电子信息与工程学院

文华班

电磁场与电磁波期末作业

课程名称：电磁场与电磁波

实验名称：平面波仿真实验

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Problem one

Theoretical Calculation

Question: There is an incident plane wave electric field strength as follows:

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

Fill between z=d1 and z=d2 with a medium whose relative permittivity is ε_1; between z=d2 and z=d3 with a medium whose relative permittivity is ε_2; between z=d3 and z=d4 with a medium whose relative permittivity is ε_3.

(1) Find the instantaneous expressions for the electric field strengths of the total and reflected fields in the region z<d1;

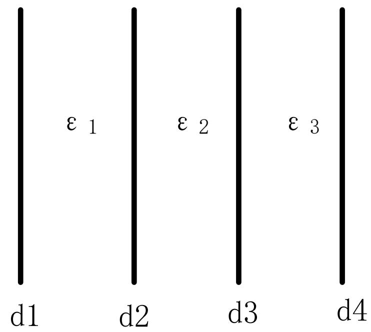

Fig 1 The Field

(2) Find the instantaneous expressions for the electric field strengths of the total and projected fields in the region z>d4.

Solution:

Parameter Definition

For Wave Impedance η

$$\eta_1 = \frac{\eta_0}{\sqrt{\epsilon_1}}, \eta_2 = \frac{\eta_0}{\sqrt{\epsilon_2}}, \eta_3 = \frac{\eta_0}{\sqrt{\epsilon_3}}$$

For Phase Constants β:

$$\beta_1 = \frac{\omega\sqrt{\epsilon_1}}{c}, \beta_2 = \frac{\omega\sqrt{\epsilon_2}}{c}, \beta_3 = \frac{\omega\sqrt{\epsilon_3}}{c}$$

Equivalent Impedance Calculation

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

$$Z_{in4} = \eta_0$$

Equivalent impedance of medium 3:

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

Equivalent impedance of medium 2:

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

Equivalent impedance of medium 1:

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

Reflected and Total Field Intensities

For the region z<d_1, the reflection coefficient is

$$\Gamma_1 = \frac{\eta_{eq1} - \eta_0}{\eta_{eq1} + \eta_0}$$

·The incident electric field is:

$$E_i(z,t) = E_0 e^{j(\omega t - kz)}$$

·The reflected electric field is:

$$E_r(z,t) = \Gamma_1 E_0 e^{j(\omega t + kz)}$$

·The total electric field is:

$$E_{total}(z,t) = E_i(z,t) + E_r(z,t) = E_0 e^{j(\omega t - kz)} + \Gamma_1 E_0 e^{j(\omega t + kz)}$$

·The instantaneous electric field intensity (real part) is:

$$E_{total}(z,t) = \mathrm{Re}(E_0 e^{j(\omega t - kz)} + \Gamma_1 E_0 e^{j(\omega t + kz)})$$

Simulation Model

Simulation: A plane wave with a frequency of 2.4 GHz propagates along the positive z-axis, with the electric field oriented towards the +x axis and an amplitude of 1 V/m. The phase center of the plane wave is at the origin, with an initial phase of 0. Between z=50 mm and z=60 mm, the medium is filled with a relative permittivity of (2+0.3). Between z=60 mm and z=80 mm, the medium is filled with a relative permittivity of (3+0.3). Between z=80 mm and z=110 mm, the medium is filled with a relative permittivity of (4+0.3).

At t=T/4, determine: The instantaneous electric field intensity of the reflected field and the total field along the line segment defined from (50 mm, 50 mm, 0) to (50 mm, 50 mm, 220 mm).

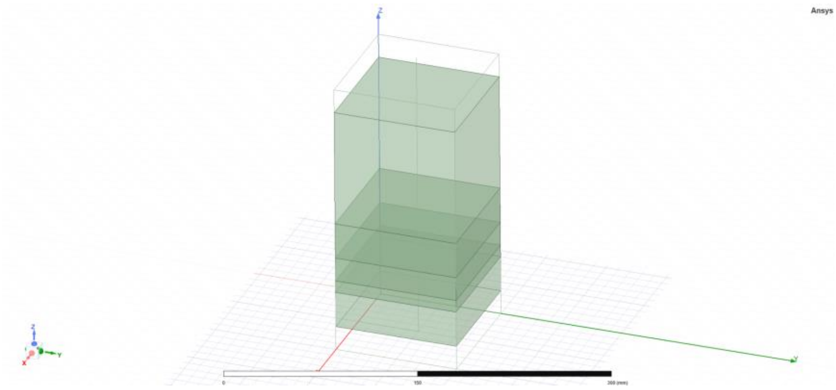

Fig 2 Simulation Model

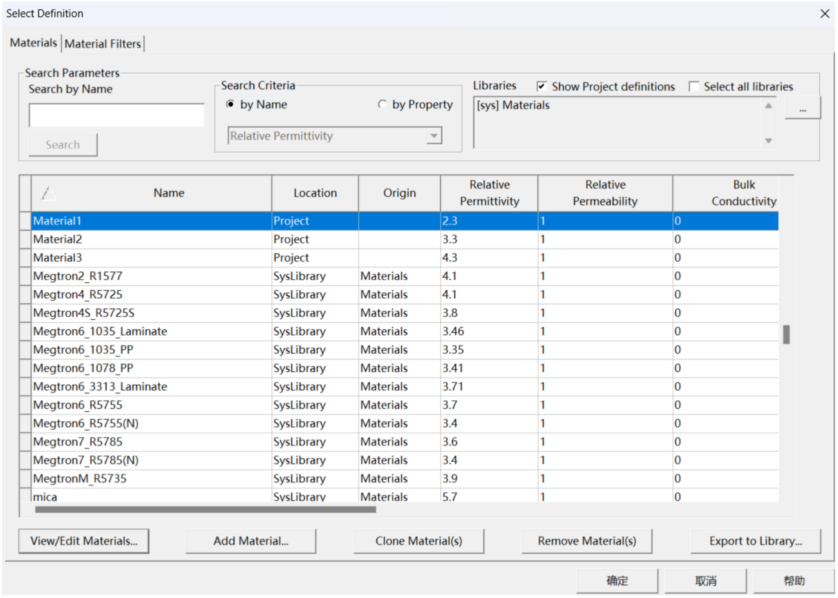

Fig 3 Simulation Model

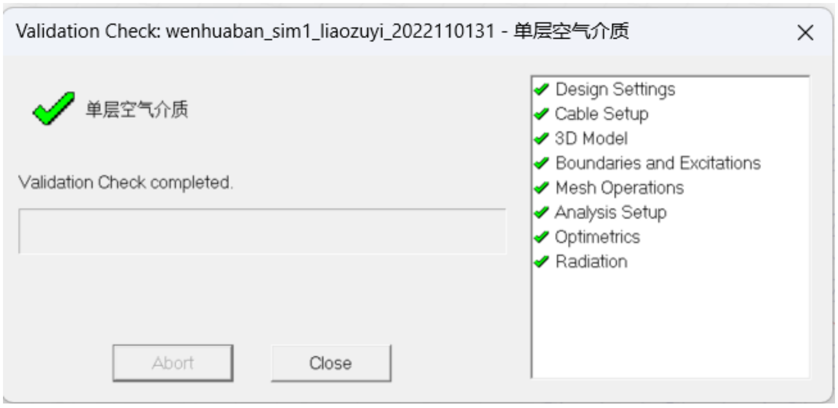

Fig 4 Validation Check

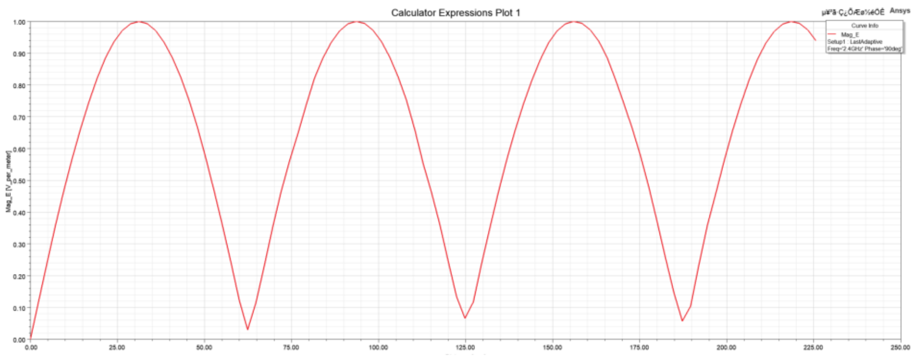

Fig 5 Incident Fields in HFSS

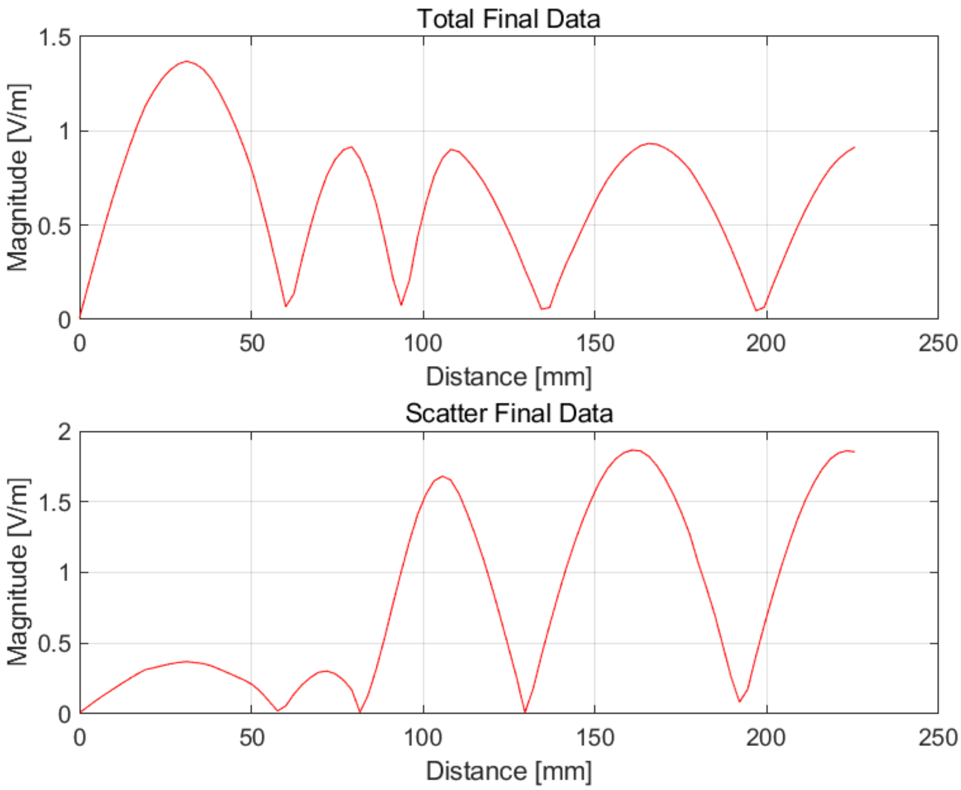

Fig 6 Total Field and Scatter Field in HFSS (matlab plot)

Simulation Result(matlab):

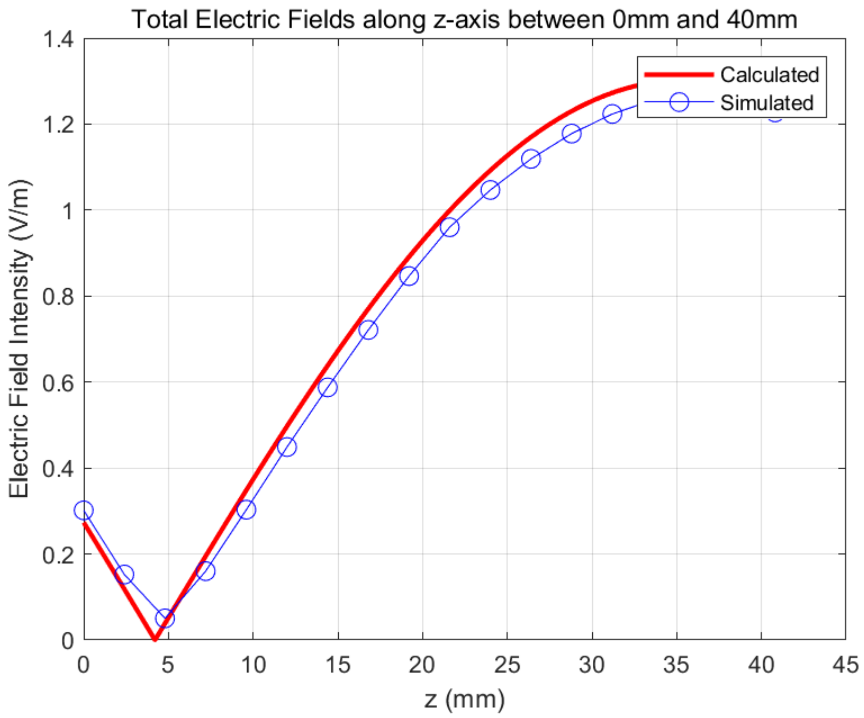

Fig 7 Comparison of the Total Field

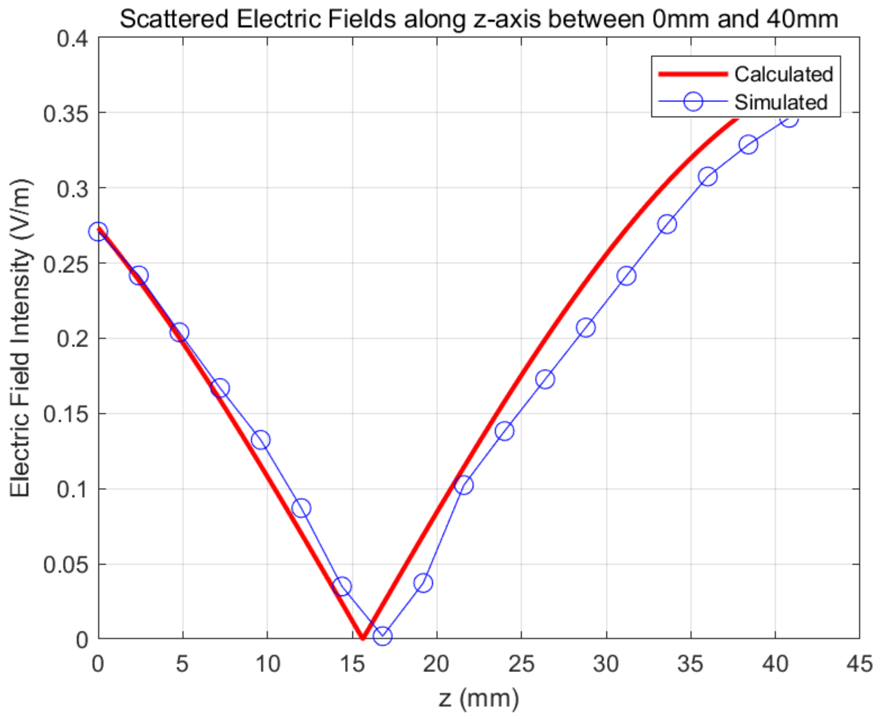

Fig 8 Comparison of the Scattered Field

Analysis and Discussion:

Total Electric Field Intensity Analysis:

Within the range of 0mm to 40mm along the z-axis, the theoretically calculated total electric field strength shows a trend of initially decreasing and then increasing. The maximum values occur near the starting position (0mm) and the end position (40mm). Around z=15mm, the total electric field strength reaches its lowest point and then begins to increase. Simulation results also show a similar trend in the variation of the total electric field strength along the z-axis from 0mm to 40mm. Data points and theoretical curves largely overlap, particularly in areas where the electric field strength changes significantly, demonstrating good agreement between simulation results and theoretical values.

From the result graphs, it is evident that the theoretical calculation results (red line) align closely with the simulation data (blue dots), indicating that the theoretical model is accurate and reliable in describing electric field strength. Minor deviations may be due to approximations in numerical calculations and discretization errors in the simulation process, but the overall error is within an acceptable range.

Scattered Electric Field Intensity Analysis:

The scattered electric field strength within the range of 0mm to 40mm along the z-axis also shows a similar trend of decreasing and then increasing. The maximum values occur at the starting and end positions, with the lowest point around z=15mm. Simulation results match the theoretical calculation trends, with data points distributed around the theoretical curve. The scattered electric field strength gradually increases after z=20mm and generally aligns with theoretical values.

The simulation results of the scattered electric field align well with theoretical calculations, validating the accuracy of the theoretical model in predicting scattered electric field strength. There are minor deviations, likely due to discretization and numerical errors in the simulation model, but these deviations have little impact on the overall results.

Discussion:

Although the theoretical calculations and simulation results generally align well, there are minor discrepancies at certain points, possibly due to:

Numerical Errors: There may be approximations in the theoretical calculations, especially when dealing with complex media layers, which can be more pronounced at certain locations.

Simulation Errors: Errors introduced by meshing and numerical discretization in the Ansys HFSS simulation process may cause slight differences between simulation results and theoretical values.

Material Properties: The physical properties of actual materials may differ from the ideal models, particularly the accuracy of the dielectric constant, which could affect the results.

Experiment conclusion

Consistency Verification: The theoretical calculation results are highly consistent with the simulation data in terms of the trends of total electric field strength and scattered electric field strength. The theoretical model has successfully predicted the changes in electric field strength across different media layers, validating its accuracy in electromagnetic wave propagation studies.

Electric Field Strength Variation: Within the range of 0mm to 40mm along the z-axis, both the total and scattered electric field strengths exhibit a trend of initially decreasing and then increasing. Significant changes in electric field strength occur at the interfaces of media layers, indicating pronounced reflection and transmission phenomena at the boundaries of different media layers. This phenomenon confirms the theory of electromagnetic wave propagation.

Error Analysis: The minor discrepancies between theoretical calculations and simulation results are primarily due to approximations in numerical calculations and discretization errors in the simulation process. These errors are acceptable within the experimental scope and do not significantly impact the overall accuracy of the results.

Overall, this experiment successfully validated the laws of electric field strength variations as plane waves propagate through different media layers, with both the theoretical model and simulation tools demonstrating high accuracy and reliability. This provides a solid theoretical and practical foundation for further research on electromagnetic wave propagation.

五、指导教师批阅意见：

成绩评定：

指导老师签名：

年　　月　　日