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MAFIA RELEASE 3.X

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Abstract

The new release of MAFIA is now available in version 3.1. The well-proven release 2.x version is now operational in 22 countries at over 120 locations. Over the recent years, the MAFIA codes have been completely overhauled. A new coherent user interface was designed which includes online help,macros, symbolic variables,do-loops,flexible file handling, built-in editor, mnemonic command names, and an easy-to-understand menu structure. The range of applicability has been extended by adding new solvers for electrostatics and magnetostatics, particle-in-cell simulation, and antenna radiation analysis. All two-dimensional solvers for frequency- and time-domain simulations (URMEL and TBCI) have been rewritten and incorporated into MAFIA. With this new version of MAFIA, which is now available, the user has a coherent computing tool for solving Maxwell's equations in 2D and 3D for a wide range of problems.

Introduction

The MAFIA family of codes which solve MAxwell's equations by the Finite Integration Algorithm is widely used in the computer-aided design of accelerator components. Rf cavities and vacuum junctions, collimators and magnets (to name but a few) have been successfully designed using these programs. The programs use Maxwell's equations in their integral form and produce a set of matrix grid equations which are then solved. A full description of the derivation of these equations can be found in the literature [1].
The allocation of the three dimensional field components is on a rectangular grid, using the Yee lattice [2]. The analytical properties of the matrix operators are preserved on the discrete grid [3]. Hence this method has the advantage that, after the eigenvalues of the problem are calculated, the numerical results can be tested for their physical correctness and any spurious solutions removed automatically.

The Programs

The 2D Programs

It is very useful to have 2D versions of the 3D programs for cylindrically symmetric structures and for exploratory tests before a large 3d model with many mesh points is calculated. The MAFIA package includes 2D versions of the 3D programs using the same user interface, mesh generator and post processor.

The Mesh Generator, M

The mesh is defined in cartesian coordinates and allows a non-equidistant grid. r-z coordinates will be available in release 3.1 for use with 2D versions of the programs and r-ϕ and r-ϕ-z will be added for release 3.2. Each rectangular cell may be divided in half along a diagonal to give a better approximation to the input geometry. Within this mesh of rectangular cells material fillings may be defined in various ways. Rectangular bricks may be filled with material. Cylinders of arbitrary cross-section with axis parallel to one of the coordinate directions and figures of revolution obtained by rotating an arbitrary plane shape through a given angle may be generated.
Filaments represent line currents or wire electrodes and a large choice of pre-defined shapes is available.
At all stages *Diagnostics and Interactive Graphics Display* is provided to facilitate the visualisation of the geometry and to allow the user to check the input. Each input shape can be displayed superimposed on the approximated mesh model. Then mesh lines can be interactively added or deleted and the effect of the regenerated mesh on the mesh model is immediately displayed. Two dimensional cuts along any mesh plane can also be plotted. Finally the mesh model, with or without hidden lines, can be viewed in three dimensions and can be rotated.

The Static Solver, S

The Static code, S, solves Maxwell's Equations for electro- and magneto-static problems [4]. The electrostatic potential Φ, the field **E**, the flux **D** and the electrostatic charge distribution q can be calculated, or alternatively the magnetostatic field **H** and the flux **B**. An "open" boundary condition is included which uses an iterative method to analytically approximate the potential on the boundary, thus enabling a much smaller mesh to be used for the same problem. Ideally conducting or ideally permeable materials may be defined in all the 3D codes. In addition S allows materials with finite, non-zero and anisotropic ϵ and μ or with ϵ and μ dependent on the field strength and the non constant distribution may also be calculated. Filaments may carry linear currents or be defined as lines of constant potential. The solver uses an SOR over-relaxation method where the accuracy of the solution is an optional input parameter. A multigrid solver is also available for large problems.

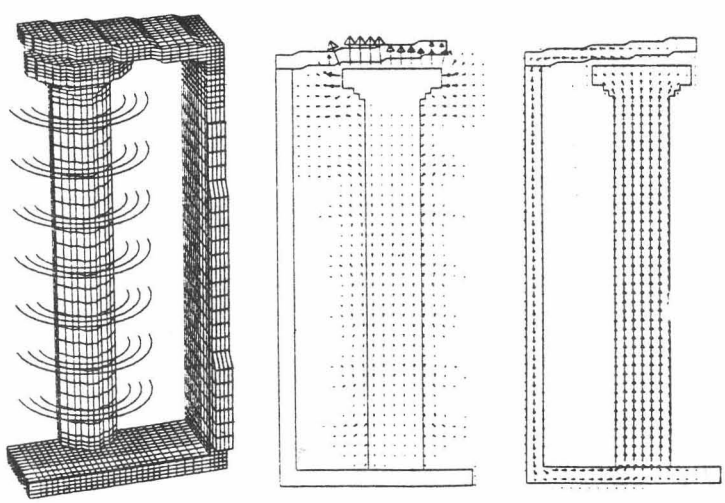

Figure 1: Modelled geometry of body and coil of a relais and arrow plots of the H- and B-field exited by a constant current and calculated with S.

The Frequency Domain Solver, R/E

The MAFIA codes R and E run in sequence, solve Maxwell's equations in the frequency domain. The material properties and the boundary conditions are defined in R where the matrices are set up. Periodic boundary conditions have been added in release 3.0. Then E calculates the fields E and B and the eigenfrequencies. As diagnostics, the accuracy of the frequencies is given and the quantities $div\mathbf{D}$, $div\mathbf{B}$ and $|curl\mathbf{E} - k^2\mathbf{E}|$. The Solver uses the SAP [7] eigenvalue solver, which has been much improved in both speed and accuracy using a method which combines iteration and modified polynomials. Several hundred modes can be calculated. *The 2D Version* of R/E (formerly called URMEL) can be used to obtain the frequencies of rotationally symmetric modes with azimuthal field variation and arbitrary angular mode numbers, (monopole, dipole etc.). The cutoff frequencies of waves in longitudinal waveguides can also be calculated using x-y geometry.
Figure 2 shows the modelled geometry of a multi-cell accelerating cavity with coupler and the E-field distribution of a $2\pi/3$-mode calculated calculated by E.

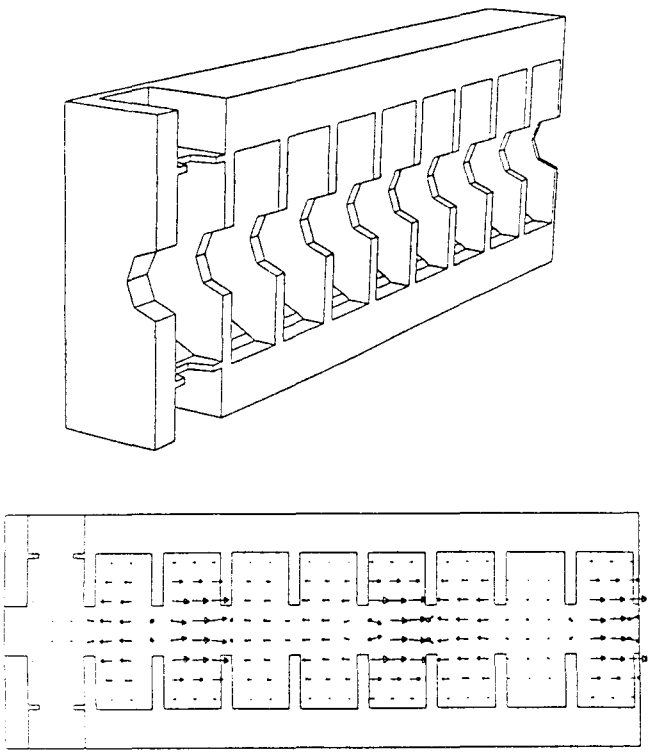

Figure 2: One half of a modelled nine-cell accelerating structure (above) and the arrow plot of a $2\pi/3$-mode calculated by E (below).

The Time Domain Solver, T3

T3 calculates the fields created by a moving, rigid bunch of particles [5] providing the E- and B-fields at user-specified time steps, the fields as a function of time at user specified positions and the longitudinal and transverse wake potentials. In addition the calculation of the propagation of transient electromagnetic waves has been add in release 3.1.
"Open" boundary conditions are available to simulate an infinite beam pipe or open space. The transverse bunch position, the charge distribution within the bunch, the particle speed and the number of time steps to be performed are all input parameters. A window option is also available for ultra-relativistic particles. The *2D Version* T2 (the former TBCI) calculates the diffraction of TM waves in addition to transient fields and transverse and longitudinal wake potentials.
Figure 3 illustrates the scattering of a plane wave by an electronic device consisting of a dielectric plate carrying some ICs surrounded by a partial metallic shielding. The exiting plane wave is propagating from above towards the top of the shielding. The arrow plots show the scattered time-harmonic E-field (real and imaginary part) surrounding this device.

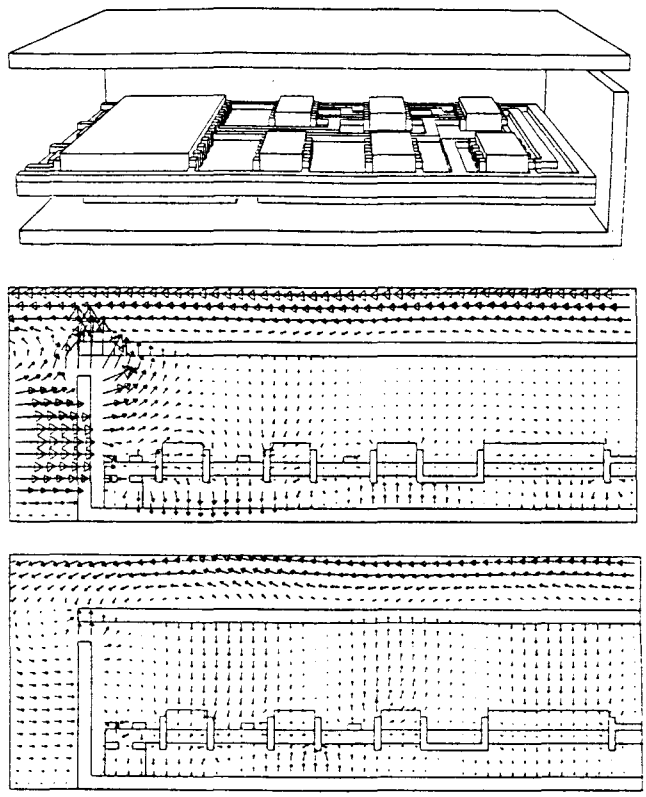

Figure 3: Modelled geometry of a dielectric plate carrying an array of ICs (above and middle) surrounded by a metallic shielding. Scattered time-harmonic E-field in a cutplane exited by a plane wave propagating from above and calculated by T3 (below).

The Self Consistent Time Domain Solver, TS3

TS3 is a particle-in-cell code, which enables the simulation of rf-klystrons, electron sources etc. Maxwell's equations and the equations of motion for the particles are solved self consistently, so that particle trajectories can be calculated taking space charge into account. The charge distribution within the bunch is also calculated. The initial conditions for the velocity, position and charge density of the particles are defined by the user. Static or resonant fields can be preset on the mesh.
In the *2 $\frac{1}{2}$D Version*, TS2 [6] both the initial field and the particle distributions have angular symmetry.

The Postprocessor, P

In the postprocessor, secondary results may be calculated from the fields, fluxes etc. which have been calculated. Field energy, power loss, shunt impedance and integrals over lines, areas and volumes can be obtained. The results can also be represented graphically.

Arrow plots are used to represent a 3D vector field in a mesh plane, isoline and contour plots show a scalar field or a vector component in a mesh plane and line plots show the variation of the same along a line. All plots and calculations can be restricted to windows.

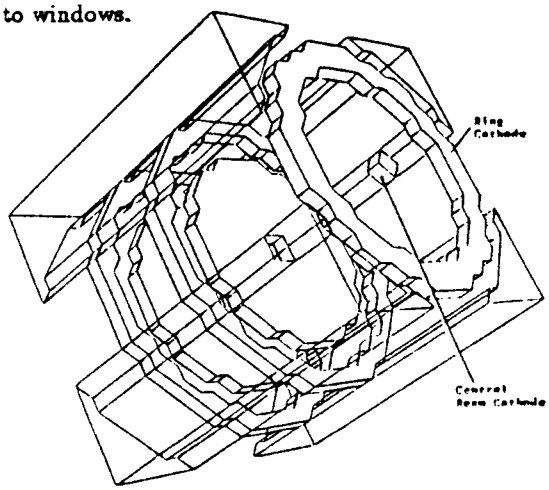

Figure 4: Two cell Wakefield Transformer, beam direction along the z axis,calculated by TS3. The central beam is accelerated by the wakefields which are produced by the ring beam which surrounds it.

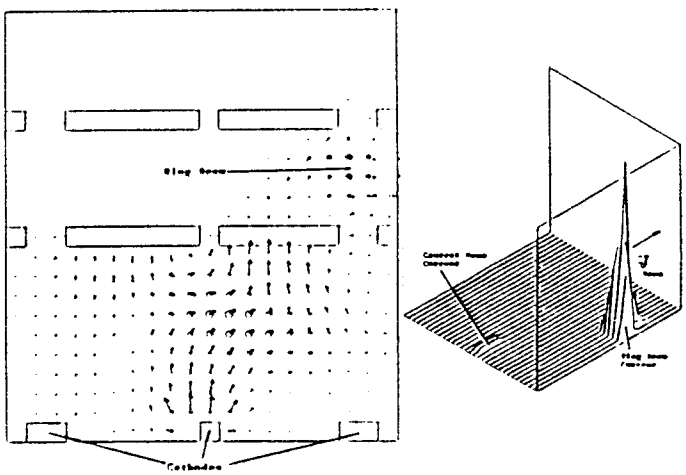

Figure 5: Arrow plot of the E-field and isoline plot of the current in a cut along the beam axis, a quarter of the ring beam current was generated.

MAFIA Release 3 - The Environement

Many new features are included in release 3. The powerful *Command Processor* includes a *Macro Facility* and *Symbolic Variables* and enables the construction of *Do Loops* over a range of commands. The *Command Error Checking* facility issues diagnostic messages. *Flexible File Handling* is a feature. Sequential files are used for print output, non-interactive command input and for recording the commands of an interactive session. *Profiles* can be created for particular modules, for individual users or for groups. There is a *Built-in Editor* both for these files and for command sequences which have been entered interactively, these may be edited and then immediately executed. The main MAFIA *Data Base* is a direct access file where all the results are stored. Up to twenty output devices are available for *Graphics Output*, e.g. metafile, terminal, plotter etc. *Mouse Input* is also provided for. The *Menu-controlled User Interface* includes an *On-line Help Facility*. The codes are *Completely Hardware Independent*.

Memory Requirements

The required memory for 32 bit accuracy using 100,000 nodes varies between 3 Mbyte for the mesh generator M and 14 Mbyte for both the eigenvalue solver E and the particle in cell code TS3 (for 100,000 particles). The other codes use 8 Mbytes or less. T3 includes a window option which enables 1,000,000 nodes with 100,000 nodes in the window for 11 Mbyte.

Hardware and Software Requirements

MAFIA Release 3.0 consists of separate source modules for each program and a utility library of routines common to all the programs. These are written in standard fortran77 and will run on any computer with an error-free ANSI-FORTRAN77 compiler. A built in facility will switch operation from single to double precision, avoiding the compatability problems of the standard. All installation dependant operations are called via a system interface and a graphics interface. These latter ensure that the programs are fully portable and installation independent. Thus MAFIA runs on any machine, e.g. IBM 3090 and IBM Risc 16000, DEC, SUN, APOLLO, HP, CRAY and many more. Similarly any graphics system may be used, e.g. GKS, PHIGS, DISSPLA.

Conclusion

A definite step forward in the computer aided design of accelerators has been achieved. The physical correctness and dependability of the Release 2 MAFIA is combined with the new modules S and TS3 and compatible 2D versions under one unified user interface. Release 3.0 is now ready for distribution, including the programs M, R, E, S, P. The 2D versions of R/E and S and the modules TS3, TS2, T3, T2 will be available towards the end of the year with release 3.1. Release 3.2 will include the eddy current module W3 and an automesh facility for M as well as r-ϕ-z coordinates.

References

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