Industrial Requirements for Electromagnetic Field Computation Software

Introduction

In this article an overview will be given of the present and future requirements for electromagnetic field computation software within industry, specifically within a large global electronics company such as Royal Philips Electronics, which is based in Amsterdam, The Netherlands. This company consists of 7 product divisions with 60 different businesses and has a strong technology basis. 7.3% of the sales is spent on R&D (2,280 million Euro in 1999), with 17.000 people working in development and 3000 people in research laboratories in 6 countries. The research activity is divided in one third Company Research with corporate funding and two third Contract Research funded by the product divisions. Furthermore there is a great deal of co-operation with major universities and research institutes in the world.

The Product Divisions are Semiconductors and Components in close relation with Consumer Electronics, Lighting, Medical Systems, Domestic Appliances, and the IT company Origin. Philips is a large-scale producer with, to name a few examples, sales of over 11 million shavers, 2.4 billion incandescent lamps, 30 million picture tubes and 54 billion passive components per year, and a daily production of 50 million Integrated Circuits and semiconductors.

Background

The need for commercial general purpose EM software within industry (Philips) is evident for all the obvious reasons, such as the fact that design cycles are becoming very short, prototyping is not possible anymore or too expensive, etc. The developments of general purpose EM simulation tools within Philips was stopped about 10 years ago, because the internal Philips market for such tools was too small to compete with the commercial tools which were becoming more and more mature. At this moment Philips Research acts as the central support site of EM simulation software within Philips on a semi-commercial basis. Furthermore a number of development centres are using commercial software independently.

For the same reasons development of general purpose software for Mechanical Modelling stopped already 15 years ago, and the same thing happened with Semiconductor Device/Process Modelling software, but this took place approximately 5 years ago. Circuit Simulators were considered to be strategic for a long time, because of the specific Philips models for transistors and components, but here reconsideration might be expected. Philips compact models for transistors have become public domain now [1]. However, a lot of development of special dedicated EM software is still going on for those activities for which general purpose software is not suited, e.g. due to computing times, accuracy, lack of functionality, etc. or for strategic reasons. In the next paragraph we will give some examples of these activities.

Application examples

Within the business unit Display Components a number of dedicated tools are used, such as tools for modelling of deflection units for TV's and monitors, and space charge analysis tools for modelling of Cathode Ray Tubes (CRT). Furthermore, for magnetic shielding of TV's from the earth magnetic field, a special program (shell) was written around commercial software to model degaussing phenomena. Also for ray tracing through combined deflection fields and stray-fields commercial software is used in combination with in-house developed software.

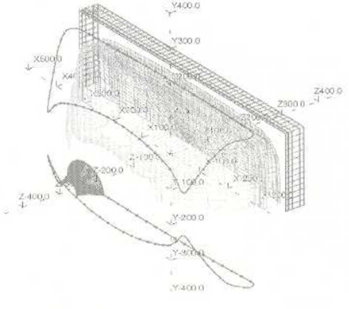

Fig .1 FEM model of a CRT screen

For development of rotating shavers an activity is taking place to couple an EM simulator with the Philips in-house circuit simulator Pstar for motor design. Here, for different rotor positions, the field energy is converted to a motor-inductance matrix to be used in the circuit simulator to predict the motor behaviour from the motor geometry.

Within Philips Medical Systems commercial software is used for the calculation of shielding of MRI magnets in hospitals and mobile trucks, and for verification purposes of in-house software for magnet or gradient coil calculations. A number of radio frequency (RF) design tools for MRI magnets and gradient-coils, using both analytical and numerical methods, have been developed. One of these tools, for instance, calculates the optimal current distribution (minimal magnetic energy) for a given field inside and outside the conductors, including eddy currents, for RF scanning systems. Another tool calculates fields and circuit parameters of RF antennas (quasi-analytically). Finally Method-of-Moments simulation of RF-coils and/or objects in a RF-field with commercial software is performed.

Some other typical applications within Philips, for which commercial EM software is used, for all the obvious reasons, are x-ray devices (both for analytical and medical purposes), rotational and linear motors and actuators (vacuum cleaners, shavers, etc.), loudspeaker systems, recording heads, medical scanning systems, inductive heating for manufacturing, optical pick-up units for DVD, lighting applications and transformers.

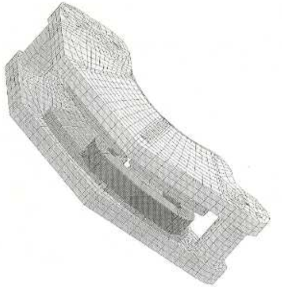

Fig.2 FEM model of a voice coil motor for CD players

In general the Corporate Research/Development Centres are making permanent use of commercial EM simulation software, mostly on powerful UNIX workstations, whereas in (pre-) development centres attached to production sites mostly commercial PC versions are used. In some areas, such as development of power electronics, most people are still designing magnetic components with analytical methods. The reasoning behind this is mainly that 3D numerical modelling is too complicated or time consuming since the cost of making several prototypes is not prohibitive in this specific application area, whereas, 2D numerical software is not accurate enough. In some cases the accuracy advantage with respect to analytical methods will be lost and the time effort disadvantage will remain, provided that the analytical methods can be applied reasonably straightforward.

Within the Mechatronics development centre of the Centre for Industrial Technology (CFT) many different disciplines (mechanical, thermal, acoustic, etc.) are used for the design of controlled actuator systems, where each discipline demands very different models with different levels of detail used by different people, which makes the necessity to integrate or to couple many different disciplines in one software tool in general not very feasible. In some special cases strong coupling can be useful, such as calculation of forces on magnets. As an example of an application where EM software is essential consider the design and development of wire-bonders and wafer-steppers for the IC manufacturing business. The first design is done mostly electronically. After this design phase one (and only one) prototype is built, which in general is more than 90% correct. Finally, after some last modifications the final machine is built.

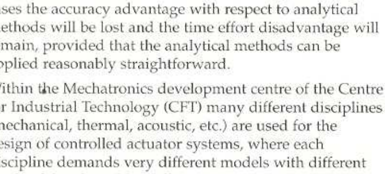

Fig.3 Integrated inductive components on a PCB

We want to make some observations here about the user-friendliness (User Interface) of commercial software packages. Our experience is that in general a new user can learn how to use a modern commercial 2D EM simulation package in 1-2 days, most people within Philips can do without explicit training now. 3D software is in general more difficult, with a learning time of 3-5 days and explicit training is preferred. More effort has to be put into making the 3D software easier to use, such as better solid modelling, meshing and adaptation. However, there is always the fear that the software is made too easy to use, so that the wrong people may use it.

Projects on EM software

In the past a number of European Esprit projects have been carried out, which were dedicated to new developments of EM simulations tools, where Philips acted as an end-user of the commercial software. The PARTEL project was carried out as part of a High Performance Computing and Networking (HPCN) initiative, which aimed at producing efficient parallel versions of existing commercial simulation codes on a wide range of parallel architectures [2]. Conclusion of this project, from an industrial (Philips) point of view, was that for most applications small scale parallelism on networks of workstations or PCs (4-8) is efficient and therefore quite feasible, whereas large scale parallelism on super-computers/multi-processor systems is only in a limited number of applications really feasible.

Fig.4 Epoch design optimisation environment

The EPOCH project objectives were to set up an open-ended Design Optimisation Environment capable of driving a set of parametric analysis tools [3]. Furthermore to couple this environment with an effective 2D and 3D electromagnetic analysis environment with advanced analysis potential for detailed design, and to provide built-in HPC capabilities to allow an effective exploitation of the system features. A number of industrially relevant test cases, such as a CRT design and a thin film recording head design, were used to test the environment.

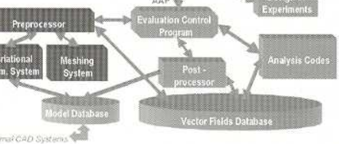

Fig.5 Thin film recording head design

Conclusions of this project were that the open architecture of the EPOCH environment allows users to choose different optimisation algorithms, analysis codes, design of experiments facilities and to add new components. The combined use of design of experiments and optimisation facilities, in particular, can provide novel and valuable statistical guidance in the design synthesis process. For most test cases simultaneous evaluations of objective functions on a number of different processors (coarse grain parallelism) turned out to be preferable to making use of parallel analysis codes (fine grain parallelism) in terms of efficiency and ease of use.

RF simulation tools

Originally the two worlds of EM field computation software and circuit simulators were quite different worlds altogether. But with increasing frequencies these worlds are approaching each other fast. Originally the EM field solvers were mainly used for static and eddy currents calculations, in the last few years extended to wave phenomena, making use of methods such as Finite Elements and Boundary Elements.

Circuit Simulators were originally used to calculate the circuit behaviour of circuits on Printed Circuit Boards (PCB) and Integrated Circuits (IC) for low frequencies. Because of the increase of high-frequency applications, these environments had to be extended to microwave and RF systems, where EM analysis systems, mainly based on Method of Moments (MoM), Boundary Elements or Transmission Line Methods, were developed to take high-frequency effects into account (the Kirchhoff assumption is not valid anymore). With application of EM methods on circuits, also the size of the problems increases.

Vendors, who were in the field of low-frequency EM field computation software in the past, are now extending their software towards the Electronic Design area. When you look at this world of PCB and IC design software, one of the observations one can make is that it is a very fast world and sales ranking lists of vendors are changing rapidly, whereas the original EM simulation software market is rather stable comparably.

Within Philips a "2.5D" tool called Fasterix has been developed, based on the Boundary Element Method, to calculate layout effects on PCB's [4]. For high frequencies these effects cause a change in functionality, which may in some cases even be exploited, or creates disturbances in the environment (Electromagnetic Compatibility, EMC). Fasterix uses a quasi-static approximation (losses only as a correction) and the tool is valid up to frequencies of several GHz, where geometrical details are smaller than the wavelength (electrically small but geometrically very complex structures). A node reduction algorithm has been implemented to reduce the equivalent circuit that is generated. These equations can then be solved with a Spice-like circuit simulator. The advantage is that this circuit needs to be calculated only once, and not for each frequency. Then the circuit simulator is used for a frequency sweep, which in general is very fast due to the node reduction (model reduction). This method has a large advantage compared to e.g. the MoM method, where for each frequency a complete new calculation has to be done. With Fasterix it is possible to analyse complete PCB's, for instance a complete FM Radio Tuner PCB of considerable complexity has been analysed [5]. Another application where Fasterix is very useful is in IC package modelling to calculate the parasitic components of a package, such as capacitances and inductances. Such models are used later on in circuit simulators, to include effects of the IC and package on PCB's.

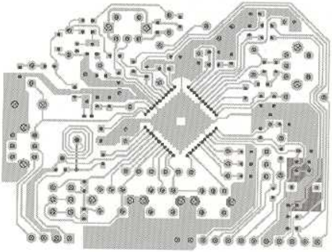

Fig.6 PCB of an FM radio tuner

In the near future and maybe already in some present day situations, also IC's are showing problems due to high-frequency effects. Due to the smallness of IC's, these effects are becoming important for higher frequencies than for PCB's. The main problems with IC's are EMC from the IC itself, cross talk resulting in noise on the IC and problems with delay times on transmission lines. However, the main problem compared to PCB's is that the substrate material, silicon, is (semi-) conductive, so that the method of Fasterix does not apply as such, but has to be enhanced. Also the skin effect is very important on IC's, of the same order as the thickness of the wires and clock lines. Capacitive sidewall effects of the wires are also important.

Since the complexity of IC's is increasing exponentially, there is an increasing need for advanced software [6]. There is a need for new design methodologies and for more accurate models. Wiring and interconnection problems are becoming more and more important.

New projects

One of the new projects that are proposed is an extension of the standard magnetics simulation to micro-magnetism modelling for magnetic recording purposes. Also a number of future projects have been proposed and planned with regard to EM simulations of PCB's and IC's. A number of projects are already taking place, such as a University project on fast algorithms for MoM for EMC simulations.

The highly capable communication devices and systems for the Information Society will require higher frequency and bandwidth operation with multi-technologies integration (digital, RF, packaging). Therefore the IDEAL project has been proposed to consider Signal Integrity & EMC as an integrated part of systems development and a new design methodology to meet this challenge based on a co-operative working environment covering the functional, physical and electrical domains. The project objectives are the definition, implementation and validation of an advanced electronic design environment enabling EMC & SI control. Validation of this environment will be done on the basis of trials in real design situations, such as mobile phones, spectrum control and automotive applications.

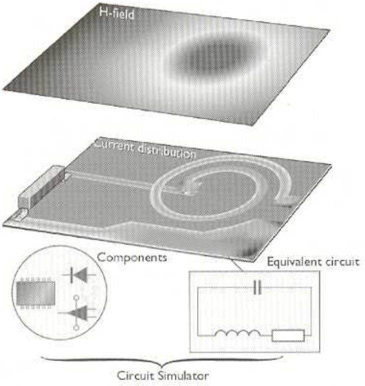

Fig.7 EMC simulation with Fasterix

Another project is involved in extending the specific EMC functionality of Fasterix. Addition of 3D structures to the layered "2.5D" models and coupling with a 3D field solver to include radiation effects are being considered.

Looking at commercial software, which has become available in recent years, software based on the Finite Difference Time Domain (FDTD) Method, has generated a lot of interest within Philips recently, especially in relation to interconnect problems on PCB's and IC's. It turns out that this method is well proven, robust and accurate. The method itself is quite old and based on the Yee Algorithm (1966), but only recently computer systems have become powerful enough to make efficient use of this method in full wave simulations. Other methods, such as MoM, Finite Element Time Domain and Finite Integration Time Domain are also being considered. Lossy and anisotropic media can be easily taken into account, making the FDTD method suited for analysis of interconnect on silicon.

Finally, the LEONIDAS project has been proposed to model the influence of the interconnect layers on the circuit behaviour in IC's. We anticipate an extension of the PCB simulator Fasterix towards IC applications for frequencies up to 30 GHz covering the following subjects: development of interconnect models with side-wall effects for IC, description of R, L and C between metallisation and environment, investigation and development of algorithms to cover parasitical influences (dielectric, substrate and radiation losses), optimisation of the stability of the models, integration of the tool in a known design flow and finally checking the simulation results with measurements on real IC's. The enhancements will be done by combining expertise at Philips Research with those at Universities.

Future requirements

One of the main problems is to have reliable 3D error estimation and adaptive mesh generation to generate results with required accuracy. In general one can play with the cell size, the size of the simulation domain, boundary conditions and the number of time-steps for transient calculations. The user is required to experiment, until certain accuracy is reached, but in practice this is not done (because the colour pictures are nice enough). Also problems with robustness, element shapes (especially in air-gaps) and user control of 3D tetrahedral mesh generation give rise to improvements. This is closely related to the way one can set up a model (pre-processing).

Further enhancements and improvements to commercial EM field simulation tools, both in 2D and 3D can be seen, among others, in the following areas:

- coupling to Spice-like circuit simulation tools
- simple hysteresis models (e.g. Preisach)
- transfer of magnetisation from one solution to another
- micro-magnetism modelling
- coupling with mechanical equations in rotational modules
- user definable speed variation and coupling to rigid body dynamics
- better calculation of electron-optical parameters, spherical aberration, etc.
- coupling to computer algebra packages (Mathcad, Mathematica, etc.)
- improved 2D error estimation and adaptation
- adaptive time-stepping in transient problems with predictable error level
- easy interfaces to "standard" CAD systems (e.g. SAT files)
- pre-conditioning for more reliable conjugate gradient convergence for non-positive definite systems
- non-linear convergence algorithms
- cogging torque calculations

Conclusions

As far as the industrial requirements are concerned the EM simulation software developers are not allowed to rest on their oars. There still are a lot of developments possible and desirable. First of all in terms of enhancing the speed, size and accuracy of existing software and algorithms. Also a number of new developments and improvements in the low-frequency EM field simulators are essential, such as better 3D modelling and improved adaptive mesh generation. Finally there is great need for EM simulation tools, connected to the Electronic Design environments to model RF effects in PCB's, EMC effects from complete consumer electronics systems, and interconnect effects on IC's.

References

[1] Philips Compact Models:
http://www-us.semiconductors.philips.com/Philips_Models/

[2] R. Janssen, M. Dracopoulos, K. Parrott, E. Slessor, P. Alotto, P. Molfino, M. Nervi, J. Simkin, "Parallelisation of Electromagnetic Simulation Codes", *IEEE Trans. on Mag.*, vol. 34, no. 5, pp. 3423-3426, 1998

[3] C.P. Riley, R.C.F. McLatchie, C. Glasgow, R. Janssen, T. Gutiérrez, J. Simkin, P. Brochet, C. Furmaniak, F. Gillon, G. Molinari, P. Alotto, J-F. Lemoine, G. Drago, "An Environment for the Optimisation of Electromagnetic Design", *Compumag'99, to be published in IEEE Trans. on Mag.*

[4] R. du Cloux, G.P.J.F.M. Maas, A.J.H. Wachters, "Quasi-static Boundary Element Method for Electromagnetic Simulation of PCB's", *Philips Journal of Research (Elsevier)*, vol. 48, no. 1-2, pp. 117-144, 1994

[5] T.A.M. Kevenaar, E.J.W. ter Maten, "RF IC Simulation: State-of-the-art and Future Trends", *Proceedings of the Sispad'99*, Kyoto, September 6-8, 1999, pp. 7-9

[6] J. Niehof, N.J. Pulsford, I. Lodema, J. Meeuwis, "Electromagnetic Simulation of Real-life Circuits", *to be presented at SCEE-2000*, Warnemünde, Germany, August 20-23, 2000

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New Directions in Computational Modelling

Introduction

The biennial Compumag Conference has been an international forum on all aspects of computational electromagnetics since 1976. The organisers grasping the opportunity offered by the timing of the meeting in Sapporo last November in the closing months of the 20th century decided to host a panel discussion on future developments. Accordingly a number of specialists were asked to make short presentations on the possible new directions of research in their areas of expertise. After the presentations a general discussion was held.

The topics selected were as follows:

- New directions in fundamental methods for solving field problems presented by **Alain Bossavit** (EDF France)
- Virtual Reality and Augmented Reality presented by Professor **M Hirose** (University of Tokyo)
- The role of industry and government in shaping new problem areas presented by **Larry Turner** (Argonne National Laboratory)
- The impact and demands of advance technology in academic education presented by **Lauri Kettunen** (Tampere Technical University)

The panel was chaired by **Bill Trowbridge** (Vector Fields Ltd).

The purpose of the panel was to highlight interesting areas that could have an important effect on future developments. *Could* is the operative word here as the business of prediction is uncertain. It is a commonplace that the sharper the forecast the fuzzier the outcome; or as the philosopher Francis Bacon wrote in 1625, *Dreams and predictions ought to serve but for winter talk by the fireside.* So many predictions made in the past have been profoundly wrong and we all have our favourites, one of mine is by Lord Kelvin who said in 1895 that heavier than air flying machines were impossible. But we should remember also that he said, *when you can measure what you are speaking about and express it in numbers, you know something about it.* So perhaps we should follow the advice given to the Irish historian, Conor Cruise O'Brien by his doctor *to cut back on predictions.* A compromise is look at where we are today and try and set reasonable goals for the future.

It has to be said that the paradise promised by the digital computer revolution that began in the seventies has not yet been gained. Ironically, in both the recent and remote past designers have often used computer analysis techniques to predict the performance of a device after it has been specified, then to use the same analysis methods heuristically to refine the parameters to try and achieve a better solution. This paradigm is now changing as robust and practical methods for optimisation and inverse problem solving have become available. Optimisation processes[1] often involve field computation to evaluate the cost functions and although there a number of computer codes available for this analysis the computing resources needed to explore the full design space can be prohibitive. The use of high performance computing can assist the process but the enormous number of cases involved rapidly leads to a "combinatorial explosion". So even with these advances smaller subspaces have to be defined with the attendant *risks of throwing the baby out with the bathwater.*

Nevertheless many significant advances have been made with many examples to be found in the literature. The success of the finite element method (FEM) itself in solving low frequency and static field problems has been well documented; in the Compumag series, the CFC series of conferences, and in many other places. Only a very brief summary of the panel presentations will be attempted here as it is intended to publish full versions in Compel at a later date.

New directions in fundamental methods for solving field problems

Alain Bossavit urged the community to "watch out' for friendly neighbours; i.e. to pay attention to seminal work by mathematicians and researchers in parallel fields. He gave several examples including[2]:

- E Tonti whose work adds to our understanding of methods like Finite Integration in his studies of Generalised Finite Differences.
- R Hiptmair on 'Edge Element' multi grids.
- M Costabel with his attempts to justify Maxwell's equations into a system that can be handled by nodal elements demonstrates that they will fail in some nasty cases, e.g. the use of the Lorenz gauge in re-entrant corners.
- V Rokhlin with his developments of the 'fast multipole method' in solving Integral Equations leading to *nlog n* instead of n^2 operations.
- R Kotiuga who has analysed the non-trivial topological problem of 'making cuts' in em problems

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[1] Optimisation was the subject of another panel discussion at the conference, which will be reported, in a later issue of the newsletter.

[2] For a list of references please contact Allain Bossavit at Alain.Bossavit@der.edfgdf.fr