Predictive Engineering for EMC Applications

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PREDICTIVE EMC ENGINEERING DEFINED

Recent advances in software have alleviated many of the difficulties associated with traditional compatibility design methods, and have created a much more effective approach to EMC design called predictive EMC engineering. This new approach replaces and improves upon currently employed design practices and results in better products at reduced costs. In many cases, the traditional black magic, hand waving, rule-of-thumb design approximations, and expensive, difficult-to-repeat hardware fabrication and test methods become obsolete because predictive tools enable design engineers to easily create, modify, and optimize designs on a computer *while accounting for electromagnetic effects within the design.*

For most designs, the objective is to transform an idea to an optimized design in the shortest time at the lowest cost while

Designs can be computer-created and optimized while accounting for EM effects.

ensuring electromagnetic compatibility. Many times, however, engineers overlook compatibility in their designs, necessitating significant re-design cost and time. The oversights often stem from the fact that electromagnetic field phenomena are relatively difficult to represent and understand, especially for the non-electromagnetic specialists. Predictive engineering removes these barriers for the design engineers via easy-to-use solid modeling design tools which interface with rigorous field solvers, enabling engineers to design for compatibility from the outset.

The ability to account for the effects of electromagnetic fields at the design level impacts the typical design cycle (Figure 1). With the traditional design method, an optimized design is produced only after a time-consuming and costly series of design iterations involving the participation of many specialized groups and testing facilities. With predictive engineering, designers produce an optimized and compatible design by conceptualizing, evaluating, and iterating designs on the computer. Key steps in this process are highlighted below.

The first step in the predictive engineering process is to translate a design concept to a three-dimensional solid geometric representation of the device to be simulated. Two basic methods, or a combination thereof, may be used to create solid models like those shown in Figure 2.

First, a solid representation can be built starting from simple wire frame geometries. The wire frames themselves can be created using a variety of techniques. For example, sketchers, in conjunc-

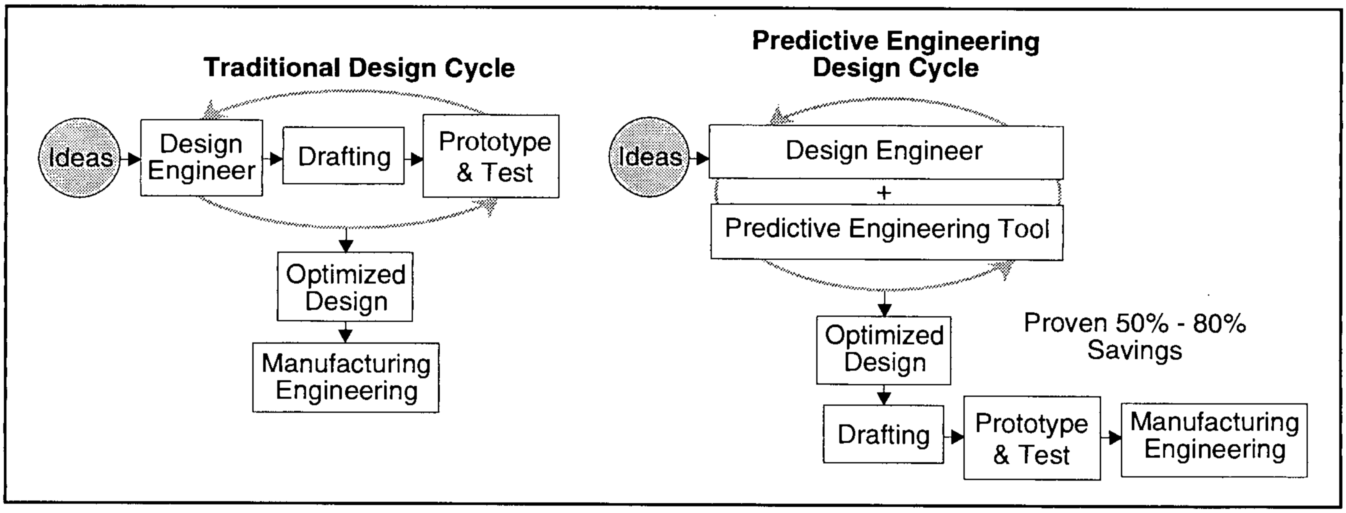

Figure 1. A Comparison of Traditional and Predictive Engineering Design Cycles.

tion with geometrical constraints, easily transform rough hand drawings into wire frame entities. Translators, which import existing geometries from third-party computer-aided design (CAD) databases, can also be used to create wire frame geometries from pre-existing designs. Finally, wire frame geometry can also be input by hand in a manner similar to basic drafting. Extrusion, rotation, and translation operations ultimately transform the wire frame geometries to three-dimensional solids.

In the second technique, solid models are created from solid primitives in the shapes of cones, spheres, boxes and cylinders. Arbitrarily shaped three-dimensional solids are created from the solid primitives via Boolean union, subtract, and intersect operations.

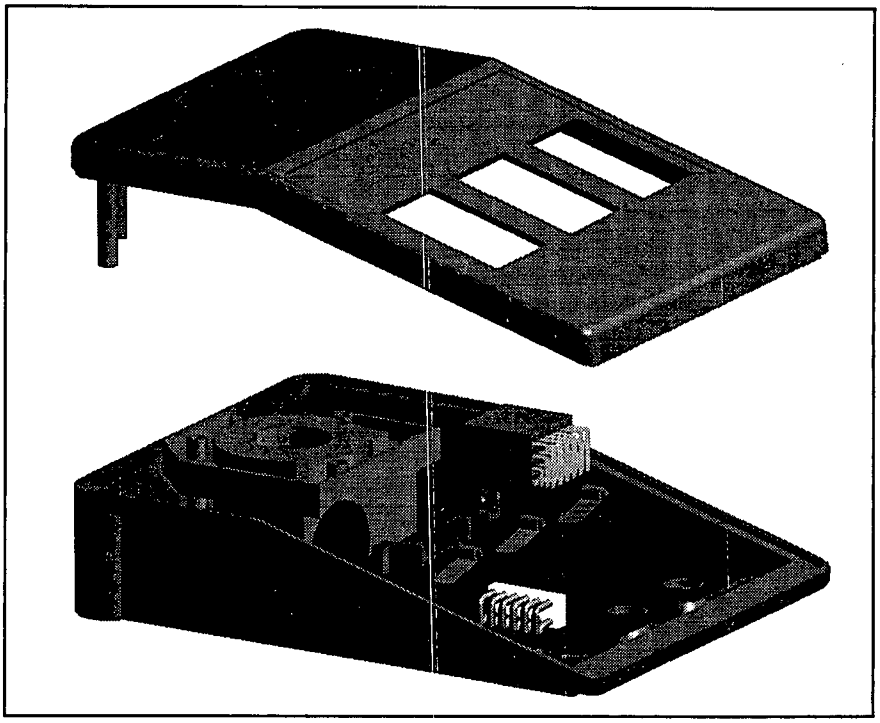

Figure 2. *A Semi-exploded Solids Model of a Computer Mouse Assembly.*

A key feature in optimizing a design is the ability to easily alter design parameters, such as material and dimension, of an already existing design without having to entirely rebuild the model. Parametric features facilitate this reconstruction of existing designs through a respecification of only the design parameter which requires modification.

For EMC simulation, the solids modeler must also create representations of certain electromagnetic features of the device including material composition and boundary conditions. The application of sources and excitations, simulation frequencies, and input signal waveforms are integral to the solid modeling process.

In the predictive engineering design cycle, the engineer only needs to interface with the solids modeler, because the field solver automatically solves for the electromagnetic fields in the background for the device under consideration. While the design engineer does not need to know the details of the field solver, the field solver must possess many key features which are critical to the success of the predictive EMC engineering process. First, the solver must be able to account for all electromagnetic fields within either bounded or unbounded mediums because devices and components must remain compatible regardless of whether they are contained in shielded enclosures. Secondly, the field solver should be able to simulate the impact of various material properties on electromagnetic performance within the device. The ability to simulate finite conductivity, lossy dielectrics and magnetic materials is mandatory for predicting the performance of real-life designs. Since lumped circuit elements are often used to control device performance, the field solver must also be able to account for the effects that resistors, inductors, and capacitors have on the electromagnetic behavior in a design.

After the field solver calculates the electromagnetic fields, various results need to be extracted depending upon the type of simulation performed. Typical results include inductance and capacitance matrices, induced currents, and radiated electric and magnetic fields.

The results from the predictive engineering cycle are often fed back into other CAD tools. For example, inductance and capacitance matrices calculated within the predictive engineering tool are often written out in the form of a SPICE netlist and read into a SPICE type program. In addition, the geometry from optimized trace routings or seam gasket configurations are often fed into routing or machining databases for prototype fabrication.

WHY PREDICTIVE EMC ENGINEERING?

There are numerous benefits to the predictive engineering approach to EMC design. Some of the advantages are discussed below.

Like traditional design and test methods, predictive EMC engineering enables engineers to obtain performance data. However, the predictive method provides an improved means to *help understand why* devices perform as they do because electromagnetic field distributions can be visualized within the device under test.

The predictive method also enables designers to test different scenarios on the computer. For example, the shielding performance of seam gaskets with various material compositions can easily be quantified even if the material is not currently available. And since devices are simulated on the computer, there is no need to wait for the arrival of parts to perform the testing. This ability results in the *reduction of cost and time* in the product design cycle.

Since the predictive method is significantly more streamlined than traditional design techniques, optimized designs are created in less time enabling design engineers to evaluate more design alternatives or perform other work.

Cycling through the design on the computer enables the predictive engineering process to be closely coupled to existing computer-aided engineering (CAE) tools. Links to existing CAE tools further streamline the design process by facilitating the import of existing designs and the export of optimized designs between third-party databases and the predictive engineering tool.

Significant obstacles to obtaining valid EMC tests may include ensuring that all test equipment is properly set up and calibrated, and that all tests are performed under controlled environments including quiet test facilities. Repeatable and controlled tests are ensured using predictive engineering tools because the simulation environment is explicitly defined by the user under conditions inherently free of external noise. In addition, the *simulation computer costs are significantly lower than the cost of test hardware.*

The advantages described above explain how the predictive engineering approach improves product profitability by:

- reducing product development costs and time to market, and
- increasing projected income by bringing compliant products to the market sooner.

PREDICTIVE EMC ENGINEERING ILLUSTRATED

The following three discussions illustrate common problems in which predictive EMC engineering tools can be employed. The problems described depict only a portion of the spectrum of potential applications. All simulations were performed using an EMC predictive engineering tool.

PREDICTING SHIELDING EFFECTIVENESS OF A SEAM GASKET

The metallic enclosure simulated here consists of a box with a removable lid as shown in Figure 3. A ferrite gasket rests in the seam of the enclosure between the box and lid. Major components of the model include the metallic enclosure base, the seam gasket, the metallic enclosure lid, a loop excitation placed in the center of the enclosure, and the surrounding air. The objective of this simulation is to calculate the electromagnetic leakage through the seam over a 1 - 10 MHz frequency range with different gasket material compositions to determine the best gasket materials for the application.

Significant components in this simulation are the material constants used to simulate the seam gasket. Three different gasket material constants, summarized in Table 1, are used in the simulation to evaluate electromagnetic leakage.

Figure 4a illustrates the sensitivity of electric field strength vs. frequency in the surrounding air. The three traces correspond to seam gaskets with the material constants shown in Table 1. The results shown on the graphs demonstrate that the "electrically lossless" gasket 1 produces the greatest electric field leakage while the other two "electrically lossy" gaskets produce less electric field leakage. Since the imaginary part of ε_r (ε_r'') is equal to σ/ω, the effective ε_r'' for gasket 3 is roughly six orders of magnitude greater than ε_r'' for gasket 2 at 1 MHz, making gasket 3 highly lossy. This fact is illustrated in Figure 3 by the large amount of electric field attenuation.

Figure 4b illustrates the magnetic field intensity vs. frequency for the same three seam gaskets. Because gaskets 1 and 2 have the same conductivity and permeability, one can expect their magnetic field losses to be roughly the same. Since gasket 3 has the same permeability as gaskets 1 and 2 plus additional conductivity, the magnetic field losses are expected to increase. Figure 4 does indeed depict this phenomenon. An electric field contour plot for the gasket #1 analysis at 1 MHz is shown in Figure 5. The contour plots for the other frequencies and gasket cases are similar to the plot shown in Figure 5.

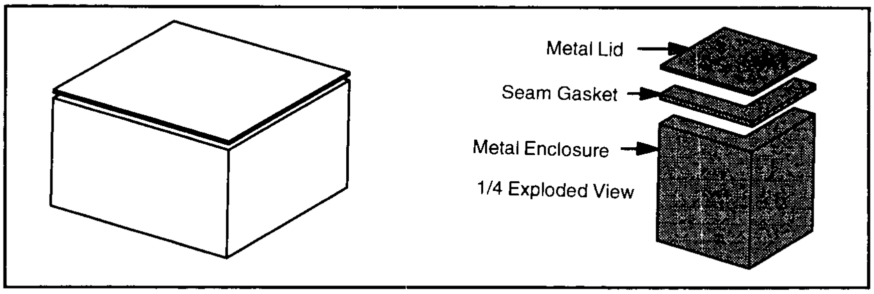

Figure 3. *Three-dimensional Metallic Enclosure.*

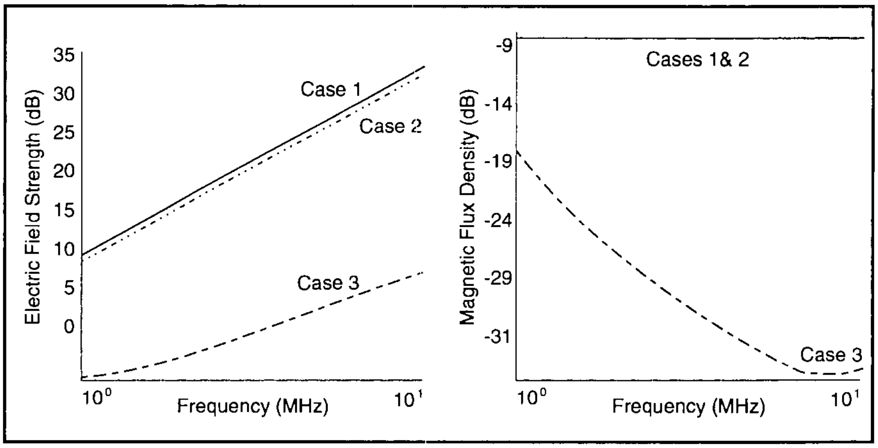

Figure 4a. *Electric Field Shielding vs. Frequency.*

Figure 4b. *Magnetic Field Shielding vs. Frequency.*

GASKET	μ_r	σ	ε_r
1	100 - j100	0.0	10 - j0.0
2	100 - j100	0.0	100 - j100
3	100 - j100	1000	10 - j0.0

Table 1. *Material Constants.*

PREDICTING CGLR MATRICES OF A CONNECTOR ASSEMBLY

An important area of concern for manufacturers of electronic packaging, circuit boards, or other devices with multiple conductors, is the generation of unwanted voltages and currents through electromagnetic coupling between conductors. A method of predicting these voltages and currents involves calculating the capacitance (C), conductance (G), inductance (L), and resistance (R) matrices of the device.

A 24-pin connector (Figure 2) model is used to calculate the circuit matrices. This simulation quantifies the self-capacitance, inductance, and resistance of a specified pin of the connector and compares the predicted results to experimental values (Table 2).

The resulting circuit matrices are typically output to a SPICE type circuit simulator via a SPICE netlist. The circuit simulator is then used to quantify ground bounce, signal distortion, or induced signals on quiet lines.

PREDICTING THE IMPACT OF GEOMETRIC DISCONTINUITIES ON SIGNAL INTEGRITY THROUGH A VIA HOLE

Figure 6 illustrates a view of a

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typical trace/via configuration in a multi-layer circuit board. The analysis performed here simulates the propagation of a gaussian pulse as it enters the circuit board on the top layer, and follows the pulse as it traverses down the via and out the bottom layer of the circuit board. The simulation is performed in the xz plane through the center of the trace/via to obtain the approximate behavior of the propagating pulse.

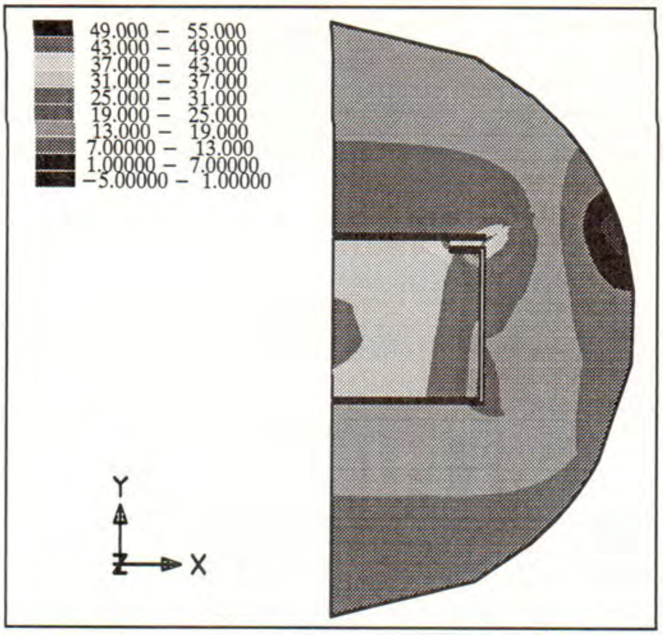

Figure 5. *Electric Field Contours Through a 2-Dimensional Cut Surface Illustrating the Spatial Variation of the Electric Field.*

	SIMULATED	EXPERIMENTAL	% DIFFERENCE
Capacitance	2.58 pF	2.62 pF	1.53%
Inductance	11.44 nH	10.6 nH	7.93%
Resistance	29.3 mW	N/A	

Table 2. *Simulation vs. Experimental Value of Key Parameters.*

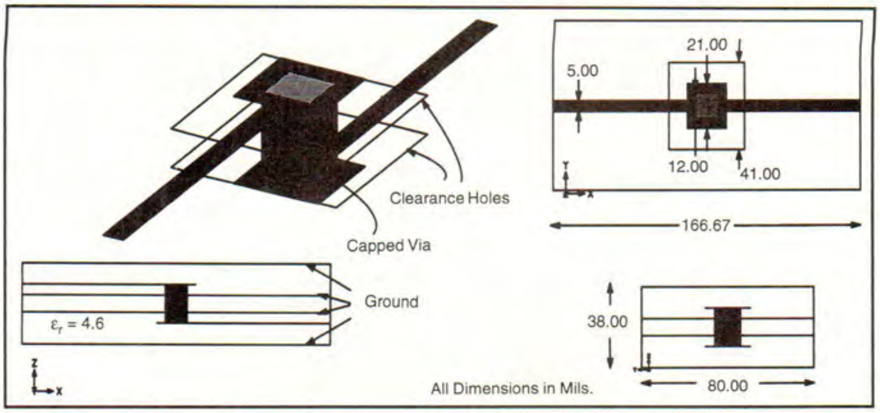

Figure 6. *The Trace Configuration Through the Three-layer Board.*

The electric field of the incident pulse is z polarized and conforms to the following function.

$$\vec{E}_Z = \mathrm{EXP}\left\{\left[\frac{(t-2T_0)}{T_0}\right]^2\right\} \quad (1)$$

where

$T_0 = 40\Delta t$

$\Delta t = 0.037$ ps

Results of the simulation are best viewed as an animation of the electric field versus time. Figure 7 illustrates the electric field intensity at four key instances in time. The first snapshot in this figure illustrates clean propagation of the pulse as it begins propagating down the trace.

As shown in the second snapshot, the characteristic impedance of the guiding structure changes near the clearance holes, creating a source of reflection. The reflected energy here propagates back towards the source between the upper trace and the upper clearance hole layer. The transmitted energy tends to split between going down the via and continuing on between the via cap and the upper model boundary. The high frequency components of the pulse are assumed to continue on between the via cap and the model boundary while the low frequency pulse components are assumed to continue down the via.

The third snapshot shows the pulse jumping from the end of the via cap down to the first ground plane layer containing a clearance hole. It also indicates a second source of reflection at the end of the via cap. The reflected energy from this discontinuity propagates back to the source between the upper trace layer and the upper model boundary. The fourth snapshot simply illustrates the pulse continuing to propagate towards the right hand model boundary.

SUMMARY

Predictive engineering software for the EMC industry is currently in its infancy. Until now, there was little need for simulation software. In addition, the available software tools could not meet most industry requirements. Today, there is a strong need to build compatibility into designs. Advancements in software technology now make the predictive engineering approach preferable to conventional hardware fabrication and test methods because predictive engineering enables better products to be produced at lower cost.

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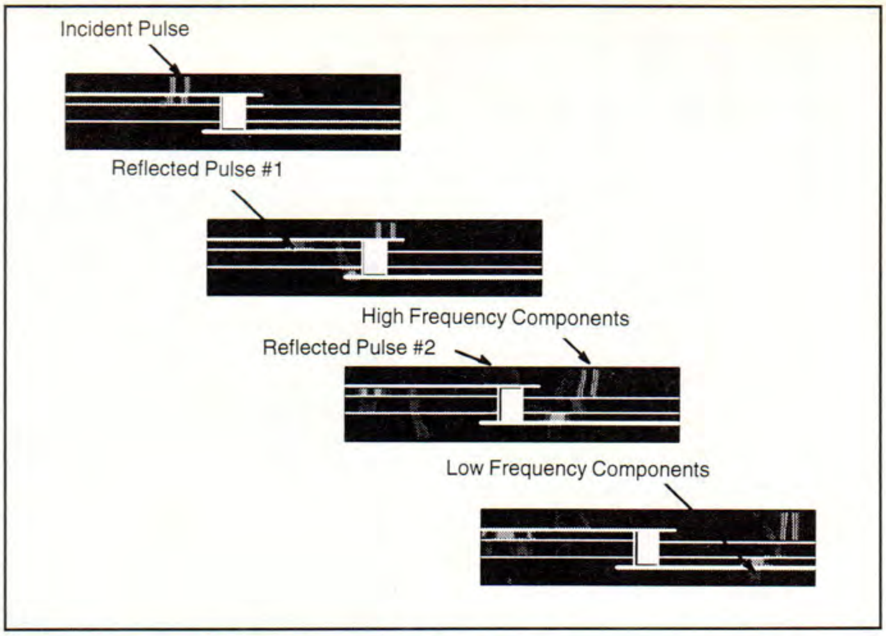

***Figure 7**. Timed Snapshots of the Pulse as it Traverses Through the Multilayer Circuit Board.*