EE691 Applied EM- FDTD Method (Spring 2012)
Computer Project 3- 2D Parallel-Plate Waveguide

Overview

Consider the non-magnetic (μ_0), dielectric-filled ($\varepsilon = \varepsilon_r \varepsilon_0$), two-dimensional (2D), perfect electrical conductor (PEC), parallel-plate waveguide with discontinuities shown in Figure 1. We will inject a transverse, with respect to the direction of propagation, electromagnetic (TEM) wave on the input side. This wave can propagate in both the $\pm z$-directions. The discontinuities in the waveguide will partially reflect and transmit incident waves, and generate other modes. However, the frequency range of the incident pulse and waveguide dimensions are selected so that the other modes are cut-off in the waveguide. In other words, they don't propagate, and exponentially attenuate away from the discontinuities. Therefore, the fields at the input and output ports are essentially TEM, if the ports are a sufficient distance from the discontinuities. This is important in order for the simple absorbing boundary condition (ABC) discussed in class to work correctly.

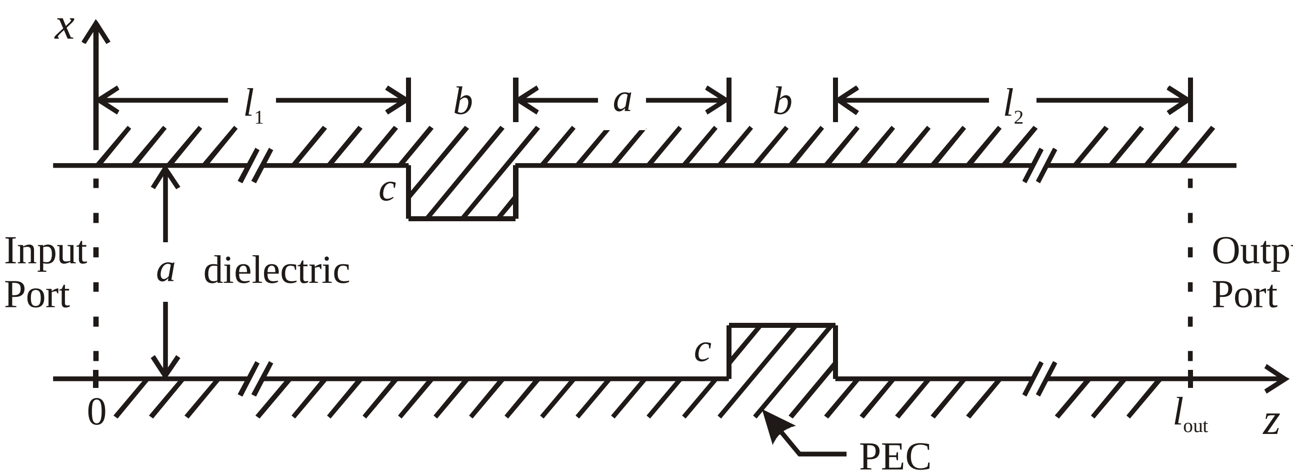

Figure 1 Problem Geometry for a 2D Parallel-Plate Waveguide

Tasks

You may use the programming language(s) and/or mathematics package(s) of your choice for the numerical calculations and plotting results.

1) For the problem shown in Figure 1, the structure and material properties are lossless and independent of the coordinate y and there no electric or magnetic current sources. If an applied/incident wave is of the form $\bar{\mathcal{E}} = \hat{a}_x \, \mathcal{E}_x(x,z,t)$, what mode(s), as defined here and in the text (e.g., $TE_?$, $TM_?$, & $TEM_?$), can or will exist in the waveguide? What field components correspond to each of these modes? For the mode or modes, list the governing differential equations. Start with Faraday's and Ampere's Laws. In order to model the entire problem shown in Figure 1, which mode should be selected? List the FDTD field update equations needed to model this mode in the dielectric in standard form with coefficients in terms of v_p and η. Use field locations as shown in Figure 1 of the Chapter 3 notes.

2) For the problem shown in Figure 1, the plate separation distance is a = 12 cm, $l_1 = l_2 = 4a$, dimensions of the discontinuities are $b = a/2$ and $c = a/3$, and velocity of light in the dielectric is $v_p = 2.5 \times 10^8$ m/s. Using an additive source, apply a time-delayed unit-amplitude Gaussian pulse $g_D(t) = e^{-0.5\left(\frac{t-\tau_d}{\tau_p}\right)^2}$ to $\bar{\mathcal{E}} = \hat{a}_x\, \mathcal{E}_x(0 \le x \le a, z = 0, t)$. Select the characteristic time $\tau_p = 1.25\left(\frac{a}{v_p}\right)$ and time-delay $\tau_d = 6\left(\frac{a}{v_p}\right)$ to ensure that the incident wave turns on smoothly. Select your spatial step sizes based on the frequency content of the applied wave and problem geometry shown in Figure 1. Limits- use square lattice ($\Delta = \Delta x = \Delta z$) and $\Delta \ge 1$ cm. (Hint: which field components need to be exactly located on the PEC boundaries to satisfy electromagnetic boundary conditions?) Using S = 0.5, calculate Δt. Calculate and tabulate the values of v_p, ε_r, η, τ_p, τ_d, τ_d / τ_p, $|G_D(t=0)| / |G_D(t)|_{\max}$ (unitless and dB), $l_1 = l_2$, b, c, $l_{out} = l_1 + 2b + a + l_2$, $T = l_{out} / v_p$, $\Delta x = \Delta z$, Δt, $f_{\max} = v_p / \lambda_{\min} = v_p / (8\Delta)$, and $|G_D(f_{\max})| / |G_D(f)|_{\max}$ (unitless and dB).

3) Draw figures detailing the overall 2D spatial FDTD mesh set-up near the input, discontinuities, and output with the corresponding field variables and spatial indices (as used in code). Place simple ABCs, discussed in class, at $z \le 0$ and $z \ge l_{out}$ (actual locations depend on S and $\Delta x = \Delta z$). Give the actual FDTD update equations, with the field variables, actual coefficients, and indices, in the dielectric and for the ABCs.

4) First, write a 2D FDTD program that will model the parallel-plate waveguide shown in Figure 1 <u>without the discontinuities</u>. Make a list of relevant variables in a comment block at the beginning of the program. Make copious use of comment statements to explain what program blocks are doing. Attach code in appendix. On a single graph, plot the applied signal $g_D(t)$, field at the input port $\mathcal{E}_x(x \approx a/2, z = 0, t)$, and field at the output port $\mathcal{E}_x(x \approx a/2, z = l_{out}, t)$ versus the normalized time $t_{norm} = t/(a/v_p)$ for $0 \le t_{norm} \le 35$. Label peak values on these waves and note when they occur. Are the time delays and amplitudes correct? On a separate graph, plot the difference $\mathcal{E}_x(x \approx a/2, z = 0, t) - g_D(t)$ versus t_{norm} for $0 \le t_{norm} \le 35$. Are the ABCs operating correctly? On a single graph, plot the fields $\mathcal{E}_z(x \approx a/2, z = 0.5\Delta z, t)$ and $\mathcal{E}_z(x \approx a/2, z = l_{out} - 0.5\Delta z, t)$ versus t_{norm} for $0 \le t_{norm} \le 35$.

5) Next, modify your FDTD program so that it will model the parallel-plate waveguide shown in Figure 1. Attach changed code in separate appendix (only time loop). On a single graph, plot the applied signal $g_D(t)$ and field at the input port $\mathcal{E}_x(x \approx a/2, z = 0, t)$ versus t_{norm} for $0 \le t_{norm} \le 35$. On a separate graph, plot the field at the output port $\mathcal{E}_x(x \approx a/2, z = l_{out}, t)$ versus t_{norm} for $0 \le t_{norm} \le 35$. Label peak values on these waves and note when they occur.

6) At times $t_1 = \tau_d + 0.25T$, $t_2 = \tau_d + 0.5T$ (i.e., when the peak of the applied Gaussian pulse should be about centered between the discontinuities), and $t_3 = \tau_d + 0.75T$, make 2D contour plots of the electric and magnetic field strengths, normalized by the maximum electric or magnetic field strengths, for the area $0 \le x \le a$ and $0 \le z \le l_{\text{out}}$. Comment on what is happening to/with the electric and magnetic fields at these times.

7) Extra credit: Make 2D 'quiver' plots (i.e., a contour plot that shows vectors) of the electric field vectors at times t_1, t_2, and t_3 for the area $0 \le x \le a$ and $0 \le z \le l_{\text{out}}$. Comment on what is happening to/with the electric field vectors these times.

Hint: Parts 6) & 7) will require interpolating the fields to common locations. For example, you might select the grid/lattice locations of a magnetic field component and interpolate all the other fields to those locations.

Report

Write a report covering your results. The report should be as short as possible, while remaining complete in its description of your work. General format: Cover page, Introduction, Body (break down by assigned tasks), Conclusions/Summary, & Appendices(s). Use 12 point Times New Roman font with 1.25/1.5 line spacing. The report must be totally produced on a computer using, among other software, a word processor, an equation editor, and a data plotting package.

Due Monday March 26, 2012.