Learning About EM Theory and EM Modeling by Analyzing Printed Circuit Boards in an Enclosure

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Abstract

Understanding electromagnetic theory requires more than an ability to apply Maxwell's equations to specific problems. Students in electromagnetics should be taught to visualize field distributions and anticipate solutions to basic problems in electromagnetics. Numerical EM modeling codes can be an excellent visualization tool. They also allow students to solve a variety of real-world problems that emphasize the relevance of the EM concepts presented in a course. This paper shows how simple printed circuit board structures can be used to illustrate basic field theory concepts. After modeling a number of these structures, students learn to visualize solutions to new structures even before they are modeled.

Introduction

Undergraduate electromagnetics classes tend to be among the most difficult courses in an electrical engineering curriculum. Students in these classes must be taught vector calculus and learn to work in different coordinate systems just to solve the most basic electromagnetic problems. The relationship between these basic problems and real-world engineering problems can be difficult for students to grasp.

Because the courses are difficult, many students convince themselves that EM theory is not relevant to the type of electrical engineering work they will eventually be doing. Many of them do not expect ever to solve another field problem once they have completed the required undergraduate EM courses. Electromagnetics instructors may even encourage this attitude among students if the classroom examples and demonstrations fail to illustrate applications of EM theory to other areas of electrical engineering. Traditional class demonstrations involving tin cans, balloons, ping-pong balls, and pendulums are both educational and entertaining, but they do not convince the students who are interested in computers or communications that EM theory is relevant to their engineering careers.

Trends in EM Education

There are two engineering trends that promise to revolutionize electromagnetics education. The first trend is the proliferation of high-speed microprocessor circuitry. Microprocessors are found in all kinds of electric and electronic appliances including televisions, audio equipment, coffee makers, pencil sharpeners, and electric shavers. A new automobile may have dozens of microprocessors and commercial jet aircraft may have hundreds. It is becoming very difficult for graduating electrical engineers to find a job that does not require designing or working with high-speed microprocessor circuits. It is also becoming much more difficult to get high-speed microprocessor systems to function properly and meet electromagnetic compatibility requirements without a basic understanding of EM theory.

The second trend that promises to have a significant impact on electromagnetics education is the increasing availability and sophistication of computer EM modeling techniques. Computer modeling enables students to solve problems that are much too complex to solve analytically. This means that EM instructors can assign problems that demonstrate applications of EM theory to real-world engineering challenges.

Computer modeling techniques also make it much easier for the student to visualize the solution by plotting the results over a region in space. Once a problem has been solved, it is relatively little extra work to make minor modifications to a structure and analyze it again. This makes it easier for the student to learn what effect various attributes of the structure have on the solution.

Teaching Electromagnetics

There are arguably three levels at which students may learn electromagnetic theory,

1. understanding the math
2. being able to work the problems
3. being able to visualize the important parameters.

For example, a student who understands the algebra and complex number theory necessary to solve a simple transmission line matching problem has a level 1 understanding of transmission line stub matching. If the student can consistently calculate the correct stub length and location, then level 2 has been achieved. The student who can visualize the standing wave pattern (perhaps with the aid of a few calculations), and then come up with a reasonable estimate for the best stub length and location has attained a level 3 understanding of transmission line stub matching. This student can probably estimate the bandwidth over which a "reasonable" match will be achieved and is generally able to determine the best stub matching solution under various conditions.

These same three levels of understanding exist for other aspects of electromagnetic theory such as field propagation in waveguides, modes in resonant cavities, current distributions on antennas, and antenna field patterns. These levels of understanding usually occur in the order presented, however it is possible for a student to achieve them in any order. For example, engineering technicians who frequently work with radio and microwave frequency hardware, often achieve a level 3 understanding of many aspects of electromagnetic theory without ever achieving level 1 or level 2. Engineers who rely on computers and numerical methods to do field calculations may not be familiar with the mathematics involved in the calculations and yet they still may have a level 2 and level 3 understanding of the topic. Undergraduate and graduate courses in electromagnetic theory must strive to instruct students at all three levels.

Students who develop just a level 1 or level 2 understanding of EM theory are not likely to apply it to real engineering problems and will soon forget most of what they learned. For example, a student who is proficient at calculating the length and position of matching stubs may be well prepared for situations involving a mismatched line that needs to be matched with a stub. However, this particular situation may never arise. The student may encounter a number of similar problems (e.g. the need for notch filter) where a stub may be the perfect solution, but the potential for applying the theory to these new problems may not be recognized.

The best way to instill a level 3 understanding in students is to encourage them to plot fields and/or currents rather than to ask for a specific numerical answer. Also, students should be asked questions of the form "*If this parameter is changed in this way, how will the result be affected?*" These types of questions get the student to think about physics of the problem.

While many college instructors already use this approach to teach transmission line theory, it is not as common for 3D field theory. The primary reason for this has been that 3D field calculations are tedious and there are a limited number of problems that students can be expected to solve. However, with the help of numerical modeling codes, it is becoming easier to solve a number of interesting EM field problems with real-world applications and quickly plot the results.

PCB Structures in an Enclosure

One type of structure that is useful for demonstrating EM field theory concepts, and also has practical applications, is the printed circuit board in a metal enclosure. A simple example is illustrated in Figure 1. Normally, currents in the circuit are calculated using transmission line or circuit theory and the enclosure is ignored.

As an example of how students can use numerical modeling techniques to help develop a level 3 understanding of a basic field problem, the structure in Figure 1 was analyzed using the EMAP finite element modeling code [1]. The amplitude of the **x**-component of the electric field in the plane of the circuit is plotted in Figure 2 at four frequencies.

At most frequencies, the circuit behaves like a shorted transmission line and the field is primarily confined to the region between the conductors. However, at frequencies away from the circuit resonance, the field away from the circuit can be much stronger than the field within the circuit. This is especially true at frequencies that excite a resonance of the enclosure.

These results may not surprise engineers with EM modeling or measurement experience, but they make a lasting impression on students in undergraduate electromagnetics classes. Students learn to recognize that the fields within the circuit may not be the only fields of importance and that under some conditions a circuit's enclosure can have an effect on the operation of the circuit. By experimenting with various circuit sizes, positions, frequencies, and dielectric materials; students can develop a feeling for the way in which different parameters affect the results. Pretty soon, students can predict how new configurations will behave without even running the modeling code.

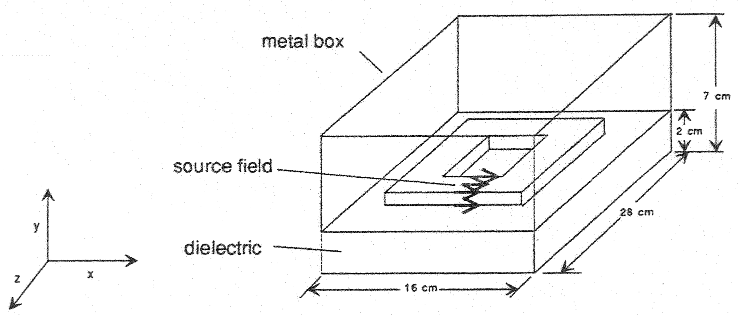
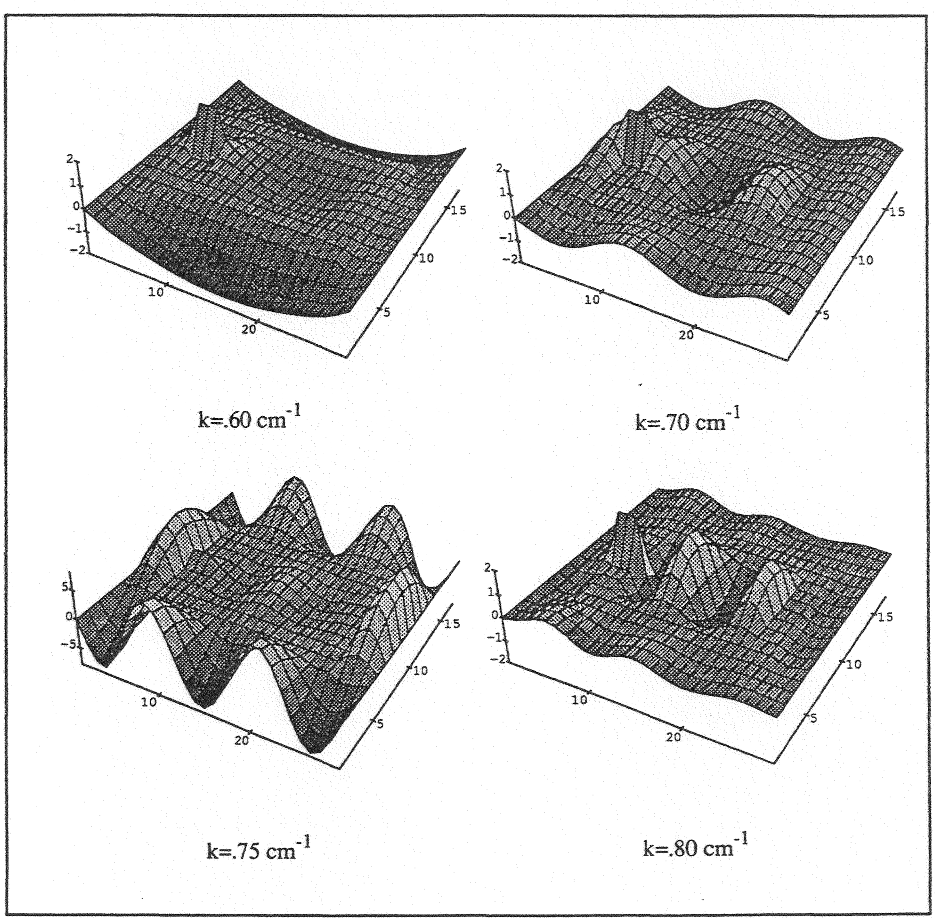


Figure 1: Printed circuit board structure in an enclosure



k=.60 cm^{-1} k=.70 cm^{-1}

k=.75 cm^{-1} k=.80 cm^{-1}

Figure 2: x-component of electric field at four frequencies

With two loop circuits placed in an enclosure as shown in Figure 3, it is relatively easy to demonstrate how fields from one circuit are coupled to another. With a little practice, students can learn to design and orient circuits to maximize or minimize the coupling between them.

Conclusions

The availability of easy to use 3D numerical modeling techniques provides instructors of undergraduate and graduate electromagnetics classes with a unique opportunity to give students hands on experience with electromagnetic field calculations. Using these techniques, students gain an awareness of the practical applications of EM theory and develop a feeling for how fields behave in different circumstances. Numerical modeling assignments can make the course more interesting

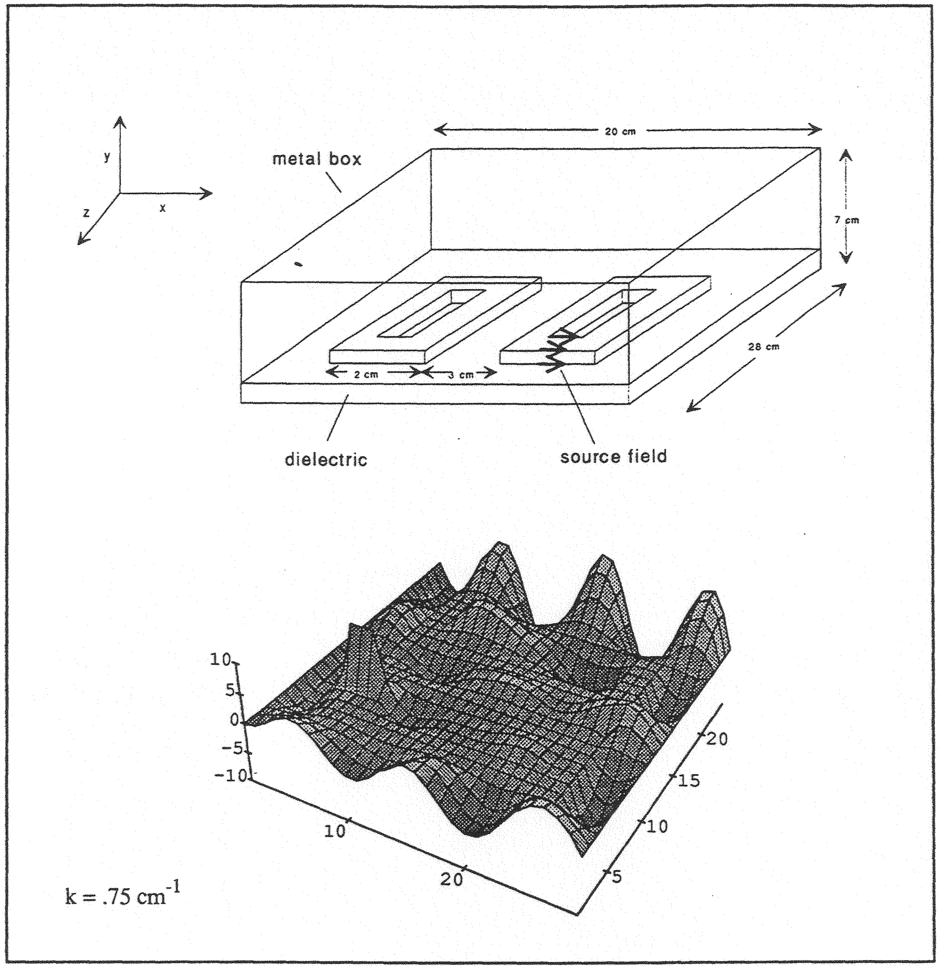


Figure 3: Two loop circuits in an enclosure

for the students and at the same time help the student to achieve a level 3 understanding of the topic. With a little practice, students can learn to design and orient circuits to maximize or minimize the coupling between them.

References

[1] T. Hubing, M. Ali, and G. Bhat, "EMAP: A 3-D, Finite Element Modeling Code for Analyzing Time-Varying Electromagnetic Fields," to be published in the *ACES Journal: Special Issue on Computer Applications in Electromagnetics Education*