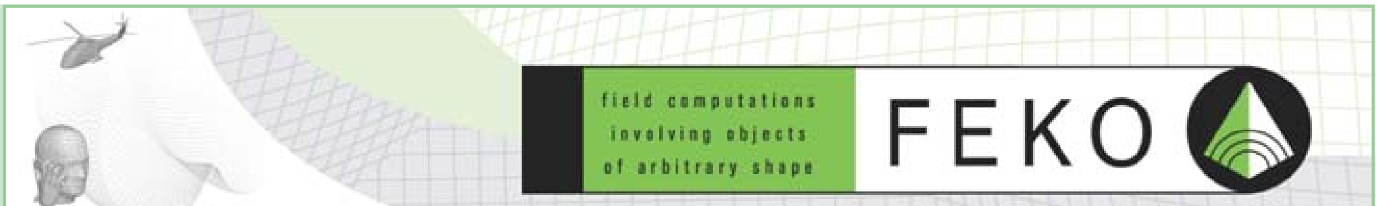

QUARTERLY: September 2005

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Introducing the hybrid Method of Moments/Finite Element Method (MoM/FEM)

The hybrid MoM/FEM has recently been introduced with FEKO Suite 5.0. This formulation exploits the benefits of both techniques and enables FEKO to solve certain classes of electromagnetic problems with optimal efficiency. The calculation of fields inside a human standing in front of a base station antenna is a typical example where the MoM/FEM hybrid is the most suitable formulation.

The FEM is very well suited for modelling inhomogeneous dielectric bodies. The tetrahedral elements used in the volume discretisation for the FEM allow for accurate geometrical representation of volumes with curved surfaces. The formulation, furthermore, allows for the variation in the material properties from tetrahedral element to tetrahedral element. Although the FEM is based on a volume mesh, i.e. like the Volume Equivalence Principle (VEP), the formulation results in a sparse matrix equation which scales better, with the increase in frequency, than the MoM based VEP.

The MoM, being source based, is an ideal formulation for open boundary radiating structures. A major advantage of the MoM above field-based (differential equation based) methods such as the FEM or FDTD is that the free-space region between structures does not have to be discretised.

A combination, or hybrid, of these two methods would therefore offer the advantages of each in the appropriate regions.

Memory Requirements of MoM/FEM

The memory requirement for a hybrid MoM/FEM is dependent on the following:

- Coupling between all elements in the MoM region (i.e. MoM matrix):

$$O\{(N_s+N_{mom})*(2N_s+N_{mom})\}$$

- Coupling between each unknown on the MoM/FEM boundary (i.e. coupling matrix):

$$O\{N_s^2\}$$

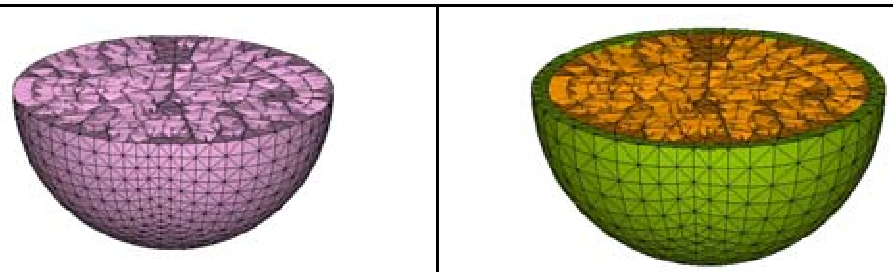
- Interaction between FEM elements (i.e. FEM S-matrix):

$$O\{N_{fem}^{1.5}\}$$

Where the number of MoM-, FEM- and MoM/FEM boundary unknowns, are represented by N_{mom}, N_{fem}, and N_s respectively. Therefore:

$$\text{Total Memory} \sim k_1*(N_s+N_{mom})*(2N_s+N_{mom}) + k_2*(N_s^2) + k_3*(N_{fem}^{1.5})$$

It should be clear that one way to reduce the memory requirement is to make the elements on the MoM/FEM boundary, N_s, as few as possible. A dielectric with a high ε_r requires a finer mesh ($\lambda_d/10$) leading to a high value for N_s and large memory requirements. One way to reduce N_s is to introduce a free-space region around the dielectric which is then also meshed using tetrahedral elements of which the size changes rapidly from the dielectric to the MoM/FEM boundary where the mesh can be $\lambda_o/10$. The air layer can be meshed coarser than the dielectric region creating a transition between the dielectric mesh and the MoM free-space region. Although the number of FEM elements increase, the number of boundary elements, N_s, which are more significant from a memory point of view, decreases. This leads to an overall reduction of the total memory requirements. Note that the MoM/FEM boundary is now not on the surface of the dielectric sphere but on the outer surface of the air region. This is illustrated in Figure 1.



13,706 Tetrahedra. | 20,920 Tetrahedra.

Figure 1, MoM/FEM boundary on the dielectric vs. MoM/FEM boundary on the outer surface of a free-space region (green) placed around the dielectric.

The hybrid MoM/FEM in FEKO.... continued

"The MoM/FEM hybrid exploits the benefits of both techniques and enables FEKO to solve certain classes of electromagnetic problems with optimal efficiency..."

"It is important to remember that the MLFMM becomes more and more attractive the larger the structure becomes..."

"...introduction of a free-space (air) region around the head reduces the number of unkowns on the MoM/FEM boundary..."

Comparison between the MoM, MLFMM and MoM/FEM hybrid for solution of dielectric body in front of a GSM base station

A dielectric sphere placed in the near-field of a generic GSM 900 MHz base station antenna (configuration shown in Figure 2) will be used to illustrate the advantages offered by the hybrid MoM/FEM formulation. The sphere diameter is

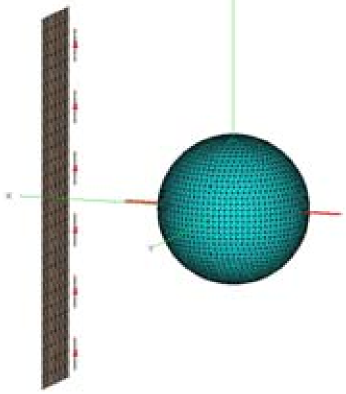


Figure 2, Configuration for comparison of SEP, VEP and MoM/FEM.. (Antenna has 336 triangles and 30 segments.)

equal to 0.6m (i.e. 2.55λ_d) and ε_r= 2. The Surface Equivalence Principle (SEP), the Volume Equivalence Principle (VEP) and the hybrid MoM/FEM were used and their respective models are shown in Figure 3.

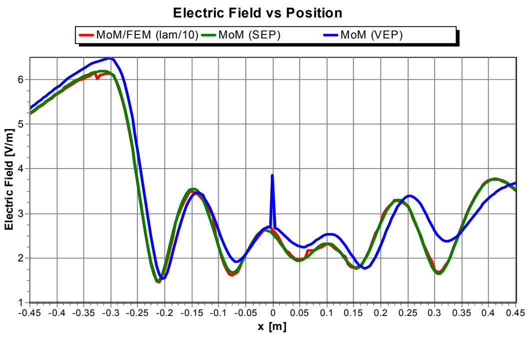


Figure 4, Electric fields through sphere.

Near fields were calculated on a straight line (see red line in Figure 2) parallel to the x-axis and slightly offset from the sphere's centre.

The results from the MoM/FEM and the MoM (SEP) compare very well. The results from the MoM (VEP), however, differ in two ways. Firstly there is a large discontinuity (spike) at position x=0. This was caused by the fact that the near-field sampling point is coincident with a cuboid edge at this position. When this happens, FEKO will issue a warning: *"WARNING 593: The observation point of a field calculation is not allowed to be in the vicinity of the surface of a cube"*. Although FEKO would still compute the field value, users must be aware of the possibility of an invalid result. It is often good practice to make sure that near-field sampling points are not coincident with the geometry before a FEKO run. This can for example be done by introducing a small offset on sampling points (i.e. sample at x=0.01 instead of x=0).

Secondly there is an overall difference between the MoM/FEM and the MoM (VEP) results. This can be attributed to a difference between the volumes of the different sphere models. Whereas the FEM and the MoM (SEP) spheres have the same volume, that of the cuboidal sphere (VEP) is slightly different (0.103936277m^3) due to the staircase meshing.

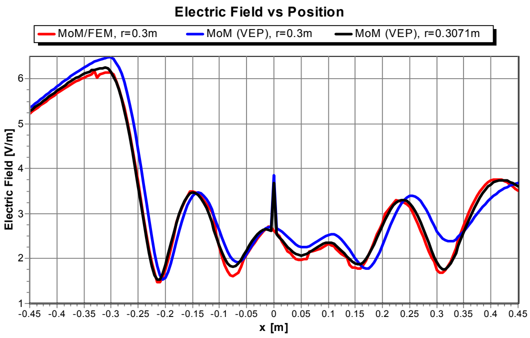


Figure 5, Electric fields with increased radius for VEP sphere.

This error can be compensated for by increasing the radius of the cuboidal (VEP) sphere such that its volume (for r=0.3071m V=0.11248662m^3) would be closer to that of SEP and the FEM spheres. (The exact volume of a sphere with radius r=0.3m is 0.11309733m^3). The results for this compensated sphere (radius enlarged to 0.3071m) are compared to those from the original VEP sphere (radius=0.3m) and the FEM in Figure 5. A very good match between the FEM, MoM (SEP) and MoM (VEP) is now obtained.

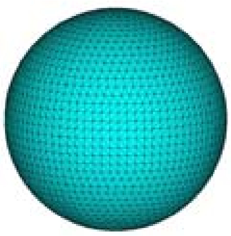
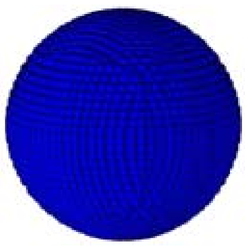
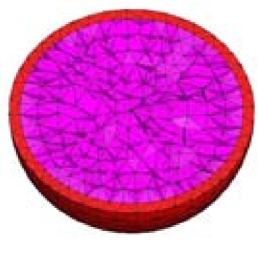
Surface Equivalence Principle	Volume Equivalence Principle	MoM/FEM
 4,240 Triangles	 8,992 Cuboids	 20,920 Tetrahedra

Figure 3, Sphere models for different formulations (Triangles, Cuboidal, Tetrahedra).

Computational Resource Comparison

The computational resource requirements for the different techniques are shown in Table 1. The VEP is, as can be expected, not an efficient formulation for this specific application. The VEP is however more appropriate for modelling structures where small dielectric bodies are present. Although the MLFMM (using VEP) requires less memory (6 GB) than the MoM solution (17 GB) it still is inefficient compared to the SEP and the MoM/FEM.

The SEP (with MLFMM) is in this case a reasonably attractive method where both the memory and the run-time are similar to the MoM/FEM solution. If the dielectric sphere was highly inhomogeneous the MoM/FEM would have very similar resource requirements. The SEP, although it can handle several partially inhomogeneous regions which can also be nested, would require more resources proportional to the number of new regions introduced by the inhomogeneity. The FEM would be the obvious choice for inhomogeneous biological bodies.

It is important to remember that the MLFMM becomes more and more attractive the larger the structure becomes (i.e. the benefit of the MLFMM can only be seen at electrically large structures). For this example the MoM and the MLFMM solutions are closer to the breakeven point where resource requirements are similar.

Calculating electric fields inside human head using MoM (SEP) and MoM/FEM.

For the second case the sphere is replaced by a more realistic model of a human head with permittivity ε_r= 60 and conductivity σ =*1 (S/m).* The memory requirement and the solution time for SEP and MoM/FEM is similar. The MLFMM (SEP), as applied to the low ε_r sphere, resulted in a memory and run-time reduction. This is however not generally true and convergence problems can be experienced when using the MLFMM (SEP) on dielectric bodies with high dielectric constants, as in this case of a human head.

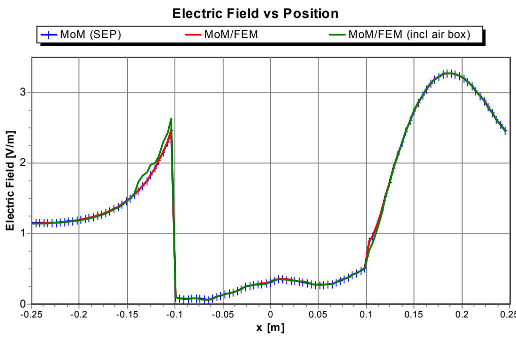


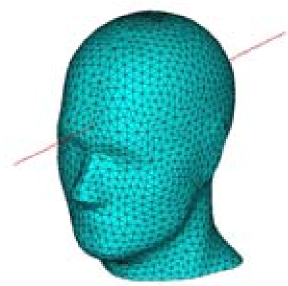
Figure 6, Fields through human phantom head.

The introduction of a free-space (air) region around the head reduces the number of unkowns on the MoM/FEM boundary, N_s. The advantage of adding the air region around the dielectric is clearly evident from the memory and run-times as compared in Table 2. A comparison of the electric fields along a line through the head is shown in Figure 6 and it is clear that they effectively have the same accuracy.

Conclusions.

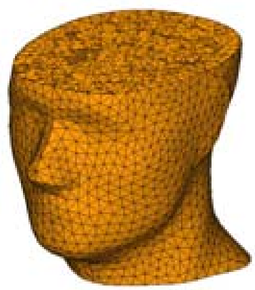
The hybrid MoM/FEM, which has been introduced with Suite 5.0, extends the number of techniques available to simulate dielectric regions. Given their comparable accuracy the computational resource requirements become the most important consideration when choosing which of these techniques should be used. This choice will depend on the specific type of problem. The MoM/FEM has been illustrated here only for the case of a dielectric structure in front an antenna. Although the current implementation enables the analysis of many other EM problems future extensions will extend its applicability.

Surface Equivalence Principle.



4,182 Triangles

MoM/FEM.

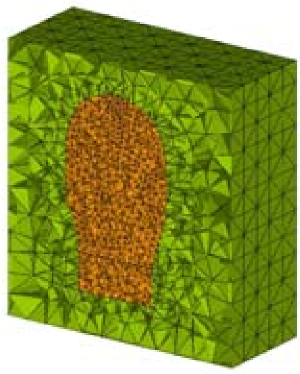


48,416 Tetrahedra,

N_s = 6,282x2 on

MoM/FEM Boundary

MoM/FEM. With air box around head



68,092 Tetrahedra,

N_s =2,586x2

MoM/FEM Boundary

TABLE 1: Resource Requirements for Base Station Antenna and Sphere ε_r= 2.

Solution Method	Memory	Unknowns	Time
MoM (VEP)	17 GB	34,454	11.5 h *
MoM (SEP)	2.6 GB	13,214	30 min
MLFMM (VEP)	6 GB	34,454	7 h
MLFMM (SEP)	646 MB	13,214	15 min
MoM/FEM (with air layer)	640 MB	494(MoM), N_s =2,592x2(MoM/FEM Boundary), 131,028 (FEM)	6 min.
MoM/FEM (no air layer)	1.5 GB	494(MoM), N_s =4,608x2(MoM/FEM Boundary), 83,950 (FEM)	10 min.

* Cluster of 15 AMD Athlon CPU's, each 1GHz with 1GB RAM, process out-of-core.

TABLE 2: Resource Requirements for Base Station Antenna and Head ε_r= 52 and σ =*1 (S/m).*

Solution Method	Memory	Unknowns	Time
MOM (SEP)	2.5 GB	13,040(MoM)	33 min
MoM/FEM (no air box)	2.8 GB	494(MoM), 6,282x2(MoM/FEM Boundary), 302,397 (FEM)	44 min
MoM/FEM (with air box)	923 MB	494(MoM), 2,586x2(MoM/FEM Boundary), 429,564 (FEM)	9 min

News and Events

FEKO Short Course 1-2 July, Washington, DC

The FEKO Short Course in Washington focused on the new features and new GUI (e.g. CADFEKO and POSTFEKO) of FEKO Suite 5.0

FEKO Short Courses

Sept 1—2	Gauteng, South Africa.
Sept 14—15	University of Stellenbosch, South Africa.
Sept 26—27	Los Angeles, CA.
Oct 3-7	Paris, France. (During European Microwave Week a 1 day training on CADFEKO will be offered.)

Exhibitions

Sept 5—7	EME Mannheim, Germany.
Sept 22—23	Antenna Systems, Santa Clara, CA.
Oct 3—7	European Microwave Week, Paris, France.
Oct 11—12	EMC-UK, Newbury, U.K.
Oct 30-Nov 4	AMTA, Rhode Island, USA.
Nov 9—11	MWE 2005, Pacifico Yokohama, Japan.
Nov 9—11	EMC/China, Shanghai,
Dec 4—7	Asia-Pacific Microwave Conf, Suzhou, China
Dec 6—9	Asia-Pacific Symp on EMC, Taipei, Taiwan.

VII. Annual German FEKO Users Meeting (26 October, Stuttgart)

In addition to the Annual User Meeting a one day training session will be held focusing on CADFEKO.