness for a PC tower

- The goal of this study is to investigate the shielding effectiveness for a PC tower
- The tower is radiated from the front at different frequencies and the field leakage into the tower is studied
- Although the tower is electrically large at higher frequencies, the detailed geometry and holes of the shielding make it suitable to solve with FDTD combined with GPU acceleration; furthermore a single FDTD run can capture the behavior at across the broad frequency spectrum
- Field results are compared at different frequencies to understand the effectiveness of the tower shielding

Cut plane through the center of the tower geometry: the tower is 44x90x136 cm

Around 1 GHz the spacing between the boards acts like a cavity causing standing wave patterns in the tower where some areas inside are better shielded than other areas. At higher frequencies more field leaks into the tower and the field spreads more evenly through the tower.
Pacemaker Antenna Design

• Initial antenna performance simulated with homogeneous flat phantom
  • the device is positioned 5mm below the surface and simulated with MoM solver
• The performance is then verified using an anatomical model (humanbodymodels.com)
  • the pacer is positioned accordingly in the phantom and simulated with the FDTD solver
• The link budget shows that device telemetry will be possible up to 10m for -31dB antenna source power

Antenna Design for Implanted Pacemaker

- Comparison of 2 different antenna designs at 2 different operating frequencies
  - Design #1: monopole design at 900 MHz
  - Design #2: PIFA design at 400 MHz offers superior gain performance than design #1

Pacemaker Antenna SAR Compliance

<table>
<thead>
<tr>
<th>Standard</th>
<th>Basic Restriction</th>
<th>Factor below Standard (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE (North America)</td>
<td>2W/kg 1g cube</td>
<td>1.3%</td>
</tr>
<tr>
<td>ICNIRP (Europe)</td>
<td>2W/kg 10g cube</td>
<td>0.367%</td>
</tr>
</tbody>
</table>
Implant Safety for MRI - Transfer Function

- Implants need to be certified for safe usage in MRI systems (SAR, temperature)
- Simulating the full simulation MRI + human + implant is too complex when the implant lead is consider, and must be solved in steps:
  - the implant and lead are simulated in a homogeneous liquid with properties similar to muscle tissue
  - a transfer function for the lead is derived to determine the response for a 1 V/m tangential piecewise, excitation along the length of the lead
  - with the knowledge of the transfer function and incident field, the SAR and heating due to the RF MRI field can be estimated at the lead tip

Implant Safety for MRI – Lead Geometry Simulation

- Despite the stepwise approach to estimate implant safety, the simulations are still complex when considering realistic models
  - typically the leads used for the implants have significant detail < 1mm
  - multiple conductors run along the length of the leads and are often twisted in helical configurations to allow for flex in the lead
  - FEKO’s MoM solver is well suited to this problem: wires can be resolved with segments reducing the computational requirements
  - this can be considerably faster than e.g. solving the problem with FDTD where many time steps will be required due to the small geometric detail

MRI Compatibility of a Hip Replacement

- The setup is for assessing compliance of a hip implant in a 3T volume coil:
  - at 124 MHz $\lambda_{\text{muscle}} \approx 30 \text{cm}$: could be resonant effects
  - an ASTM (2009) rectangular phantom is used for the setup
  - filled with muscle tissue simulating liquid
  - the implant is positioned in the phantom at a location where large field gradients occur
  - field interactions, SAR distribution, and spatial peak averaged SAR values are calculated
  - the temperature increase can also be calculated
Thermal Analysis in FEKO

• Lua script based implementation of the Pennes Bioheat equation, including
  • SAR - metabolic processes adds heat
  • Thermal conductivity - spreads heat
  • Blood perfusion - removes heat (amount is temperature dependent)
  • Air convection - removes heat
  • Thermal radiation - removes heat
  [http://www.feko.info/support/lua-scripts/thermal-analysis]

Injectable Implant – 2.45 GHz

• In [1] a design is proposed at the ISM band (2.45 GHz)
  • the diameter of the implant in small enough that it can be injected into the skin (without surgery)
  • Link budget requires antenna gain $G_{TX} > -17$dB for short range communication < 20m

Thank you!

www.altairhyperworks.com/feko