Integrated EM Immunity Design and Diagnosis System for Electronic Devices

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Abstract— **This paper presents an integrated electromagnetic immunity design and diagnosis system for EMI/EMC scenarios assessment and analysis of electronic devices/equipments. The system is capable of modelling and analyzing electromagnetic emission and interference therefore to evaluate the immunity level of devices under test via analytical/numerical methodologies. It will also be customized so that it can be used for the design verifications and parameter calculation.**

Key words: EMC, Electromagnetic Emission, EMI, Immunity, Susceptibility.

I. INTRODUCTION

With the increasing data rate in the processing and communication in the electronic devices/systems when using advanced technologies, electromagnetic interference (EMI) from one device/system to another becomes an inevitably critical problem to the designers. The requirement of electromagnetic compatibility (EMC) which includes EMI and electromagnetic susceptibility (EMS), becomes more stringent to enable the system to have higher EM noise immunity level and lower radiation characteristics. To achieve higher EMC level amongst the electronic systems, the victim system shall be hardened to withstand a higher level of EMI (susceptibility) and the culprit system shall be properly designed such that it emits a low level of EMI (emission). To ensure that radiated emissions from an electronic product are kept under control, the international regulatory bodies have enforced mandatory radiated EMI limits for different categories of electronic products. The maximum allowable radiated EMI limits are very stringent and pose design challenges to the electronic product designers. Traditional EMC tests are carried out in the post product design stage in the lead time. Once built, it is only then that product is tested to see whether or not it conforms to the relevant standards. This can prove to be very expensive in terms of time, cost, and the potential need for retrofit modifications. Moreover, the physical and climatic environments, plus the wear and tear and misuse that systems may be subjected to over their lifetimes can also cause circuit EM behaviour to alter, and can degrade the performance of EM mitigation measures such as shielding, filtering, decoupling, and transient suppression. Therefore, the project management and product design cycles become much longer and more challenging. Therefore appropriate EMC design techniques [1] are required, based on qualitative and quantitative assessments of the reasonably foreseeable worst-case EM and physical environments over the lifetime of the system.

Commercial software packages are feasible nowadays to predict electromagnetic radiation characteristics with simpler structures from electronic to electrical devices. However, all toolkits are focused on the EM emission and coupling behaviors through numerical technologies, such as finite-differential-time-domain method, finite element method, and etc. [2], which are often time-consuming. There is also no comprehensive EMI modeling and not much work done yet in EM immunity which is another important characteristic for electronic systems.

This paper thus describes the work which aims to evaluate the EMI phenomena and immunity level of electronic systems via an integrated EMC modeling methodology development. The software package includes developing the modeling and analysis technologies to deal with EMI/EMS problems, the experimental validation approach to verify the modeling technology performance and providing the strategic design guidelines for applying the EMC methodologies and techniques in the physical system design, EMC standards and specifications, and EMC challenging and benchmark problems integration ultimately.

II. SYSTEM ARCHITECTURE

The objective of EM immunity computer modeling and simulation is to create a representation of real life EMC problems that can be examined and analyzed by computer resources as an alternative to building a physical electronic system, exciting it, and measuring the generated fields, by using integrated analytical and numerical methods. The basic guideline for the software system development is therefore: the analytical/numerical algorithms are simple and fast in producing results, and the programming of these algorithms is robust, and a minimum possible number of modules in the solver are realized for sufficient analysis.

As the simulation system aims to allow modeling of the associated physical problems to be conveniently made and fast evaluation of the EMC performance to be obtained, the object classes required for electromagnetic problems analysis have thus been defined within the system. The immunity system architecture is shown in Fig.1.

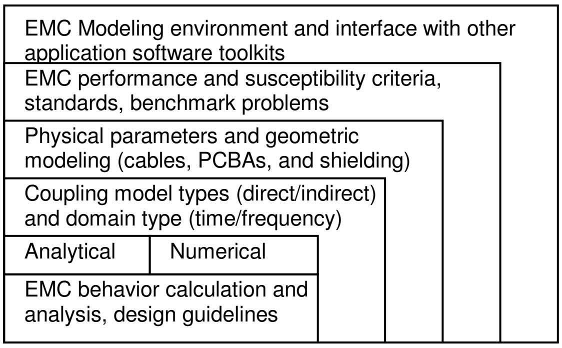

Fig. 1 Architecture of integrated EM immunity system

In the initial data preparation phase of the modeling, the global parameters such as the geometric structure can be obtained by using data sheets or other engineering CAD tools. The range of design variables and modeling constraints should be specified as well. Whilst numerical technologies will be developed to efficiently and accurately characterize the EMC/EMI problems, analytical technology will also need to be developed to solve specified EM problems, such as coupling between cables, or between cable and printed circuit board (PCB), and etc.. It is an effective alternative to numerical technology for specific EMC problems. The analytical technology may not give accurate simulation but it is much faster to give a rough but effective prediction of EM behavior for designer. The Computational EM techniques based hybrid methodology, which integrates the analytical technology and numerical methods, will be developed in the system to solve real life EMC problems and provide the inspection and prediction of results, such as conducted/radiated emission, conducted/radiated immunity, from the interim and final design. The system structure is thus developed and depicted in Fig. 2.

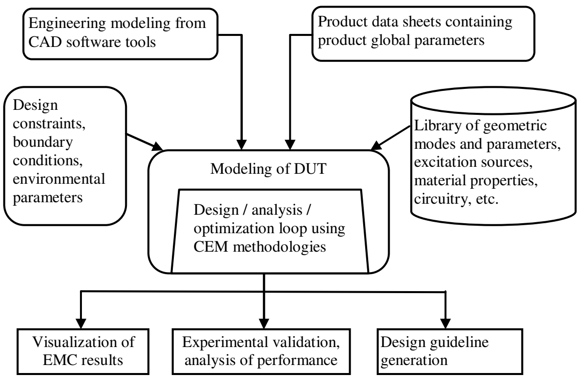

Fig. 2 System structure of integrated EM immunity design

The main functions developed in the system include: a) analysis of electric field based on analytical/numerical methods, which includes far-field and near-field profiles, planar regional distribution, and 3D radiation pattern; b) analysis of magnetic field (far-field and near-field) and its distribution; c) S-parameters and characteristic impedance calculation; d) analysis of E/H field coupling; e) Prediction of signal deterioration; f) assessment of immunity level at component level, board level, and system level.

III. GEOMETRY MODELING AND SOLUTION METHODOLOGY

The past geometric modelers have almost always been designed as general purpose tools with no specific application in mind. This system modeler is thus rather different in that it is mainly targeted for use in supporting electromagnetic analysis applications with requirements to model both object and free-space. This means that more emphasis must be on the ability of geometric functions in the modeler to deal robustly with ‘pathological cases’ of touching curves and surfaces and so forth. Furthermore, the type of shapes often involved in EMC analysis dictates accuracy requirements which are unusually stringent. Such shapes are characterized by features with a wide range of dimensions, typically a small slot/holes in an ‘ordinary sized’ artifact. Thus the actual requirement is for a geometric modeler with a large ‘dynamic range’ rather the ability to represent small dimensions.

Based above consideration, the geometric modeler is satisfied with the following constraints:

1) The basic data element is block, which is consisted of vertices, edges and faces.
2) Each of the edges is shared by exactly two faces (regions).
3) Each of vertices is shared by exactly three edges.
4) No independent vertex, edge or face.

The logical structure of the geometric modeler is shown in Fig. 3. The topological information describes the adjacency relationships between topological elements (such as vertices, edges, faces, blocks), i.e., how these elements are connected, for example, the ordered list of faces that generate a block, or the ordered list of edges that generate a face, or the group of edges to which a vertex belongs, or the vertices of an edge, etc.

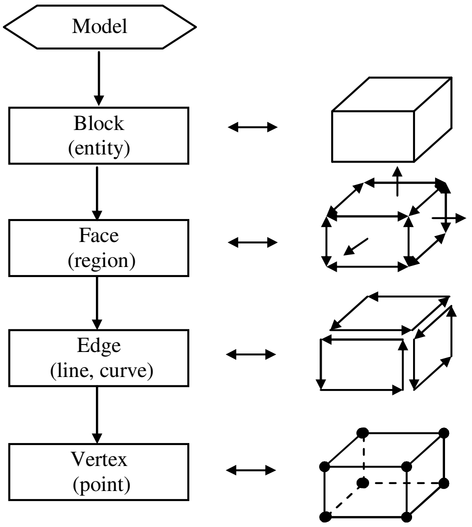

Fig. 3 Topological structure of the geometric data

The geometric data classes are generally defined as:

```
CBlock : public CObject
{
    Constructor & destructor;
    Block no.;
    Faces on this block;
    Material property;
    Excitation source;
    Boundary condition;
    etc.;
}

CFace : public CObject
{
    Constructor & destructor;
    Face no. ;
    Block no. to which the face belongs;
    etc.;
}

CEdge : public CObject
{
    Constructor & destructor;
    Edge no. ;
    Face no. to which the edge belongs;
    If the edge is arc:
        Radius, centre pint, angle, concave or convex;
    etc.;
}

CVertex : public CObject
{
    Constructor & destructor;
    Vertex no. ;
    Edge no. to which the vertex belongs;
}
```

Dynamic linked 'list' method [3] is introduced in the system for creating, modifying, and accessing the data, which is shown in Fig. 4.

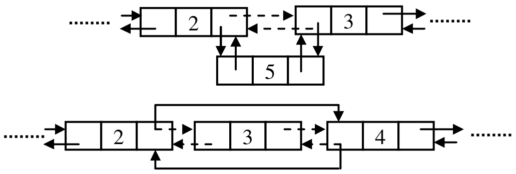

Fig. 4 Inserting and removing one data in linked list

The parametric design in which the geometry of a design is being stored with variable coordinates and dimension parameters, and the corresponding instance of the design is evaluated after the assignment of concrete dimension values, will be employed in the system. Much tedious work can be reduced and the effect of key parameters on the EMC performance can also be evaluated conveniently and efficiently.

With the complexity increasing of advanced electronic systems, it becomes much challenging to model and analyze EMI/EMC problems for a whole system without any characterization and pre-evaluation. One effective approach is to breakdown the system structure into smaller and simpler parts, so that a more tractable and efficient EMC modeling and analysis can be realized.

Most electronic systems can be diversified to intra-system type and inter-system type due to the sources, coupling paths and victims. They will typically be breakdown to components, cables, printed circuit boards (PCB), and cavity/box in this immunity analysis system. Closed form solutions based on cavity Green's functions and equivalence principle are efficient techniques for canonical cavity structures with apertures [4]. Transmission line models (TLM) will be employed to estimate the EM coupling on cables [5]. The EMI problems of PCB interconnects will be modeled and analyzed by using partial element equivalent circuits (PEEC) [6]. Different to other software toolkits, the experimental validation will also be introduced in the immunity analysis system development. The physical measurements' data will be imported and analyzed in the system. The analytical and numerical simulation functions are thus enhanced and optimized through the experimental data integration and validation.

IV. SIMULATION AND ANALYSIS

To facilitate understanding the system objectives and functions, a simple model of two parallel cables is employed as an example and the distributed circuit model is illustrated in Fig. 5. The behavior of the transient voltage *v(x, t)* and current *i(x, t)* on these two cables excited by a lumped excitation source can be described as

$$\left.\begin{aligned}\frac{\partial v(x,t)}{\partial x}+Ri(x,t)+L\frac{\partial i(x,t)}{\partial t}=0\\ \frac{\partial i(x,t)}{\partial x}+Gv(x,t)+C\frac{\partial (x,t)}{\partial t}=0\end{aligned}\right\} \qquad (1)$$

Where x denotes the longitudinal direction of the cables and R, L, G, and C are the constant per unit length resistance, inductance, conductance, and capacitance, respectively, of the two cables. For most insulated transmission lines, the distributed conductance term $G \approx 0$.

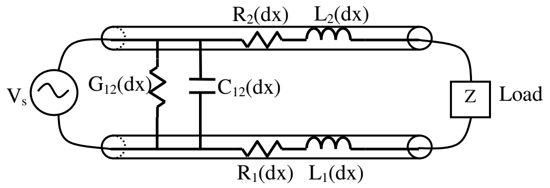

Fig. 5 Distributed model of parallel cables.

With the exciting source of 1V and matched load impedance, EM characteristics of the parallel cables are predicted by using the immunity diagnosis system. The S-parameters are calculated and illustrated in Fig. 6. The dotted and solid lines represent S11 and S21, respectively. Fig. 7 depicts the E-field performance for the parallel cables model.

Furthermore, interconnects on two PCB boards which are connected through two cables are modeled and is shown in Fig. 8. S-parameter and E-field performances are simulated and illustrated in Fig. 9 and Fig. 10, respectively, by using the immunity simulation system.

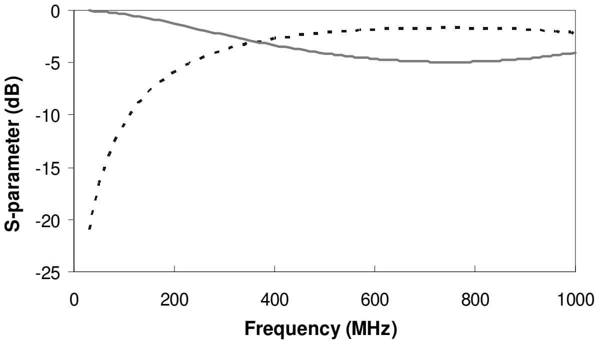

Fig. 6 S-parameters of parallel cables.

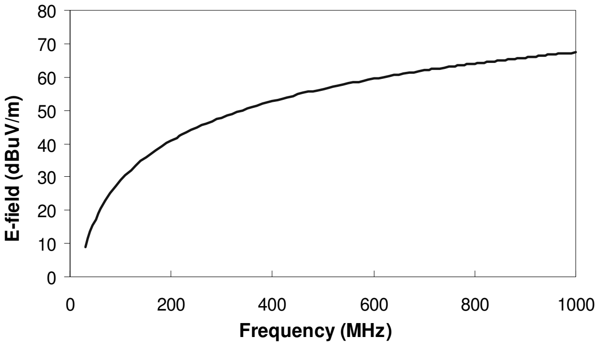

Fig. 7 E-field profile of parallel cables.

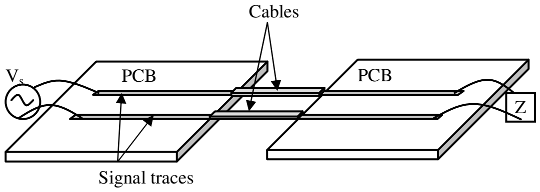

Fig. 8 Model of PCBs with interconnects and cables.

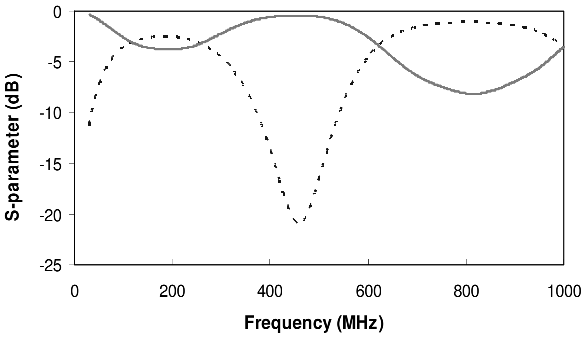

Fig. 9 S-parameters of PCB assembly model.

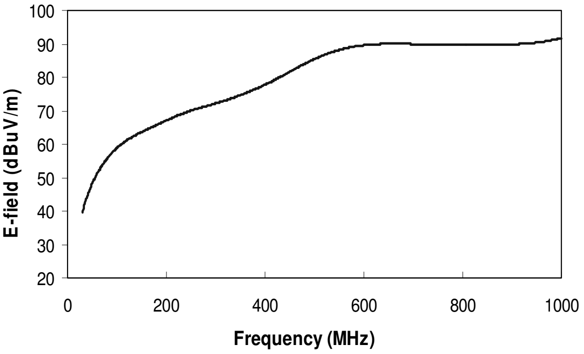

Fig. 10 E-field profile of PCB assembly model.

V. CONCLUSION

The simulation system of EM immunity is potentially much faster and cheaper than taking a prototype or existing piece of equipment to a test lab. Most importantly, it allows the engineer to "look into" the equipment and predict how the circuits react when a fast transient burst is injected into the equipment which is impossible with actual physical testing. EMC computer modeling comes to the rescue as a very useful aid as it will allow us to simulate and solve the real life EMC problems during the design stage before prototyping is done. This immunity simulation system will hence to effectively solve EMC problems and meet the industry requirement and EMC standards, especially tackle the immunity problems. With this tool, the tedious developmental cycle in the design stage is shortened through computational modeling and simulation, translating into time and cost savings for the industry.

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