Lab 1：Magic Tee

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Introduction

Experimental objective

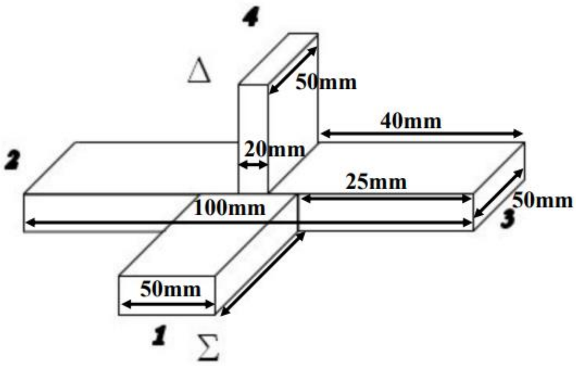
This experiment is to simulate Magic Tee, a commonly used waveguide device in microwave engineering, using HFSS, which is a software mainly for field simulation, to investigate some characteristics of Magic Tee, mainly the transmission characteristics between different ports. Next, we introduce the software HFSS and the waveguide device Magic Tee used in this experiment.

1. HFSS

HFSS, which stands for High-Frequency Structure Simulator, is a powerful and widely used software application in the field of electromagnetic simulation and analysis. It is developed by ANSYS and primarily serves the purpose of simulating and analyzing high-frequency and high-performance electronic components and devices. It is a software tool used for electromagnetic field simulation and analysis. HFSS allows engineers and researchers to simulate the behavior of electromagnetic fields in complex structures and devices. This is crucial for understanding how electromagnetic waves interact with various materials, components, and structures. Therefore, HFSS is a valuable tool in the design and development of high-frequency electronic systems, enabling engineers to model, analyze, and optimize electromagnetic behavior in a wide range of applications, from antennas and RF components to signal integrity and electromagnetic compatibility studies.

2. Magic Tee

Magic tee, also known as a magic tee junction, is a passive microwave device commonly used in microwave engineering for signal splitting and combining applications. It is typically used in waveguide systems and exhibits certain properties that make it particularly useful for various microwave applications. The magic tee consists of a waveguide with four same ports, arranged in a T-shaped configuration. It can be obtained by rotating one module to get the other parts, which are then united. Its approximate shape is as follows:



It possesses several key characteristics. Firstly, a primary feature of the magic tee is its ability to provide high isolation between the two diagonal ports, typically referred to as "E" ports. This means that microwave signals entering one E port are effectively isolated from the other E port, making it suitable for applications like signal combining and power division. Secondly, magic tees are designed to be symmetrical, which means that the device is not sensitive to the input direction of signals. The symmetry is crucial for ensuring consistent performance in a variety of microwave systems. Thirdly, magic tees can be used for both signal splitting and signal combining. When a signal is fed into one of the E ports, it is divided into two equal parts at the cross-section of the T-shaped waveguide. Conversely, when two signals are applied to the E ports, they are combined into one output signal at the common port, known as the "H" port. And magic tees are fundamental components in microwave and RF engineering, commonly used in applications such as antenna systems, radar systems, and communication systems. They play a crucial role in distributing microwave signals with minimal interference and can help achieve the desired signal routing and isolation in these systems.

S-parameters

S-parameters, or Scattering Parameters, are a set of parameters commonly used in the field of microwave and RF (Radio Frequency) engineering to describe the behavior of linear electrical networks and components, particularly those operating at high frequencies. These parameters are used for characterizing signal flow, power transfer, and impedance matching in various microwave devices and systems. S-parameters are typically represented as a matrix of complex numbers and provide important insights into the performance of a component. S-parameters are a set of numerical parameters used to describe how electrical signals interact with components and networks at high frequencies. They are typically represented as a matrix of complex numbers, often denoted as S11, S12, S21, and S22, where:

S11 (Reflection Coefficient) parameter represents the reflection of a signal at Port 1 when a signal is applied to Port 1, and all other ports are terminated with their characteristic impedances. It indicates how well the component matches the input signal and provides insights into the input impedance.

S12 (Transmission Coefficient) characterizes the transmission from Port 1 to Port 2 while the other ports are properly terminated. It reveals the loss or gain in the transmission and the effect of the component on the signal.

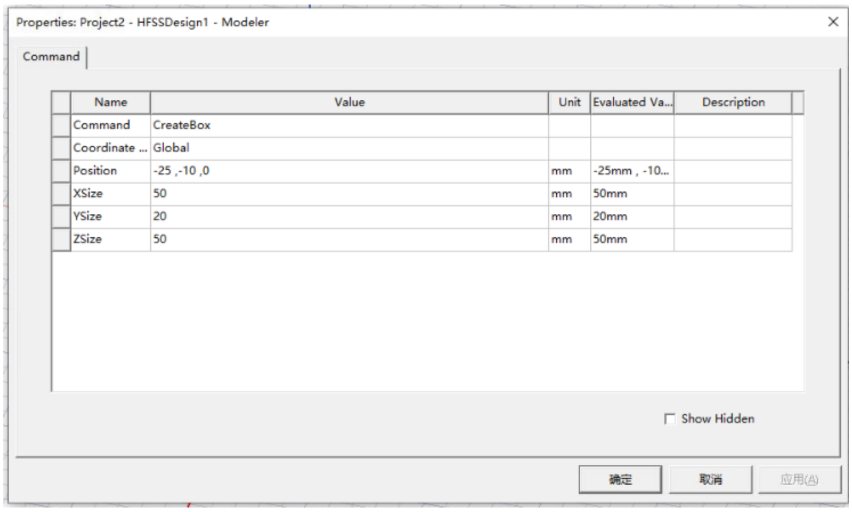
S21 (Forward Transmission Coefficient) represents the transmission from Port 2 to Port 1 with the other ports correctly terminated. It describes how well the component passes signals from one port to another, considering any loss or gain.

S22 (Reflection Coefficient) parameter indicates the reflection at Port 2 when a signal is applied to Port 2, while the other ports are terminated. It provides information about the output impedance and how well the component matches the output signal.

S-parameters are valuable for the design and analysis of microwave circuits and components. Engineers use these parameters to assess the performance of devices, optimize impedance matching, evaluate signal loss or gain, and understand the behavior of complex networks in microwave systems. S-parameters are essential tools for ensuring the efficient and accurate operation of high-frequency devices and systems.

Lab results & Analysis:

First, we physically modeled the Magic Tee. Based on the dimensions on the material description, we first selected the initial coordinates and the length dimensions of each side of the initial rectangular module. Here we first create the topmost rectangular square of the Magic Tee. Its dimensions and coordinate information are set as follows:



Properties: Project2 - HFSSDesign1 - Modeler

Command

Name	Value	Unit	Evaluated Va...	Description
Command	CreateBox			
Coordinate ...	Global			
Position	-25 ,-10 ,0	mm	-25mm , -10...	
XSize	50	mm	50mm	
YSize	20	mm	20mm	
ZSize	50	mm	50mm	

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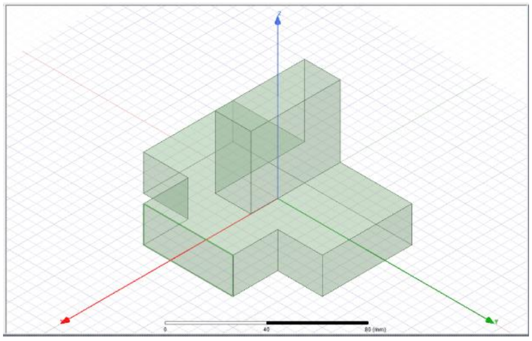
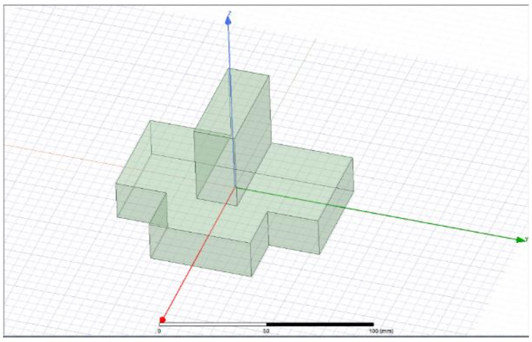
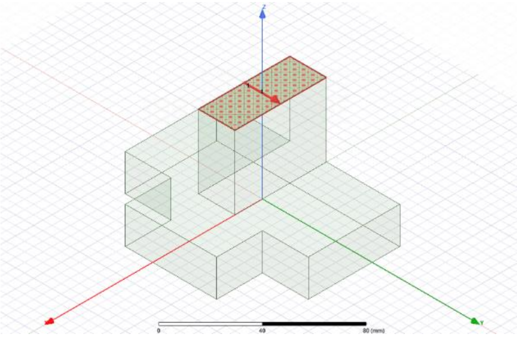
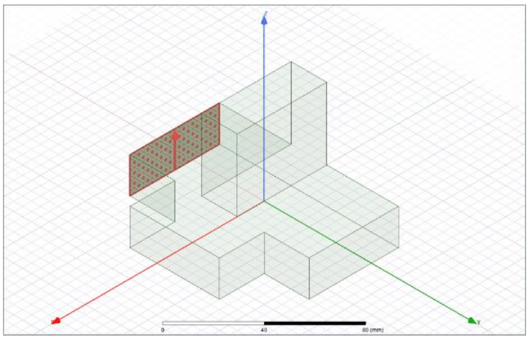
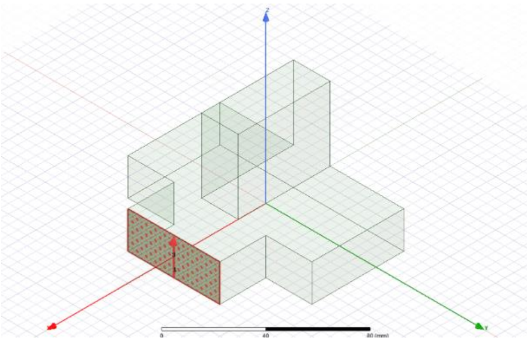
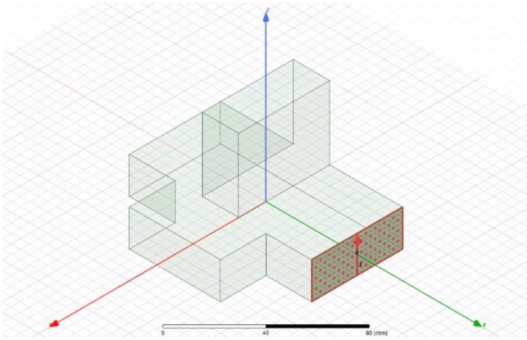
Then we will create the first module first rotated 90 degrees around the x-axis, and then the resulting rotated module rotated 90 degrees around the z-axis, the additional formation of two modules, and finally all the modules will be united, we can get the magic Tee as shown in the figure below:

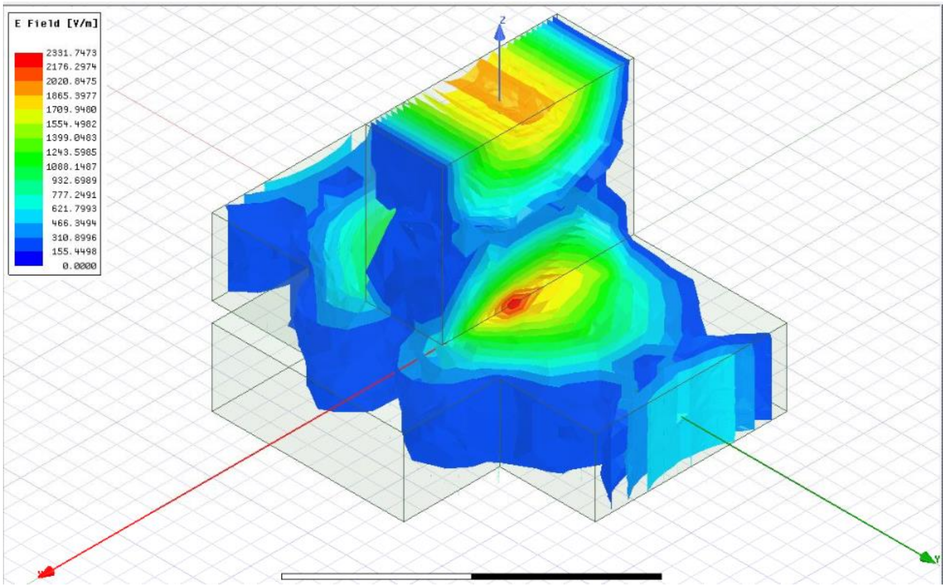
Next, we want to set up the waveguide port excitation, which for the Magic TeeL has a total of two settings:

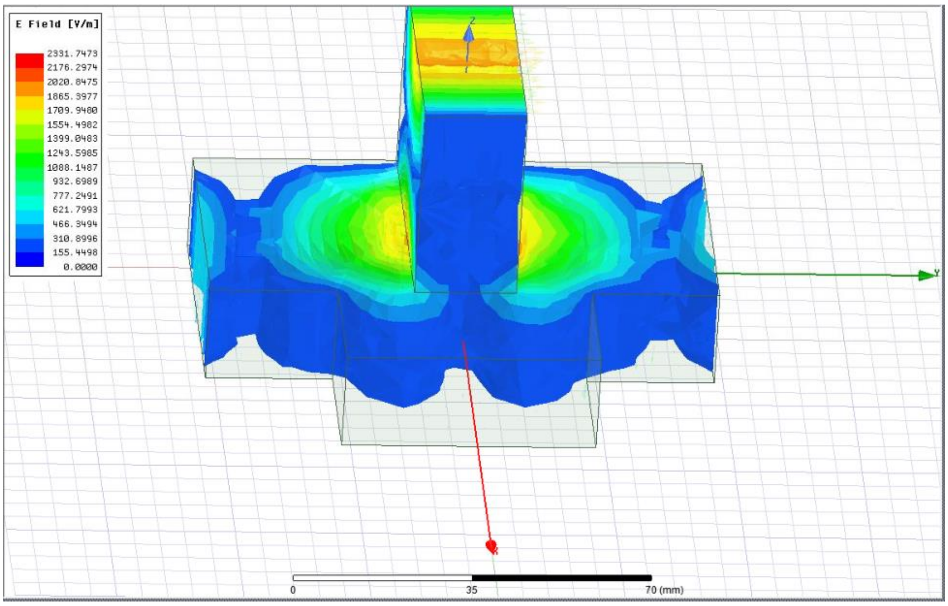
1. **The input is the top of the entire Magic Tee and the other three ports are the outputs, which are set up as follows:**

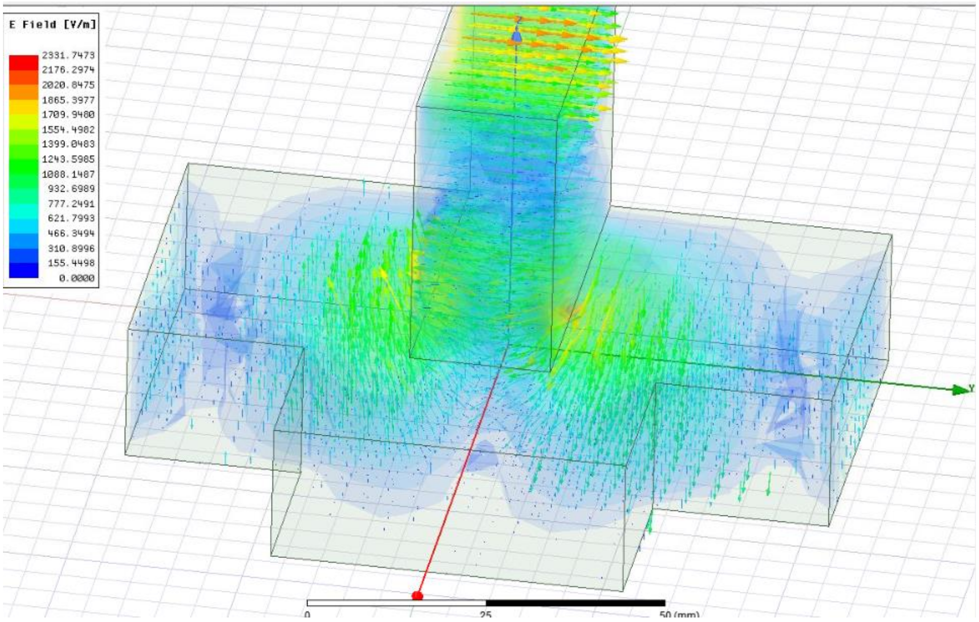
Theoretically, if the waveguide ports are set up in this way, i.e. the top is set as incidence port, then the wave input from the waveguide arm port 1 is oddly symmetric with respect to the plane of symmetry of the magic Tee. Consequently, the power of this odd-symmetric wave will be equally divided between waveguide arms 2 and 4 and the electric fields in 2 and 4 are in opposite directions. However, no power is coupled into waveguide arm 3 because the odd-symmetric wave cannot pass in this arm.

We can simulate the electric field distribution map of the Magic Tee to view the phenomenon and verify the above theory. First, we can plot the distribution of the magnitude of the electric field strength across the module through simulation as follows:



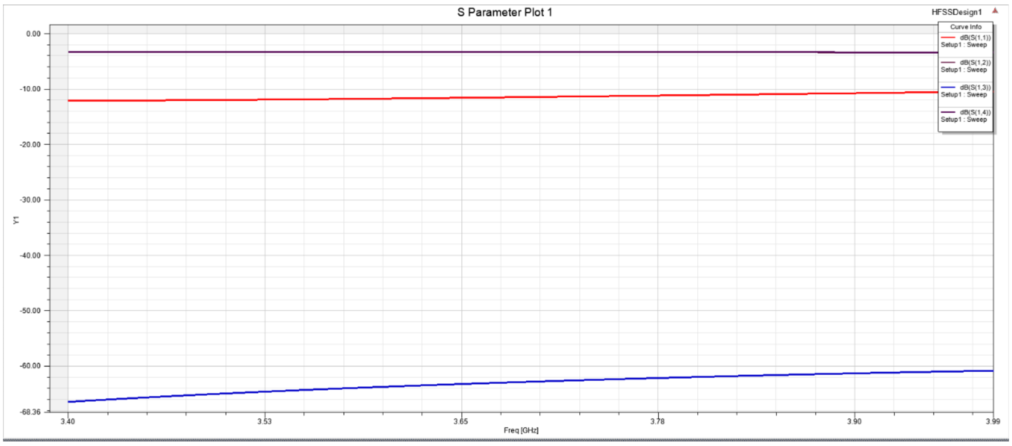


From the simulation diagram above we can see that the electromagnetic wave incident from port 1 will be emitted from ports 2 and 4, and no electromagnetic wave is emitted from port 3. Moreover, by observation, we can find that the magnitude of the electric field strengths at ports 2 and 4 are equal and the distribution are symmetric. This also verifies our theory above. In order to observe the direction of the electric field, we can draw the electric field vector distribution diagram as follows:



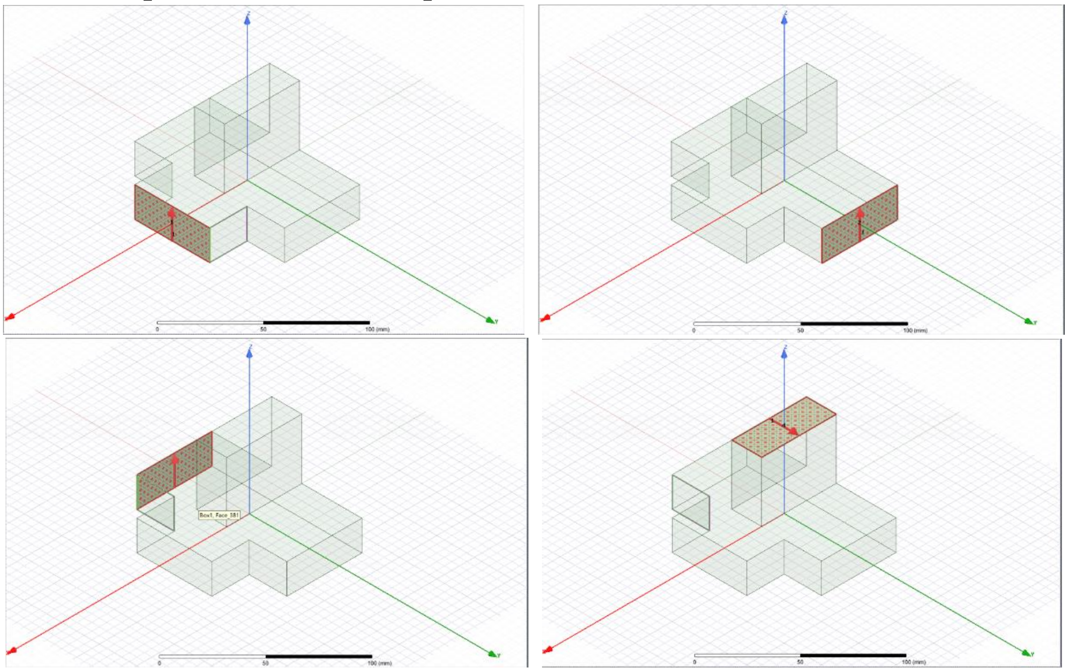
By looking closely at the vector diagram above you can see that the direction of the electric field vectors in the left and right arms of the Magic Tee (i.e. the arms in the direction of port 1 and port 2) are indeed opposite which is consistent with the above theory.

Next, in order to better analyze the transmission characteristics between individual ports, we can draw the S-parameter curves for each port as follows:



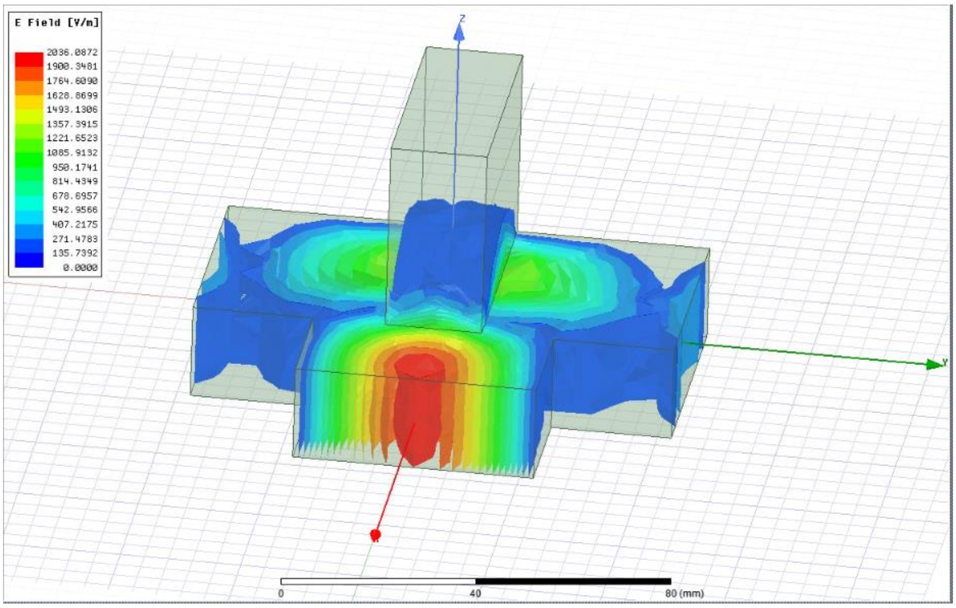
We analyzed the values of four S parameters including S (1,1), S (1,2), S (1,3), S (1,4) and plotted the above figure, according to this figure we can do some analysis, we can find that the values of S (1,2) and S (1,4) are equal and maximal, which means that the output situation of port 2 and port 4 is symmetrical and the ratio of wave is maximal in these two outputs. S (1,1) has the second largest value, which indicates the extent to which the wave is input at port 1 and reflected back to port 1. It can be seen that a good deal of the wave is still reflected back to the input, but the extent of the reflection is less than at the outputs at ports 2 and 4. Finally the value of S (1,3) is the smallest and much smaller than the previous three, indicating that very few waves are indeed output at port 3. These parameters are consistent with the results obtained from both theory and simulation.

2. **The input is the front of the entire Magic Tee and the other three ports are the outputs, which are set up as follows:**



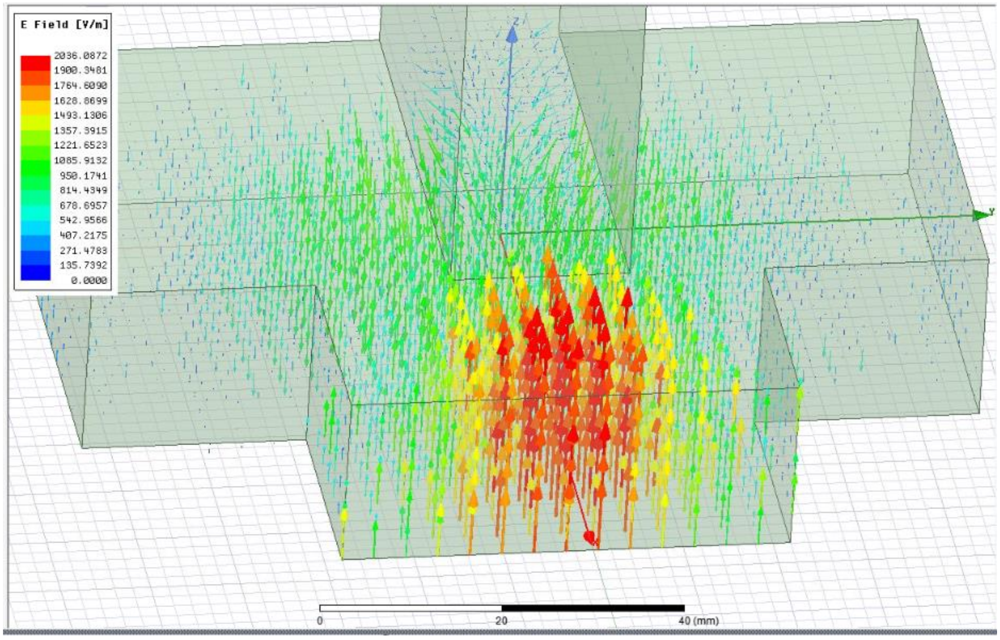
In a theoretical analysis, the wave input from the front waveguide arm port 1 is even-symmetric because it will excite even-symmetric waves in waveguide arms 2 and 3, and the electric fields in 2 and 3 are in the same direction. At this point, no power can be conducted into waveguide arm 4 because this arm does not support an even symmetric wave.

Similarly, we can verify this conclusion by simulation, first we plot the magnitude distribution of the electric field strength. It is as follows:

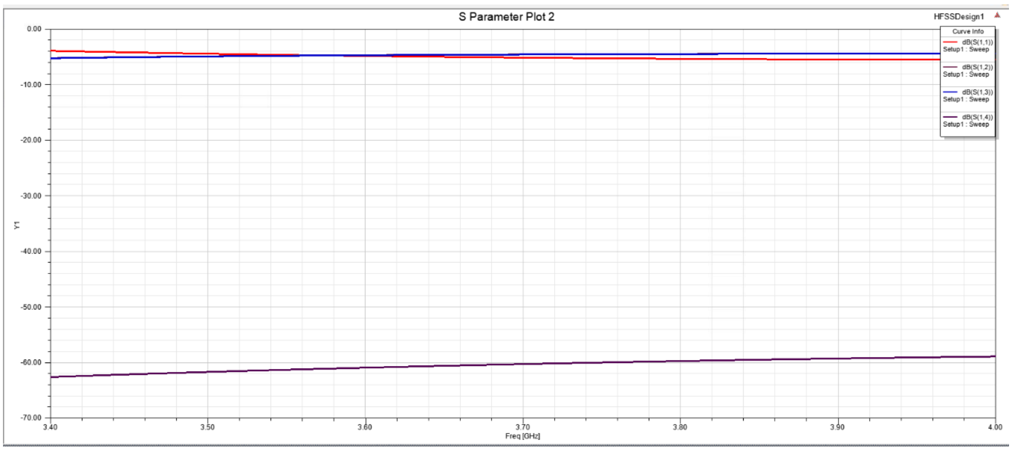


From this figure, we can clearly see that the electromagnetic wave input from port 1 will be output from ports 2 and 3, and that there is almost no electromagnetic wave output from port 4, and that the distribution of the electric field strength of the waves output from ports 2 and 3 is symmetrical and their amplitudes are equal.

Then we can observe the relationship between the direction of the electric field by drawing the distribution of the electric field vectors again, as shown below:



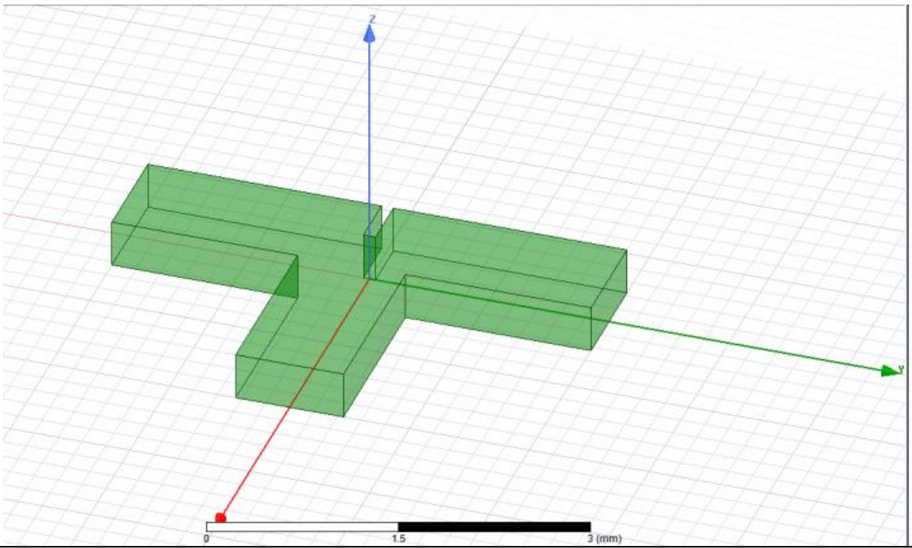
From this figure, we can see that the direction of the electric field vectors in the left and right arms (the arms corresponding to ports 2 and 3) are the same, which corroborates the conclusions drawn from our theory.
Similarly, we can make the relationship curve of S-parameters to further analyze the transmission relationship between ports as follows:

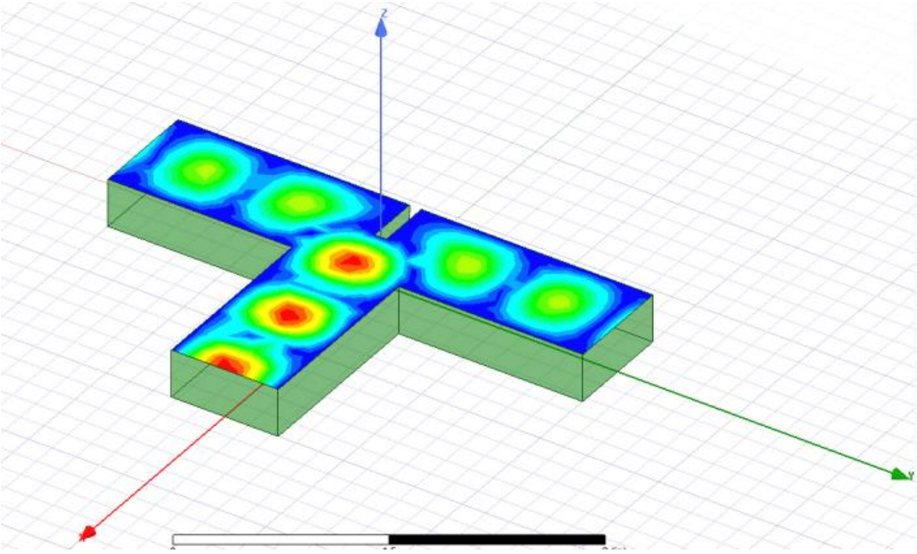


Similarly, we analyzed the values of four S parameters including S (1,1), S (1,2), S (1,3), S (1,4) and plotted the above figure, according to this figure we can do some analysis, we can find that the values of S (1,2) and S (1,3) are equal and maximal, which means that the output situation of port 2 and port 3 is symmetrical and the ratio of wave is maximal in these two outputs. S (1,1) has the second largest value, which indicates the extent to which the wave is input at port 1 and reflected back to port 1. It can be seen that a good deal of the wave is still reflected back to the input, and the extent of the reflection is comparable to the outputs at ports 2 and 3. Finally the value of S (1,4) is the smallest and much smaller than the previous three, indicating that very few waves are indeed output at port 4. These parameters are consistent with the results obtained from both theory and simulation.

Experience

Screenshots from the classroom





Problems that I meet

At the beginning of making Magic Tee's 3D model drawing for physical modeling, I was more puzzled about its dimensions and geometric relationship, I don't know what the specific geometric relationship is like, after checking the online information, I learned that they can be derived from the rotation of a rectangular module, so I deduced its specific dimensions and geometric relationship, and finally succeeded in making a model drawing of it.

Secondly, when plotting its electric field vector distribution, I found that the symmetry derived from different ports of incidence is opposite, that is, if the input is at the top, the direction of the electric field on the two output arms is opposite, and if the input is at the front, the two directions will be the same, and I was more puzzled about this at first, and then, after searching for information on the Internet, I learned about the theoretical explanations that underpinned the results of this simulation.

Harvest from this experiment

Through this experiment, I can use the software HFSS more skillfully, and I am clearer and more familiar with the whole process of modeling and simulation. Meanwhile, through this experiment, I also got to know a waveguide device like Magic Tee for the first time, knew its structure, understood its physical properties, including the transmission relationship between different ports when it transmits electromagnetic waves. And through the simulation, it made me deepen my knowledge and memory of the above knowledge, and also had a visualization. In addition, through the experiment, I understood the meaning and role of S-parameters, probably knew the significance of S-parameters, and learned how to draw S-parameter curves and get the physical properties of the device by analyzing the S-parameter curves. By analyzing the S-parameter curve and analyzing the electric field amplitude and vector distribution graph of the waveguide, I can get some properties of the waveguide, and in this analyzing process, my analytical

ability has been further improved.	
Score	98