Discovery Learning Apprenticeship Project Summary

Absorption of High-Frequency Surface Waves Above Planar High-Speed Circuits

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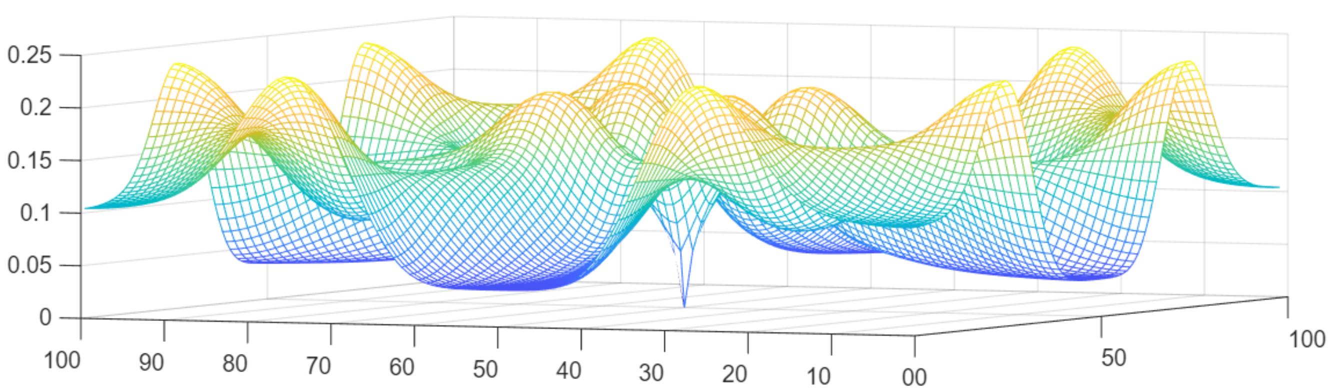

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1 Problem Statement and Research Objectives

Electromagnetic simulation plays a fundamental role in the design of high-speed digital and RF systems. One widely used computational technique is the Finite-Difference Time-Domain (FDTD) method. While many simulation approaches primarily provide frequency-domain information, FDTD offers the unique ability to resolve the individual components of the electric and magnetic fields directly in the time domain.
Although extremely powerful, FDTD still exhibits limitations that are often overlooked. As circuits operate at increasingly higher frequencies, understanding where standard simulation methods begin to break down becomes critical. The objective of this research is to expose and quantify the fundamental limitations of FDTD when modeling high-frequency surface waves above planar circuits, such as PCB traces. My role is to implement controlled 3D simulations in MATLAB and contribute toward establishing guideline criteria that could be adopted by industry or used to motivate new numerical approaches.

2 Technical Background

This project builds on established work in computational electromagnetics, focused on limitations of the FDTD method. In order to do this research, a solid understanding of both foundational and modern perspectives is required.

The primary foundational material comes from the course texts ECEN 5524 *Computational Electromagnetics for Signal Integrity* and ECEN 5514 *Principles of Electromagnetics for High-Speed Digital Engineering*, written by Mohammed Hadi, who oversees this project. These resources document the formulation of FDTD using finite differences as well as its inherent susceptibility to numerical errors, and have therefore served as the basis for my understanding of FDTD.

An understanding of more recent developments, such as those presented in Hadi's 2011 IEEE paper on near-field PML optimization, provides direction for where current research is headed and how FDTD continues to be refined. Together, these resources supply the technical background necessary for this project and enable me to evaluate the method's limitations in the context of ongoing research.

3 Methodology

Finite Difference Time Domain is a simulation method that involves solving Maxwell's time dependent equations using finite differences. Finite differences are a way of replacing derivatives with subtraction; instead of computing a continuous derivative such as

$$\frac{\partial E}{\partial x}.$$

FDTD approximates this derivative by evaluating how the electric field changes between two neighboring points on the grid:

$$\frac{E(x+\Delta x)-E(x)}{\Delta x}.$$

This converts Maxwell's equations, normally expressed using continuous derivatives, into algebraic update equations that a computer can compute step by step. Each field component (E_x, E_y, E_z, H_x, H_y, H_z) is updated using these small changes induced by neighboring components on the grid. A visualization of this algorithm can be seen in figure 1, where the electric field components are staggered at the edges of the cell while the magnetic field components occupy the faces.

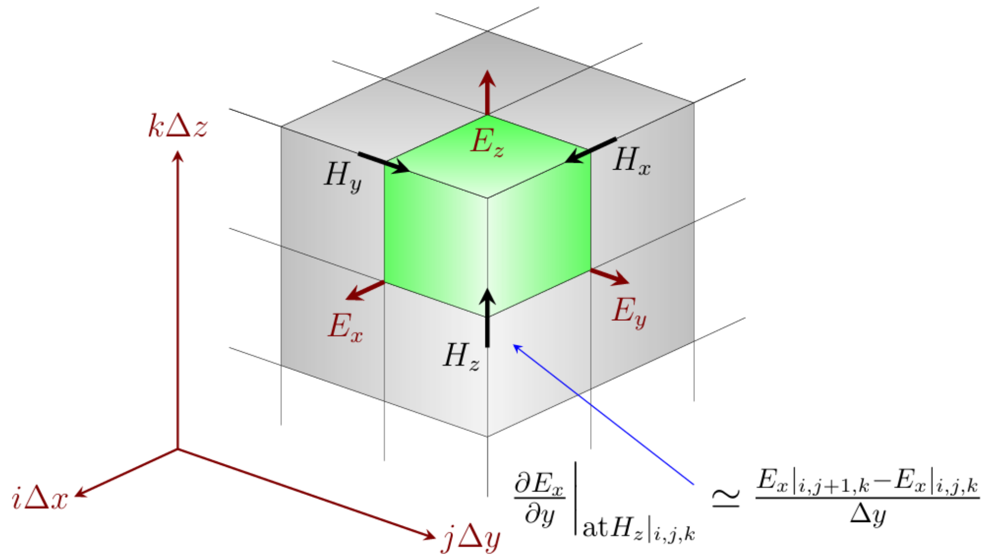

Figure 1: FDTD Grid Cell as seen in *Computational Electromagnetics Lecture Notes*

This numerical framework forms the basis of the simulations used for experimentation. The remainder of the methodology consists of running controlled simulations and comparing their results with modified experimental simulations in MATLAB. The time domain field values will be collected and the resulting data will be interpreted using plots and error-comparison graphs to analyze the trends in the data. By systematically examining how small changes influence the numerical results, my research aims to highlight the numerical discrepancies the FDTD method.

4 Facilities, Equipment, or Other Requirements

All research is performed using MATLAB on a workstation capable of supporting large grid domains and memory intensive computations. Supporting materials include ECEN supplemental course material and relevant supplemental research papers. Because small code modifications can produce significantly different simulation behaviors, this research also depends on careful documentation and version tracking. No physical laboratory hardware or additional experimental equipment is required.

5 Timeline

Month	Objective	Completion Status
September	• Review Maxwell's equations • Gain familiarity with FDTD discretizations • Develop numerical dispersion analysis tool in MATLAB	X
October	• PEC plate implementation in MATLAB • MATLAB data collection probe implementation • Establish baseline plane wave reflection behavior using large simulation domain	X
November	• Complete three absorbing boundary experiments (Perfectly Matched Layer) • Process and evaluated probe-measured reflections from PML experiments • Generate and compare absolute error plots for PML experiments	X
December	• Finish data interpretation from PML experiments • Finalize standard PML simulation results	
January	• Begin CPML analysis • Design CPML experimental setups	
February	• Optimize CPML parameters for high-speed and high-frequency applications	
March	• Prepare presentation material and potential DLA Expo material	
April	• Complete final research report	

6 References

1. M. F. Hadi, ”Near-Field PML Optimization for Low and High Order FDTD Algorithms Using Closed-Form Predictive Equations,” in IEEE Transactions on Antennas and Propagation, vol. 59, no. 8, pp. 2933-2942, Aug. 2011, doi: 10.1109/TAP.2011.2158955.

2. M. Hadi, “ECEN 5514 Lecture Notes,” Principles of Electromagnetics for High-Speed Digital Engineering, University of Colorado Boulder, 2025, PDF.

3. M. Hadi, ECEN 5524: Computational Electromagnetics for Signal Integrity, University of Colorado Boulder, Spring 2025, lecture notes (PDF).