Recent Extensions in FEKO Suite 5.4

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Abstract— **Many new features have been included in the latest release of the electromagnetic simulation package FEKO Suite 5.4 from July 2008. This paper aims at giving an overview of the major new features added to the computational kernel, which are: Modelling of periodic boundary conditions for 1-D and 2-D periodic structures, the inclusion of waveguide port excitations within the MoM/PO hybrid method, the parallelisation of the MoM/FEM hybrid method for distributed memory systems, and also the modelling of complicated cable harnesses by a new interface to the cable modelling code CRIPTE.**

I. Introduction

FEKO [1] is a general electromagnetic field solver package originally based on the Method of Moments (MoM) in the frequency domain, but with many extensions using hybridisation schemes with high frequency techniques like Physical Optics (PO) or Uniform Theory of Diffraction (UTD). The combination of MoM with the Finite Element Method (FEM) and fast integral equation techniques (Multilevel Fast Multipole Method, MLFMM) are supported in FEKO, as well as many other features (e.g. planar Green's function, adaptive frequency sampling, rigorous parallel processing etc.).

In this paper we aim at presenting new features which were added to the computational kernel of FEKO in the Suite 5.4 release from July 2008. Section II focuses on the inclusion of periodic boundary conditions for 1-D and 2-D periodic structures. In Section III we introduce the extension of the MoM/PO hybrid method by a special waveguide modelling technique (so far only available for MoM or MLFMM). Section IV deals with the parallelisation of the MoM/FEM hybrid method for distributed memory systems, while in Section V a new interface of FEKO to the cable modelling code CRIPTE is presented, which allows to solve both radiation and irradiation problems involving 3-D geometries and complicated cable harnesses (e.g. in the automotive environment).

II. Periodic Boundary Conditions

The periodic boundary conditions (PBC) enable FEKO to analyse an infinite periodic structure by simulating only the single unit cell element. This will minimise the total number of unknowns and the computation time. For high accuracy the PBC implementation uses the Ewald transformation in order to get fast convergence for the infinite sums. In this formulation the periodic Green's function is written as the sum of a modified spatial portion and a modified spectral portion. The number of terms in the infinite sum is determined automatically. The PBC includes both 1-D and 2-D periodic boundaries as described in [2, 3]. The two examples below include an infinite cylinder and a frequency selective surface (FSS) to demonstrate the 1-D and 2-D PBC, respectively.

A. Infinite Cylinder

In Fig. 1 an infinite cylinder is modelled as a finite cylinder with 1-D PBC at the two ends. The incident field is a *z*-polarised plane wave. The diameter of the cylinder is varied and the scattered electric field is computed versus the observation angle. In Fig. 2 the computed scattering width (SW) is in very good agreement to that in [4, pp. 607].

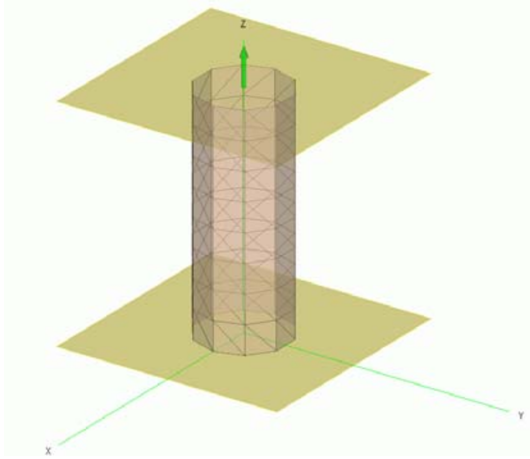

Fig. 1 Infinite cylinder with 1-D periodic boundaries.

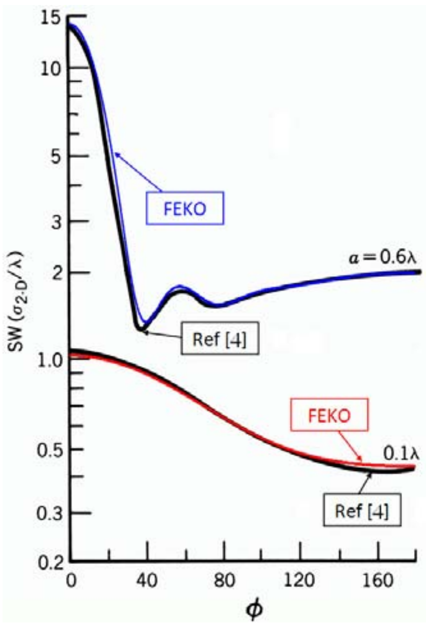

Fig. 2 Scattering width (SW) versus angle for the infinite cylinder [4].

B. *Frequency Selective Surface*

An infinite periodic array of Jerusalem-crosses was analysed using the 2-D PBC. The magnitude and phase of the reflection coefficient versus frequency are shown in Fig. 3 and Fig. 4, respectively. This is for a normal incident plane wave. Excellent agreement to the published results from [3] can be seen.

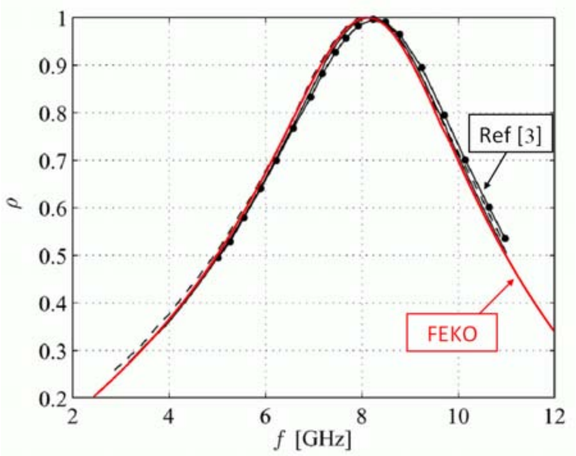

Fig. 3 Magnitude of the reflection coefficient for the FSS.

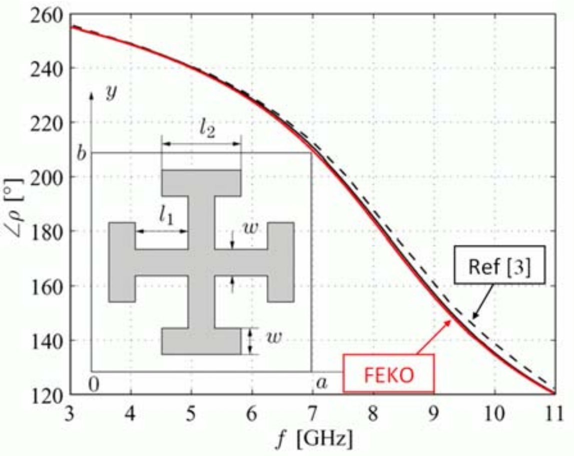

Fig. 4 Phase of the reflection coefficient for the FSS.

III. Waveguide ports and Physical Optics

The waveguide port feature in FEKO enables efficient excitation and termination of waveguide component models. This has been extended in Suite 5.4 to be used in a hybrid Method of Moments/Physical Optics (MoM/PO) context.

A. *Horn-fed Parabolic Reflector Antenna*

A horn-fed parabolic reflector antenna example (antenna design taken from [5]) is shown in Fig. 5. Large reflectors are difficult to simulate as they become very large in terms of wavelength, thus with the traditional MoM a high strain is placed on resource requirements. FEKO offers accurate high frequency techniques for more efficient reflector simulations, e.g. the Multilevel Fast Multipole Method (MLFMM), and Physical Optics (PO).

Fig. 5 Configuration for the horn-fed parabolic reflector antenna example.

In order to validate the implementation of the waveguide port feature in connection with the MoM/PO hybrid method, the horn-fed reflector antenna was simulated with the traditional MoM, hybrid MoM/PO decoupled (i.e. neglecting coupling of the PO region back onto the MoM region), and also with the MLFMM. The waveguide port excitation was used to excite the horn antenna with the TE_{10}-mode. The resource requirements for the sequential solutions are compared in Table I. Simulations were all performed on the same AMD Opteron machine (2191 MHz, 16 GByte RAM) using the sequential FEKO solver.

TABLE I
Resource Requirements for Horn-Fed Parabolic Reflector

Method	No. of Unknowns		Memory	Run-Time [h:min:sec]
	MoM	PO		
MoM	42194	0	13.280 GByte	9:22:04
MoM/PO	6272	35922	309 MByte	29:33
MLFMM	42194	0	461 MByte	22:25

Vertical gain patterns are compared in Fig. 6 for the three simulations. Results are in excellent agreement.

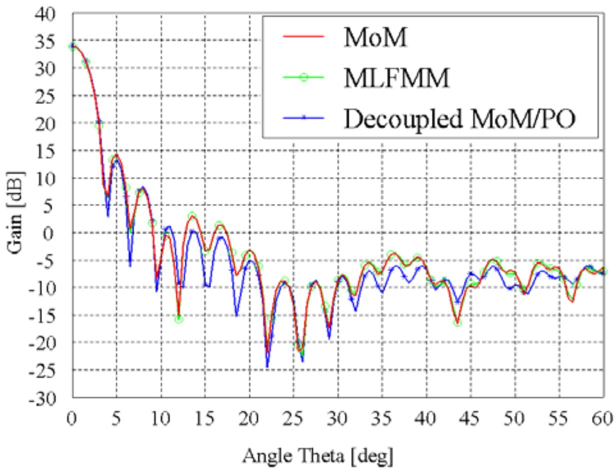

Fig. 6 Gain pattern in the vertical cut-plane for the horn-fed parabolic reflector antenna.

IV. Parallelisation of the Hybrid FEM/MoM in FEKO for Distributed Memory Environments

The hybrid FEM/MoM technique in FEKO is a versatile solver, it enables for instance an optimal solution for complex dielectric bodies in proximity to metallic structures [6]. The key phases of this hybrid solution are the following: Dense MoM matrix computation and factorisation; dense coupling matrix computation; sparse FEM matrix computation; pre-conditioner computation; and solving the mixed sparse-dense system of linear equations using iterative techniques and pre-conditioning.

Prior to Suite 5.4 FEKO supported parallel processing for distributed memory environments with all the existing techniques, except for the hybrid FEM/MoM. The parallel implementation of the hybrid FEM/MoM solution in FEKO involves all the key phases mentioned above. An example from the mobile phone industry, shown in Fig. 7, will be used to aid the discussion on the parallel implementation. The goals are twofold, namely to reduce the memory requirement per process by exploiting distributed memory platforms and to reduce the run-time by exploiting multiple parallel processes to share the computational load.

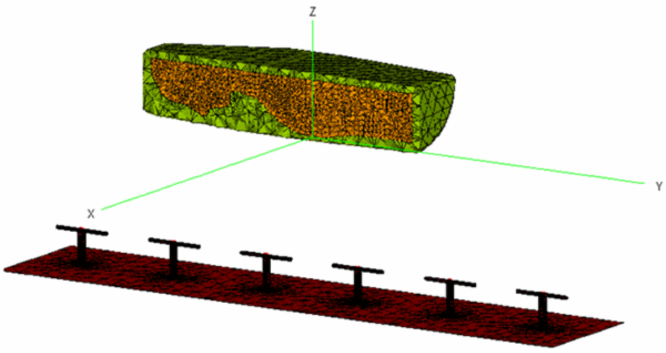

Fig. 7 Benchmark FEM/MoM example of a phantom in front of a mobile phone base station antenna.

The first parallelisation goal is achieved by using distributed memory storage for all the memory intensive parts, i.e. the dense MoM matrix, dense coupling matrices, sparse FEM matrix, pre-conditioner. The parallel efficiency for the peak memory requirement per process as a function of the number of processes is depicted in Fig. 8. The scaling is not perfect (100% would mean that memory can be split ideally amongst all involved processes) due to the duplication of some memory on each process for the geometry data and several arrays for the iterative solver, but it is still fairly good and enables the solution of larger problems on cluster computers with distributed memory.

The key to reduction in the run-time lies with keeping communication between processes to a minimum. This is relatively straightforward for some phases of the solution, e.g. the MoM and FEM matrix elements are computed locally on each process. However, for other phases of the solution communication between processes is unavoidable, e.g. for calculation of the LU-decomposition of the dense MoM matrix, computation of the dense coupling matrices, setup and application of the preconditioner, and the matrix-vector product during the iterative solution.

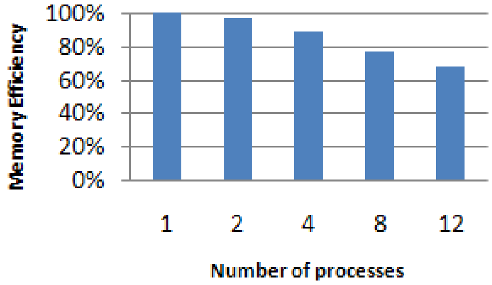

Fig. 8 Parallel memory efficiency for the benchmark FEM/MoM example.

The relative contribution from each of the solution phases to the total run-time is problem dependent, and therefore the overall parallel run-time efficiency will not be representative for all FEM/MoM examples, unless all phases have been parallelised with a similar efficiency. A decomposition of the run-times for the different phases of the solution for the benchmark example considered here is shown in Fig. 9.

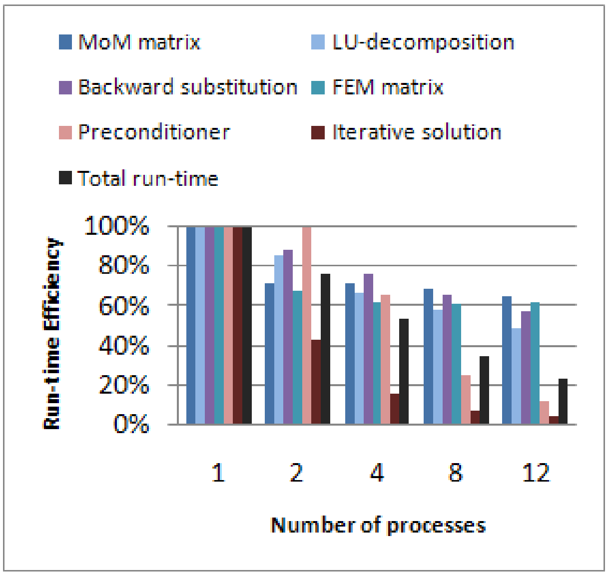

Fig. 9 Parallel run-time efficiency of the different solution phases for benchmark FEM/MoM example.

Even though fairly good efficiency has already been obtained for most of the solution phases, the cause of the bottleneck in the solution time is the multilevel pre-conditioner that is currently used. It involves a distributed sparse LU-factorisation and thus requires communication during the calculation phase, and in its application during the iterative solution. Other pre-conditioners are under investigation at the moment to further improve the parallel run-time efficiency.

V. Cable Modelling with FEKO and CRIPTE

Accurate modelling of complex cable bundle networks in their operating environment poses a great challenge to electromagnetic simulation tools. The complex and detailed structure of the cable bundles make the required resources for a full wave solver excessive, while simulation using network modelling software alone does not properly take into account the influence of surrounding structures. Similar to the existing FEKO/CableMod interface, also an interface to the cable code CRIPTE has been implemented to provide a hybrid solution for these challenging electromagnetic compatibility (EMC) problems.

Two types of calculations are generally required when performing EMC calculations with complex cable bundles; these are radiation from cables and coupling of external fields into cables (irradiation). For simple single conductor cables both calculations can be performed directly in FEKO without requiring external cable modelling software. This allows the solution using the FEKO/CRIPTE interface to be verified with the full FEKO calculation.

B. *Irradiation calculation*

Irradiation calculations are performed when the coupling of fields from an external source into the cable bundle is investigated. The irradiation example here consists of a transmission line with a dielectric coating above a horizontal plate with partial vertical sides shown in Fig. 10.

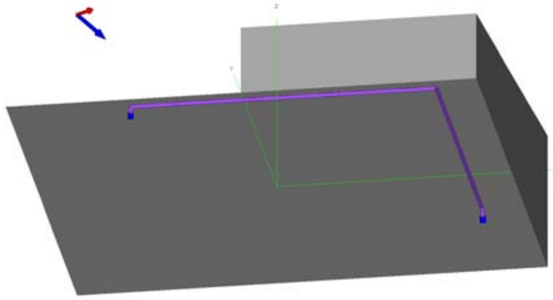

Fig. 10 Image of the transmission line above the horizontal plate with partial vertical sides and RHC plane wave excitation.

In order to simulate a typical transmission line with balanced feed and high impedance relative to ground the transmission line is terminated with an impedance of 15 kΩ on both sides. A right hand circularly polarised (RHC) plane wave is used as excitation and the current through one of the terminations is calculated from 30 to 300 MHz. The electric and magnetic fields along the cable path calculated in FEKO were used as source in CRIPTE to determine the common mode current on the cable shown in Fig. 11.

C. *Radiation calculation*

When the common mode current distribution on the cable bundle is known, the fields radiated by the cable and the coupling of these fields with other structures can be investigated. The radiation example consists of a similar structure used for the irradiation example. The transmission line (characteristic impedance of approximately 240 Ω) with a dielectric coating is excited by a voltage source with an internal impedance of 240 Ω. The transmission line is terminated at the other end with a 360 Ω resistance. The common mode current distribution on the transmission line is calculated in CRIPTE and then used as excitation to obtain the electric field at a constant radius. The same calculation was performed using FEKO only and a comparison of the electric field magnitude is shown in Fig. 12.

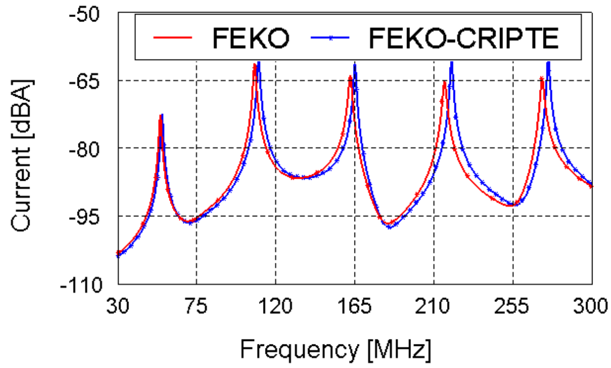

Fig. 11 Comparison of the current calculated using the FEKO/CRIPTE hybrid solution and FEKO standalone.

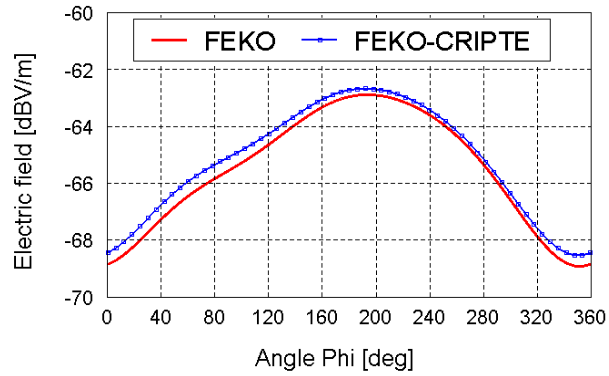

Fig. 12 Magnitude of the electric field calculated at 60 MHz and ϑ=35° using the FEKO/CRIPTE hybrid calculation and FEKO standalone.

VI. Conclusions

Several extension of the computational code FEKO in the latest release Suite 5.4 have been presented. Future work is aimed at enhancing these techniques or adding new ones, e.g. improving the parallel pre-conditioner performance for the MoM/FEM hybrid method.

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