ECE 61800: Numerical Electromagnetics
Project 1

Date Assigned: 02/01/2024
Date Due: 02/29/2024

1 Project Overview

This project covers the implementation of a computer code using the finite difference method to solve problems in electromagnetics. All project code and reporting should be prepared individually, however, you may discuss with other students in the class about the project to "debug" your implementation. A list of suggested project topics are included later in this document. If you wish to work on a different topic, you need to clear this project with Dr. Roth before beginning to ensure the suitability of the topic for this class and that you will have enough time to complete the proposed project.

The main deliverable for this project will be a written formal report that details the work that was completed. At a high-level, this report will cover the formulation of the mathematical problem solved, the discretization approach used, and a discussion of the validation of the computer code via numerical results generated. A detailed grading rubric for this report is included later in this document, and a high-quality example from a previous semester will be uploaded to Brightspace. *(Note: please do not distribute this prior student's work to others or online, and obviously any form of plagiarism will be treated according to the academic misconduct policies of the course.)* If you are unsure about whether you are including enough validation data or depth in your report, you are encouraged to reach out to Dr. Roth prior to the project due date to get preliminary feedback. Students should also submit their computer code in a human-readable format to ensure each code implementation is unique. For the code submission, please provide the direct files (e.g., .m or .py files) as opposed to exporting the code into some intermediary like a Word document. The report and code should both be submitted electronically via Brightspace.

Generated on January 29, 2024 by T. E. Roth, Purdue University.

2 Suggested Project Topics

1. Develop a 2D FDTD program using Yee's method to calculate the radiation of an infinitely long electric current in an open region that contains different inhomogeneities. The open region **must** be terminated using PMLs. After validating that the source radiates correctly in a homogeneous open region, use your code to study **at least two** of the following:

   (a) The diffraction pattern produced by an infinitely long current source radiating in the presence of an infinitely long conducting sheet with one slot. Compare the diffraction pattern of this case with that of an infinitely long conducting sheet with two or more slots.

   (b) The scattering produced when an infinitely long current source radiates in the presence of an infinitely long conducting cylinder of various cross sections (e.g., rectangular, circular, etc.).

   (c) The scattering produced when an infinitely long current source radiates in the presence of an infinitely long dielectric cylinder of various cross sections (e.g., rectangular, circular, etc.) and material properties.

   (d) Compare the performance of various approximate boundary conditions to terminate the open region. You should consider different PML parameters (thickness, conductivity profile, etc.) as well as two different ABCs (e.g., first- and second-order). **Completing this item can yield up to 5 points of extra credit to the total project score.**

2. Develop a 1D FDTD program to study the scattering of a plane wave from a dispersive or nonlinear material. You may use a PML or an ABC to terminate either or both of the ends of the simulation region. **Completing this item can yield up to 5 points of extra credit to the total project score.**

3. Solve Laplace's equation for various "shielded" transmission line structures that support TEM or quasi-TEM modes. Validate that your code is working by considering at least one geometry where reasonable analytical formulas exist for the line capacitance (e.g., a coaxial line or a stripline). For the geometries studied, plot the equipotential lines and static electric field distribution. For transmission lines that are not naturally "shielded" (e.g., a microstrip trace or a coplanar waveguide), ensure that the "extra" shield conductors are placed far enough away from the desired parts of the transmission line geometry that they minimally affect the solution. Possible transmission lines

to study include: coaxial line, microstrip line, stripline, coplanar waveguide, grounded coplanar waveguide, slotline, etc.

4. Develop a 3D FDTD program using Yee's method to solve a wave propagation problem within a closed waveguide structure with regular shaped ports (e.g., rectangular cross sections that support well-known mode patterns). Terminate your ports using an absorbing boundary condition that can absorb the dominant mode of the waveguide at the location of the port (details on this boundary condition can be found about midway through Section 9.3.3 of your textbook, and does not require any knowledge of the finite element method to implement). **Completing this item can yield up to 10 points of extra credit to the total project score.**

5. Use the finite difference method to solve one problem of interest to you (clear the problem with Dr. Roth prior to starting). Make sure to plan for some way to validate your code's performance for your selected problem.

3 Rubric

1. Title & Abstract (5 points)
   (a) Title and abstract are concise, but informative.
   (b) Abstract should properly convey the main information contained in the work, the methods used, and the problems studied.
2. Introduction and Conclusion (10 points)
   (a) Introduction should discuss relevant background and history of the problem to be studied and the methods used in the work, supported by relevant references from textbooks and the literature (around 4 or 5 references is likely plenty for this report). Introduction should also finish with a paragraph discussing the organization of the remainder of the paper.
   (b) Conclusion should succinctly summarize the content of the work and mention possible directions for further study, improvements that could be made to the numerical methods, etc.
3. Formulation & Discretization (30 points)
   (a) Equations that are to be solved numerically are appropriately derived from a well-established starting point (e.g., Maxwell's equations).

(b) Assumptions or approximations of the derivation are clearly communicated.

(c) Basic process of the numerical discretization is clearly communicated for all important/distinct equations. For example, you may need to show the derivation of a time-stepping formula in your report; if there is another time-stepping formula you use that is almost identical to the first one you don't need to show all the intermediary steps, just the final result.

4. Numerical Results (45 points)

   (a) Validation data is shown to demonstrate correct implementation of the numerical method. Sufficient details on the numerical results and validation data should also be included so that someone else could conceivably implement their own tool and replicate your results. Sample items to cover would be sizes of the simulation region, spatial and temporal step sizes, kind of excitation waveform considered, relative permittivity and permeability of materials, etc. (Note: this is not an exhaustive list of what should be covered).

   (b) Additional numerical results are presented to show utility of the numerical method. Again, sufficient detail is provided for simulation parameters that a reader can understand the content of the simulation and recreate it themselves.

   (c) Figures are legible and aesthetically-pleasing (Matlab/Python plots are fine). Figure captions are concise, but informative. Figures are referenced and discussed appropriately within the text of the report.

   (d) Note: your code must correctly implement the numerical method to approach reaching full points in this category of the rubric.

5. Writing Style (5 points)

   (a) Grammar, word use, spelling, etc. are of an overall good quality.

   (b) Best practices for writing mathematical prose are followed (equations are treated as part of the sentence, equations are numbered, "user-friendly" references to previous equations, etc.). See here for basic guidelines to consider.

   (c) Equations are typeset in an aesthetically-pleasing manner.

   (d) Note: if the writing style is particularly poor, additional points will be subtracted from other aspects of the report (e.g., Formulation & Discretization or Numerical Results).

6. Coding Style (5 points)

   (a) Code is formatted and organized in an easily-readable manner. Descriptive variable and function names are used as appropriate.

   (b) Sufficient comments are used to make the code more easily interpreted by another person.