FEKO
Recent improvements and future roadmap

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New Features in FEKO 2017

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FEKO 2017 Major Features

- FDTD parallelisation
- RL-GO improvements (since 14.0)
- 3D anisotropic material support
- MLFMM stabilisation (14.0.420)
- Extensions to the loft operator
- New mesh engine
- Improved windscreen visualisation
- 2D graph text and shapes
- Cartesian surface graph plot type (14.0.430)

- New version numbering adopted by HyperWorks: HyperWorks 14 to HyperWorks 2017
RL-GO Improvements

- Improved algorithm for automatically selecting the initial ray launching increment (14.0.410)
  - Often speeds up run time
  - Same or improved accuracy

<table>
<thead>
<tr>
<th>Version</th>
<th>Convergence accuracy</th>
<th>Memory (MByte)</th>
<th>Time per angle (s)</th>
<th>Total runtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.0</td>
<td>Low</td>
<td>49.36</td>
<td>0.87</td>
<td>10.2 minutes</td>
</tr>
<tr>
<td>14.0</td>
<td>Normal</td>
<td>49.36</td>
<td>38</td>
<td>7.62 hours</td>
</tr>
<tr>
<td>2017</td>
<td>Low</td>
<td>42.52</td>
<td>0.66</td>
<td>7.8 minutes</td>
</tr>
<tr>
<td>2017</td>
<td>Normal</td>
<td>42.52</td>
<td>31</td>
<td>6.24 hours</td>
</tr>
</tbody>
</table>

Tank 8m in length (265λ at 10 GHz)

RCS of a tank at 10 GHz, horizontal plane

KCS (dBiM) vs. Azimuth [deg]
RL-GO Improvements

- Significantly less memory for uncoupled MoM/RL-GO examples with point sources and plane waves (14.0.420)

- Example
  - Monopole antenna (MoM)
  - Dielectric radome (RL-GO)
  - Frequency: 9.5GHz
  - 56 MoM basis functions
  - 2116 far field points
  - 5000 near field points

<table>
<thead>
<tr>
<th>Version</th>
<th>Memory</th>
<th>Runtime (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.0</td>
<td>1.04 GByte</td>
<td>7.2</td>
</tr>
<tr>
<td>2017</td>
<td>20.46 MByte</td>
<td>5.4</td>
</tr>
</tbody>
</table>
RL-GO Improvements

- Near field aperture source transformation example
  - Near field aperture source with 812 samples transformed into 6 spherical mode sources

<table>
<thead>
<tr>
<th>Solution</th>
<th>Memory</th>
<th>Runtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.0.400 RL-GO (normal accuracy)</td>
<td>Not enough memory (32 GByte machine)</td>
<td>-</td>
</tr>
<tr>
<td>14.0.400 RL-GO (low accuracy)</td>
<td>1.44 GByte</td>
<td>5.94 hours</td>
</tr>
<tr>
<td>2017 RL-GO (normal accuracy)</td>
<td>10.20 MByte</td>
<td>23.16 minutes</td>
</tr>
<tr>
<td>2017 MoM (with near field source)</td>
<td>2.66 GByte</td>
<td>19.62 minutes</td>
</tr>
</tbody>
</table>

Result comparison between ray launching geometrical optics solutions since FEKO 14.0.400. The method of moments solution is shown as reference.
MLFMM Stabilisation

- Additional stabilisation option for the MLFMM (14.0.420)
- Addresses models with severe convergence problems
  - Large problems with intricate detail

Spiral

Corrugated waveguide horn

Aircraft including engine inlets with fan blades

Solver settings

- None
- Solve model with the multilevel fast multipole method (MLFMM)
- Solve model with the adaptive cross-approximation (ACA)

MLFMM Stabilisation

Residual

Number of iterations

0 100 200 300 400 500 600 700 800 900 1000

MLFMM

Stabilised MLFMM
New Mesh Engine

- Generates improved meshes
- Meshes often consist of fewer mesh elements
  - Reduction of resources and faster simulation
- Faster mesh creation
- Adheres more strictly to specified mesh sizes
- Successfully meshes some models that were previously problematic
- Legacy mesh engine still available, but will be discontinued in future releases
### New Mesh Engine

**Faster mesh creation**

<table>
<thead>
<tr>
<th>Relative mesh size</th>
<th>Number of elements</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Legacy</td>
<td>New</td>
</tr>
<tr>
<td>1.25*(\lambda/8)</td>
<td>53 512</td>
<td>46 800</td>
</tr>
<tr>
<td>(\lambda/8)</td>
<td>82 186</td>
<td>68 226</td>
</tr>
<tr>
<td>0.8*(\lambda/8)</td>
<td>129 457</td>
<td>113 454</td>
</tr>
</tbody>
</table>

![Waveguide helix model](image)

![Legacy mesh engine](image)

![New mesh engine](image)
**New Mesh Engine**

*Faster mesh creation*

<table>
<thead>
<tr>
<th>Mesh size [m]</th>
<th>Number of elements</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Legacy</td>
<td>New</td>
</tr>
<tr>
<td>1</td>
<td>16 819</td>
<td>7 964</td>
</tr>
<tr>
<td>0.1</td>
<td>38 026</td>
<td>16 681</td>
</tr>
<tr>
<td>0.05</td>
<td>73 295</td>
<td>42 619</td>
</tr>
</tbody>
</table>

![Legacy mesh engine](image1)

![New mesh engine](image2)
Replace Mesh

• Replace the mesh of an unlinked mesh or model mesh

• Typical workflow
  • Create model with configurations, ports and solution settings applied to the mesh elements
  • Export the mesh and modify it with other tools such as HyperMesh or SimLab
  • Re-import the mesh into CADFEKO
  • Solution settings and ports are transferred to the new mesh
  • Default mesh properties applied to any new mesh labels that did not exist before
Cartesian Surface Graphs

- Released with 14.0.430, extended in 2017
- Allows 3D data to be displayed on a 2D graph
- Axes represent independent parameters
  - Angles (for example, theta and phi)
  - Frequency and position
- Quantities like radar cross section (RCS), gain or near fields plotted by colour
- Result types supported in this release
  - Far fields, near fields, S-parameters, custom datasets, maths scripts, and data imported from file
2D Graph Text and Shapes

- Graphs have been extended with options to add text and shapes that allow improved reporting from within the FEKO interface
- Text boxes (horizontal or vertical text)
- Shapes
  - Lines
  - Single arrows
  - Double arrows
  - Rectangles
  - Circles

Graph with text and shapes to indicate where the field values exceed the standard.
Several phases within the MTL calculation have been optimised to accelerate run time.

- Speedup factors of 2x to 34x (and even higher) are observed depending on:
  - The cable problem (harness details and cross section)
  - The solution request (radiation or irradiation)
  - The frequency range
FEKO 2017.1 Feature Update

April 2017
FEKO 2017.1 Major Features

• Cache file stores cable per-unit-length parameters
  • Speeds up continuous frequency range calculations

• Near field aperture source optimisation for PO and LE-PO
  • Speeds up near field aperture processing

• Network voltage sources supported together with the RL-GO solver

• Current and charge requests are now stored in separate *.os and *.ol files

• Parameter sweep extended to allow sweeps of more variables
PO and LE-PO Aperture Source Optimisation

- Speedup of near field aperture processing
- Automatically converts an equivalent aperture excitation into its corresponding spherical mode representation
- Similar to the extension for RL-GO released in FEKO 14.0
  - Computational requirements of simulations with aperture excitations are proportional to the number of near field points used in the source
- Supported for full PO coupling or no coupling
- Not supported for the iterative hybrid MLFMM-PO/LE-PO method
FEKO 2017.2 Feature Update

July 2017
FEKO 2017.2 Major Features

- FEM solver
  - Improved handling of PEC regions embedded in dielectric regions

- FDTD solver
  - Specification of convergence criteria
  - Irradiation MTL cable analysis

- POSTFEKO
  - Near field quantities for electric and magnetic flux density display

- Optimisation
  - Near field optimisation goal: normalised electric and magnetic flux density
  - Far field optimisation goal: realised gain
FEM Handling of PEC in Dielectric Regions

- Easier to model PEC parts such as vias and pins in FEM models
  - PEC regions can now be included as part of the FEM solution
  - Alternative 1: Model regions as free space – FEM/MoM boundary
  - Alternative 2: Model regions as dielectric – adds to FEM unknowns
- May reduce memory and runtime requirements

Cutplane view showing vias from the model (zoomed out view top) meshed as PEC tetrahedra
FDTD Termination Criteria

Example: GPS aperture-fed CP patch antenna

- Aperture-fed circularly polarized patch with one slot and two stubs\(^1\)
- Far field calculated at 1.55 GHz
- Reflection coefficient calculated from 1.4 GHz to 1.7 GHz

<table>
<thead>
<tr>
<th>Convergence threshold</th>
<th>Number of iterations</th>
<th>Total simulation time [min]</th>
<th>Convergence at termination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto</td>
<td>162 000</td>
<td>37.5</td>
<td>-101.3 dB</td>
</tr>
<tr>
<td>1e-3</td>
<td>82 000</td>
<td>25.0</td>
<td>-60.6 dB</td>
</tr>
<tr>
<td>5e-3</td>
<td>72 000</td>
<td>19.6</td>
<td>-46.2 dB</td>
</tr>
</tbody>
</table>

FDTD Termination Criteria

Example: GPS aperture-fed CP patch antenna
MLFMM Improvements

- The stabilised MLFMM supports specifying the residuum for the stopping criteria

- The MUMPS sparse LU preconditioner is used for extremely large MLFMM problems
  - Problems where matrices have more than \(2^{31} - 1\) entries can now be solved with either the MUMPS sparse LU preconditioner or the fall-back SPAI preconditioner

An aircraft including engine inlets with fan blades as example of a large MLFMM problem that could benefit from additional stabilisation.

The Solver settings menu showing the “Stopping criterion for residuum” field that now also applies to the stabilised MLFMM.
Electric and Magnetic Flux Density Display and Optimisation

- New POSTFEKO near field result quantities for flux densities
- Electric flux density (electric displacement field, \( D \)) \([\text{C/m}^2]\)
  \[
  D = \varepsilon E
  \]
- Magnetic flux density (B-field) \([\text{T}]\)
  \[
  B = \mu H
  \]

The B-field (magnetic flux density) of a wireless power transfer coil at 25 kHz (cut-plane view showing one of two coils).
FEKO 2017.2.1 Update

August 2017
MLFMM Memory

Traditional distributed MPI implementation → poor parallel memory efficiency

Caused by data duplication:
• transfer functions
• geometry

Generic ship → 3.18 million unknowns

Total memory efficiency
MPI-3 Shared Memory

Running with 40 procs on single node

Sum of the peak memory of all procs
985.6 GByte \rightarrow 659.6 GByte (33% reduction)

Breakdown in GByte:

Geometry arrays: 457.8 \rightarrow 226.8 (50% reduction)

Model setup and basis function: 236.9 \rightarrow 5.9

Other, e.g. worker arrays: 220.9

FMM arrays: 370.4 \rightarrow 276.5 (25% reduction)

FMM near field matrix:

FMM far field matrix:

Fourier trans. basis functions: 101.8

Transfer function: 104.5 \rightarrow 9.7

Interpolation and filtering: 38.1

Matrix-vector-multiplication: 103.7

Generic Ship Example
35.6 million unknowns
23.7 million triangular patches

Intel(R) Xeon(R) CPU E7-4820 v3 @ 1.90GHz;
4 physical CPUs with a total of 40 processors found
(multi-core CPUs with max. 10 cores per physical CPU)
(installed memory 1009.796 GByte)
MPI-3 Shared Memory

- Running with 64 procs on 8 nodes
- Previously 64 copies of geometry & transfer function arrays
- Now only 8 copies

**TABLE I**

<table>
<thead>
<tr>
<th></th>
<th>Distributed MPI</th>
<th>MPI3-SHM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>724</td>
<td>93</td>
</tr>
<tr>
<td>MLFMM</td>
<td>663</td>
<td>497</td>
</tr>
<tr>
<td>Other*</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Total memory</td>
<td>2187</td>
<td>1390</td>
</tr>
</tbody>
</table>

* This includes everything else, i.e. preconditioner, work arrays, etc.

36% reduction

Intel(R) Xeon(R) CPU E5-2683 v4 @ 2.10GHz;
8 nodes with 512 GByte each; installed memory = 8*512 = 4096 GByte
each node has 2 physical CPUs with a total of 32 processors found (multi-core CPUs with max. 16 cores per physical CPU)
MPI-3 Shared Memory - Conclusions

• Stabilised MLFMM preconditioner improves convergence without sacrificing memory

• Parallel memory efficiency is improved using MPI-3 shared memory (multiple procs on the same node in a distributed memory cluster)

• “Fat” nodes with as much memory and cores preferable for MLFMM
FEKO 2018 and Beyond…
Coming Soon…

- **FEM**
  - Improved preconditioners
  - also for GPU
- **Cable modelling**
  - Cable core as return path – rather than geometry
- **RL-GO**
  - further performance improvements
  - Transmission\Reflection coefficients for complex surface modelling
- **MLFMM**
  - Further reductions in parallel memory usage
- **CADFEKO**
  - Refactoring to improve performance
Ongoing Research and Development

- **MLFMM**
  - Improve convergence and reduce memory further

- **Domain Decomposition (DDM)**
  - DDM allows non-conformal meshing (multiscale problems)
  - Multi-solver: each domain own solver (MoM / MLFMM / FEM / ACA / etc.)
  - Eliminates tedious mesh clean-up of mechanical CAD models
Questions?