Lab 7：Microstrip Patch Antenna

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Introduction

1.1 Experimental goal

Comprehend the modeling and simulation of microstrip patch antenna. Gain skills in employing HFSS for both modeling and simulation, along with optimization techniques.

1.2 Introduction of Patch Antenna

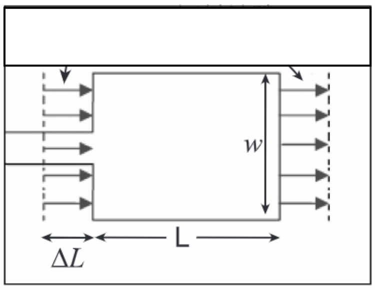
Microstrip Patch Antenna is a common and widely used antenna design in RF communication systems. This antenna utilizes the structure of a microstrip line and a metal patch, offering several advantages including low cost, compact size, lightweight, and ease of integration. The Microstrip Patch Antenna typically consists of an insulating substrate, a metal patch, and a ground plane. The metal patch is located on one side of the insulating substrate, while the ground plane is on the other side. A microstrip line connects the patch and the feeding point. The antenna operates based on the resonance of the microstrip patch. By adjusting the geometry and dimensions of the patch, the antenna can resonate at specific frequencies, achieving effective radiation. Microstrip Patch Antenna has many features, it is more compact compared to traditional antennas, making it suitable for space-constrained applications. And manufactured with simple materials, the antenna is cost-effective, making it suitable for mass production. The manufacturing and integration processes are relatively simple. The antenna can be integrated with other circuit components on the same insulating substrate, increasing system integration.

1.3 The principle of Patch Antenna

In theory, we can use the transmission line model to analyze microstrip antennas. The radiating patch of the microstrip antenna, with a length approximately equal to half the wavelength, has a width of w, substrate thickness of h, and wavelength of λ. The radiating patch, dielectric substrate, and ground plane can be considered as a section of low-impedance microstrip transmission line with a length of half a wavelength, and the transmission line is open-circuited at both ends. Since the thickness is much smaller than the wavelength, the electric field along the thickness direction remains relatively constant.

For simplicity in analysis, we can also assume that the electric field along the width direction is constant. Thus, radiation can be essentially considered as originating from the edges of the open-circuited side of the radiating patch. The electric field at the two open-circuited ends can be decomposed into vertical and horizontal components relative to the ground plane. Because the length of the radiating patch is approximately half a wavelength, the two vertical component electric fields at the open-circuited ends have opposite directions, while the horizontal component electric fields have the same direction.

Therefore, the horizontal component electric field at the two open-circuited ends can be equivalent to two slits on an infinite plane with in-phase excitations. The width of these slits is delta L (approximately equal to the substrate thickness h), the length is w, and the slits are separated by half a wavelength. The electric field in the slits is uniformly distributed along the w direction, and the electric field direction is perpendicular to the w direction.



The various parameters of the microstrip patch antenna can be calculated. Assuming the dielectric constant of the substrate is εr, the operating frequency of the rectangular microstrip antenna is f, and the speed of light is c, the width W of the radiating patch is determined by the following equation:

$$W = \frac{c}{2f}\left(\frac{\varepsilon_r + 1}{2}\right)^{-\frac{1}{2}}$$

Taking into account the edge shortening effect, the actual length L of the radiating patch is:

$$L = \frac{c}{2f\sqrt{\varepsilon_e}} - 2\Delta L$$

In the equation, ε_e is the effective permittivity, and ΔL is the effective length of the radiating slit, which can be calculated using the following formulas:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}}$$

$$\Delta L = 0.412h\frac{(\varepsilon_e + 0.3)(W/h + 0.264)}{(\varepsilon_e - 0.258)(W/h + 0.8)}$$

In this case, we use the FR4, the εr=4.4, h=1.6mm, and frequency is 2.4GHZ, we can calculate to the dimension using the equations above: W0=38.04mm, L0=28.5 for patch, and for quarter-wavelength line, we can set the dimension: W1=1.2mm, L1=17.71mm, and for feedline: W2=3.1mm, L2=mm. It's worth noting that the above are empirical formulas. We don't have to strictly adhere to these parameters in our design. For example, in this experiment, we set the width to 45mm and then optimize L_0.

Lab results & Analysis:

Requirement:

Center Frequency：2.4 GHz

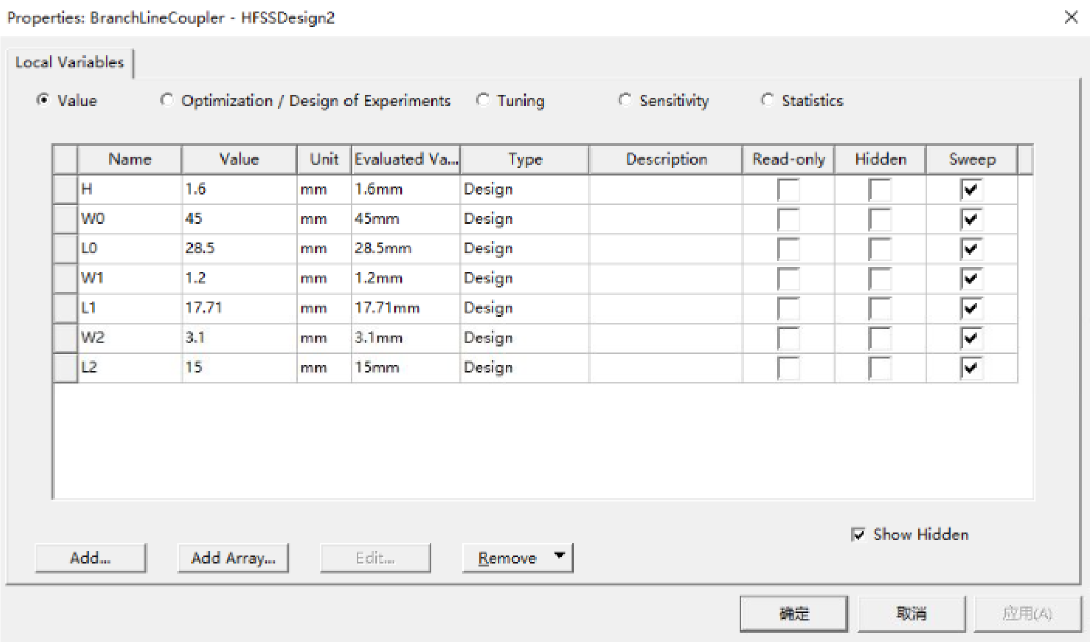
Substrate：FR4，1.6mm

Bandwidth：50MHz

Set W0 = 45mm，Observe GainTotal

HFSS:

First, we define the variables used in the HFSS simulation process which are shown as follows:



Properties: BranchLineCoupler - HFSSDesign2

Local Variables

Value　Optimization / Design of Experiments　Tuning　Sensitivity　Statistics

Name	Value	Unit	Evaluated Va...	Type	Description	Read-only	Hidden	Sweep
H	1.6	mm	1.6mm	Design		☐	☐	☑
W0	45	mm	45mm	Design		☐	☐	☑
L0	28.5	mm	28.5mm	Design		☐	☐	☑
W1	1.2	mm	1.2mm	Design		☐	☐	☑
L1	17.71	mm	17.71mm	Design		☐	☐	☑
W2	3.1	mm	3.1mm	Design		☐	☐	☑
L2	15	mm	15mm	Design		☐	☐	☑

Show Hidden

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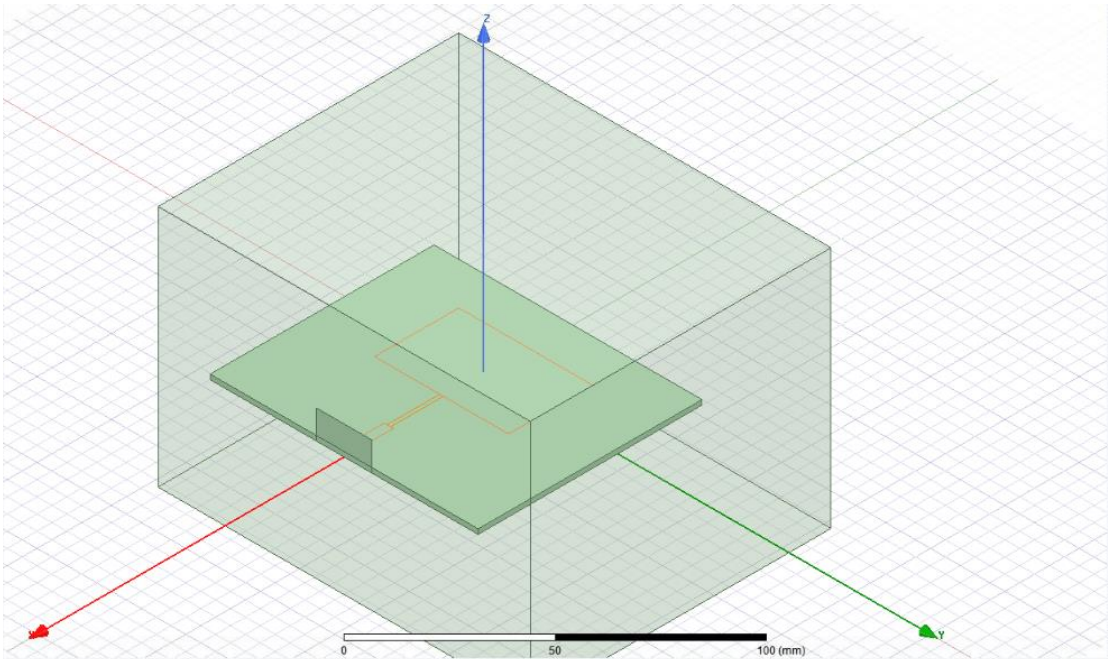
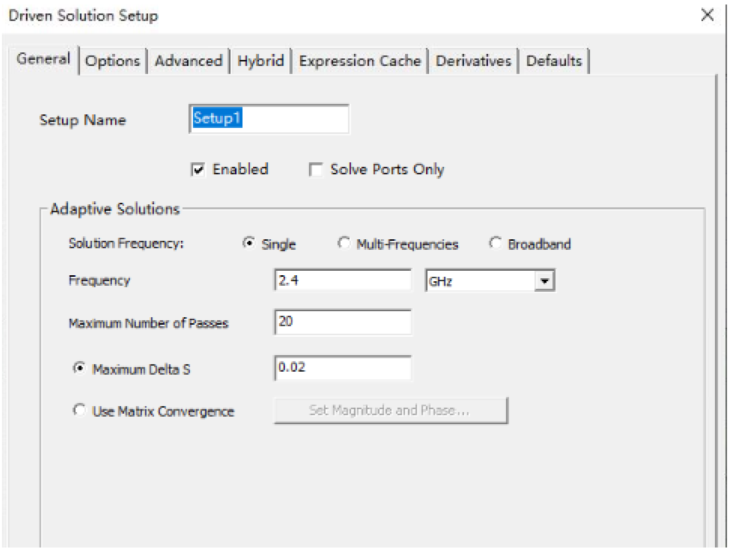
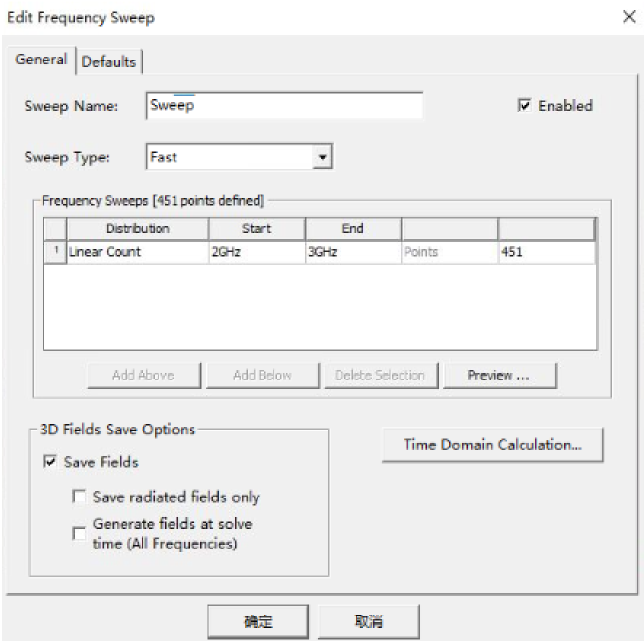
确定　取消　应用(A)

The structure of HFSS is below:

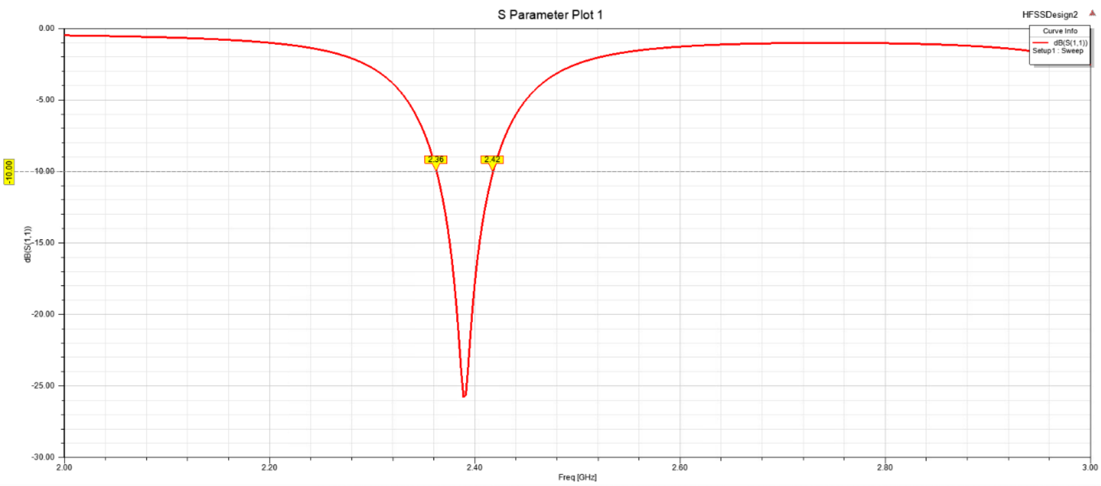


The we design the sweep:

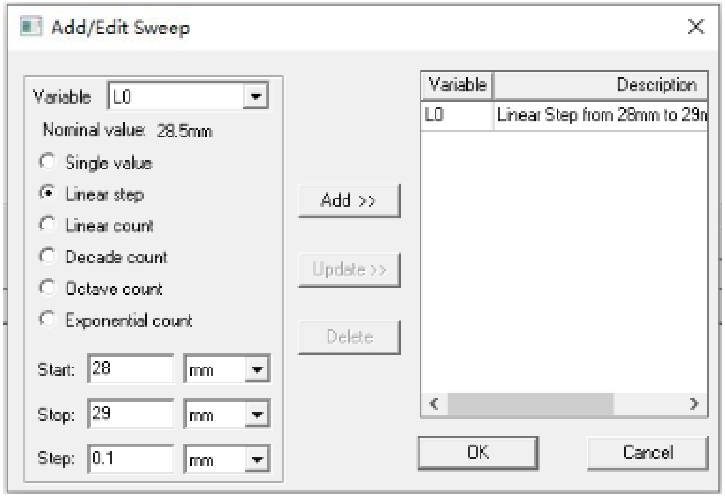




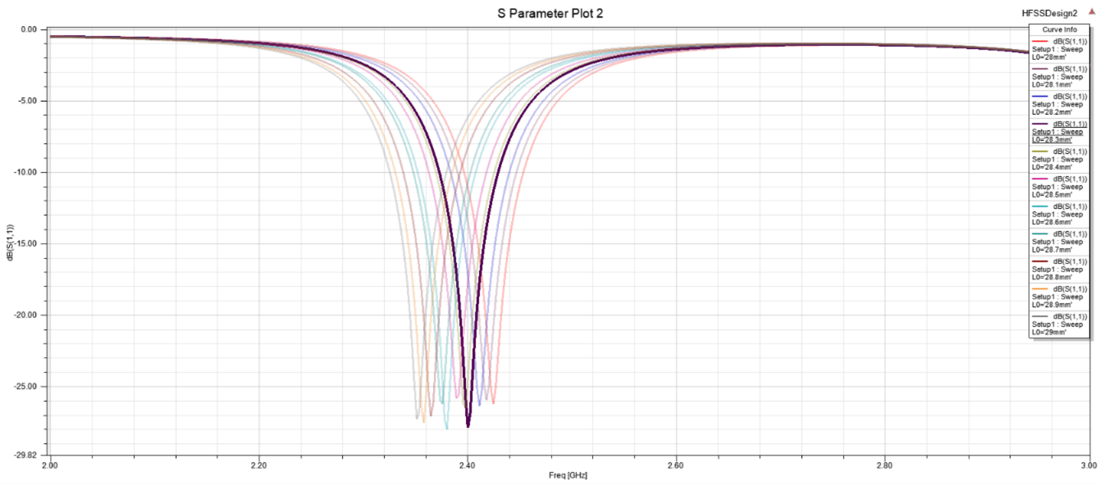
The simulation result is that:



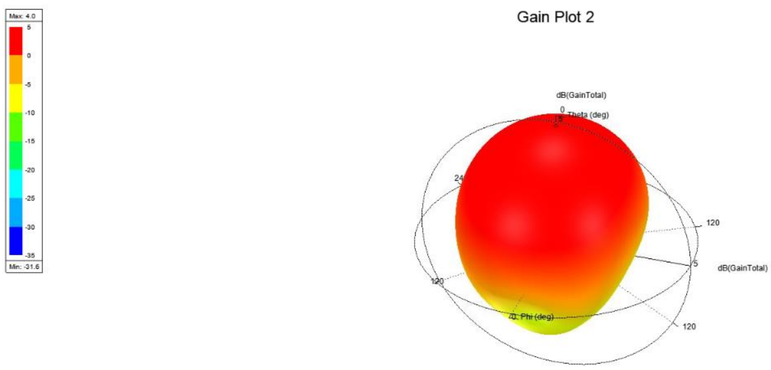
From the graph, it can be observed that the matching result is not optimal; the curve does not reach its minimum at 2.4 GHz. Therefore, fine-tuning of the value for L0 is needed. As the difference is not significant, we set the parameter sweep precision to be finer, ranging from 2.8 to 2.9 with a step size of 0.1:



The results are shown as below:



From which we can find that the optimal value of L0 is 28.3mm. so we set the L0 to 28.3mm. Then we can observe the far field 3D polar plot as follows:



Experience During this learning process, I have attained a comprehensive understanding of patch antennas, starting with grasping their basic concepts. Delving deeper into the intricacies, I've learned the methodologies for calculating the precise dimensions of a patch antenna, a crucial aspect of its design. Additionally, my knowledge has expanded to include insights into the equivalent model of microstrip patches, providing a valuable foundation for further analysis and optimization. As part of my skill development, I've also become adept at creating 3D gain plots in HFSS, enhancing my ability to visualize and analyze the antenna's performance in a three-dimensional space. Overall, this learning journey has equipped me with a well-rounded knowledge of patch antennas, encompassing both theoretical concepts and practical skills in simulation and analysis.	
Score	98