Progress of Expert Systems in Electromagnetic Engineering*

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Abstract  It is urgent to solve various problems in electromagnetic (EM) engineering under the increasingly complicated environment. Some expert systems (ES) come into being just to keep up with the demand for solving these problems. Combined with the analysis of development of ES technology and the development trend of EM engineering software in recent years, the application of ES technology in EM engineering is discussed, and especially the progress of complete ES in electromagnetic compatible (EMC) is introduced.

Key words  electromagnetic (EM) engineering;  expert system;  knowledge-base;  engineering software;  electromagnetic compatible (EMC);  electromagnetic interfere(EMI)

Present-day electromagnetic (EM) systems mostly work under very complicated environment. For example, the interconnection encapsulated structure in microwave and millimeter wave monolithic integrated circuit (MMIC) (especially, 3D MIC) and the high-speed IC must ensure super-integration and high-reliability interconnection; scattering problems of EM wave on the surface of stealthy material must be solved in stealthy technology; there exist problems of interaction between EM wave and complicated objects needed to be solved in geological survey by electrical exploration. The increasingly deteriorated EM environment and the increasingly harsh demand for working circumstances of anti-interference circuit make it an urgent problem to improve the anti-interference performance of electronic equipments.

The most widely used method of analyzing problems in EM engineering is to simulate by using commercial EM simulation software and to work out a comparatively exact result. Such simulation software based on full-wave analysis technology (such as finite-difference time-domain (FDTD), finite element method (FEM), moment of method (MOM)) have the merit of more universality and high accuracy but need a large amount of computation (high time-cost). Difficulty of simulation is increasing exponentially and it is hard to ensure the correctness of simulation result, especially in the analysis of large electric size or complicated EM systems. Therefore, computer aided design (CAD) has been adopted in most cases to optimize the design of complicated EM engineering.

That is computing an object function on a large scale by iteration until convergence takes place and the optimal value is obtained. There are a lot of approaches to optimizing CAD model, among which artificial neural network (ANN) model is comparatively effective and accurate. ANN model can not only build model for EM property in complicated systems during the process of optimizing CAD model but also compute quickly.

Based on EM simulation and CAD modeling, to build fast and accurate knowledge base of expert systems (ES) and to realize ES with some artificial intelligence (AI) in EM engineering are what research and development of EM engineering must undergo[1]. Now EM engineering software is growing in the direction of AI, having more and more strong ability to handle intellectually in a certain professional field and a large number of physical model libraries have been set up. A big step has been taken toward solving EM engineering problems under complicated environment.

1 Technological Development of Expert System

With the advance of theoretical research and development practice in ES, some new technology, such as data base (DB) technology, multi-media technology, component object model (COM) technology, network technology, fuzzy control technology, neural network (NN) technology, etc. has been melted into the research and application of ES technology, which has drawn widely attention in engineering field[2-8]. The application of new

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technology not only bring about some achievements in the research of such crucial technology in ES as knowledge representation, knowledge base, knowledge acquisition, inference engine, but also brings into being some new integrated ES, such as NN ES, fuzzy ES, internet-based ES and CAD ES, etc. expanding increasingly the application area of ES\cite{9,10}.

Knowledge representation and knowledge base are important parts of ES. Generative rule representation method and frame representation method are the most often used traditional methods of knowledge representation\cite{11}. With of development of ES technology, many new methods of knowledge representation and knowledge base appear, such as knowledge representation method based on object-oriented (OO) technology, knowledge base method based on DB technology, knowledge representation method and knowledge base method based on artificial NN technology. Among these new methods, the OO technology is becoming a leading technology in computer science field because of the merit of advanced modularity, encapsulation and inheritance. Moreover, this method emphasizing on object in a system and on the relationship between objects is a true reflection of intrinsic things in real world, so it is a most structured knowledge presentation method.

The automatization of knowledge acquisition is always one of the important research goals in ES. Automatic knowledge acquisition has two methods: one is knowledge engineers acquired from domain expert and the other is machines automatic study process. In recent years, some new knowledge acquisition technology come into being, such as knowledge acquisition technology based on coarse theory, based on genetic algorithm (GA), based on ANN, based on data mining (DM) technology. DM also called knowledge discovery in database (KDD) is a newly merging technology with development of DB technology and AI technology in most recent years. This technology can detect stealthy, useful and undetected information and knowledge from a great deal of incomplete, noise, fuzzy and random data.

Classical inference engine includes forward reasoning and backward reasoning which are rule based reasoning (RBR) but have the disadvantages of low efficiency of reasoning, and weak self-adaptability. In recent years, case-based reasoning (CBR) and fuzzy reasoning (FR) develop to a different extent. Combined reasoning technology from the combination of various reasoning technology have already become a hot topic in the development of ES inference engine, such as integration of rule-based reasoning and case-based reasoning, the integration of rule-based reasoning and fuzzy reasoning, the integration of case-based reasoning and fuzzy reasoning, and case-based reasoning and fuzzy reasoning based on ANN.

Technology in every aspect of ES develops continually. However the development of independent ES is becoming rare. The general development trend is to melt ES technology into various engineering software and make ES become a subsystem of engineering software which thus can help to solve problems in a certain professional field. Only when those subsystems with professional ability to handle are combined systematically, can they deal with effectively the engineering problems in the complex environment. For example, internet-based ES technology has been applied into the field of EM engineering, and the application is focused on parallel-computation and grid-computation to solve complicated problems. Other ES technology has been widely used in the field of EM engineering, which will be discussed in the following sections.

2 Application of ES Technology in the Field of EM Engineering

Actually, very few complete ES is applied in the domain of EM engineering except in EMC. However, ES technology is really applied in many aspect of EM domain. With the development of software engineering and improvement of various numerical computation methods in EM, the research and development of EM engineering software is growing rapidly and it is applied in more and more EM domains. At the same time, the application of ES technology leads to many “function blocks” to deal with various professional domains in EM engineering software, and the process of handling has increasingly strong intelligence ability, even though the ordinary engineer use them, they would get the same result of analysis as experts can do, which speed up the generalization and application of these engineering software.

2.1 Characteristics and Functions of Commonly Used EM Engineering Software

Agilent ADS (advanced design system), which is developed by American Agilent Corp. has been widely
used in many universities and research institutes. This simulation software offers a guide to a new kind of filter design and it can analyse and optimize planar circuit as well as analyse and synthesize RF/microwave circuit by using intelligence user interface (UI). Moreover, it can allow users to define the range of frequency, material characteristics, parameters, and produce automatically key passive device model according to the demand of user. It deals with the design and analysis of from chip to system and especially can realize the synthesis analysis and optimization of digital or analog, linear or nonlinear circuits in the field of frequency-domain or time-domain. At the same time, it can analyse the rate of finished products with the simulation results. It increases the design efficiency of the complex circuits and becomes an effective tool for engineering designer. Its rapid circuit simulation offers the initial design result and then the accurate simulation result is obtained by MOM. ADS offers guidance to the design of different circuits, including filter, amplifier, bluetooth, mixer, oscillator and passive device. The guidance to the design of MMIC is added in the latest version, making the design more convenient.

CST MICROWAVE STUDIO developed by Computer Simulation Technology Corp. is also a commonly-used EM simulation software. It combines EM components through scatter parameters and divides a complicated system into smaller units. It can analyze quickly and decrease the working memory of the system through the description of parameter of every unit performance in the system. The accuracy of the system is not affected because CST considers the high-order modes between different units and the system is validly divided. It is characterized by: 1) The adoption of nearly perfect boundary approximation (PBA); 2) More convenient study and use of CST MWS due to visual GUI; 3) Saving large mount of time because of the automatic input of CAD data; 4) Rapid generation of needed structure parameter by designers through optimization of products by advanced optimization software packages.

Ansoft HFSS developed by America Ansoft Corp. is broadly used in research institutes, corporations and universities. HFSS is well in designing various kinds of radiators and solving eigen mode. Recently, this corporation has developed Ansoft design 1.0 combining circuit design, EM simulation with printer board design. Ansoft HFSS uses some patent technologies, such as self-adoptation enmeshment, ALPS speedy sweep frequency, tangential component. It integrates structure modeling systems which keep up with industrial standards, provides flexible and prolific macro language, visual post-processor and unique field calculator which can analyse and display various field distribution of complicated environment. “Optometrics” packages can be used to scan and optimize any parameter to find a optimal parameter value.

Microwave Office 2002 developed by the Applied Wave Research Corp. is high-frequency EM simulation software. It simulates microwave planar circuit by two simulators: VoltaireXL and EMSight. A component library is set up in the simulator “VoltaireXL” and the components needed in microwave circuit can be picked up when building circuit models. In the component library, inductance, impedance, capacitance, resonance circuit, microstrip line, stripline, coaxial-line, etc. are among the passive devices components. Among the non-linear components are bipolar transistor, field effect transistor (FET), diode, etc. The simulator “EMSight” is a simulation software package of 3D EM, and it can be used to analyze high-frequency planar circuit and structure of antenna. This simulator has the merit of combining modified spectral domain MOM and visual GUI, speeding up the computation. In addition, some new functions are added: intellectual synthesis of filter, phase-noise analysis of oscillator, simulation engine of 3D planar, making simulation of certain complicated problems more effective.

FEKO, which is developed by ANSYS Corp., has truly realized the combination of MOM and PO/UTD and thus it can take exact EM computation entirely according to user’s demands. This software simulates by using hybrid methods. MOM is used in critical region; PO/UTD is used in other important region (general large planar or curved face). Satisfactory accuracy and speed can be acquired according to user’s demands when hybrid methods are combined to solve different EM problems.

FIDELITY, which is developed by Zeland Corp., is based on non-uniform grid FDTD 3D EM simulation software. It can solve problems of field distribution in filled complex dielectric region. It has the following merits: 1) model 3D metal and non-insulated medium structure; 2) it has high efficient FDTD simulation engine in process of the non-uniform grid; 3) arrange and locate the geometry objects and can edit and
examine; 4) build models for coaxial waveguide and rectangle waveguide with filled anisotropic medium; 5) it has functions of automatic grid generation, grid optimization for the input geometric structure; 6) it can realize different boundary condition for different boundary (such as PML); 7) it has functions of pre-processing and post-processing, including extracting S parameter and displaying real-time field distribution.

In essence, these commonly-used EM engineering programs make rigid EM simulation on the basis of full-wave technology (such as FDTD, FEM, and MOM). They sometimes use hybrid methods or other approximate algorithms (such as PO/UTP) to compute according to different EM problems. They optimize objects by building a large number of CAD models. They also build physical models for often-used devices and apply computational engines (software packages) in some special fields. Modeling by using CAD with industrial standards makes construction be more easily realized. VBA which provides advanced language interface for users increases the flexibility of application. A large number of microwave component libraries have been built in order to make the building of circuit models more convenient. Comparatively intellectual design guide has been offered for common application. Visible and interactive GUI has been offered in order to make users input information more conveniently. Real-time and dynamic display of computing results has been realized. They can solve more and more complicated problems and more intelligent operation. These are the demonstration of the development trend of EM engineering software in recent years and will surely become the future development trend of EM engineering software development. And this trend is actually the result of the wide application of ES technology. So it is necessary to make detailed analysis of some ES technology used in EM engineering domain.

2.2 Analysis of Application of ES Technology in EM Engineering Domain

Automatic enmeshment technology is an important part of EM engineering, now most EM engineering programs use automatic meshing split which is an important ES technology. A structured orthogonal grid enables a fine sampling of the geometry and electromagnetic fields while retaining minimal memory requirements. Simulations using several million mesh points are easily performed. This efficient organization of information enables the fast broadband calculation in the time domain. The meshing process itself is performed by an expert system, which only needs three basic pieces of information in order to create an accurate representation of the studied structure, that is, the spatial sampling rate of the electromagnetic wave, the sampling rate of the geometry and the maximum allowable inhomogeneity of the grid. Using default parameters will provide excellent results.

The user interface acts as a pre-processing system of ES that performs syntactic and semantic analysis of user input data that are relevant to the problem. It is also an important approach to knowledge acquisition. Friendly and efficient interface technology provided for users makes it convenient to study and operate properly; and visible and interactive GUI used in EM engineering field is rightly a kind of comparatively mature interface technology. Integrated modeling system of industrial standard (CAD) can be used to input quickly complex structure models and it can acquire automatically simulation parameters according to automatic meshing split technology and intellectual design guide. Users can control more flexible simulation parameters by advanced VBA language interface technology integrated in engineering software. These acquisition technologies of simulation parameters are virtually equal to knowledge acquisition in ES.

Knowledge base is an important part of ES. In EM engineering, a large number of microwave component libraries have been set up in order to build complicated circuit models; intellectual “guide libraries” have been set up in order to design ordinary circuits for filters, amplifiers, mixers, etc; simulation “engine libraries” have been set up in order to make computation in some special EM domain; many optimization tool libraries have been built for optimization design of products; and physical algorithm libraries have been built for choosing the best method to compute various cases. In fact, these various types of “libraries” function in the same way as knowledge bases in ES do. With the expansion of the field of application of knowledge base in EM engineering field, more and more professional knowledge bases will be built. And with such bases, ordinary engineers can directly take out related knowledge from knowledge bases when designing complicated systems, which thus can increase the
design speed and its accuracy and make design simpler and more reliable.

The mentioned above is just the application cases of all kinds of ES technology in EM engineering but not of complete ES systems. The presently application of really complete ES in EM is focused on EMC.

3 Applications of ES in EMC

The problem of electromagnetic compatibility (EMC) appears at many levels of design from IC through multi-chip modules (MCMs), PCBs, to subsystem which have shielding and external cables, and systems of interconnected subsystems. Since modern electromagnetic equipment must acquire the strict standards of EMC, many design tools for EMC have come forth.

The expert system of PBC is based on symbolic reasoning techniques, currently under development in the University of Missouri-Rolla, and it can predict the problem of radiated EMI levels from printed circuit boards [12-13]. The main advantage of such a system over conventional software is that the expert system does not require the user to be an expert in EMC or circuit design.

Fig.1 shows the basic structure of the EMC expert system of PCB’s. The expert system consists of four stages. Using board layout and component input data, the characteristics of all the nets and their signals are identified in the net classification stage. This information is passed to the evaluation algorithms, which search for possible radiation or susceptibility problems. There are four different radiation algorithms: the differential-mode radiation algorithm, the current-driven common-mode radiation algorithm, the voltage-driven radiation algorithm, and the radiation by I/O coupling algorithm. The differential-mode radiation algorithm calculates the direct radiation from signal traces (which is usually negligible in well designed boards). The current-driven common-mode radiation algorithm determines how well each circuit is able to drive common-mode currents onto the cables or enclosure by way of magnetic field coupling. The voltage-driven radiation algorithm focuses on electric field coupling. Finally, the radiation due to noise coupled directly to traces that conduct energy off the board is calculated by the radiation by I/O Coupling algorithm.

The automobile EMC expert system, which has been being developed in the University of Missouri-Rolla, can detect potential EMC problems early in automobile design [14]. PCB and automobile EMC ES have a lot of common ground: they both consist of four stages, they both use EMC files and component libraries as input method and they both use experienced models designed by EMC. However, they have difference because of different domains of application: input modes of automobile ES are more than that of PCB, user’s online input is added in automobile ES, coupling model of external EM with electric wires are added in automobile ES because of the more deteriorated EM environment than PCB ES, coupling between electric wires concerned with high current is added in automobile ES, and noise interference models of power bus are added in automobile ES while only common-mode interference between voltage sources and driving sources is considered in PCB ES.

The expert system applied in PCBs has been a Hotpoint in research field in recent years because of the increasing demand for solving EMC/EMI problems which result from the increasingly growing speed and frequency signs in PCBs [15]. There exist many other mature commercial software tools, among which the most widely used are QUIET EXPERT developed by Mentor Graphics Corp., Hot Stage EMI and Hot Stage PI by Zuken Corp., DEMITASNX And EMI Stream by NEC Corp [16-18].

More applications of expert systems in EMC can be found in http://www.emclab.umr.edu website.
4 Conclusions

More and more practical problems need to be solved as a result of the increasingly complicated EM environment. It is an inevitable trend that EM software grows in the direction of artificial intelligence. The application of ES technology in EM engineering field has rightly answered for this trend. Through the analysis of the application of ES in EM engineering field, we can see good prospect of application of complete ES in this field. Therefore, it is necessary to research the ES technology used in EM engineering field in order that more complete ES should be realized, and so EM engineering software might become more intellectual.

References


Brief Introduction to Author(s)

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