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ABSTRACT

Time–Domain Electromagnetic(EM) codes are increasingly being applied to coupling problems in order to supplement and complement the experimental efforts in this area. Both Finite–Difference Time–Domain (FDTD) and Finite–Element Time–Domain (FETD) techniques are employed to calculate the fields and currents inside of a shielding body. The size of the relevant detail in realistic systems, however, currently limits the usefullnes of these codes. This detail problem is investigated, and a number of proposed solutions to it are evaluated. Finally, some example problems, representative of current modelling capabilities, are presented.

INTRODUCTION

Numerical modelling is increasingly being used to complement linear–coupling experiments. There are a number of reasons for this. As interest moves from simple "generic" objects to realistic military systems, analytic solutions become intractable. Codes also have the distinct advantages over experiment that arbitrary incident fields may be applied and field quantities may be sampled at any point or volume. Once the model has been validated with experiment, changes and parameter studies are usually easier with software than with experiment. These facts combine to make simulation codes a powerful tool for understanding the physics involved in coupling to a particular geometry.

Despite these pluses, codes also have many limitations. As applied to realistic coupling problems, these can be summed into a single word: DETAIL. The size of most systems of interest in comparison to their smallest relevant features can be many orders of magnitude. Coupling problems are particularly difficult, since the two main features of interest are entrance slots and seams of millimeter dimensions and internal cavities of up to meter dimensions. **This is the single biggest problem in coupling modelling and is pushing the state–of–the–art.** The following sections discuss the various problems this introduces. Following this is a discussion of current research directions.

It should be noted that this discussion is equally true for both finite–difference and finite–element codes. In both cases, we are assuming time–domain modelling, since EMP–type applications require results for a broad frequency range. A frequency–domain approach requires a different code run for each data–point and becomes much too slow for broad–band investigations of complex objects.

THE PROBLEM OF DETAIL

As a typical problem for the following discussions, consider a missile in which the electronics area is to be modeled. The whole area is 30 by 30 by 60 cm. The major coupling path is a circumferential slot that is about 1 mm high. Interior bulkheads also have slots of this dimension.

The first obvious problem is one of computer memory. For a finite–difference code with uniform gridding (ref. 1), the cells must be a maximum of 1 mm. This yields a minimum of 54 million cells. Add in some boundary cells for a radiation condition and the number approaches 60 million cells. This is a big problem. Bigger than virtually any machine can now solve.

The size of details is not the only constraint on cell size. Sampling criterion demand that the cell size be less than the smallest wavelength of interest; a current rule of thumb is 10 cells per wavelength. So, for the problem above, if the simulation is to run to 18 Ghz, there is a minimum cell size of 1.7 mm. This requires 12 million cells *independent of the smallest detail in the problem.*

An obvious solution to the detail problem is to use finite–element and its variable grid–size capability. This does not really solve the problem. To avoid reflections, the grid size can not change too quickly and there are limits to how small a cell can be made. Also, the high amount of overhead memory required for finite–element works against you. Thirdly, the limit on cells size due to wavelength still remains. And lastly, finite–element is actually worse for the next major problem: Time.

The Courant stability condition requires that no field be able to propagate further than one cell in a single time step. Thus the upper limit on the time step is determined by the smallest cell in the entire problem. Therefor, as the size of the interesting detail decreases, the time step also decreases, and longer and longer runs are needed to get the same frequency content. Finite–element solvers must also obey this limit and have the added drawback of being less efficient than finite–difference routines. Finite–element also suffers more heavily in the third problem of detail: mesh generation.

For large, detailed systems, some sort of computer assisted model generation is a must (ref. 2). One of the most promising of these is "solids modelling" which is used extensively by the mechanical–engineering community. In this method, the user combines canonical shapes in an abstract space to build the desired complex shape. High quality graphics present the abstract "solid model" for review. This model is then "meshed": the actual FD or FE grid is generated from the solid model. This final step is actually quite difficult, even for the simple rectangular grid of finite–difference, and is an area of continuing research.

Once models are generated, some sort of computer assisted verification and analysis is also very important. With large models, it is very difficult to know if you have a correct representation of reality, but the simulation code can easily produce answers that *look* reasonable. High quality graphics tools can present the finite difference model and display problems. Automatic analysis is a fairly new field in which the computer itself attempts to find mistakes in the mesh. As more complex objects are modeled and mesh sizes increase, this tool will become increasingly necessary.

In summary, highly complex coupling problems introduce three difficulties. First, small aperture dimensions require small cell sizes and large amounts of memory. Second, these small cell sizes create small time steps and cause long computer runs. Third, complex geometries have gone beyond the ability of humans to mesh "by hand" and demand computer assistance. Mesh generation is an active research topic at LLNL and elsewhere and looks to be soluble. Any effort to do serious coupling modelling, however, must solve the first two problems as well. The next section is a brief overview of several proposed solutions.

METHODS OF SOLUTION?

One of the most appealing methods of solution is that of "sub–gridding". In this procedure, the area containing the offending detail is worked almost as a separate finite–difference problem, with its own resolution and time step. To interface with the larger problem, the grid size and time step must be integer fractions of the larger problem. To avoid large numerical reflections at the interface, the grid size must not change too drastically. Yee and Kasher have demonstrated a 2 to 1 sub–grid for finite–difference that works fairly well for a single propagation direction (ref. 3).

In applying sub–gridding to EM coupling problems, however, one must remember the very small size of important details in real systems. In our example problem, if you set the cell size at 1 cm for a reasonable 54 thousand cells, 4 levels of sub–griding are necessary to represent the slot. Besides the extreme difficulty in writing a general code to keep track of all these separate grids, it is likely that spurious reflections would dominate the solution.

Another method of solution is to coarsely mesh the entire problem, at 1 centimeter say, so that the slot area is entirely contained in a single cell. A special algorithm may then be created that describes the physics of the slot in that cell. This algorithm is then applied instead of the regular finite–difference routine. Yee, Pennock, and Kasher (ref. 4) have demonstrated this technique for a 30 x 30 x 100 cm square box for slot dimensions down to .38 mm. The results are quite promising.

The disadvantage with the "thin-slot algorithm" approach is that a different algorithm is necessary for each new slot geometry encountered. Lapped joints, screw lids, or slots that twist in three dimensions seem to occur in different combinations in every problem and each requires a new algorithm. While this is not an insurmountable difficulty, it means that each new project must include development and verification time for the new algorithm.

An entirely different approach is that of applying integral equation methods to the coupling problem. Integral equations have shown great success in solving slot in screen problems. The idea, then, is to represent an incoming wave on a "simple" conducting body containing a slot using time–domain integral equations. The internal cavities are then solved by finite–difference time–domain methods, driven by the slot.

This method would have several advantages. It is no longer necessary to grid the exterior of the object or to compute radiation boundary conditions. This frees up a significant amount of memory and computation time. Also, integral equations methods have been demonstrated to give very good solutions to the slot problem.

On the other hand, there are several problems. Integral equation methods require a Green's function for the space they operate in. Deriving the Green's function for a missile with several coupling paths is not impossible, but may prove difficult – and it must be done for each new problem.. Deriving the Green's function for the interior of a body is intractable and thus, internal slots (inter–cavity) must be modeled with some other method. Finally, the effort to integrate these two methods is probably not trivial.

CURRENT APPLICATIONS TO COUPLING

Work is progressing at Livermore and elsewhere to apply current modelling capabilities to coupling problems as well as to extend these capabilities using the methods described above. Following are descriptions of three "sample problems" that are exemplary of current work in the Livermore coupling modelling effort. These are not state-of-the-art problems, rather they are the type of problem that is far enough behind state-of-the-art that one can have good confidence in the results.

A current project at Livermore is modelling coupling into a land-mine. As a first step, we meshed and experimentally measured the mine-case with a simplified lid. The grid and results are shown in figure 1. This is a very coarse mesh, being only 22 x 22 x 10 cells of dimension .575 cm. Agreement is very good for such a "quickie" test.

The second sample experiment is a simple rectangular box with a circumferential seam. This is an idealized object for studying similar seams in missiles and RVs. The box is 10 x 10 x 33 cells, each 3.048 cm on a side. The gap is the minimum size allowable without special algorithms, 1 cell. The mesh and results are shown in figure 2. Note the very good agreement in both location and Q factors of the resonances.

Finally, the same box was modeled using the thin-slot algorithm of Yee and Kasher (refs. 3,4). In this case, the slot is .78 mm high in a 1.54 mm thick wall. The results are quite good (figure 3), still predicting resonances and Q's very well. Note that the ratio of cavity height to gap width is 1300, a significant difference.

SUMMARY

In applying numerical modelling techniques to EM coupling experiments, the complexity and detail of the objects cause many difficulties. In particular, the size of important coupling paths such as slots and seams can be many orders of magnitude smaller than important volumes such as internal cavities. These features require large amounts of computer memory, cause small time steps and long computer runs, and demand specialized software to assist in model creation. Solid modelling techniques look promising to solve the latter difficulty, but no general method is yet available to solve the thin slot problem. Several methods, including sub-gridding, thin-slot algorithms, and integral equation techniques, look promising, but each needs work to be a general solution to the problem.

Current workers in coupling modelling routinely model "generic" objects such as cylindrical cans or square boxes. These are used to understand the basic physics, mode structures, and coupling paths in their more complex analogs. At present, this is the strength of EM modelling in coupling physics. The modelling of complex real systems must wait for the future.

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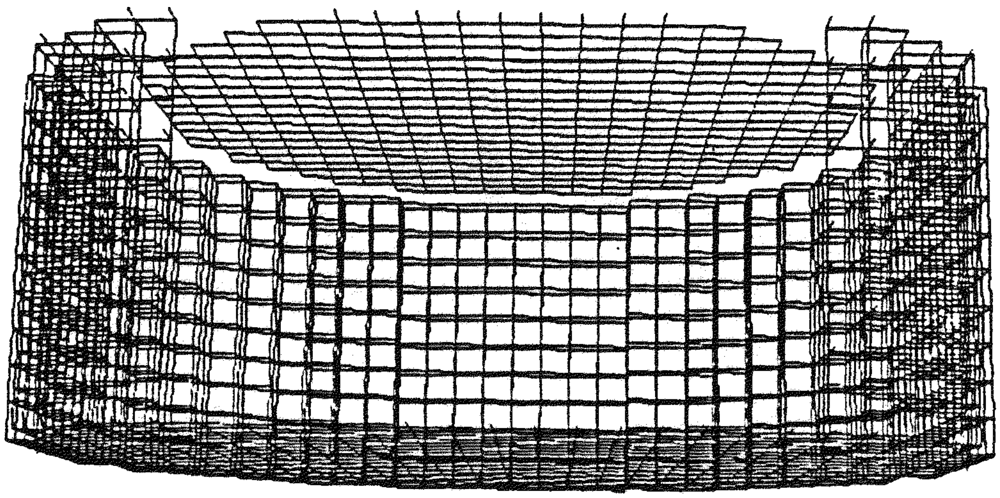

Figure 1a: Mine Mesh

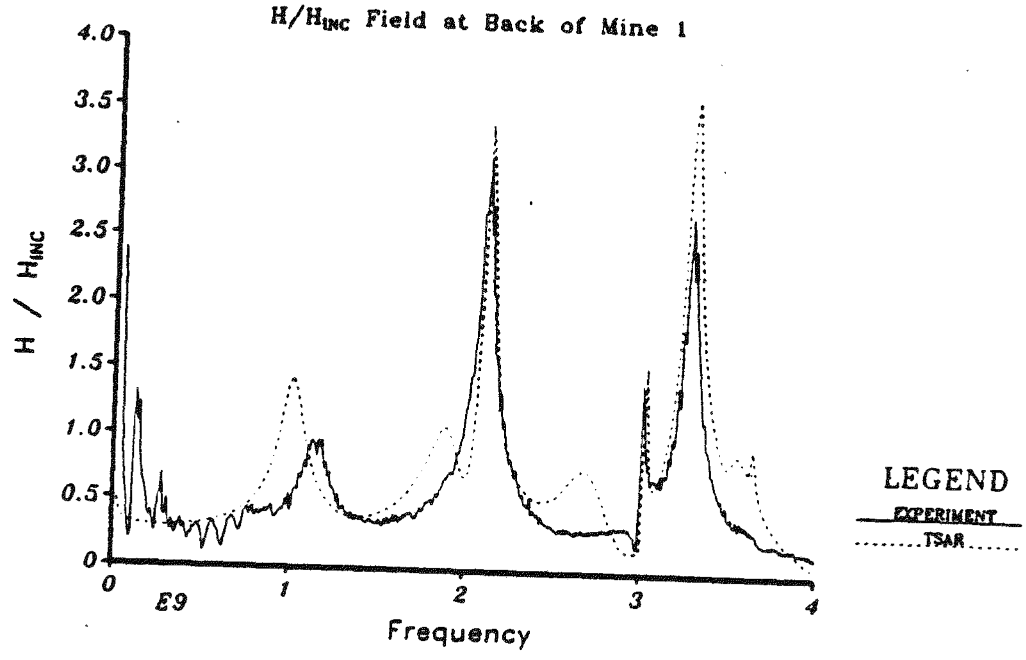

Figure 1b: Mine Data

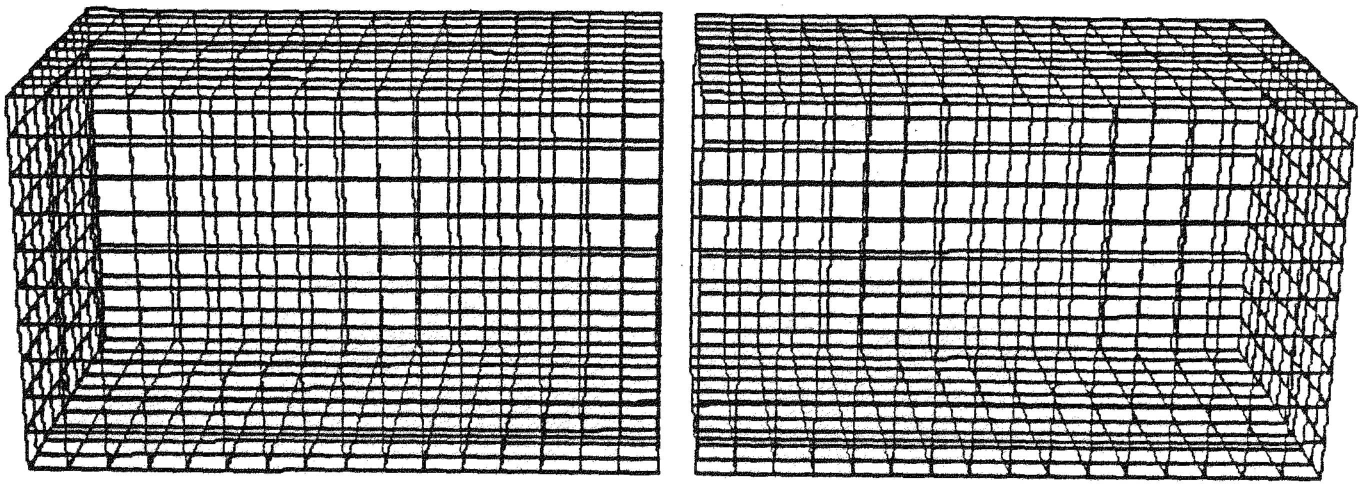

Figure 2a: Box Mesh

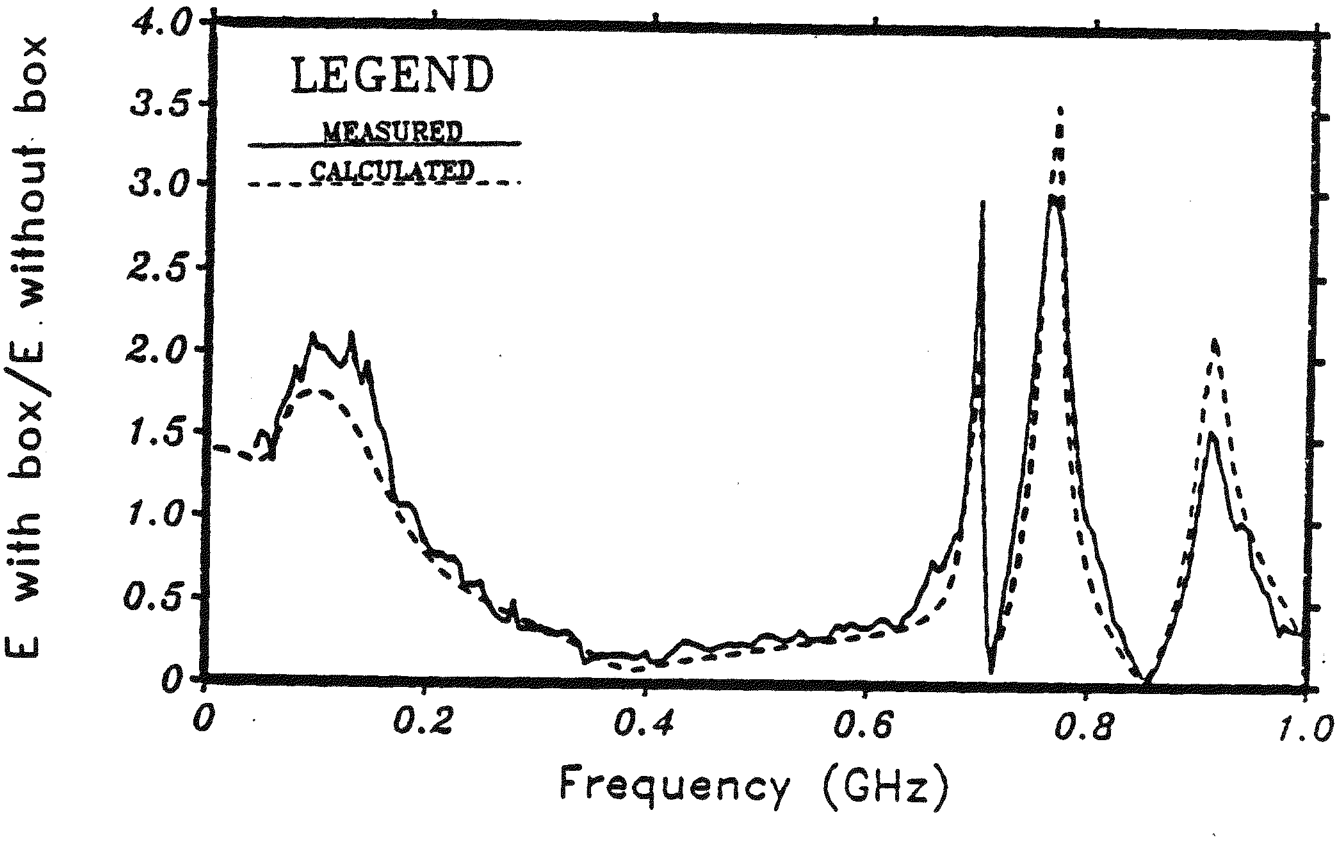

Figure 2b: Box Data

Figure 3: Box Data with Thin Slot