深 圳 大 学 实 验 报 告

课程名称：电磁场与电磁波

实验名称：平面波仿真实验

学　　院：电子与信息工程学院

专　　业：电子信息工程

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实验时间：2024年6月12，19日

报告提交时间：2024年7月3日

一、实验结果及分析

adj = 1.5

Question:

有入射平面波电场强度如下：

$$\boldsymbol{E} = \boldsymbol{e}_x e^{j\varphi} e^{-jkz} \square (V/m)$$

在 z=d1 与 z=d2 之间填充相对介电常数为ε_1的介质；在 z=d2 与 z=d3 之间填充相对介电常数为ε_2的介质；在 z=d3 与 z=d4 之间填充相对介电常数为ε_3的介质。

（1）求 z<d1 区域内的总场与反射场的电场强度的瞬时表达式；

（1）求 z>d4 区域内的总场与投射场的电场强度的瞬时表达式。

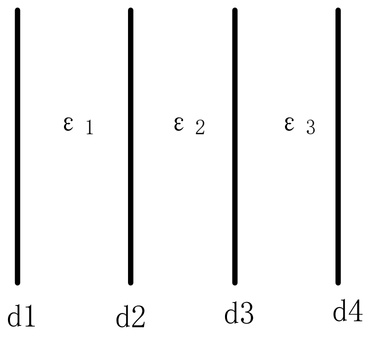

Figure 1

Solution:

➢ Equivalent Impedance Calculation:

For Input the initial impedance

$$Z_{in} = Z_0 \frac{Z_L + jZ_0 \tan\beta l}{Z_0 + jZ_L \tan\beta l}$$

where Z_0 is the characteristic impedance, Z_L is the load impedance, β is the phase constant, and l is the length of the transmission line.

For each layer of the medium, we can calculate the input impedance sequentially:

$$Z_{in4} = \eta_0$$

$$Z_{in3} = \eta_3 \frac{Z_{in4} + j\eta_3 \tan\beta_3(d_4 - d_3)}{\eta_3 + jZ_{in4} \tan\beta_3(d_4 - d_3)}$$

$$Z_{in2} = \eta_2 \frac{Z_{in3} + j\eta_2 \tan\beta_2(d_3 - d_2)}{\eta_2 + jZ_{in3} \tan\beta_2(d_3 - d_2)}$$

$$Z_{in1} = \eta_1 \frac{Z_{in2} + j\eta_1 \tan\beta_1(d_2 - d_1)}{\eta_1 + jZ_{in2} \tan\beta_1(d_2 - d_1)}$$

➢ Wave Impedance and Phase Constants for Each Layer:

For Wave Impedance η

$$\eta_1 = \frac{\eta_0}{\sqrt{\varepsilon_1}}$$

$$\eta_2 = \frac{\eta_0}{\sqrt{\varepsilon_2}}$$

$$\eta_3 = \frac{\eta_0}{\sqrt{\varepsilon_3}}$$

where η_0 is the wave impedance of free space.

For Phase Constants β:

$$\beta_1 = \frac{\omega\sqrt{\varepsilon_1}}{c}$$

$$\beta_2 = \frac{\omega\sqrt{\varepsilon_2}}{c}$$

$$\beta_3 = \frac{\omega\sqrt{\varepsilon_3}}{c}$$

where ω is the angular frequency, and c is the speed of light.

- Reflected and Total Field Intensities

For Reflection Coefficient γ_1:

$$\gamma_1 = \frac{Z_{in1} - Z_{in4}}{Z_{in1} + Z_{in4}}$$

For Reflected Electric Field Intensity E_r:

$$E_r = \gamma E_{in}$$

For Total Electric Field Intensity E_{total}:

$$E_{total} = E_{in} + E_r$$

Simulation:

仿真模型：平面波频率为 2.4GHz，沿 z 轴正向传播，电场指向+x 轴且幅度为 1V/m，平面波相位中心在原点，起始相位为 0。在 z=50mm 与 z=60mm 之间填充相对介电常数为（2+adj）的介质；在 z=60mm 与 z=80mm 之间填充相对介电常数为（3+adj）的介质；在 z=80mm 与 z=110mm 之间填充相对介电常数为（4+adj）的介质。

当 t=$\frac{T}{4}$，求

（1）由（50mm，50mm，0）到（50mm，50mm，40mm）确定的线段上，反射场和总场的瞬时电场强度；

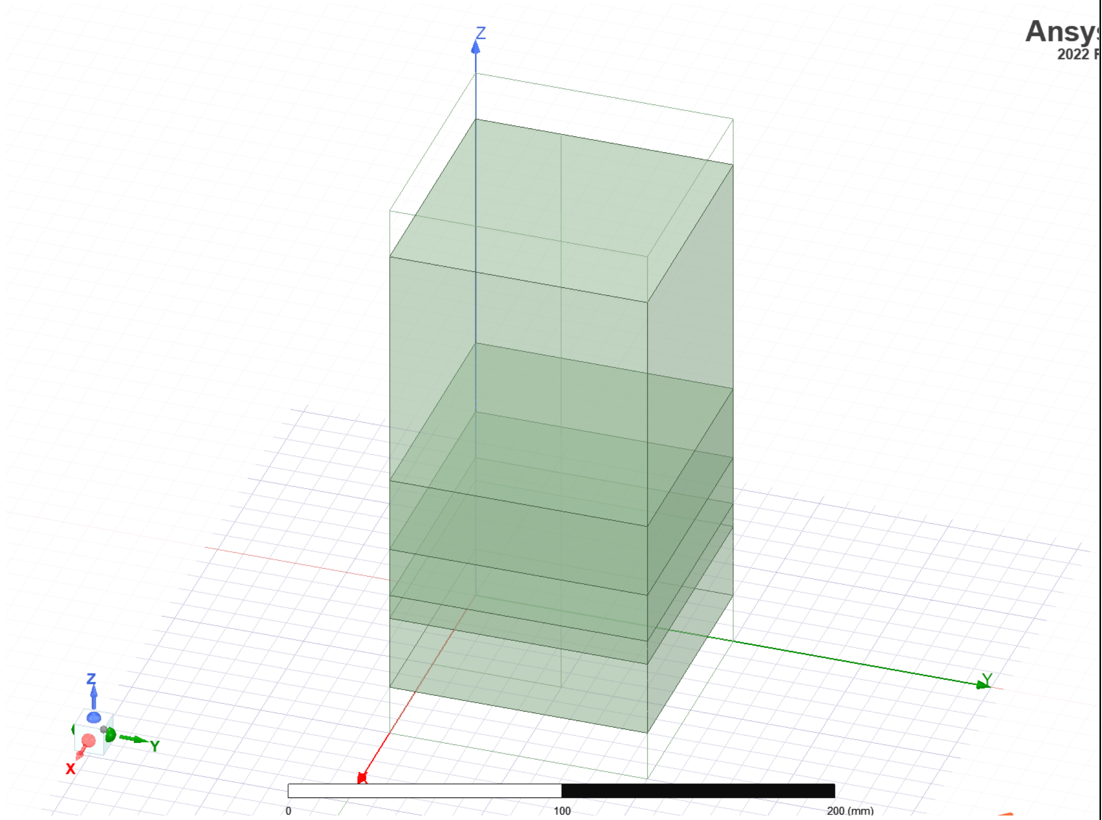

Figure 2 simulation model

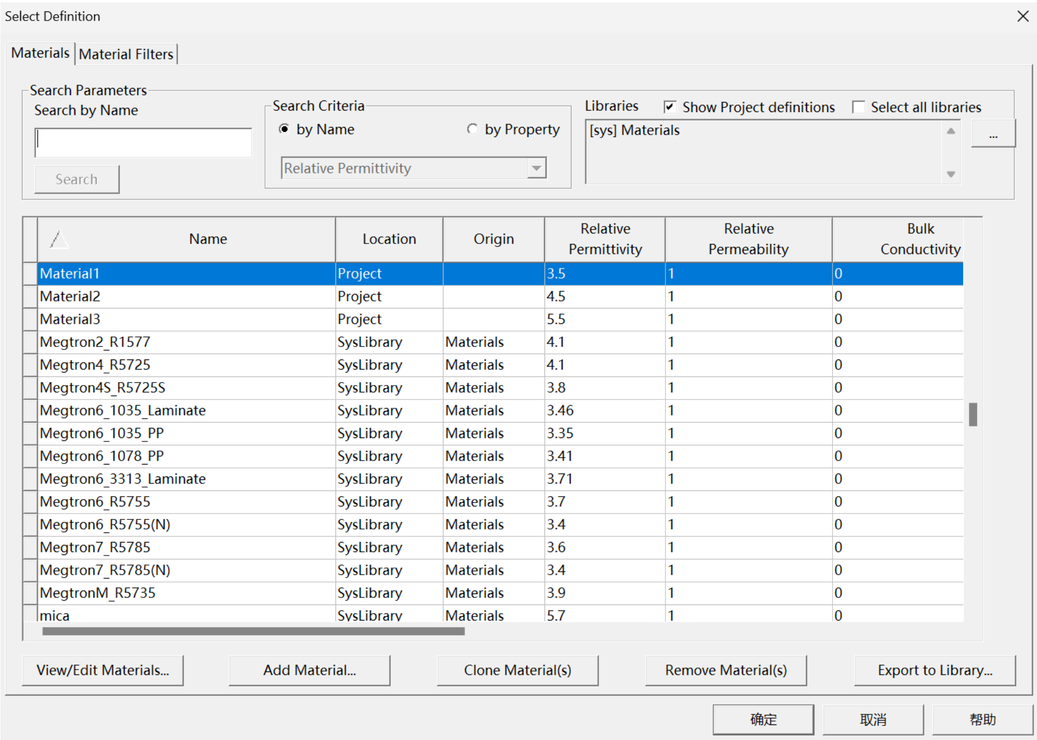

Figure 3 material parameters in HFSS

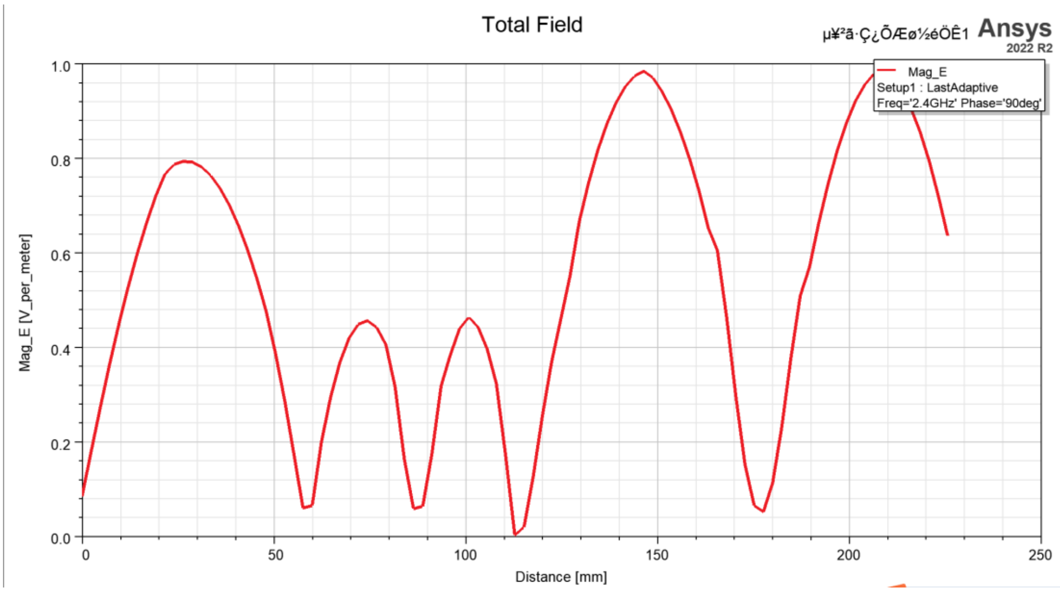

Figure 4 Total field in HFSS

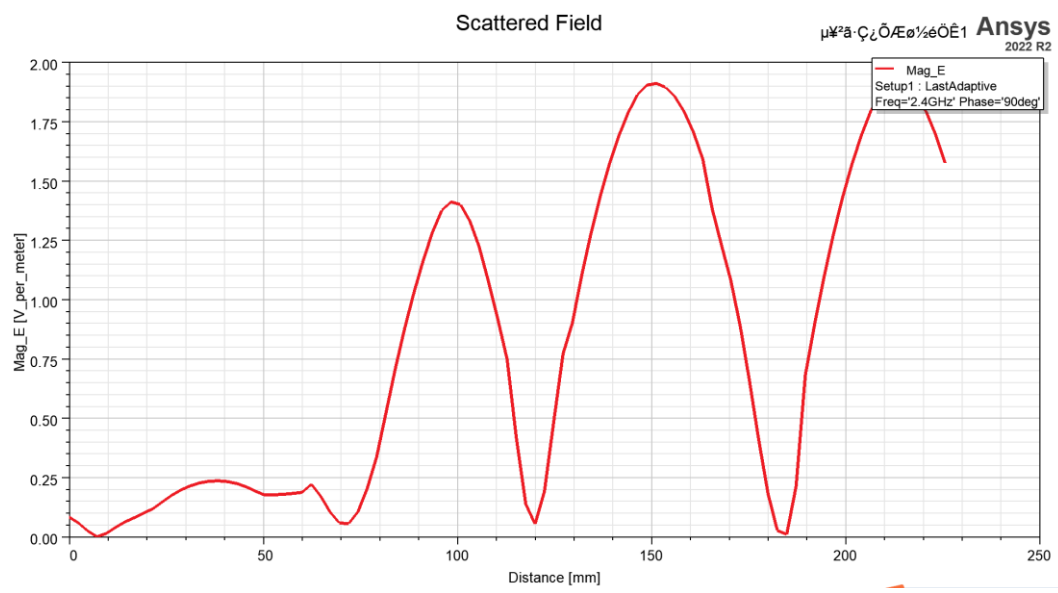

Figure 5 Scattered field in HFSS

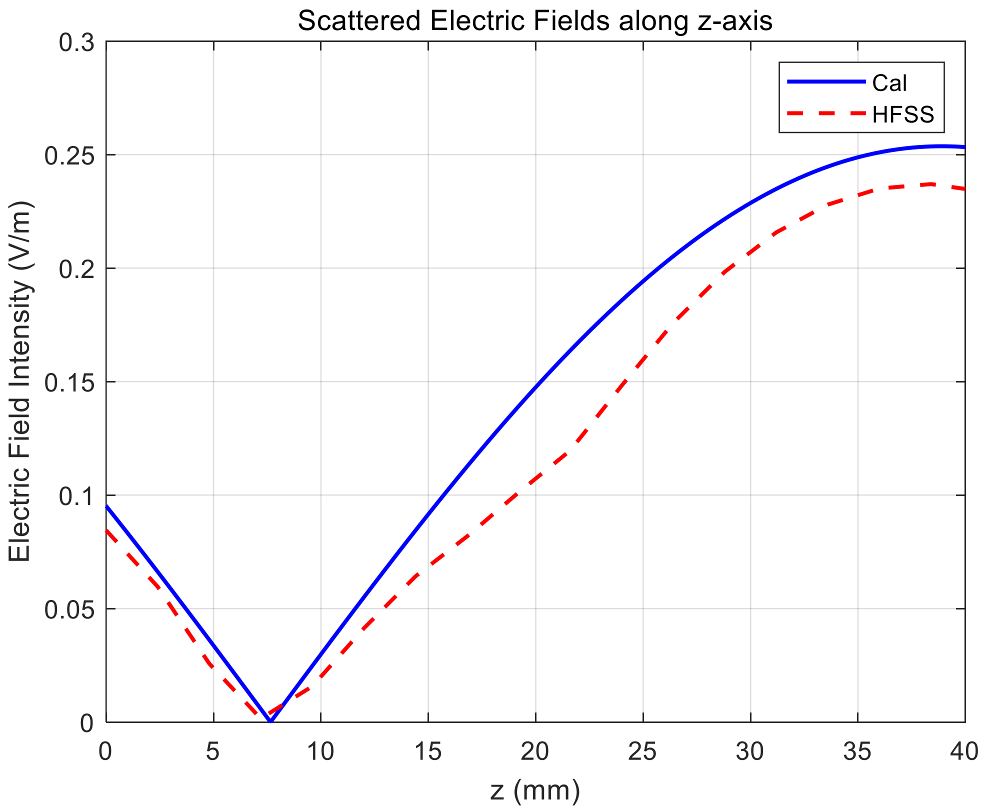

Figure 6 Comparison of scattered fields

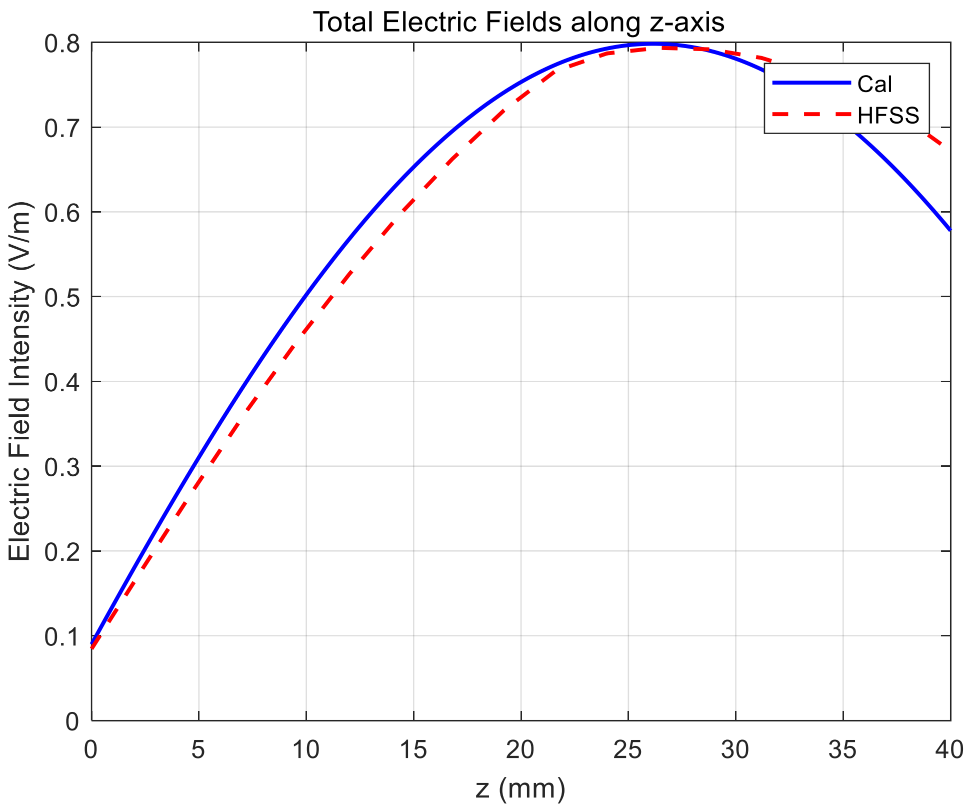

Figure 7 Comparison of total fields

Analysis:

In this experiment, we analyzed the propagation and reflection of a plane wave at different dielectric boundaries using both theoretical calculations and HFSS simulations. The incident wave had a frequency of 2.4 GHz and was propagating along the z-axis with its electric field pointing along the x-axis. The medium was segmented into three layers with varying relative permittivities, which altered the wave propagation characteristics and introduced reflections at the boundaries.

From Figures 4 and 5, it can be observed that at t=T/4, the distribution of the total electric field and reflection field along the z-direction.

Because there is a significant difference between my theoretical calculation results and simulation results in this experiment, I will conduct a comparative discussion from both theoretical and simulation perspectives:

- **Analysis of scattered fields:**

In Figure 6, we observe a comparison between the scattered fields obtained from HFSS simulations and theoretical calculations using MATLAB. The objective is to evaluate how well the HFSS simulation aligns with theoretical expectations.

- **Theoretical (cal)**: The calculated scattered electric field shows a clear oscillatory pattern, starting with a high value at z = 0mm, decreasing to nearly zero around z = 7mm, and then increasing again towards z = 40mm.
- **Simulation (HFSS)**: The simulated scattered electric field shows the same trend as the simulation, but also exhibits oscillations, first decreasing and then increasing. However, compared with the theoretical results, the simulation results of HFSS are smaller when z>7mm.

- **Analysis of total fields:**

Figure 7 compares the total electric field intensity along the z-axis as determined by HFSS simulations and MATLAB theoretical calculations. The total field includes contributions from both the incident and reflected waves.

From the graph, it can be seen that the trend and phase of the total electric field in both theoretical and simulation are the same, increasing from z=0mm to a peak near z=26mm, and then beginning to decrease. Moreover, it can also fit well in terms of amplitude, and the theoretical calculation results and simulation results in the total field can fit well.

However, when z>26mm, the theoretical calculation results begin to be greater than the simulation calculation results, but the difference is only slight. I think the reason for the different amplitudes is still due to the inaccurate reflection field mentioned earlier. Because the total field is the sum of the reflected field and the incident field.

- **The reasons for differences between Theoretical and Simulation may include:**

The treatment of boundary conditions and media: The treatment of boundary conditions and media in simulation may differ from the assumptions in theoretical calculations, especially in the interface treatment between different media layers.

The interaction between incident and reflected waves: In practical simulation, the interaction between incident and reflected waves at the interface of the medium may affect the electric field, and these complex interactions may not be fully considered in simple theoretical calculations.

二、实验结论

In this experiment, I successfully established a model for the incidence and reflection of electromagnetic waves in multi-layer media, and theoretical and simulation results can also fit well. In the results, the trend of the total electric field and the reflected field can be observed, and the trend of the theoretical and simulation results is the same, except for phase deviation in the reflected field and amplitude deviation in the total field. Finally, through this experiment, we have deepened our understanding of electromagnetic wave propagation in multi-layer media and have also learned how to use HFSS simulation software, laying a foundation for subsequent engineering learning.

三、指导教师批阅意见：

成绩评定：

指导老师签名：

年　　月　　日

备注：