—Viewpoints—

Some Comments on Electromagnetic Dimensionality

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The dimensionality of electromagnetic analyses are usually described as being 2-D, 2.5-D, or 3-D. Unfortunately, it seems there are different ideas of what each dimensionality means. This open letter to the microwave community is to express my personal opinion as to their meaning and to invite the presentation of alternative meanings and justifications. Perhaps, in a few years, we can all, with a little give-and-take, agree.

Many of the differences in meanings are caused by the different way in which microwave engineers and electromagnetic researchers look at problems. I have spent nearly a decade in each of these fields and have seen several interesting situations arise because of these differences. Here, the important difference is that a microwave engineer looks at the current while an electromagnetics researcher often looks at the fields.

For example, take an analysis of planar 2-D circuits, the problem on which I did my dissertation. At that time, I found that microwave engineers would immediately describe it as a 2-D analysis because it includes only two dimensions of current. If you say 2-D to an electromagnetics researcher, he immediately thinks of things like infinite lengths of coax and waveguide. Given the same problem, the electromagnetics researcher sees 3-D fields and describes the analysis as 3D. This was the situation during my dissertation. Since I respect the opinions of both groups and since I had just been introduced to chaos theory, I decided a compromise was in order and I took the average: 2.5-D. This was in 1985, and, as far as I know, *it was the first time that fractional dimensionality* was used to describe an electromagnetic analysis.

Now take as an example an analysis of 3-D planar circuits in layered dielectric. Current flowing in the third dimension can be used to represent, for example, vias. This happens to be the problem we solved in 1989. However, because the term 2.5-D has become popular and because the analysis allows only layered dielectric, it is now sometimes described as 2.5-D. While initially quite satisfying (the layered dielectric requirement makes it, somehow, less than an analysis of 3-D arbitrary circuits, and 2.5 is less than 3), such a change in definition creates several problems. For example, if we now choose to describe a 3-D planar circuit embedded in layered dielectric as 2.5-D, what do we call problems involving a 2-D circuit embedded in layered dielectric? Another problem is the numerous scattering and antenna analysis codes which allow arbitrary 3-D structures in, sometimes, only one (layer of) dielectric, i.e., free space? The authors of these codes will be vigorous in the defense of the 3-D description of their codes. The free space problem is a special case of the (unshielded) layered dielectric problem. We cannot justify calling layered dielectric 2.5-D while we call a special case of layered dielectric 3-D.

In my opinion, it is best to keep the 2.5-D description for analyses which do not allow a single, specified field component, for example, Jz=0. But we still want to make sure that there is no confusion between the kind of 3-D analysis which requires layered dielectric and that which can handle arbitrary dielectric.

In the past we have described the 3-D layered dielectric problem as "3-D predominantly planar." This is a real mouthful and has not caught on. Recently, it was suggested that we simply call this kind of analysis "3-D Planar." Then we can call the 3-D *arbitrary dielectric analysis "3-D Arbitrary." If* a 3-D analysis allows only filamentary current, we can call it "3-D Wire." It kind of says it all, doesn't it?

To illustrate the above ideas, I classify a few popularly known electromagnetic analyses as follows:

- MININEC, NEC (public domain)—3-D Wire (used for arbitrary wire antenna analysis).
- EMSim (EEsof)—2.5-D Planar (includes an approximation for 3-D Planar).
- PMESH (UC Boulder)—2.5-D Planar.
- em (Sonnet Software/EEsof)—3-D Planar.
- LINMIC+ (Jansen Microwave)—3-D Planar.
- Compact/Microwave Explorer (Compact Software)—3-D Planar.
- HFSS (HP/Ansoft)—3-D Arbitrary.

In addition, I think we should also specify what we mean by "approximate" and "exact" in reference to electromagnetic analysis. My suggestions:

- exact—Describes an analysis whose approximations are a discretization (meshing) of the problem and the use of finite precision arithmetic. All other approximations are of equal or less significance than the use of finite precision arithmetic. As the discretization is refined, an exact analysis must converge to the exact answer as far as the numerical precision of the arithmetic used permits.
- approximate—Describes an analysis whose approximations are of significance equal to or greater than the discretization of the problem. If, as the discretization is refined, an analysis does not converge to the exact answer as far as is permitted by the finite precision arithmetic used, it is necessarily approximate.

I welcome comments and suggestions (no rotten apple throwing, please!) on the issues I have raised.