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"ADVANCED PC SOFTWARE FOR TIME DOMAIN SIMULATION IN ACCELERATOR DESIGN"

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Abstract

Recent rapid improvement in computer hardware and software technology has greatly facilitated the use of electromagnetic simulation in accelerator design. Conventional electromagnetic simulation software use either frequency-domain (FD) or time-domain (TD) methods, each of which offers relative strengths and weaknesses that must be evaluated when choosing a simulation software. However, a new approach termed the Perfect Boundary Approximation (PBA) combines the excellent performance of Finite Difference Time Domain methods (FDTD) with an accurate approximation of the geometry such as achieved by Finite Element Methods (FEM). In this paper we describe the new software "MW-Studio" and present several examples in accelerator design.

1 INTRODUCTION

In the past, the full wave electromagnetic simulation was generally not economically feasible since it required the use of supercomputers as well as a substantial knowledge of electromagnetic theory and numerical techniques. During the last decade, the three dimensional electromagnetic simulation capabilities have significantly advanced due to the tremendous progress in computer hardware technology combined with an improvement in numerical techniques. These methods for solving Maxwell's equation can be broadly classified into three categories based on the utilized mathematical formulas. These categories include the discretization by partial differential equations such as used in the FDTD (Finite Difference Time Domain) method, the variational approaches used in FEM (Finite Element Methods) and the integral equation-based methods like MOM (Moment Methods).
"MAFIA" which has been commonly used in the accelerator community, is based on the FI method (Finite Integration). The FI approach is the only known fully consistent method of transforming Maxwell's equations into a set of matrix equations for discrete values of the electromagnetic fields. The FI method can be understood as a generalized FDTD method. It is capable to solve electromagnetic problems in time and frequency domain as well as statics and problems involving moving charged particles. Although, MAFIA is a very versatile 3D electromagnetic simulation software, it has some disadvantage due to the approximation of conforming curved boundaries by prism cells. In order to improve this, a new method named PBA (Perfect Boundary Approximation) is introduced as an expansion of the FI method. This improvement will enable simulations of 3D curved structures much faster and more accurate. We present a short introduction of this new software and show several examples in accelerator component design.

2 NUMELICAL TECHNIQUE

The most satisfactory solution of electromagnetic problem is an exact analytical one. However, in most cases, analytical solution can not be obtained and we have to depend on numerically approximated solutions. Various numerical techniques have been used in order to solve the complex electromagnetic problems, but no single method will suffice for solving all the electromagnetic problems. For instance, the frequency domain methods are well suited to solving inhomogeneous nonlinear problems but are less suited to modeling open boundary problems. Whereas an integral method, like the moment method, copes naturally with the far field region, it becomes increasingly hard to implement when dealing with inhomogeneous problems. Boundaries of interested region in the accelerator design are usually finite, and thus frequency domain (FD), and or time domain (TD) methods are often used. Both FD and TD methods utilize descretization or subdivision of the domain by elements or grids and formulate Maxwell's equations into a set of matrix equations. The FI method uses orthogonal staggered grids with cell-wise constant material parameters to describe the electromagnetic properties of a material distribution within a calculation domain. The integral form of Maxwell's equations can be represented with an equivalent set of algebraic equations, called Maxwell's Grid Equations (MGE)[1] as shown in figure 1.1.

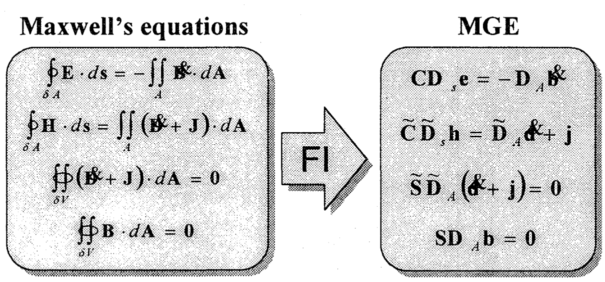

Fig. 1.1: MGE derived from Maxwell's equation by the FI method.

The key attribute of this formulation is that it retains all analytical properties of Maxwell's equations while conserving the physical and mathematical characteristics of electromagnetic fields. These features are extremely important in numerical transformations, since numerical analysis can easily lead to an incorrect solution that does not exist physically or mathematically. The other key point in this technique is that it can be applied to static, harmonic and time dependent fields, mainly because it is nothing but a computer compatible reformulation of Maxwell's equations. When specialized to time domain fields, the method contains Yee's algorithm[2] as a subset.

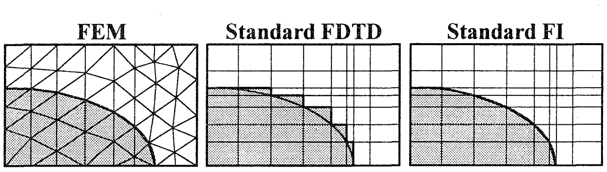

Fig. 1.2: Geometry approximation used in different numerical techniques.

Fig. 1.2 shows examples of various mesh models for FEM, FDTD and FI method for inhomogeneous curved boundaries. There is an apparent significant advantage of FEM over FDTD in domain discretization. That is one can utilize triangular or tetrahedral element in 2D or 3D case which can fit curved boundary more smoothly as shown. Even the FI-method which utilizes prism cells as well as a non-equidistant mesh has disadvantages in representing curved surfaces in general. Although, one can certainly improve the situation by increasing the number of mesh nodes, it requires more computer memory and computation time.

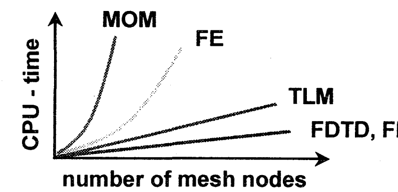

Fig. 1.3: Computation time versus number of mesh nodes for various numerical techniques.

Fig. 1.3 represents the relation between computation time vs. number of mesh nodes for various numerical techniques. The significant advantage of FDTD and the FI method over FEM or MOM is that the computation time increases linearly with the number of mesh nodes, whereas nonlinear dependence of FEM or MOM makes the computation time unreasonably high for large size problems.

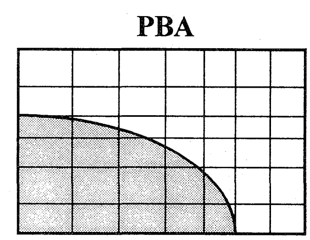

Fig. 1.4: Mesh model for the PBA method.

Fig. 1.4 shows a mesh model for the PBA method. Rather than using an approximation by prism cells, PBA considers the intersection of curved material boundaries with mesh cells precisely. This technique allows to simulate curved surfaces as well as very thin structural features accurately without using small mesh cells, resulting in lower memory requirements and smaller computation times. PBA combines the advantages of FDTD and FI-methods with an accurate, FEM like geometry approximation.

3 APPLICATIONS

3.1. Design of RF Window

RF Windows are one of the major concerns in designing high power microwave tubes and accelerators. Most of conventional RF Windows uses a pillbox like cavity operating on the TE_{11} mode. Fig. 3.1.1 shows the result of S11-parameter for a SLAC Type RF Window for frequencies between 2.5 to 6GHz.

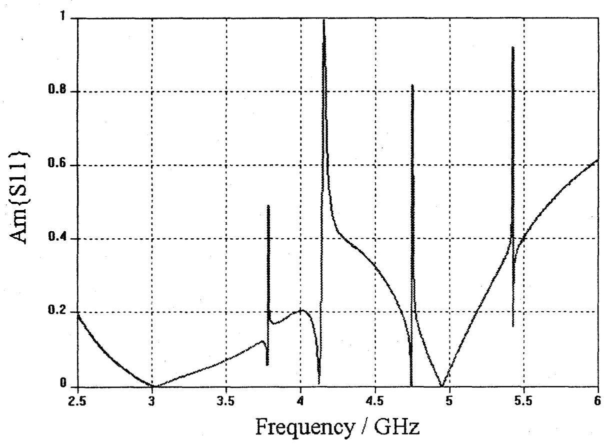

Fig. 3.1.1: Amplitude of S11-parameters of the SLAC Type RF Window.

The TM_{11} like mode which has E field components normal to the surface of ceramic disc, may aggravate the bombardment of electrons. Fig. 3.1.2 shows the $|E|$ patterns on the surface of the ceramic disc for both modes.

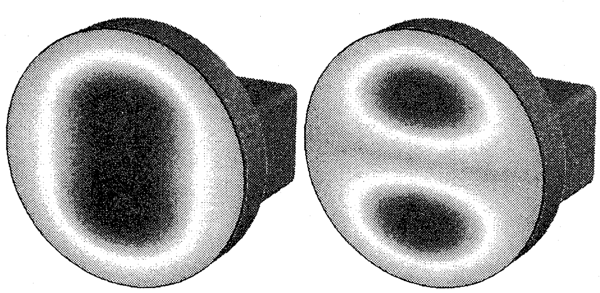
Fig. 3.1.2: $|E|$ of TE_{11} (left) and TM_{11} (right) like modes on the surface of the ceramic disc in the SLAC Type RF Window.

The total computational time was less than 30 min on a 450MHz Pentium II PC.

3.2. Accelerator Design

The time domain calculation is very useful for designing multiple cavity coupled structures such as linear accelerators. Fig. 3.2.1 shows the mesh model of a S-band, 6-cell Traveling Wave Accelerator and the magnetic field vectors at π mode resonance in a cross section. The rounded irises are considered very accurately by the PBA technique.

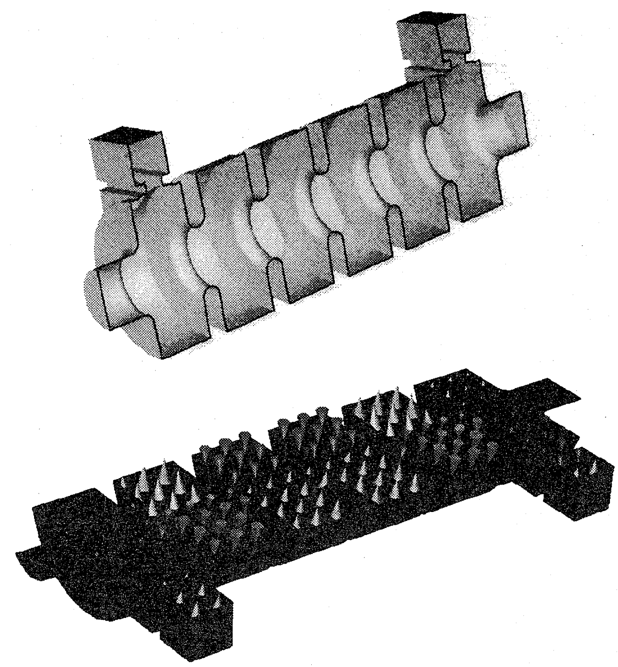
Fig. 3.2.1: Mesh model of a 6-cell Traveling Wave Accelerator (above) and magnetic field of the π mode in a cross section (below).

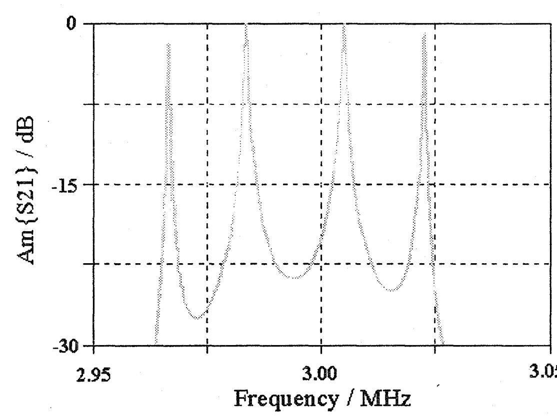

Fig. 3.2.2: Amplitude of S21 of the 6-cell Traveling Wave Accelerator.

Fig. 3.2.2 shows the amplitude of the S21-parameter. S-parameters can be obtained from a single time domain computation by using Discrete Fourier Transformation (DFT) or Auto Regressive Filter techniques that can speed up S-parameter calculations for high Q structures drastically.

REFERENCES

[1] Weiland T., "A discretization Method for the Solution of Maxwell's Equations for Six Component Fields", Electronics and Communication(AEU), Vol 31 P116 (1997)

[2] Yee K.S., "Numerical Solution of Initial Boundary Value Problems Involving" Maxwell's Equations in Isotropic Media, AP-14, S.302-307 (1996)